"GEOLOK" COMPUTER PROGRAMME

A COMPUTER BASED DESIGN APPROACH FOR DRY STACK RETAINING WALLS

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Damon Clark obtained his B.Sc. (Eng.) degree in 1976 and his M.Sc. (Eng.) in Soil Mechanics from Natal University in 1982. His Master of Science thesis was entitled "An Investigation into the Bearing Capacity of Clays". His primary experience is in geotechnical engineering, having worked within the geotechnical sections of the following geotechnical firms; D L Webb & Partners, Van Niekerk, Kleyn & Edwards, Steffen Robertson & Kirsten and Moore Spence Jones & Partners (Associate). In 1988, he formed his own engineering consultancy, Damon Clark Associates. Damon has a keen interest in computers, and has developed a number of computer programmes, the most recent of which is for the design of dry stack concrete block retaining walls.

ABSTRACT

This paper will present the rationale behind a computer programme which automatically designs dry stack retaining walls as gravity walls. In the cases with purely frictional soils, the programme utilises equations based on the Coulomb theory to determine active and passive forces applied by the soil. In cases with soils that possess both effective cohesion and effective friction, the active and passive forces are computed using an analytical adaptation of the graphical wedge technique. An optimal design is carried out simultaneously on up to three different block sizes, utilizing sliding and overturning factors of safety specified by the user, in compliance with the constraint that the line of action of the resultant force passes through the rear 2/3 of the bottom blocks. This is achieved by reducing the effective weight of the wall when the line of action of the resultant passes behind the blocks, until it is within the blocks. If its impossible to achieve the desired wall height with an acceptable factor of safety, then the user would have to either flatten the wall slope, or increase the effective block width and weight by introducing a stabilized block of soil behind the blocks. It also helps if the blocks are given a backward tilt. In practice, this can either be done by inclining the top surface of the foundation, or by setting the bottom row of blocks in wet concrete with the desired backwards tilt.

A COMPUTER BASED DESIGN APPROACH FOR DRY STACK RETAINING WALLS

1. INTRODUCTION

In recent years dry stack concrete block retaining systems have come into common usage, and in many instances are being used in preference to conventional reinforced concrete walls. Essentially these walls comprise precast concrete blocks which are stacked row upon row with a prescribed backward offset to form a retaining wall with a specified backward slope. Typically the slopes of the walls range between 55 and 70 degrees to the horizontal. During construction, each row of blocks is filled with soil in conjunction with the placement and compaction of backfill behind the wall.

It is current practice to design these walls as composite gravity retaining walls which are reliant on both the weight of the blocks and the weight of the soil infill. In designing a wall, the destabilizing force on the wall due to active earth pressures and the weight of the wall counteracting this force, are calculated based on the assumption that the stacked precast concrete blocks and soil infill, act together as a single body. Having thus computed these two forces, it is usual to ensure that geometry of the wall is such that the factor of safety both against overturning and against block on block sliding does not exceed 1.5. Often no check is carried out to ensure that the line of action of the resultant external force passes through the middle third of the base of the wall (i.e. the bottom row of blocks), which is common practice in the design of gravity walls. This middle third condition is incorporated in gravity wall designs in order to ensure that no tension exists within the structure. While this requirement is perhaps not essential in dry stack systems, what the author considers to be of critical concern in this regard, is that in many instances, the line of action of the resultant force passes behind the back of the bottom row of blocks. Under such conditions there can be no certainty as to the forces that exist between the rows of blocks. Such conditions also bring into question, the assumption that the wall acts as a single body, regardless of its height and its backward slope.

The author considers that in cases where the computed line of action of the resultant force passes behind the bottom row of blocks, the effective height and corresponding effective weight of the wall, should be reduced by an amount sufficient to ensure that the line of action of the resultant passes within the base of the bottom row of blocks. In this manual the author presents his approach to the design of dry stack retaining walls, which he has used as a basis for the development of a computer programme for the design of these walls. In the final section of the paper a few design examples are given in order to illustrate the operation of the programme. There are many different types and sizes of precast blocks available for use in the construction of dry stack retaining walls, the basic design approach is applicable to all types.

2. THE DESIGN PROCEDURE

2.1 The Basic Design Procedure

Prior to discussing each stage of the design in detail, a brief description of each stage of the design procedure for dry stack retaining walls, is given below:

(1) **Decide upon soil parameters** for both the material to be retained by the wall and the material in front of the wall, the wall friction, the foundation wall friction, and the position of any ground water. It will also be necessary to know the weight per square metre of wall face, of the blocks filled with soil, the block on block friction, and in cases where the blocks possess nibs, the shear strength of the nibs per metre run of wall.

(2) **Select a trial wall slope** and in cases where the ground slopes away from the top of the wall, determine the height of the wall.

(3) **Calculate the destabilizing forces** acting on the rear of the wall applied by the retained soil and any external loads such as a line load or a uniformly distributed load (UDL) behind the wall.

(4) **Calculate the resultant of the destabilizing forces and the self weight of the wall** for the proposed block type and size(s).

(5) **Check that the line of action of the resultant force passes behind the front third of the bottom row of blocks, and that it passes within the blocks.** If the line of the resultant passes within or ahead of the front third , then the rear of the wall would be in tension. In the design of gravity walls, it is generally considered that such a condition should not be allowed to arise. If the line of action of the resultant force passes behind the bottom row of blocks then reduce the "effective" height and corresponding "effective" weight of the wall until it passes within the blocks. The "effective" height and weight of the wall being that portion of the wall which is considered to be contributing to the resistance of the wall to both overturning about the toe of the wall and to sliding at the base of the wall.

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(6) **Check the factor of safety of the wall against overturning** using the effective weight of the wall. Generally acceptable if above 1.5.

(7) **Check the factor of safety of the wall against block on block sliding** between the lowest two rows of blocks. Generally acceptable if above 1.5. The blocks in the bottom row are invariably either set in the wet foundation concrete or are restrained from sliding off the

found by means of a concrete nib, and thus the most critical level for block on block sliding is between the lowest two rows of blocks.

(8) Through an iterative process, **determine the minimum founding depth** that will provide the required factor of safety (usually 1.5) against sliding of the wall at the level of the base of the foundation. For each trial founding depth, this involves the computation of the passive earth force that if mobilized, acts together with the frictional resistance developed along the underside of the foundation to provide the resistance to sliding.

(9) **Calculate the bearing pressures beneath the front and back of the foundation.** If these are unacceptable, then increase the width of the foundation.

(10) In the case of a design using a walling system which has more than one compatible block size, if the wall comfortably meets the design criteria when it is comprised solely of the larger blocks, the **block mix should be optimized** through the inclusion of as many of the smaller blocks as the design criteria limits will allow. For example, in the case of Loffelstein Blocks, there are L300 (300 mm long) blocks, L500 (500 mm long) blocks and L750 (750 mm long) blocks, the optimal block mix is generally the one which comprises the maximum number of the smaller L300 and L500 blocks.

(11) If the dry stack retaining wall at its selected wall slope, does not satisfy all the above design criteria then there are two basic options open to the designer, namely

(i) flatten the wall slope and repeat steps 1 to 10, or

(ii) increase the effective width and effective weight of the wall by either stabilizing a specified width of suitable backfill behind the wall or by incorporating geofabric reinforcement between rows of blocks at pre-determined spacings which tie the block wall to a body of backfill behind the wall. Then repeat steps 1 to 10.

(12) In circumstances where there could be long-term slope instability involving a large mass of soil/rock surrounding the wall, a slope stability analysis should be carried out in order to **assess the possibility of a deep seated slip failure passing beneath the wall**. Such slope instabilities typically occur in soft clayey soils or bedrock with planar weaknesses. Overall slope stability analyses are beyond the scope of this paper, suffice to say that when designing retaining walls one should always be on the lookout for adverse conditions that may give rise slope instability.

2.2 The Selection of Soil Parameters

In designing dry stack retaining walls, it is not usual to carry out extensive field and laboratory testing in order to establish appropriate soil shear strength and bulk unit weight parameters, and it is common for designs to be based on typical soil properties. For reference purposes, some typical soil properties are given in Table 1, below. It should be noted that it is assumed that the soils are purely frictional, i.e. they are cohesionless and their shear strength is solely dependent upon their internal angle of friction, ϕ. Generally earth pressures behind retaining walls are computed based on the assumption that the retained material is purely frictional. This is hardly surprising, since to the author's knowledge, although there are standard formulae and Tables of coefficients available to compute earth pressures for purely frictional soils, apart from for the case of a vertical wall with horizontal backfill, there are no such formulae or Tables of coefficients available that enable designers to readily calculate the effect on earth pressures of any cohesive component of the backfill's shear strength. Instead designers are referred to relatively cumbersome graphical techniques to compute forces on retaining walls applied by soils which possess both effective cohesion (c') and effective friction (ϕ').

TABLE 1 : TYPICAL VALUES OF SOIL PROPERTIES

TYPE OF MATERIAL	ϕ - degrees	γ - kN/m^3
Loose, sandy silt or clayey sand	25	18
Very loose, uniformly graded sand /slightly silty sand	28	17
Loose uniform sand, round grains or dense sandy silt	30	18
Dense or partially cemented uniform sand or Loose, well graded sand	33	19
Dense well graded sand - angular grains	35 - 40	20 - 22
Loose sandy gravels	35	19

The author has recently incorporated an analytical adaptation of the graphical wedge analysis technique in his dry stack retaining wall computer programme, which allows the user to enter parameters for a (c', ϕ') soil. However as will be demonstrated in a later example, attributing an effective cohesion even as low as c' = 5 kN/m^2 to the retained soil, dramatically reduces the earth pressure behind a walls, particularly behind those which slope back at 70° or less. Consequently the assignment of effective cohesion to the soil behind or in front of a wall should be done with extreme circumspection, and the author recommends that a factor of safety of at least three should be applied to the assessed or measured effective cohesion.

Wall Friction at rear of retaining wall

In most cases each row of blocks up a dry stack retaining wall has a prescribed backwards offset, and thus when the active wedge behind the wall is mobilized, its shear surface at the rear of the wall will practically be an entirely soil on soil contact. The wall friction (δ) will therefore be equal to or very nearly equal to the ϕ' of the retained material. The author generally uses a δ of between 0.8 ϕ' and 0.9ϕ'.

Foundation Wall Friction

Foundation wall frictions for rigid retaining walls such as reinforced concrete cantilever walls, are generally limited to less than or equal to 1/3 ϕ', the primary reason being that the development of full passive earth resistance requires a relatively large wall displacement. The author is of the opinion that because dry stack retaining walls are relatively flexible and less sensitive to differential displacements, a higher wall friction may be used, and provided that a displacement sensitive structure is not situated in close proximity to the rear of the wall, a foundation wall friction as high as 2/3 ϕ' may be used.

Base Friction

Provided a concrete foundation is provided for the wall, and the foundation is cast in situ the base friction (μ) may be taken as being equal to the ϕ' of the underlying soil. If no foundation is cast, then μ should be reduced to between 1/2 and 2/3 ϕ', because in such cases the base friction is developed between soil and precast concrete. It is for this reason that the author recommends that all dry stack retaining walls be supported on cast in situ foundations.

2.3 Selection of a trial wall slope

The final design's wall slope is dependent upon many factors, inter alia, the height to be retained, the nature of the soil to be retained, the slope of the ground behind the wall, whether or not external loads will be applied behind the wall, whether or not there are space constraints within which the wall must be constructed, and naturally type and size(s) of the blocks under consideration. Thus one can not be sure of selecting and initial trial wall slope that will be close to the final design's wall slope. Nonetheless, as a general rule, provided there are no space constraints, one would start off with a wall slope of between 65 and 70 degrees, and then if necessary flatten the wall slope in order to achieve a design which meets the desired design criteria. As can be seen from Figures 5 & 6, which show plots of the maximum wall height versus wall slope for three sizes of Loffelstein Blocks, the flattening of the wall slope sharply increases the maximum wall height until a wall slope of 60 degrees in the case of level backfill, and until approximately 55 degrees in the case of the ground slope of 26 degrees, thereafter no significant improvement in maximum retaining height is gained by further flattening the wall slope. This is provided one accepts the author's hypothesis that the effective wall weight should be reduced when the line resultant of action of the resultant passes behind the rear of the bottom row of blocks. This hypothesis is discussed in detail in Section 2.6. The limit beyond which no significant improvement in maximum retaining height can be gained by flattening the wall, appears to be independent of block size, but it is dependent on the ground slope behind the wall, and it will also be dependent upon the retained soil's shear strength and its weight.

In some cases there are space constraints and the wall must be built steeper than a certain prescribed angle, for example 85 degrees. Clearly in such cases there is no longer the option of flattening the wall slope in order to achieve the desired retained height. In these cases, it is unlikely that the blocks will be able to retain the desired height without either stabilizing backfill behind the wall or introducing geofabric reinforcement into the backfill. An example of a design incorporating stabilized backfill is given in Section 3.

In instances in which the ground slopes steeply down to the top of the wall, and the toe position of the wall is fixed, it is often useful to be able to calculate the height of a sloping wall relative to a vertical wall. An expression which enables one to do this is as follows:

$$h_S = \frac{h_V \sin\alpha \cos\beta}{\sin(\alpha - \beta)}$$

where h_S = height of wall with face sloping at α

h_V = height of vertical wall with the same toe position

α = angle of the front slope of the wall to the horizontal

β = angle of inclination of the retained soil

It should be appreciated that in such cases, beyond a certain wall slope, any apparent improvement gained in the block mix of a wall by flattening the wall, is negated by the increase in the wall height as a result of flattening the wall. Note the type of improvement in the block mix referred to here, is one in which the percentage of relatively cheap smaller blocks in the wall is increased while the percentage of larger blocks is reduced. If flattening the wall to increase the percentage of smaller blocks results in a higher wall, then there would only be an overall cost saving on the wall if the cost of having to use more smaller blocks, is less than the saving made on reduced number of larger blocks.

2.4 Calculation of the Destabilizing Forces

As with other types of retaining walls, the forces applied to dry stack retaining walls by the retained soil are invariably calculated based on the assumption that sufficient slight forward movement of the wall occurs to allow the development of active earth pressures. Active earth pressures are computed based on the assumption that a wedge of soil slides forward against the wall on the most critically inclined shear plane. Coulomb in 1776 initially published a solution containing formulae to calculate the active force applied by a cohesive frictional soil for the case of a vertical wall with horizontal backfill (total stresses only), and with no allowance for wall friction. In 1808 Mayniel extended the solution to include wall friction, but only for frictional non-cohesive soils. In 1906 the general solution for frictional cohesionless soils, was further extended by Muller-Breslau to allow for sloping backfill, a sloping back face to the wall and friction on the back face of the wall. Their solution as presented in Earth Pressure and Earth-Retaining Structures (C R I Clayton and J Milititsky, 1986), is given in Figure 1. The Coulomb and Mayniel solutions are also given in this book.

$$Q_a = \tfrac{1}{2}\gamma H^2 . \frac{f_1}{\sin\alpha . \cos\delta}$$

where

$$f_1 = \frac{\sin^2(\alpha+\phi).\cos\delta}{\sin\alpha.\sin(\alpha-\delta)\left[1+\sqrt{\left[\frac{\sin(\phi+\delta).\sin(\phi-\beta)}{\sin(\alpha-\delta).\sin(\alpha+\beta)}\right]}\right]^2}.$$

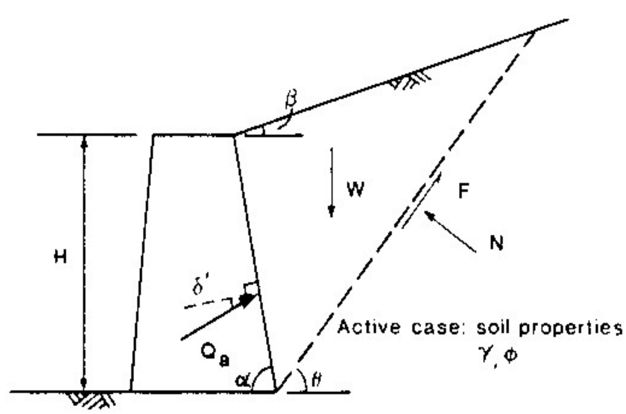


Figure 1 Muller-Breslau solution for the active force applied by a frictional cohesionless soil

In most cases designs are carried out on the basis of the Muller-Breslau solution in which it is assumed that the retained soil is purely frictional. In order to allow for soil cohesion in cases other than the straight forward case of a vertical wall with horizontal backfill, designers have had to resort to graphical techniques such as the wedge analysis illustrated in Figure 2 below. Figures 1 and 2 are taken directly from C R I Clayton and J Milititsky (1986). As mentioned above, the author has recently incorporated an analytical adaptation of this graphical wedge analysis technique in his computer programme for the design of dry stack retaining walls, which enables users to enter parameters for the effective cohesion c', and effective friction ϕ' of the soil.

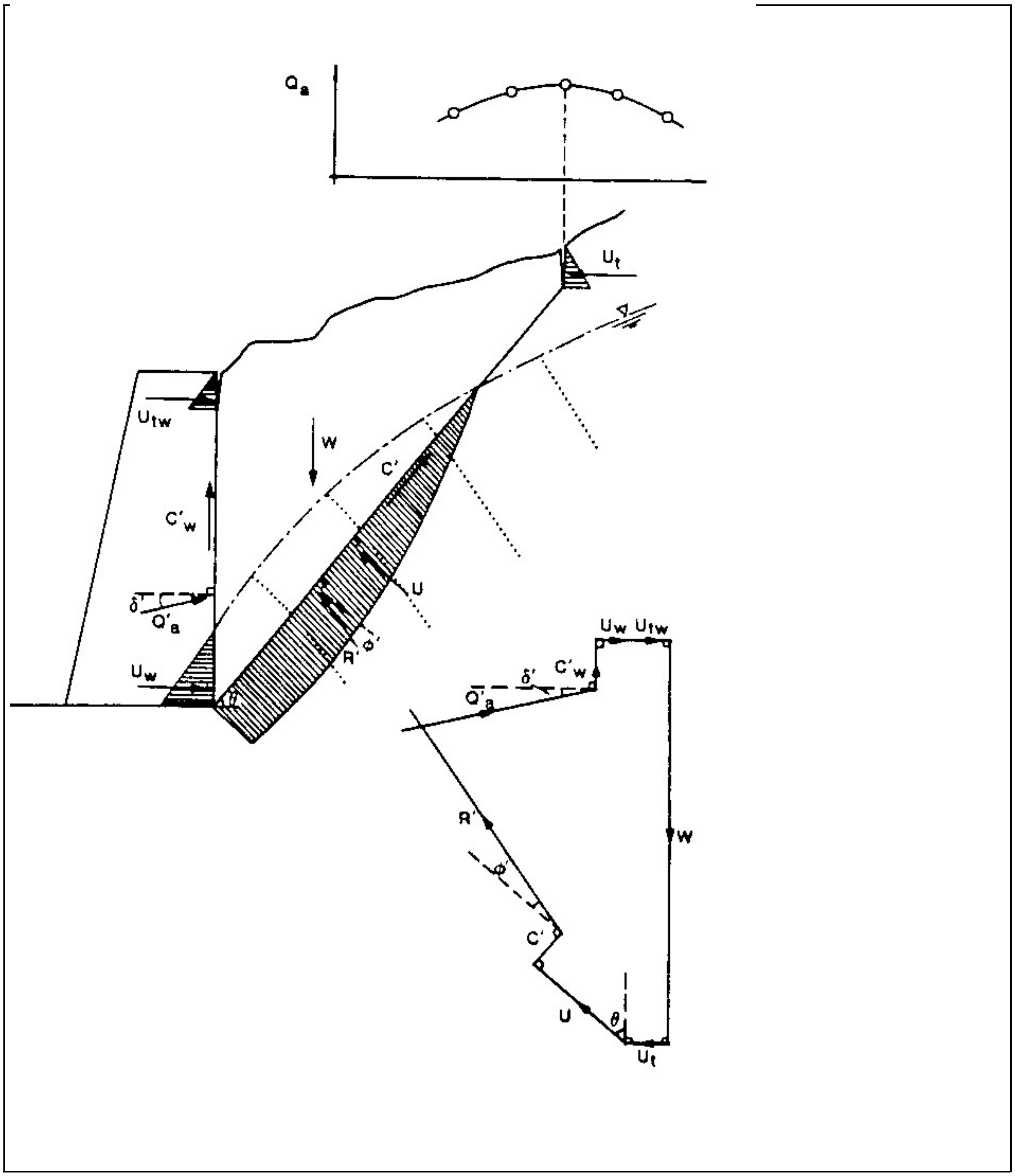


Figure 2 Wedge analysis for the active force case

Note that with the graphical wedge analysis, the inclination of the trial slip/shear surface at the base of the wedge, has to be varied until the critical surface is established, i.e. the surface that gives the maximum active force.

External Loads

In numerous books such as in C R I Clayton and J Milititsky (1986), there are standard elastic solutions for the horizontal stress increase due to point loads, line loads and loaded areas, for varying distances from and orientations to the back of retaining walls. These will not be reproduced here. At present the author's programme only enables the user to allow for either a line load applied parallel to the retaining wall, or a uniformly distributed load (UDL) applied over the entire area behind the wall. The empirical method used for assessing the effect of the line load is that of Terzaghi and Peck (1948), and it is shown in Figure 3.

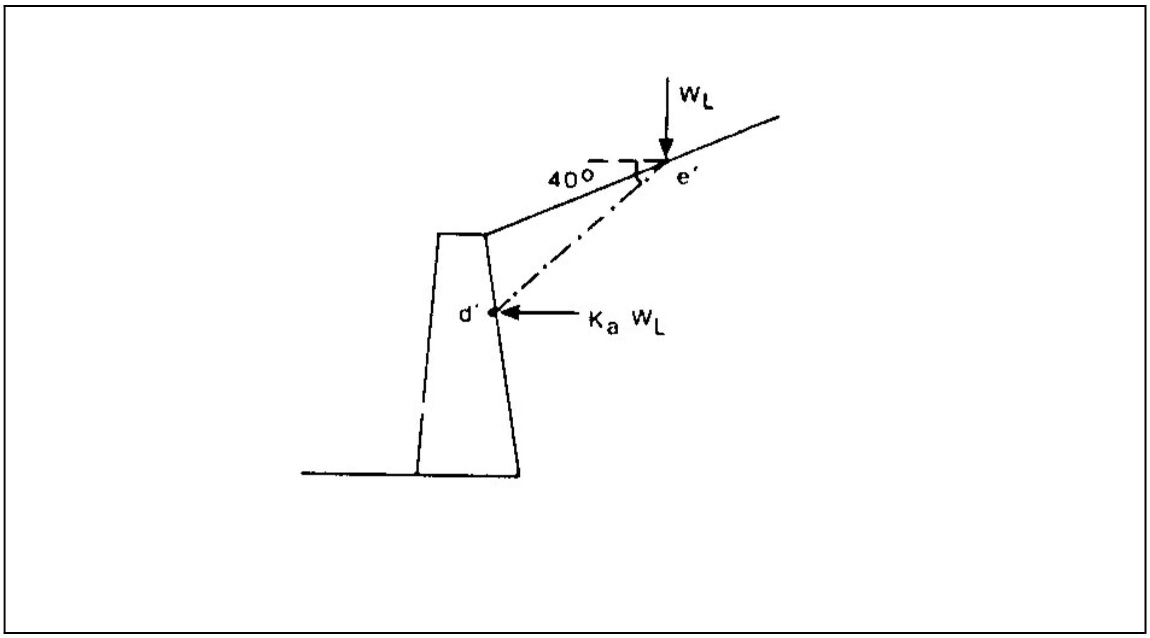


Figure 3 Method of assessing the effect of a line load (Terzaghi and Peck, 1948)

When dealing with a purely frictional backfill, the method favoured by the author for assessing the effect of a UDL behind the wall is as that of treating the load as equivalent to an extra height of soil. The expression used for the equivalent height is as given by G.N. Smith (1982):

$$h_e = \frac{w_s}{\gamma} - \frac{\sin\alpha}{\sin(\alpha+\beta)}$$

where γ = unit weight of soil
w_s = intensity of uniform load/unit area
α = angle of the back of the wall to the horizontal
β = angle of inclination of the retained soil

With the graphical wedge analysis the weight of the surcharge on each wedge is merely added to the weight of each wedge.

2.5 Calculation of the Resultant force and check on its Line of Action

The forces to be considered in analysing the stability of a dry stack retaining wall, are shown on Figure 4. The resultant force between the destabilizing forces and the self weight of the wall can then readily be calculated using a number of different approaches, one of which is as follows:

$$Q_{av.} = Q_a \,.\, \sin(\delta + \alpha - 90°)$$
$$Q_{as} = Q_a \,.\, \cos(\delta + \alpha - 90°)$$
$$Q_{uv} = Q_u \,.\, \sin(\delta + \alpha - 90°)$$
$$Q_{uh} = Q_u \,.\, \cos(\delta + \alpha - 90°)$$
$$Q_{lv} = Q_l \,.\, \sin(\delta + \alpha - 90°)$$
$$Q_{lh} = Q_l \,.\, \cos(\delta + \alpha - 90°)$$
$$\psi = \tan^{-1}((Q_{av} + Q_{uv} + Q_{lv} + W_e)/(Q_{ah} + Q_{uh} + Q_{lh}));$$
$$R = (Q_{ah} + Q_{uh} + Q_{lh})/ \cos(\psi);$$

where Q_a = active force due to earth pressures
Q_u = force on wall due to the Uniformly Distributed Load
Q_l = force on wall due to the Line Load
W_e = Effective Weight of the wall
ψ = Inclination of the resultant force to the horizontal
R = Resultant force
δ = wall friction
α = inclination of the back of the wall to the horizontal
the additional subscripts $_v$ and $_h$ signify respectively the vertical and horizontal components of the forces acting on the wall

Note that all the above forces are calculated per metre run of the wall.

Initially the effective weight of the wall is taken as being equal to the total weight of the wall, i.e. the total weight of the blocks and soil infill. Having computed the resultant force, the distance of its line of action from the toe of the bottom row of blocks is computed by taking moments of the wall weight and destabilizing forces about this point, and then dividing the moment by the resultant force. If the line of action of the resultant passes behind the back of the bottom row of blocks, then the author recommends that the effective height and corresponding effective weight of the wall be decrimentally reduced until the line of action passes within blocks. In adopting this approach one is assuming that the blocks at the top if the wall are effectively lying on and are supported by the retained slope, and that they are not contributing to the sliding resistance at the base of the wall. This approach certainly makes sense when you consider the extreme case of blocks stacked to form a "wall" to a height in excess of 10 metres at a slope of say 35 degrees, because under such circumstances the blocks over the entire height of the wall would be primarily supported by the backfill and it would be ludicrous to utilize the full weight of the wall in calculating the block on block sliding resistance at the base of the wall.

The design procedure of reducing the effective height and weight of the wall in order to keep line of action within the bottom blocks, has the effect of limiting the maximum retaining wall height that can be achieved by flattening the wall slope. This is clearly evident in Figures 5 and 6 which are plots of the maximum Loffelstein block retaining wall height versus wall slope, both for the approach of keeping the line of action of the resultant force within the bottom blocks, and for the approach of assuming that the total weight of the wall is always effective against sliding and overturning, even when the resultant's line of action passes behind the bottom row of blocks. As can be seen from Figures 5 and 6, with the former approach, down to an angle of 60 degrees with level backfill and down to 55 degrees with the ground behind sloping at 26 degrees, flattening the wall slope increases the maximum wall height, thereafter there is practically no increase in maximum wall height with decreasing wall slope. By contrast, with the latter approach there is a continued and near exponential increase in the maximum wall height when flattening the wall slope beyond 55 degrees.

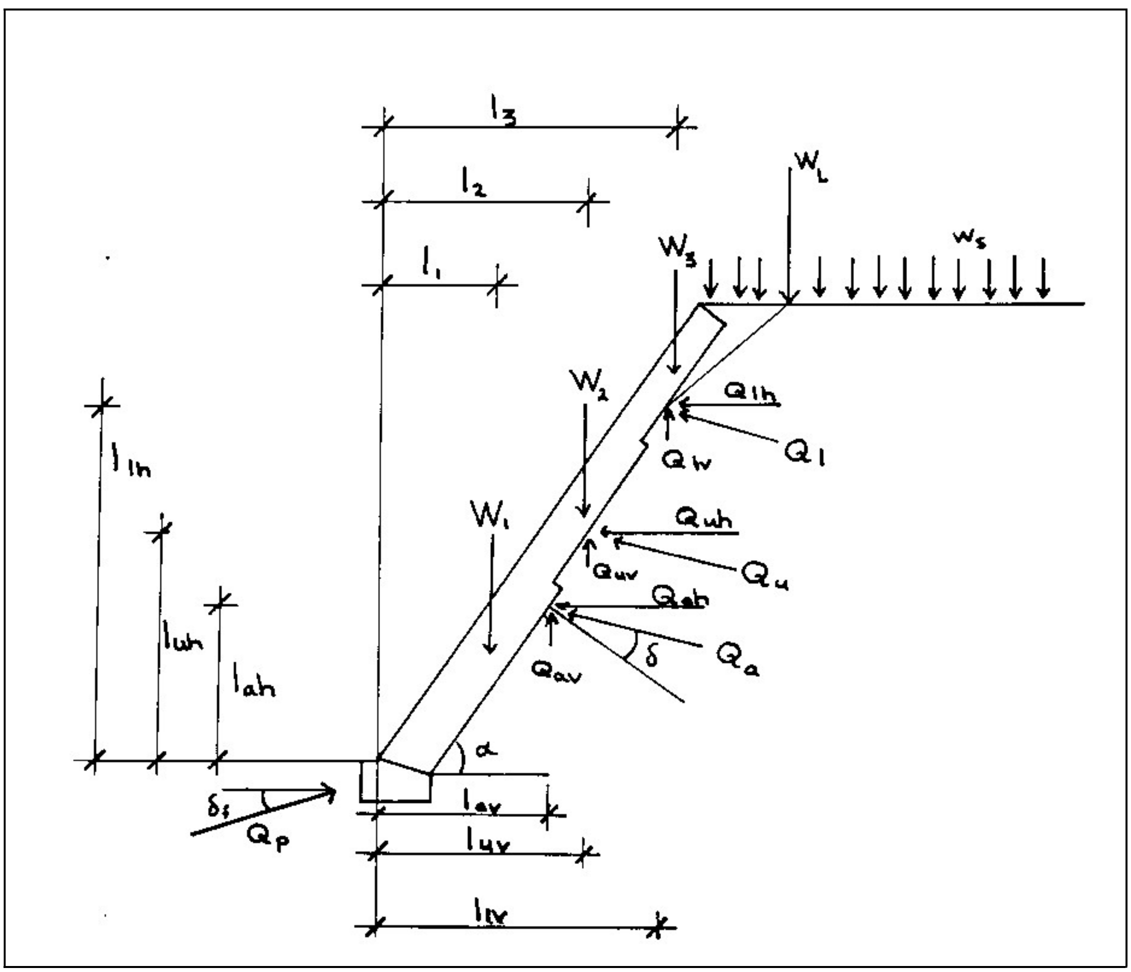


Figure 4 The forces to be considered in analysing a dry stack retaining wall

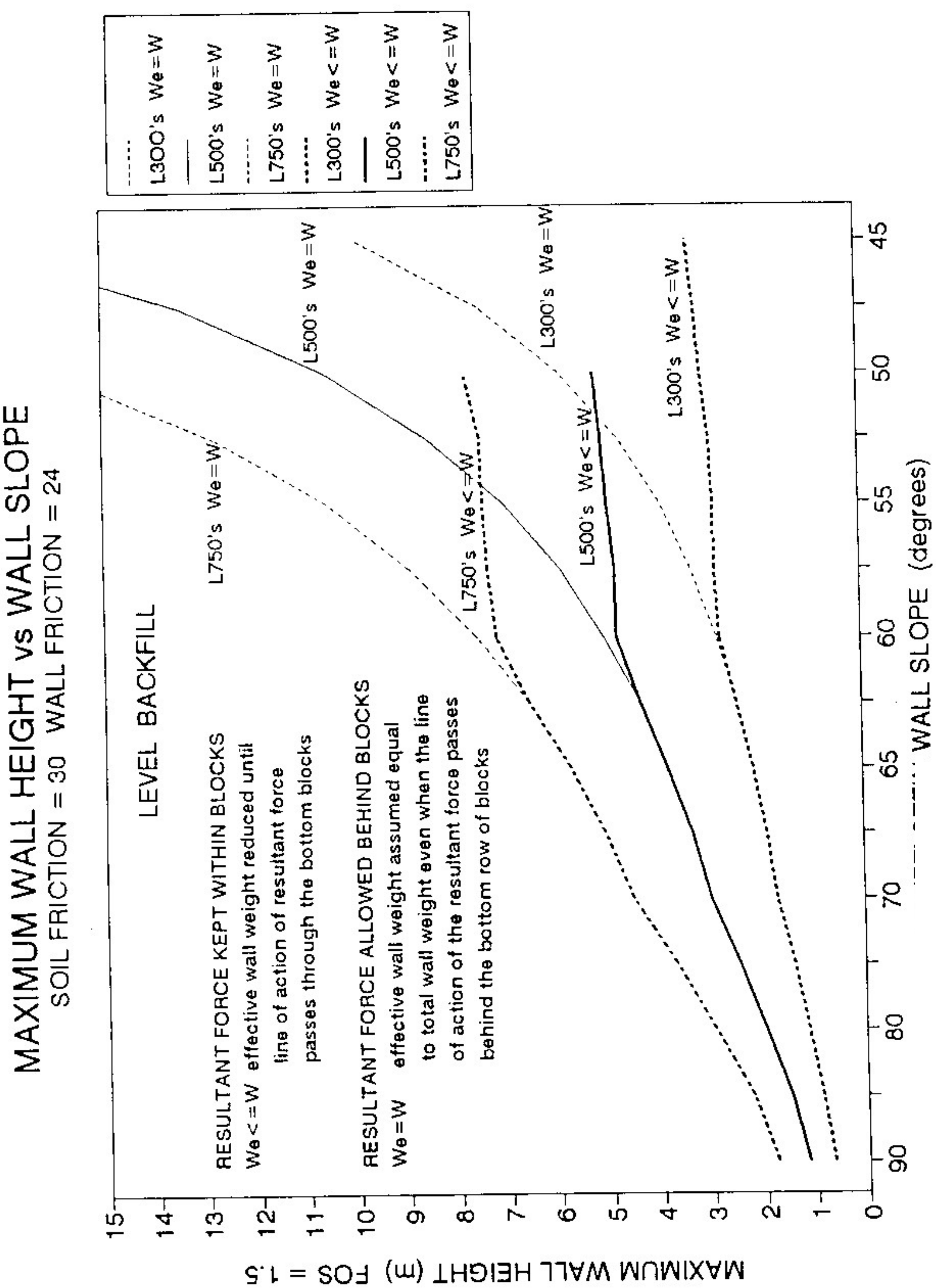

MAXIMUM WALL HEIGHT vs WALL SLOPE
SOIL FRICTION = 30 WALL FRICTION = 24
LEVEL BACKFILL
RESULTANT FORCE KEPT WITHIN BLOCKS
We<=W effective wall weight reduced until line of action of resultant force passes through the bottom blocks
RESULTANT FORCE ALLOWED BEHIND BLOCKS
We=W effective wall weight assumed equal to total wall weight even when the line of action of the resultant force passes behind the bottom row of blocks
L750's We=W
L500's We=W
L300's We=W
L750's We<=W
L500's We<=W
L300's We<=W
L300's We=W
L500's We=W
L750's We=W
L300's We<=W
L500's We<=W
L750's We<=W
MAXIMUM WALL HEIGHT (m) FOS = 1.5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
90
80
70
65
60
55
50
45
WALL SLOPE (degrees)

FIGURE 5

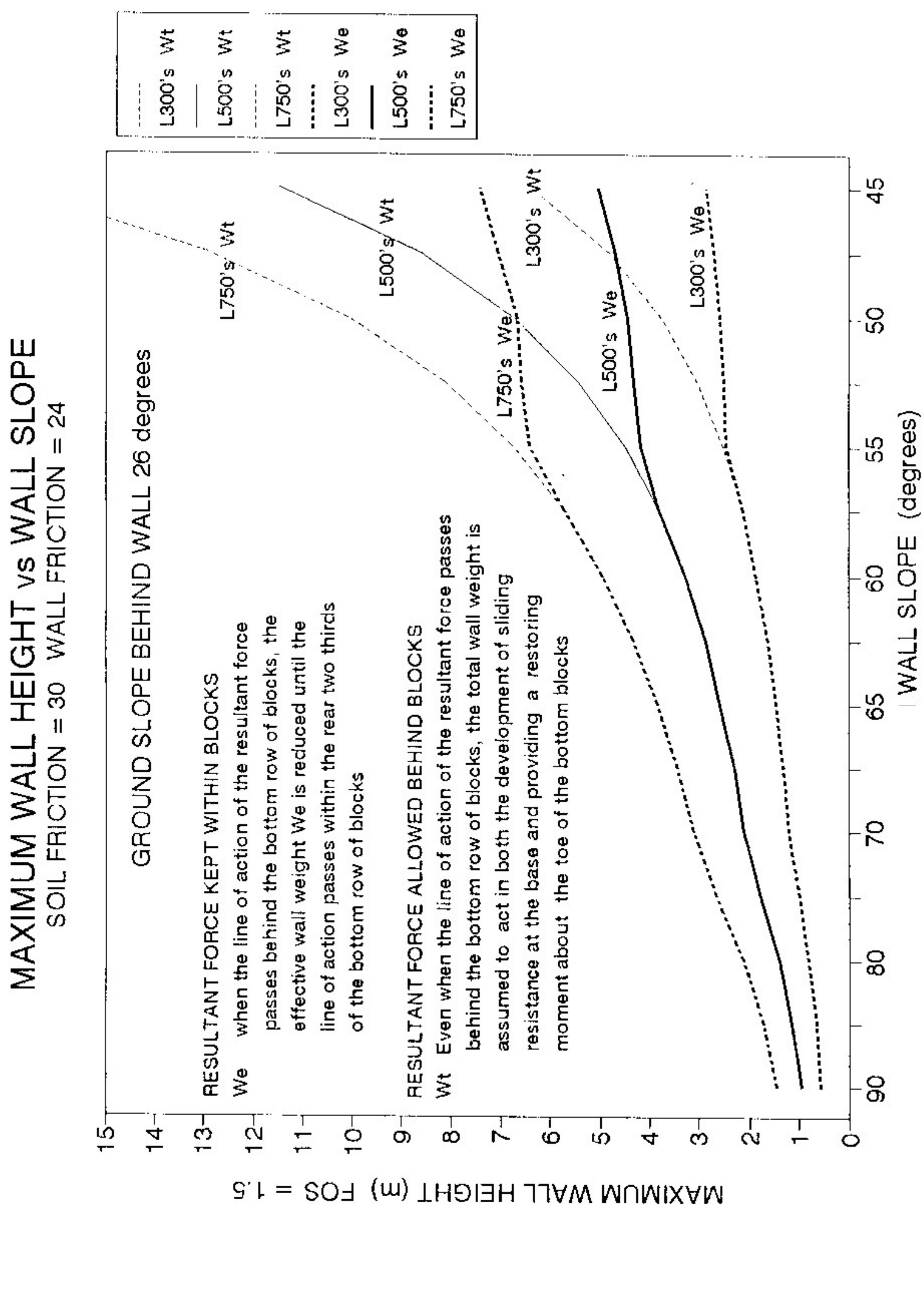

MAXIMUM WALL HEIGHT vs WALL SLOPE
SOIL FRICTION = 30 WALL FRICTION = 24
GROUND SLOPE BEHIND WALL 26 degrees
RESULTANT FORCE KEPT WITHIN BLOCKS
We when the line of action of the resultant force passes behind the bottom row of blocks, the effective wall weight We is reduced until the line of action passes within the rear two thirds of the bottom row of blocks
RESULTANT FORCE ALLOWED BEHIND BLOCKS
Wt Even when the line of action of the resultant force passes behind the bottom row of blocks, the total wall weight is assumed to act in both the development of sliding resistance at the base and providing a restoring moment about the toe of the bottom blocks
L300's Wt
L500's Wt
L750's Wt
L300's We
L500's We
L750's We
MAXIMUM WALL HEIGHT (m) FOS = 1.5
WALL SLOPE (degrees)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
45
50
55
60
65
70
80
90

FIGURE 6

2.6 Calculation of Overturning Factor of Safety

The overturning factor of safety is determined by calculating the restoring moment and the overturning moment about the toe of the second to lowest row of blocks, and dividing the restoring moment by the overturning moment. The blocks in the bottom row are invariably set in wet foundation concrete, and as a result effectively become part of the foundation. It is for this reason that overturning is considered at the level of the second to lowest row of blocks.

$$\text{Overturning Factor of Safety} = \frac{\text{Restoring Moment}}{\text{Overturning Moment}}$$

Referring to Figure 4 and to Section 2.4:

$$\text{Restoring Moment} = W_1.l_1 + W_2.l_2 + W_3'.l_3' + Q_{av}.l_{av} + Q_{uv}.l_{av} + Q_{lv}.l_{lv}$$
$$\text{Overturning Moment} = Q_{ah}.l_{ah} + Q_{uh}.l_{uh} + Q_{lh}.l_{lh}$$

The author recommends that effective weight of the wall be used in the calculation of the restoring moment. The author is aware that some designers of walls that comprise a mixture of block sizes, assume that all the soil that lies above the larger lower blocks within a projection of the back line of these blocks, see Figure 7, acts together with the wall in resisting overturning and sliding. The author is of the opinion that while this is a reasonable assumption for vertical walls, with sloping dry stack walls which typically slope at 70 degrees or flatter, there is no justifiable reason to assume that in such conditions a long narrow inclined block of soil would act as if is were part of the wall. Certainly a relatively small wedge of soil immediately above the top row of the larger blocks would contribute towards the weight of the wall, see Figure 8. However in most cases, other than when the slope of the wall is near vertical, the size of such a wedge is insignificant, and currently in the author's computer programme the contribution of any such wedge is ignored.

It is usual to take the point of application of the active force on the rear of the wall as being at a third the height of the wall (h/3) and the point of application of the force due to a uniformly distributed load (Q_u) as being half way up the wall (h/2).

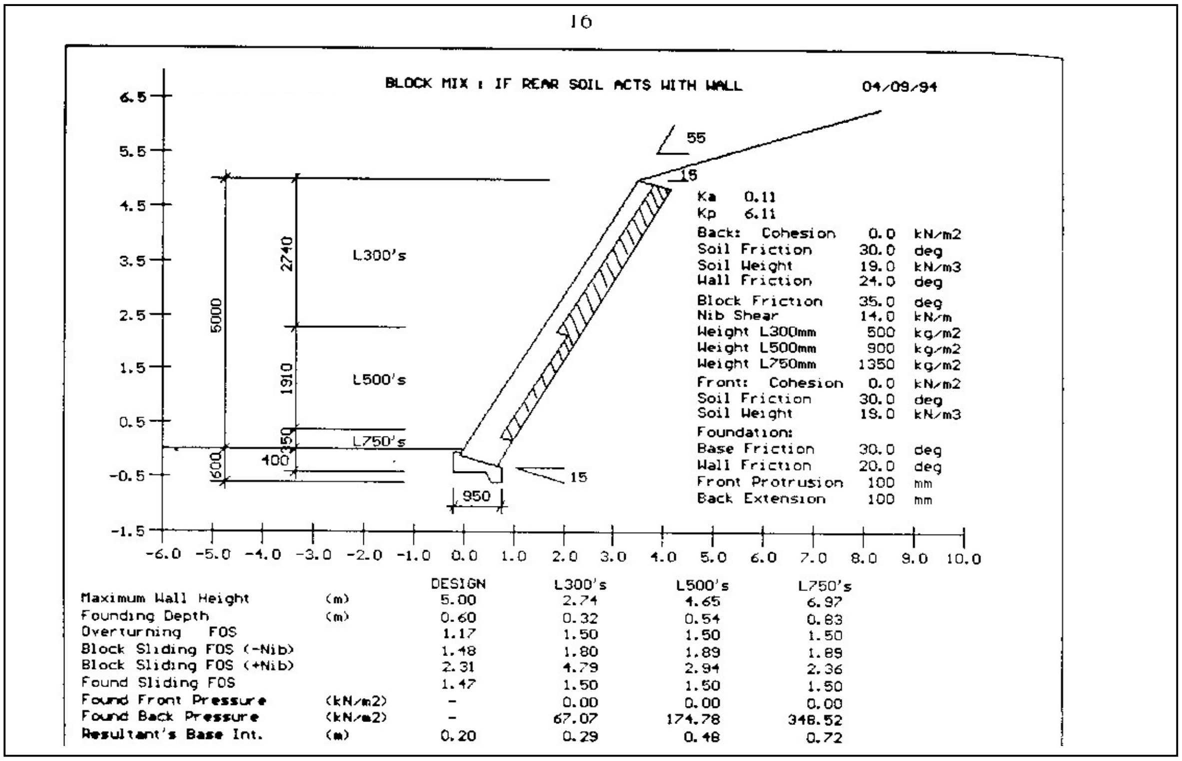


Figure 7 Diagrammatic illustration showing block of soil that some designers assume act together with the wall to resist sliding and overturning.

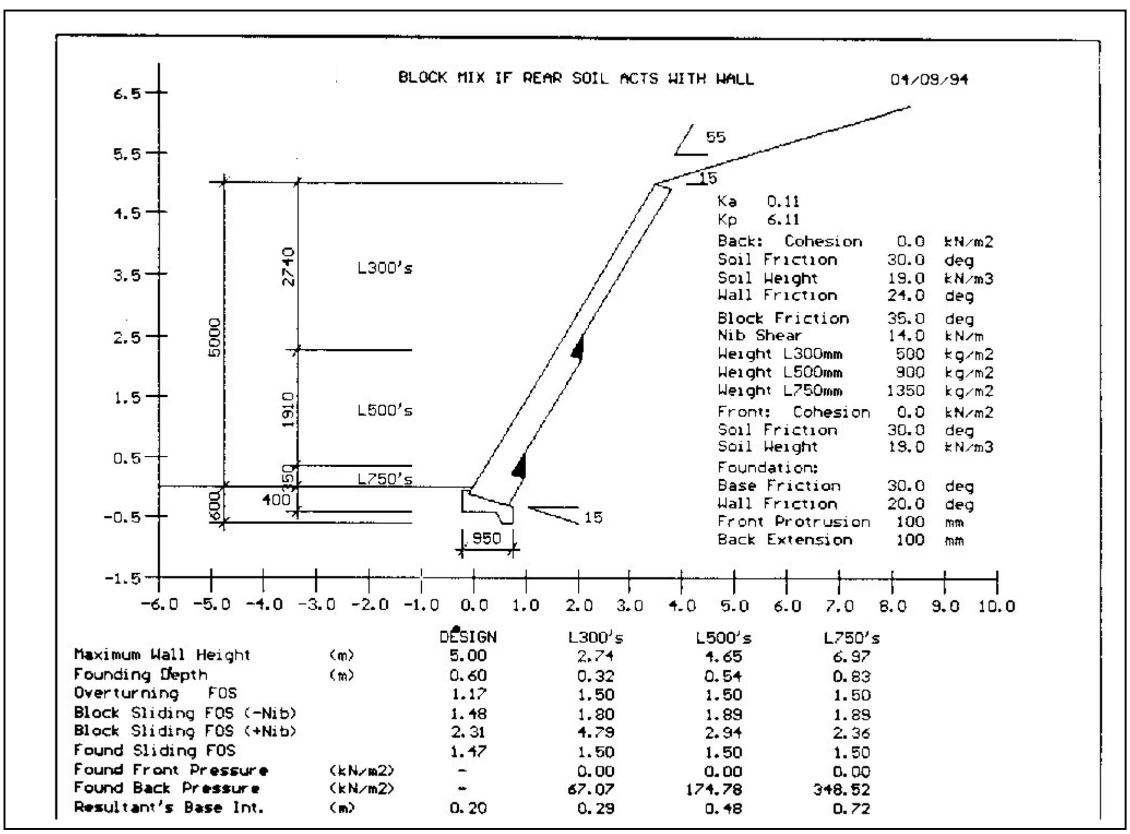


Figure 8 Diagrammatic illustration showing the scale of the wedges of soil that undoubtedly directly contribute to the weight of the wall.

2.7 Calculation of Factor of Safety against Block on Block Sliding

The factor of safety against block on block sliding is calculated at the most critical level, i.e. between the bottom two rows of blocks.

$$\text{Block on Block Sliding Factor of Safety} = \frac{\text{Resisting Force}}{\text{Mobilizing Force}}$$

where,

Resisting Force = $R \cdot \sin(\alpha + \omega) \cdot \tan(\rho) + N_S$

Mobilizing Force = $R \cdot \cos(\alpha + \omega)$

α = Inclination of the resultant force to the horizontal

ω = Backwards tilt/inclination of the blocks

R = Resultant force

ρ = block on block friction angle

N_S = nib shear strength of the blocks per metre run of wall

Note that the nib shear strength of the blocks, for block types that posses nibs, should only be taken into account if the wall is constructed so that each row of blocks is placed hard up against the nibs of the row below. In practice this is achieved by ensuring that the sum of the angle of the backwards tilt of the blocks and the design slope angle of the wall equals the maximum slope for that type of block wall. For example if the maximum wall slope of the blocks is 70 degrees, and the design slope of the wall is 55 degrees, then the backwards tilt of the blocks should be 15 degrees. The author has carried out testing to establish the nib shear strength of Loffelstein Blocks, and discovered that they can safely be assumed to have a shear resistance of 14 kN per metre run of wall. As will be seen in the examples in Section 3, this nib shear strength makes a major contribution to the block and block sliding resistance. It is thus always good construction practice to ensure that the nib interlock is achieved. With some types of retaining blocks which do not have nibs, the use of precast concrete keys wedged between rows of blocks are recommended as a substitute for nibs. In cases where such keys are to be installed, they should be included in the block on block sliding resistance in a similar manner to nibs.

2.8 Determination of a Suitable Founding Depth

Initially a trial founding depth is selected, either based on experience with walls in similar conditions or an arbitrary depth of say 0.5 metres is selected. Then the factor of safety against foundation sliding is calculated as shown on the following page. If the factor of safety is found to be too low then the founding depth would have to be increased until a satisfactory factor of safety is obtained. This iterative approach is well suited to computer analysis.

:

$$\text{Foundation Sliding Factor of Safety} = \frac{\text{Resisting Force}}{\text{Mobilizing Force}}$$

where,

Resisting Force = $(Q_{av} + Q_{uv} + Q_{lv} + Qp.\sin(\delta_f) + W_e + W_f)\tan(\mu) + Qp.\cos(\delta_f)$

Mobilizing Force = $Q_{av} + Q_{uv} + Q_{lv}$

and

Q_a = Active Force applied by the rear soil pressure down to the base of the found

Q_p = Passive Force applied by the front soil pressure down to the base of the found

δ_f = Wall Fiction between the front of the foundation and the soil

μ = Friction angle between the base of the foundation and the soil

W_e = Effective weight of wall determined as described in Section 2.6

W_f = Weight of the foundation

Note: the remainder of the variables are as defined in Section 2.5

The active force (Q_a) is calculated in the same manner as described in Section 2.4, the only difference being that the height of the active pressure distribution extends down to the base of the foundation and not just over the retained height of soil.

The foundation pushing against the soil in front of the wall, induces what is termed a passive pressure state. There is a Muller-Breslau solution for the calculation of the passive force, which is given below in the form it appears in C R I Clayton and J Milititsky (1986). As with the active case, the solution assumes that the failure occurs on a critical discrete planar shear plane, and that the soil is rigid, frictional and cohesionless.

$$Q_p = \tfrac{1}{2}\gamma H^2 . \frac{f_2}{\sin\alpha\cos\delta}$$

where

$$f_2 = \frac{\sin^2(\alpha - \phi)\cos\delta}{\sin\alpha.\sin(\alpha + \delta)\left[1 - \sqrt{\left[\dfrac{\sin(\phi + \delta).\sin(\phi + \beta)}{\sin(\alpha + \delta).\sin(\alpha + \beta)}\right]}\right]^2}$$

In most designs, the passive force resisting foundation sliding is calculated on the basis of the above equation with the founding depth substituted for H. Thus it is generally assumed that the soil is purely frictional. As with the computation of the active force, in order to allow for soil cohesion in cases other than with the straight forward cases with horizontal ground in front of the wall, designers have had to resort to cumbersome time consuming graphical techniques. One such technique is explained in C R I Clayton and J Milititsky (1986). This technique assumes a combined curved and planar slip surface. The author has recently incorporated in his computer programme for the design of dry stack retaining walls, an analytical adaptation of a graphical wedge analysis technique similar to that used to determine active forces, to compute passive forces in cases in which users wish to enter parameters for the effective cohesion c', and effective friction ϕ' of the soil. The assumption that the critical slip plane is purely planar results in a lower passive force, i.e. it errs on the conservative side.

2.9 Calculation of Foundation Bearing Pressures

The method utilized by the author for calculating the foundation bearing pressures beneath the back and front of the foundation is the standard method applicable to eccentrically loaded foundations, and essentially is as follows:

$R_V = R \cdot \sin(\psi + \omega)$
$E_f = B / 2 - X$

if the line of action of resultant force R intersects the foundation behind its front two thirds, then Found Front Pressure $= 0$
and Found Back Pressure $= 2R_V / 3 / (B - X)$

if the line of action of R intersects the foundation within its front third, then
Found Front Pressure $= 2R_V / 3 / X$
and Found Back Pressure $= 2R_V / 3 / (B - X)$

if the line of action of R intersects the foundation within its middle third, then
$M = 6 R_V \cdot E_f / B^2$
Found Front Pressure $= R_V / B - M$
and Found Back Pressure $= R_V / B + M$

where R_V = vertical component of the Resultant Force
E_f = Eccentricity of the Resultant Force from the middle of the foundation
X = Distance from the front of the foundation to the point of intersection of the line of action of the resultant force with the foundation
B = Width of the Foundation
ψ = Inclination of the resultant force to the horizontal
ω = Inclination of the top surface of the foundation to the horizontal
Note that the weight of the foundation has been ignored.

If the computed bearing pressure beneath either the front or back of the foundation is unacceptably high then it should be reduced by increasing the foundation width. Within the author's programme, this is done either increasing the protrusion of the foundation in front of the blocks or increasing the protrusion of the foundation behind the back of the blocks.

3. Design Examples Using The Author's Computer Programme

This programme automatically designs dry stack retaining walls as gravity walls using the approach outlined above. In the cases with purely frictional soils, the programme utilises the Muller-Breslau equations developed using Coulomb theory to determine active and passive forces applied by the soil. With soils that possess both effective cohesion and effective friction, the active and passive forces are computed using an analytical adaptation of the graphical wedge technique. An optimal design is carried out simultaneously on up to three different block sizes, utilizing Sliding and Overturning Factors of Safety specified by the user, in compliance with the constraint that the line of action of the resultant force passes through the rear 2/3 of the bottom blocks. This is achieved by reducing the effective weight of the wall when the line of action of the resultant passes behind the blocks, until it is within the blocks. If its impossible to achieve the desired wall height with an acceptable Factor of Safety, then the user would have to either flatten the wall slope, or increase the effective block width and weight by introducing a stabilized block of soil behind the blocks. It also helps the block on block sliding resistance if the blocks are given a backward tilt. In practice, this can either be done by inclining the top surface of the foundation, or by setting the bottom row of blocks in wet concrete with the desired backwards tilt.

Typical Application For A Dry Stack Retaining Wall

A building platform is to be cut into a 15 degree slope, and would require a 4.38 metre high vertical retaining wall to retain the slope on the upslope side of the platform. Your client requests you to design a Loffelstein block alternative to a reinforced concrete retaining wall. The soil is a uniform, cohesionless, medium to fine grained sand, and an angle of internal friction of 30 degrees is applicable to the soil.

3.1 Initial Trial Design

Firstly select the data input menu, and enter the required data.

The programme has a number of default data inputs, such as the block lengths and wall weights per square metre for Loffelstein L300, L500 and L750 blocks. You are required, should the default values not be appropriate, to input an initial trial wall slope, the wall height, the slope behind and in front of the wall, appropriate parameters for the soil in front and behind the wall i.e. the internal friction and unit weight, also the wall friction, base friction, Overturning FOS, Block Sliding FOS, Foundation Sliding FOS, foundation wall friction, a line load and a uniformly distributed load.

If the default wall slope of 65 degrees is selected, then assuming the toe of the wall is required to be in the same position as the 4.38 metre high vertical wall, the sloping retaining height would be 5.0 metres. Having entered this height and the ground slope behind the wall as 15 degrees, all other default inputs could be left unchanged, and the design of the wall as shown in Figure 9 is carried out by selecting option 5, the "Design Wall and Screen Plot of Design" option, from the main menu.

The process carried out by the computer in designing or attempting to carry out the design of the wall at this angle, is to calculate the maximum height to which you could build a solely L300 block wall, a solely L500 block wall and a solely L750 block wall. The results of this analysis are presented below the diagram in Figure 9. From these results is can be seen that for the 65 degree wall slope under the specified conditions and design criteria, the maximum height of a L300 block wall would be 1.85 metres, of a L500 block wall 3.29 metres and of a L750 block wall 4.93 metres. The programme then checks to see whether the required design height is less than the maximum L300 height, between the maximum L300 height and L500 height, between the maximum L500 height and L750 height or greater than the maximum L750 height. If the required design height is less than the maximum L300 height it computes the design factors of safety using only L300 blocks, if it lies between any of the other maximum block heights, the programmes optimizes the block mix to incorporate as many of the smaller blocks as possible. Finally if as is the case in this example, the required design height is greater than the maximum L750 block wall height the programme computes the relevant factors of safety for the wall assuming it comprises solely L750 bocks, these the biggest blocks available to it. Note that the overturning moment of 1.48, is slightly less than the required value of 1.5.

Even if the wall comprised solely of L750 blocks, did meet all the design criteria including having an overturning factor of safety of at least 1.5, it is unlikely that it would be the most economical design. Furthermore each L750 block weighs approximately 100 kg, and building up to a height of 5 metres with them would be a relatively difficult task. For these reasons it is always recommended that provided there are no space constraints limiting the degree to which you are allowed to flatten the wall, an alternative design be carried out using a flatter trial wall slope.

3.2 Example of Flattening the Wall Slope to improve/achieve the Design

In this case, if the wall is flattened to 55 degrees and the backwards inclination of the blocks increased to 15 degrees so as to maintain nib interlock between rows of blocks, then the programme generates the design shown in Figure 10. Note the wall height which has been increased to 5.39 metres on the basis of the assumption that the toe of the wall is fixed, and thus a 55 degree wall would meet the 15 degree rear ground slope at this slightly greater height. From the data input which is shown to the right of each wall, it can be checked that the remainder of the input data has been left unchanged. As can be seen, flattening the wall slope to

55 degrees, leads to a dramatic improvement in the block mix, with most of the L750 blocks being replaced by the smaller L300 and L500 blocks.

Note that through an iterative process the programme computes the exact founding depth required to give the specified factor of safety against foundation sliding, the default value of which is 1.5.

3.3 Example of Incorporating Stabilized Backfill to achieve the Design

In some cases, there are space constraints, such as the need for the wall to stay within a boundary line, that restrict the extent to which one is able to flatten the wall. For example, assume that in the above case the wall slope can be no flatter than 65 degrees. At this wall slope, L750 blocks on their own were not quite stable enough, and so one is forced is investigate other alternatives. One alternative under such circumstances is to stabilize a set width of backfill behind the blocks, with sufficient stabilization to be able to treat the backfill a part of the gravity wall. The strength of the stabilization is crucial to this solution and often is necessary to import a good quality granular backfill. It is usual to use cement stabilization and to mix it with the backfill at between 6% and 8 % by weight. The design is then carried out by increasing the default block lengths in the programme to a length equal to the length of the block plus the width of the backfill. The corresponding weights of the wall per square are is also increased to include the weight of the stabilized backfill. For example, if a 500 mm width of backfill is stabilized behind L500 blocks, then the width of this composite block becomes 1.0 metres, and the weight becomes 900 kg + 1000 kg = 1900 kg per square metre. When introducing stabilized backfill as part of the wall, the author generally does away with the option of including L300 blocks, and uses L500 blocks as the smallest block. For example, as an initial design attempt, the medium block is input as being 1.0 metres long, i.e. L500 blocks with 500 mm stabilized backfill them, and the large blocks as 1.2 metres long, i.e. L500 blocks with 700 mm stabilized material behind them. A design carried out on this basis, is shown in Figure 11.

Note that this solution requires that the entire wall be constructed using L500 blocks, and in addition the initial 3 metres of the wall should have a 500 mm width of stabilized backfill compacted behind it. It is usual to ensure that the stabilized backfill extends at least 300 mm into the blocks.

3.4 Example with the Inclusion of Effective Cohesion in the Retained Soil

Effective cohesion within the retained soil, substantially reduces the active force behind retaining walls, particularly in the case of walls that slope back at 70 degrees of less. As a consequence even an effective cohesion as low as 5 degrees, dramatically improves the block mix. This is clearly evident from the design example shown in Figure 12, when it is compared with the equivalent design for a purely frictional material which is shown in Figure 9. In view of the sensitivity of the design to effective cohesion, the assignment of effective cohesion to the soil behind or in front of a wall should be done with extreme circumspection. The author recommends that generally one designs on the assumption that there is no effective cohesion and that if one is going to utilise it a factor of safety of at least five should be applied to the assessed or measured effective cohesion.

4. Conclusion

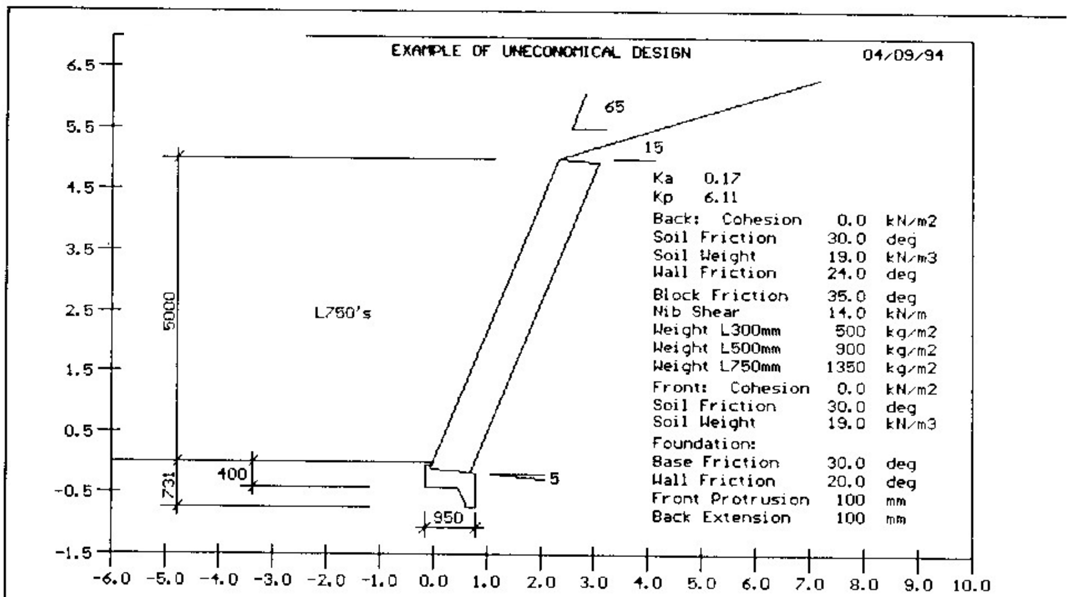
Many dry stack retaining walls have been constructed in accordance with designs based on the above method of design. A number of these walls are between 5 and 8 metres high, and they are retaining loose, cohesionless, uniformly graded medium to fine grained sands, which undoubtedly are applying high pressures to the rear of the walls. It is for this reason that more and more engineers are developing confidence in these retaining systems. The author cautions against the designing these walls to great heights using the total weight of the wall regardless of the position of the line of action of the resultant force, and believes that many of the walls designed on this basis, are still standing by the grace of soil cohesion within the retained material which substantially reduces the earth pressures. In many such cases the slopes are stable and the blocks merely serve as weathering protection. The author has seen poorly engineered dry stack walls as low as 3 metres high, which have failed. What was interesting to note in the case of one of such 3 metre high wall, was the fact many of the blocks at the base of the wall had crushed, and a back analysis by the author showed that this was approximately the height at which the resultant force would be acting through the rear of the blocks. In theory there would be infinite stress at the back edge of the blocks when the resultant force passes through or behind this point, and in practice there is no doubt that high stresses are induced in the blocks under such conditions. In the case of Loffelstein blocks, heavy duty blocks, i.e. blocks with a substantially thickened base, were introduced in order to obviate cracking of blocks in walls greater than three metres high. When building high walls with a relatively weak block type, it is good construction practice to fill every second or third block below the 3 metre retaining level with concrete.

The failure of some walls through the crushing of blocks certainly highlighted the importance of taking cognizance of the position of the resultant in design. As will have become apparent from this paper, author's design method hinges on the hypothesis that the effective weight of the wall should be adjusted in order to keep the line of action of the resultant force within the blocks. However as yet, to the author's knowledge, there has been no research into dry stack retaining systems which supports this or any other design approach. It is with a view to providing such research that the author proposes to carry out full scale testing on dry stack retaining systems.

REFERENCES

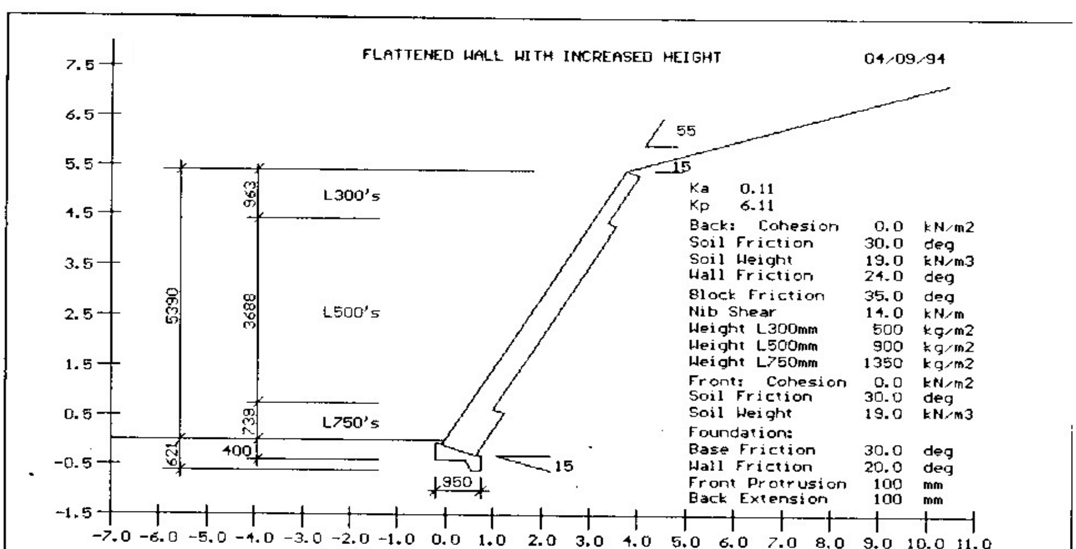
Clayton, C. R. I. and Milititsky, J. (1986). Earth Pressure and Earth Retaining Structures. Surrey University Press.

Smith, G.N. (1982). Elements of Soil Mechanics for Civil and Mining Engineers. Granada Publishing Limited.



		DESIGN	L300's	L500's	L750's
Maximum Wall Height	(m)	5.00	1.85	3.29	4.93
Founding Depth	(m)	0.73	0.26	0.47	0.71
Overturning FOS		1.48	1.50	1.50	1.50
Block Sliding FOS (-Nib)		1.37	1.37	1.39	1.39
Block Sliding FOS (+Nib)		1.77	4.26	2.31	1.80
Found Sliding FOS		1.50	1.50	1.50	1.50
Found Front Pressure	(kN/m2)	28.95	11.21	16.73	23.14
Found Back Pressure	(kN/m2)	115.95	26.62	69.44	119.73
Resultant's Base Int.	(m)	0.47	0.18	0.32	0.48

Figure 9 Example of design on initial steep trial wall slope. The use of L750 blocks over the entire wall slope is uneconomical, and construction is relatively difficult.



		DESIGN	L300's	L500's	L750's
Maximum Wall Height	(m)	5.39	2.74	4.65	6.97
Founding Depth	(m)	0.62	0.32	0.54	0.83
Overturning FOS		1.50	1.50	1.50	1.50
Block Sliding FOS (-Nib)		1.86	1.80	1.89	1.89
Block Sliding FOS (+Nib)		2.65	4.79	2.94	2.36
Found Sliding FOS		1.50	1.50	1.50	1.50
Found Front Pressure	(kN/m2)	0.00	0.00	0.00	0.00
Found Back Pressure	(kN/m2)	102.38	67.07	174.78	348.52
Resultant's Base Int.	(m)	0.56	0.29	0.48	0.72

Figure 10 Example showing the improvement in the block mix that can be achieved by flattening the slope of the wall.

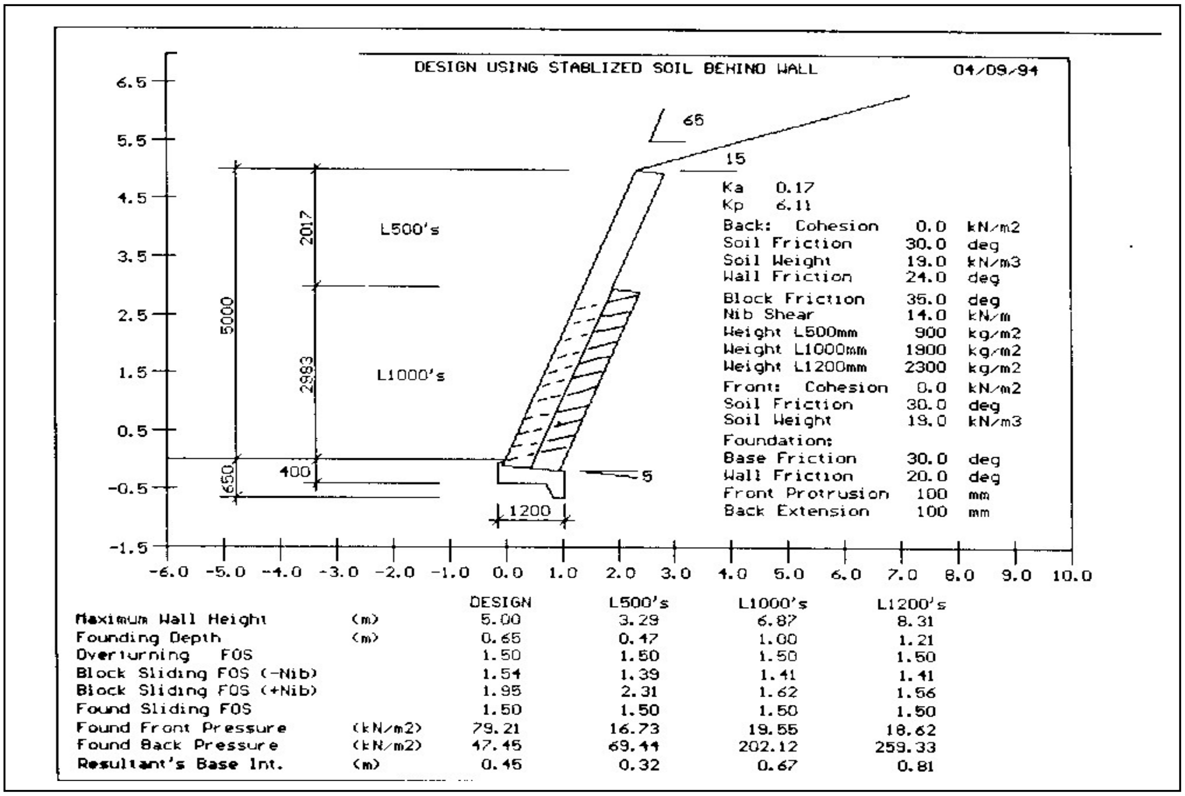


Figure 11 Example of a design in which the wall slope in kept at at steep angle, and a stabilized block of backfill is included in the design as part of the wall.

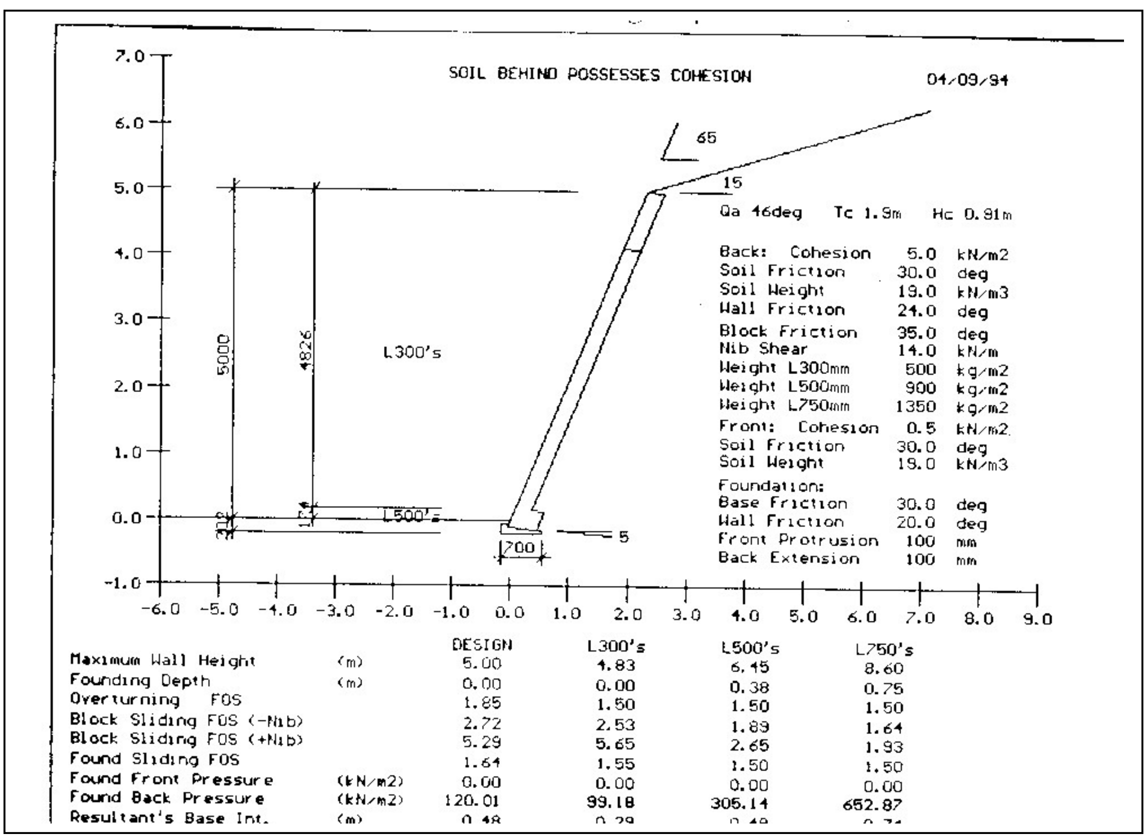
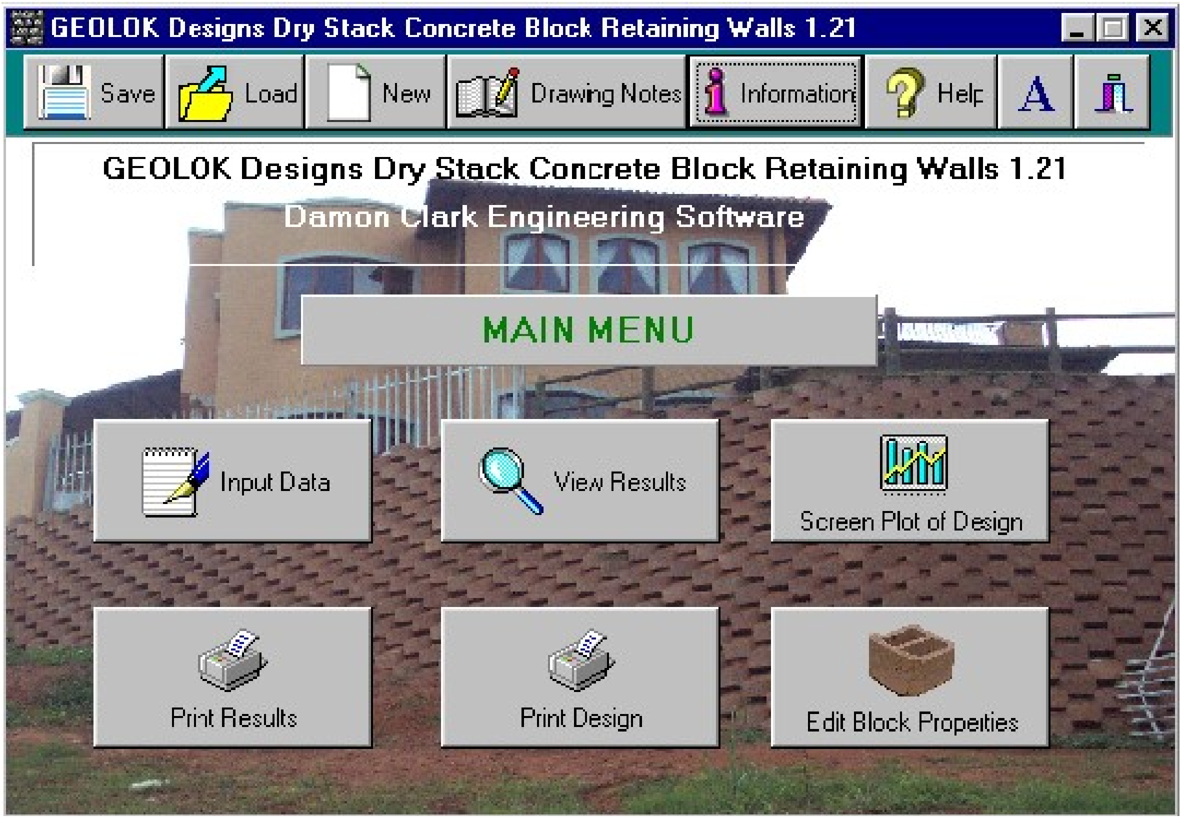


Figure 12 Design example showing the dramatic improvement in the block mix, which results if the retained soil is assumed to possess effective cohesion as well as effective friciton.

6. RUNNING "GEOLOK", ie DESIGNING GEOLOK RETAINING WALLS

Having installed the “Geolok” programme using the installation programme the following main menu will appear:

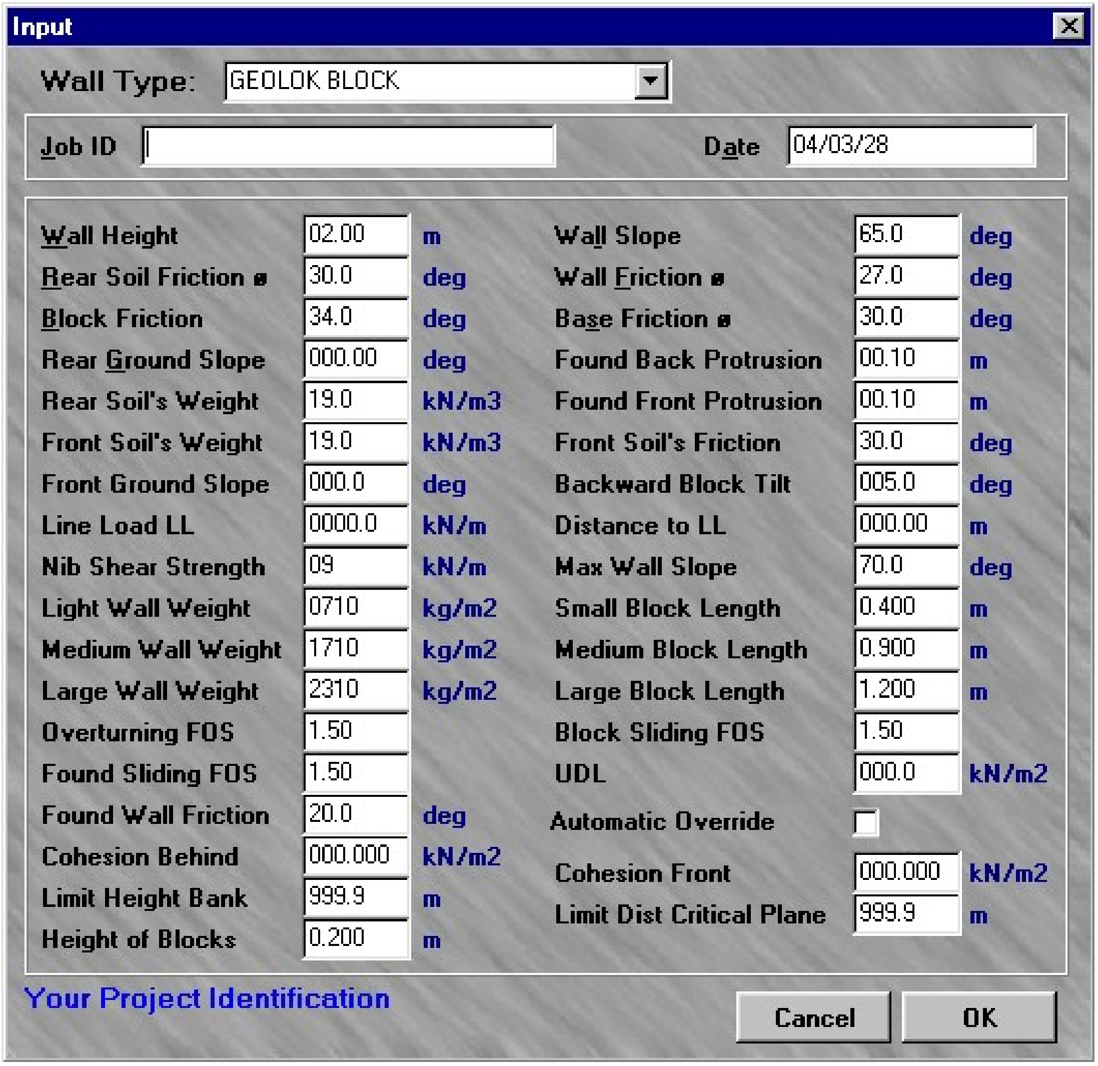


6.1 DATA INPUT

After selecting the Input Data option, by clicking on its button the data input spread sheet shown on the following page will be displayed.

You will note that default values have been assigned to many of the variables. You are able to change any of these values. It takes a short while to get use to the manner in which you are able to efficiently edit the data. This largely revolves around getting use to the toggle between the insert mode and the overwrite mode of data entry. Note any variable which is not assigned a value, is assumed to be zero.

As you move from one data variable to the next, the message line at the bottom of the data box, which reads "Your project identification" in the example box on the next page, changes to provide information on the input required for each data entry. A summary of all the information messages, is given below .



In most cases, the data prompts are self explanatory, and these supplemented with the above information messages, should be sufficient to enable you, the user, to input the relevant data. However there are a few data inputs that do perhaps require further explanation, these are:

Rear Ground Slope This is the inclination of the ground to the horizontal, immediately behind the retaining wall and is positive if inclined upwards away from the top of the wall.

Front Ground Slope This is the dip of the ground in front of the toe of the retaining wall, and is positive if sloping down away from the wall.

Automatic Override This should be utilised when you wish to test a specific wall design, which may or may not be based on an automatic design produced by the programme. In order to fully explain this, an example will be given on one of the following pages.

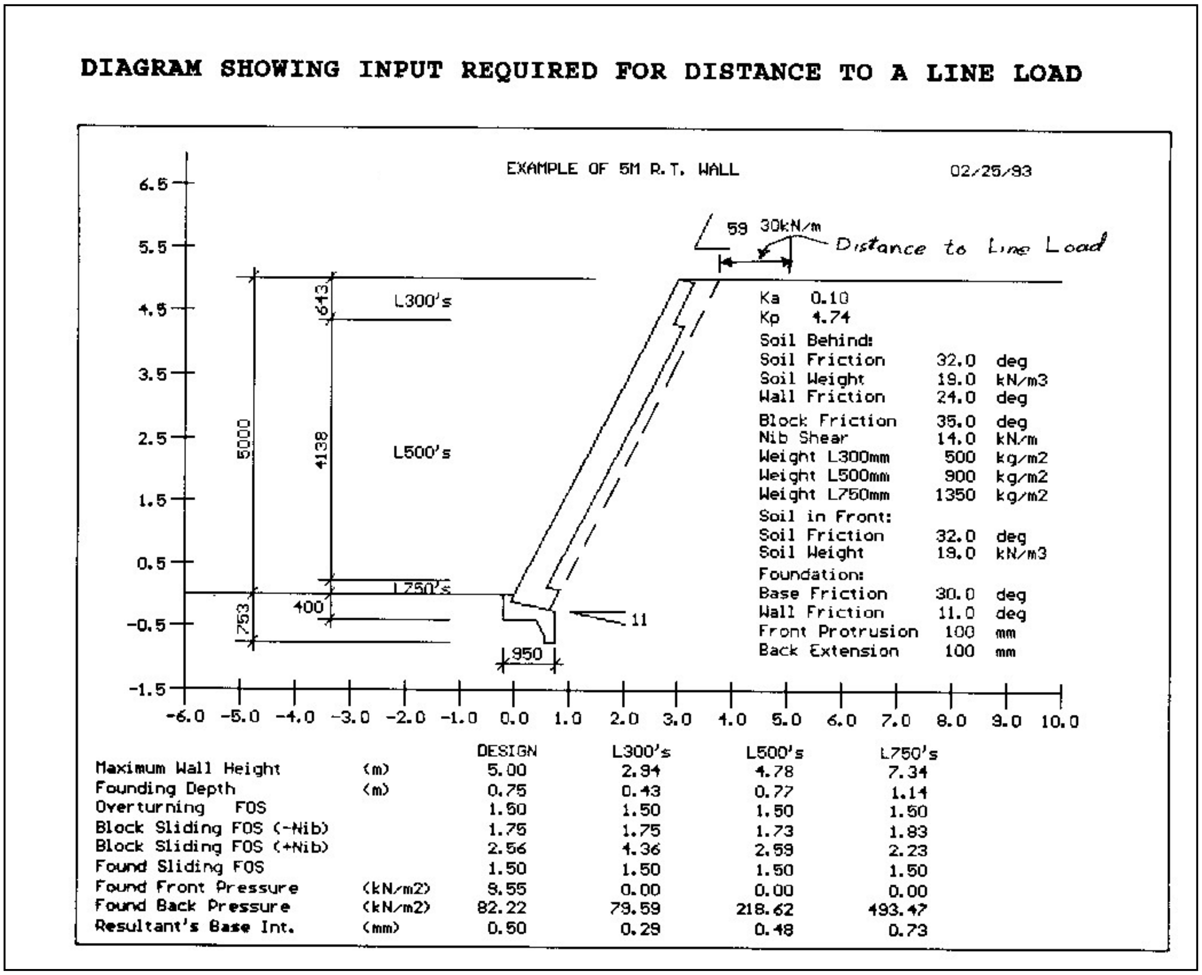
DATA PROMPT (left)	CORRESPONDING MESSAGE DISPLAYED ON SCREEN
JOB ID	'Your project identification'
Wall Height	'The total height of the retaining wall above ground'
Rear Soil Friction ϕ	'eg. Typically; loose sand ϕ=30°, dense sand ϕ=35°'
Block Friction	'Typically block on block friction is 35degrees'
Rear Ground Slope	'Slope of the ground behind the wall, must be <= rear soil''s ϕ'
Rear Soil's Weight	'The unit weight of the soil behind the wall'
Front Soil's Weight	'The unit weight of the soil in front of the retaining wall'
Front Ground Slope	'The slope of the ground in front of the wall, must be <= front soil''s ϕ'
Line Load LL	'Magnitude of the line load'
Nib Shear Strength	'The shear strength of the block nibs, Typically 14kN/m for Loffelstein's'
Light Wall Weight	'The weight per unit area of the smallest blocks eg 500kg/m2 for L300's'
Medium Wall Weight	'The weight per unit area of the medium blocks eg 900kg/m2 for L500's'
Large Block Weight	'The weight per unit area of the largest blocks eg 1350kg/m2 for L750's'
Overturning FOS	'Desired minimum overturning Factor of Safety'
Found Sliding FOS	'Desired minimum Factor of Safety against Foundation Sliding'
Found Wall Friction	'Typically δ <= (1/3)ϕ for friction between the Found's face & the soil'

DATA PROMPT (right)	CORRESPONDING MESSAGE DISPLAYED ON SCREEN
Date:	'The date, MMDDYY, can be overwritten after pressing the insert key'
Wall Slope	'The slope of the retaining wall, eg 70°'
Wall Friction δ	'Typically δ = (1/2)ϕ to (2/3)ϕ, for Loffelstein''s can use 0.9ϕ'
Base Friction μ	'Typically found is cast insitu, and $\mu = \phi$, if found precast, then μ = (2/3)ϕ'
Found Back Protrusion	'The extension of the foundation behind the bottom row of blocks'
Found Front Protrusion	'The protrusion of the foundation in front of the bottom row of blocks'
Front Soil's Friction	'The ϕ of the soil in front of the wall'
Backward block Tilt	'The backward tilt of the blocks, ie inclination of top surface of found'
Distance to LL	'Distance of the line load back from the rear of the top row of blocks'
Max Wall Slope	'The maximum slope the wall can be built at using the selected block type'
Small Block Length	'The length of the small blocks, eg 0.3m for L300's'
Medium Block Length	'The length of the medium blocks, eg 0.5m for L500's'
Large Block Length	'The length of the large blocks, eg 0.75m for L750's'
Block Sliding FOS	'Desired minimum Factor of Safety against sliding between blocks'
UDL	'Uniformly distributed load behind the wall'
Automatic Override	'Enter 'Y' if you want to specify the block mix, ie override the auto design'

There are five more available data entries that have been added since the early version of the program, viz.

Cohesion Behind	The cohesion if any of the soil/material behind the wall
Cohesion Front	The cohesion if any of the soil/material in front of the wall
Limit Height Bank	If applicable, total height from the toe of the wall to the top of the slope behind the wall.
Limit Dist. Critical Plane	Limit on distance to where the critical plane daylights behind the wall. Note that this only applies in cases where there is for example a stable rock face at a certain distance behind the wall.
Height of Blocks	

Distance to LL This is the distance to the line load back from the rear of the retaining wall, and it based on the assumption that the bottom blocks extend to the top of the wall as illustrated on the diagram below.



		DESIGN	L300's	L500's	L750's
Maximum Wall Height	(m)	5.00	2.94	4.78	7.34
Founding Depth	(m)	0.75	0.43	0.77	1.14
Overturning FOS		1.60	1.50	1.50	1.50
Block Sliding FOS (-Nib)		1.75	1.75	1.73	1.83
Block Sliding FOS (+Nib)		2.56	4.36	2.59	2.23
Found Sliding FOS		1.50	1.50	1.50	1.50
Found Front Pressure	(kN/m2)	9.55	0.00	0.00	0.00
Found Back Pressure	(kN/m2)	82.22	79.59	218.62	493.47
Resultant's Base Int.	(mm)	0.50	0.29	0.48	0.73

Note that within the Main Menu there is a **design information** button, and if you click on this the following important design information will be displayed using an html file. This information appears on the following four pages. It will be seen that additional information is given regarding the features of entering cohesion and/or limiting the total height of the retained bank including the slope (if any) behind the top of the wall and/or limiting the distance back to where the critical plane daylights behind the back of the retaining wall.

"GEOLOK" DESIGNS DRY STACK CONCRETE BLOCK RETAINING WALLS

NB there are some important notes regarding the running of the programme at the end of this design information file.

This programme automatically designs dry stack retaining wall as gravity walls. The programme utilises the Coulomb theory to determine active and passive earth pressures. An optimal design is carried out utilising Sliding and Overturning FOS's specified by the user, in compliance with the constraint that the line of action of the resultant force passes through rear 2/3 of the bottom blocks. This is achieved by reducing the effective weight of the wall if the line of action of the resultant passes behind the blocks, until it is within the blocks. If its impossible to achieve the desired wall height with an acceptable FOS, then you will have to flatten the wall slope, and it will also help if you give the blocks a backwards tilt. In practice, this can either be a done by inclining the top surface of the foundation, or by setting the bottom row of blocks in wet concrete with the desired backwards tilt.

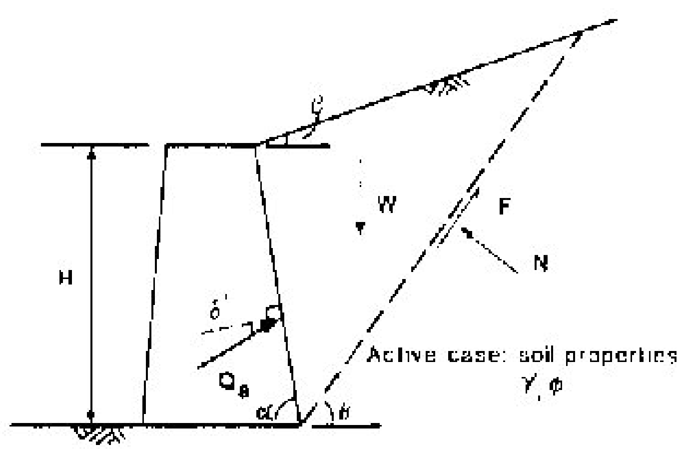
If **no cohesion is specified** and **no limit is placed on the total height of the bank being retained by the wall** and **no limit is being placed on the distance to the critical plane behind the wall,** then **the active force on the wall is calculated using the formula below.**

Figure 1:

$$Q_a = \tfrac{1}{2}\gamma H^2 . \frac{f_1}{\sin\alpha . \cos\delta}$$

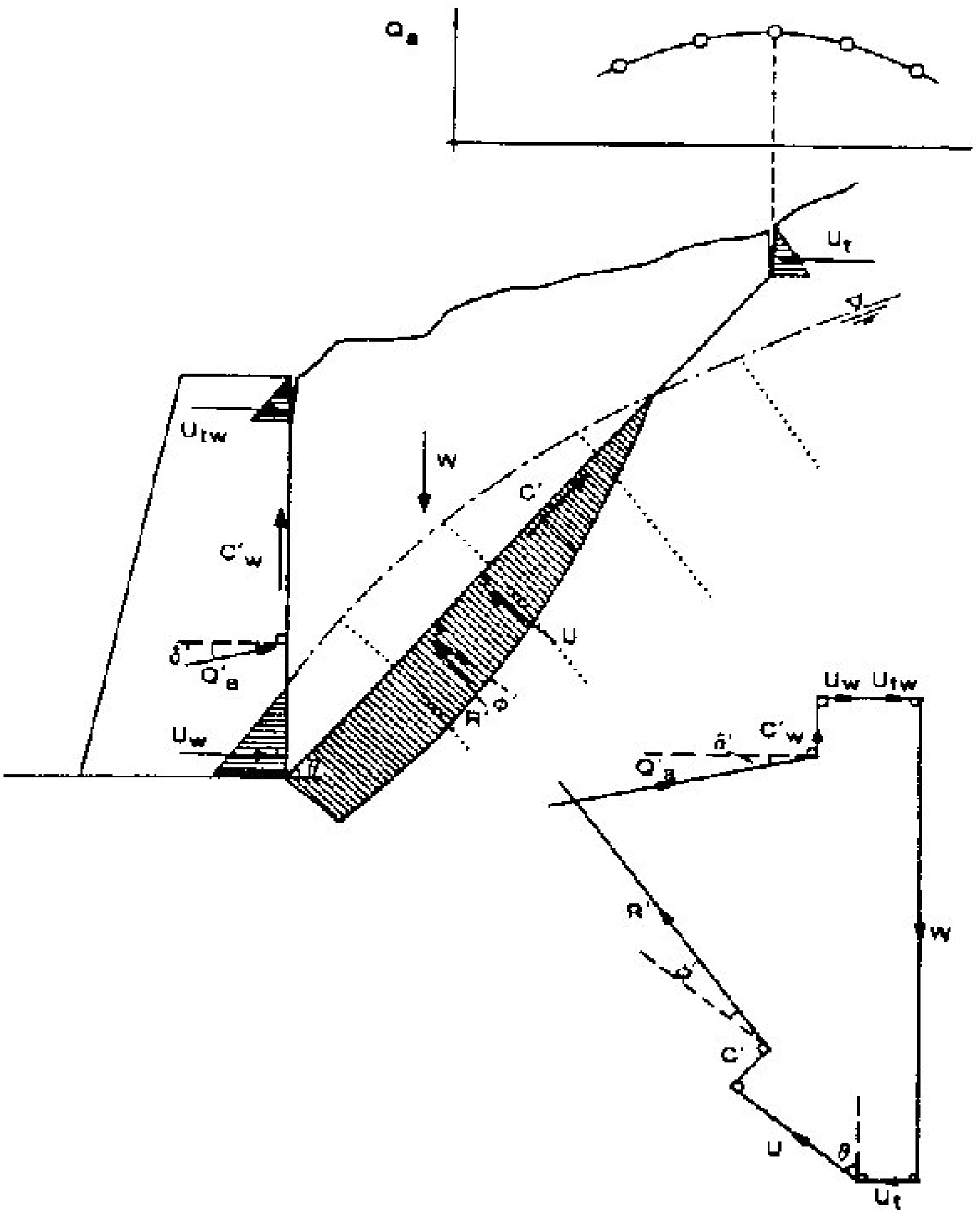
where

$$f_1 = \frac{\sin^2(\alpha+\phi).\cos\delta}{\sin\alpha.\sin(\alpha-\delta)\left[1+\sqrt{\left[\frac{\sin(\phi+\delta).\sin(\phi-\beta)}{\sin(\alpha-\delta).\sin(\alpha+\beta)}\right]}\right]^2}.$$



However if a cohesion is specified or the total height of the retained bank is limited (see Figure 3) to being less than infinite when there is sloping ground or the distance back to the critical plane is limited then a wedge analysis is carried out in order to determine the critical plane.

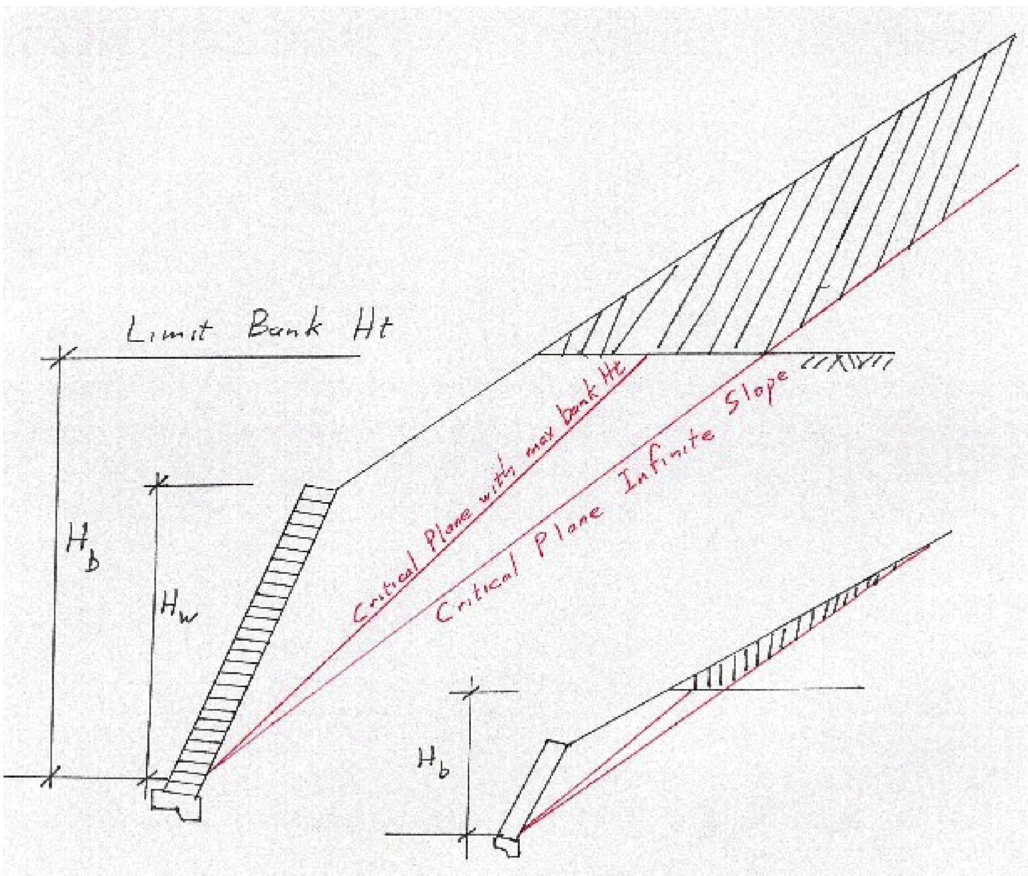
Figure 2:



NB!!! It is **invariably good design procedure to specify a very low cohesion such as 0.001 kN/m2** in order to force the programme to carry out a wedge analysis as opposed to utilising the formula. It will then show the critical plane on the graphical output.

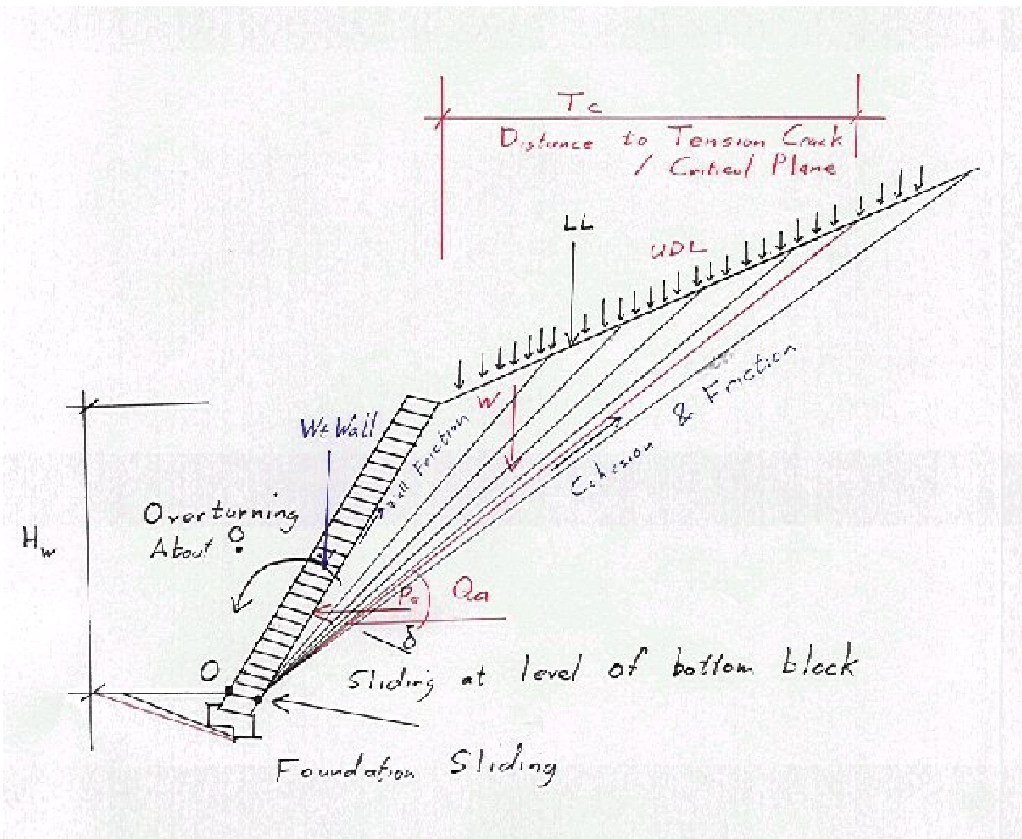
The diagram below illustrates how the height of the retained bank can be limited. Note that if the height of the bank is limited (i.e. H_b is given a value of less than 999.9), then the programme will automatically carry out a wedge analysis.

Figure 3:



The diagram in Figure 4 illustrates how the maximum distance back to the critical plane behind the top of the wall can be limited. Note that if this distance is limited (i.e. T_c is given a value of less than 999.9), then the programme will automatically carry out a wedge analysis. This is highly useful in the cases where there is a stable slope a short distance behind the retaining wall.

Figure 4:



Notes NB

Data input to model certain complex conditions may cause the automatic design's search routines to yield nonsensical results. In such cases we recommend that you use the programme to test specific designs and ignore the results of the automatic search routines.

An extremely useful feature of the programme is that the data can be edited on the graphical output screen

6.2 DESIGNING THE DRY STACK CONCRETE BLOCK WALL

The programme is extremely user frielndly and easy to run and thus a detailed description of how to run it will not be given in this manual. A brief descrition is given below.

Once you have completed your data entry,

press the Okay button to return to the main menu.

If you have assigned any unacceptable values to the data variables, then instead of returning to the main menu, an error ollowing message will be displayed. Before you are able to continue, you will have to alter these variables. In order to assist you, the data which is unacceptable, will be highlighted when you return to the data input box.

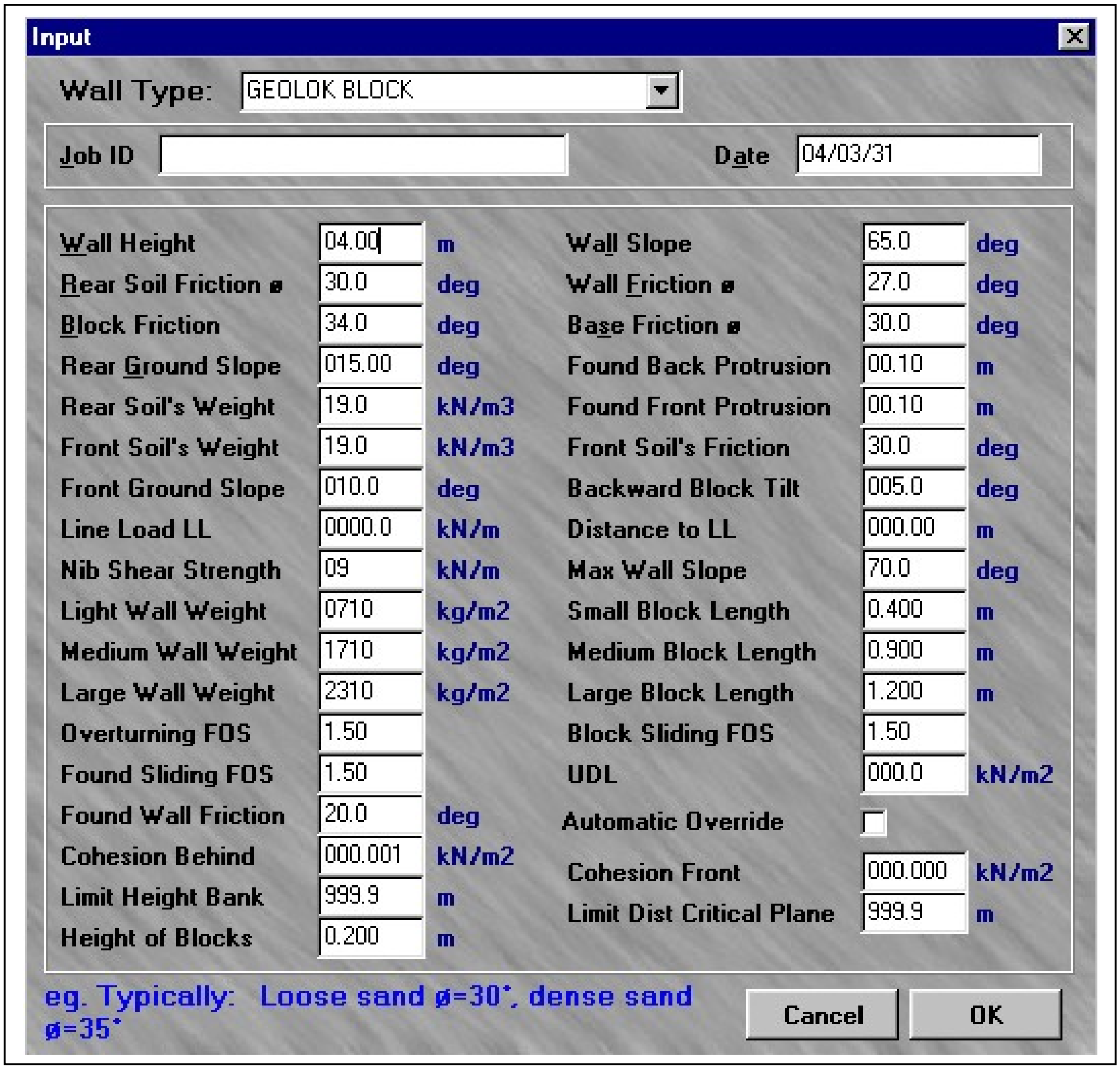
After you have returned to the main menu, you can design the geolok retaining wall by clicking on the “Screen Plot of Design”.

For example, having entered the data shown on the following page, a screen plot of the designed wall be displayed, and a hardcopy printout of the screen plot may be obtained using most common printers. An example of such a hardcopy, is shown on the following page.

A **more detailed printout of the results** obtained in the design, can be obtained from the Main Menu, by clicking the “Print Results” button.

These results may also be viewed by clicking on the “View Results” button from within the Main Menu.

EXAMPLE OF DATA ENTRY


Input

Wall Type: GEOLOK BLOCK

Job ID | Date 04/03/31

Wall Height	04.00	m	Wall Slope	65.0	deg
Rear Soil Friction ø	30.0	deg	Wall Friction ø	27.0	deg
Block Friction	34.0	deg	Base Friction ø	30.0	deg
Rear Ground Slope	015.00	deg	Found Back Protrusion	00.10	m
Rear Soil's Weight	19.0	kN/m3	Found Front Protrusion	00.10	m
Front Soil's Weight	19.0	kN/m3	Front Soil's Friction	30.0	deg
Front Ground Slope	010.0	deg	Backward Block Tilt	005.0	deg
Line Load LL	0000.0	kN/m	Distance to LL	000.00	m
Nib Shear Strength	09	kN/m	Max Wall Slope	70.0	deg
Light Wall Weight	0710	kg/m2	Small Block Length	0.400	m
Medium Wall Weight	1710	kg/m2	Medium Block Length	0.900	m
Large Wall Weight	2310	kg/m2	Large Block Length	1.200	m
Overturning FOS	1.50		Block Sliding FOS	1.50	
Found Sliding FOS	1.50		UDL	000.0	kN/m2
Found Wall Friction	20.0	deg	Automatic Override		
Cohesion Behind	000.001	kN/m2	Cohesion Front	000.000	kN/m2
Limit Height Bank	999.9	m	Limit Dist Critical Plane	999.9	m
Height of Blocks	0.200	m			

eg. Typically: Loose sand ø=30°, dense sand ø=35°

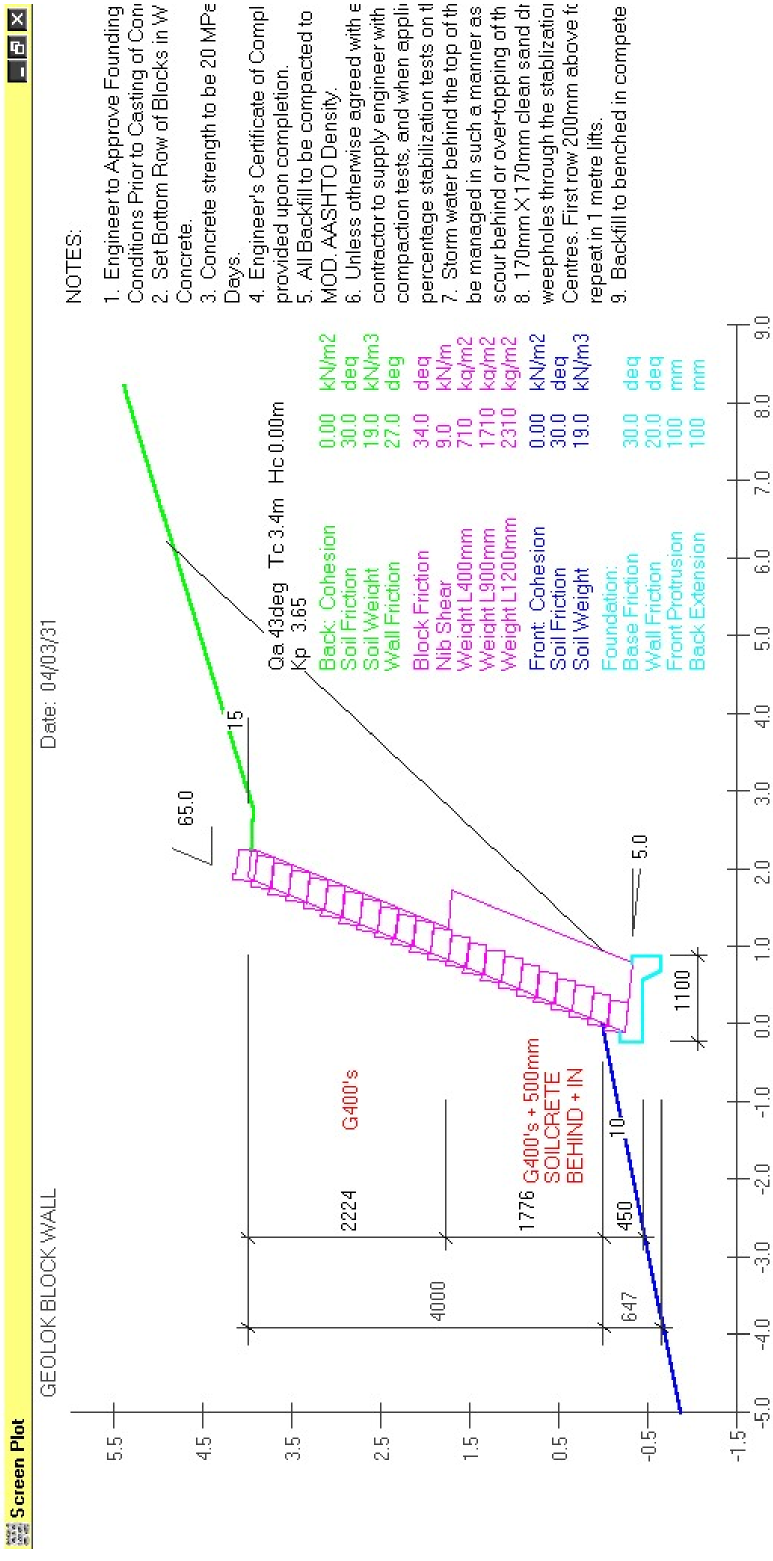
Cancel | OK

Note that an insignificant value pf 0.001 kN/m^2 has been assigned to the cohesion behind the wall in order to force the programme to carry out a wedge analysis in performing the design.

A copy of the screen plot of the automatic design arrived at by the computer using the above data, is given on the following page.

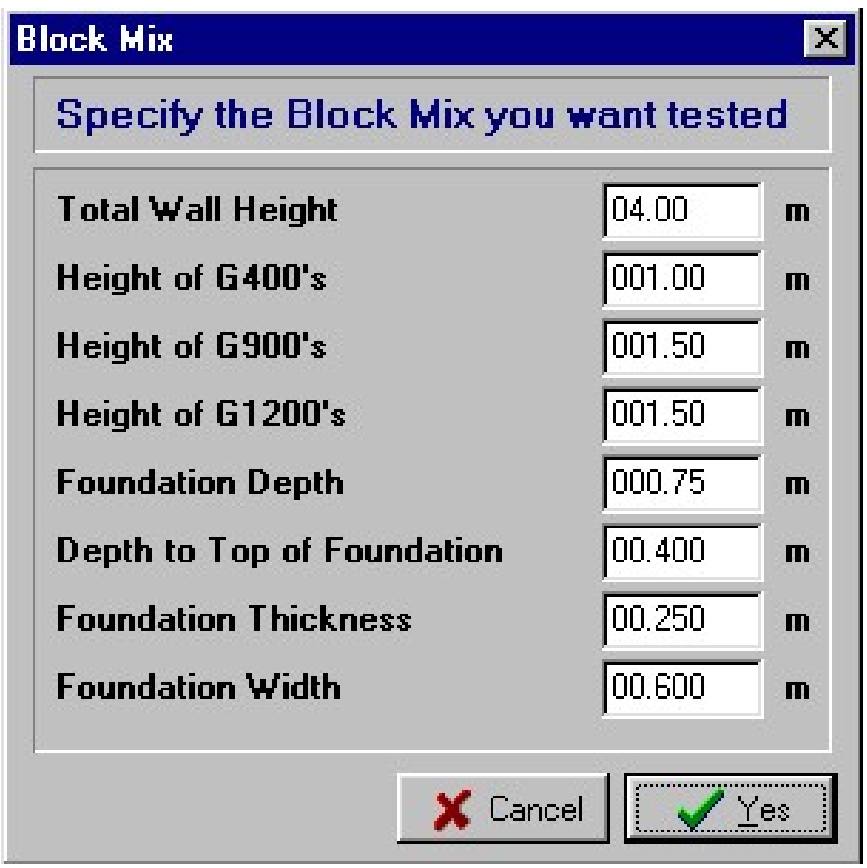
NB Note that you may edit the data from within the screen plot of the design by right clicking the mouse button. By right clicking the mouse you are also given the option of printing a hard copy of the design.

Screen plot of the automatic design determined by the computer based on the input given on the previous page.



If you study the results on the plot of the designed retaining wall, you will notice that in addition to designing the wall for the desired retaining height, results are also given for maximum height you could build a L400 wall, a L900 wall and a L1200 wall. These maximum wall heights and associated design results, are based on the assumption that these walls comprise only the one size of blocks (or blocks inclusive of their effective increase in length using soilcrete).

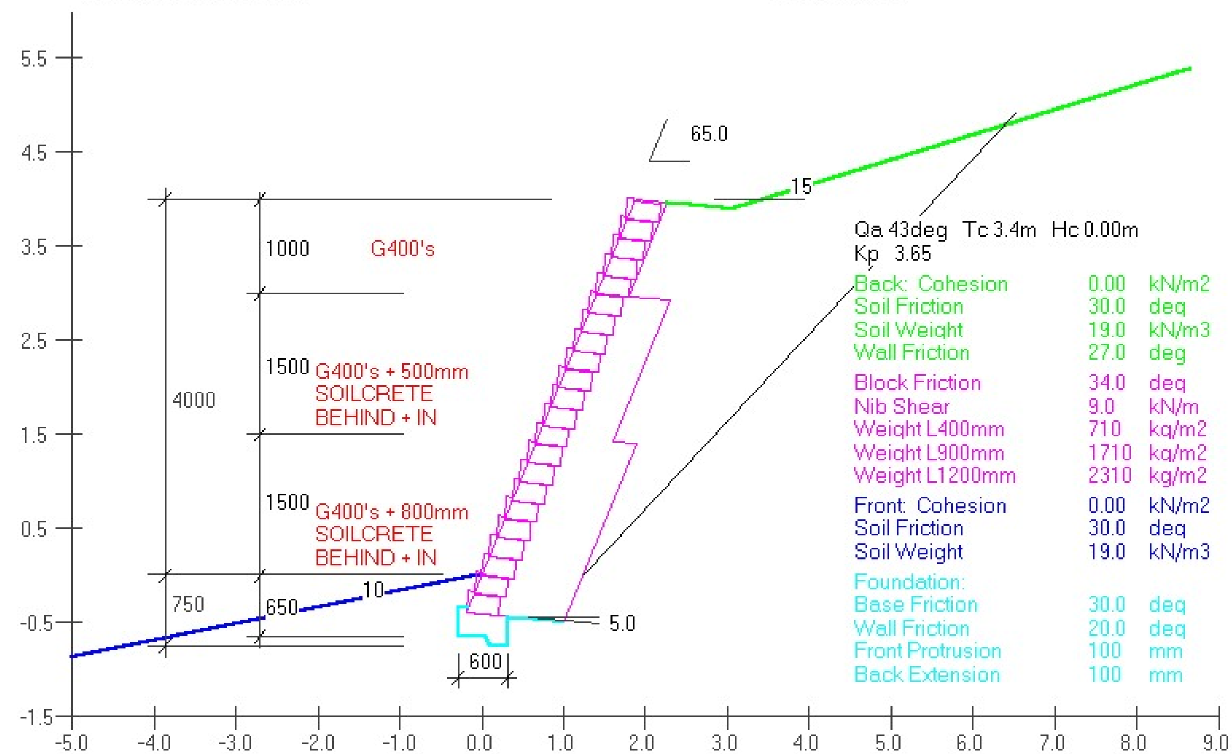
Having obtained the automatic design as above, you may wish to vary the mix of the L1200's, L900's & L400’s to suit exact multiples of the block heights, or perhaps to tie in with the mix over other sections of the retaining wall. To do so, you may either right click the mouse button from within the screen plot of the design and then select the data edit option or after you have returned to the main menu by once again clicking on the Data Input button. Now within the data input box, change the default N for "no" at the Automatic Overide prompt to a Y, for "yes". Accept the data, and the following Data Input Box for specifying the block mix, will appear on the screen. Note that a mix of blocks for the previous example's retaining wall of 4 metres height, has already been entered into this box, and you will have enter your own values.



The above messages explains the essential features of the required input, and need not be elaborated upon. The results of the screen plot of the test of the above block mix, are presented on the following page.

Screen Plot

GEOLOK BLOCK WALL   Date: 04/03/31



Qa 43deg Tc 3.4m Hc 0.00m
Kp 3.65

Back: Cohesion	0.00	kN/m2
Soil Friction	30.0	deg
Soil Weight	19.0	kN/m3
Wall Friction	27.0	deg
Block Friction	34.0	deg
Nib Shear	9.0	kN/m
Weight L400mm	710	kg/m2
Weight L900mm	1710	kg/m2
Weight L1200mm	2310	kg/m2
Front: Cohesion	0.00	kN/m2
Soil Friction	30.0	deg
Soil Weight	19.0	kN/m3
Foundation:		
Base Friction	30.0	deg
Wall Friction	20.0	deg
Front Protrusion	100	mm
Back Extension	100	mm

NOTES:

1. Engineer to Approve Founding Conditions Prior to Casting of Con
2. Set Bottom Row of Blocks in W Concrete.
3. Concrete strength to be 20 MPa Days.
4. Engineer's Certificate of Compl provided upon completion.
5. All Backfill to be compacted to MOD. AASHTO Density.
6. Unless otherwise agreed with e contractor to supply engineer with compaction tests, and when appli percentage stabilization tests on t
7. Storm water behind the top of th be managed in such a manner as scour behind or over-topping of th
8. 170mm X 170mm clean sand dr weepholes through the stablizatio Centres. First row 200mm above fo repeat in 1 metre lifts.
9. Backfill to benched in compete

		DESIGN	L400's	L900's	L1200's
Maximum Wall Height	(m)	4.00	2.74	6.51	8.59
Founding Depth	(m)	0.75	0.51	1.27	1.66
Overturning FOS		2.48	1.50	1.50	1.54
Block Sliding FOS (-Nib)		2.38	1.36	1.38	1.41
Block Sliding FOS (+Nib)		2.85	2.24	1.53	1.50
Found Sliding FOS		2.04	1.50	1.50	1.50
Found Front Pressure	(kN/m2)	22.46	11.96	6.68	0.00
Found Back Pressure	(kN/m2)	76.07	56.20	205.91	318.19
Resultant's Base Int.	(m)	0.73	0.27	0.62	0.87

Start | LOFMANNew - ... | GEOLOK De... | Lofmanadd - Mi... | WallDesign4m1... | 04:04

EXAMPLE OF OUTPUT FOR TEST OF A USER SPECIFIED RETAINING WALL

7. CONCLUSION

"GEOLOK" is a very user friendly computer programme, which is designed to be operated without reference to a user manual. It is for this reason that this manual essentially reproduces information which you as the user, are able to obtain directly from the programme. It should be remembered that one of the huge advantages of carrying out designs on the computer, is the speed at which the designs are carried out, which in turn enables one to arrive at optimal designs in short periods of time. It is with this in mind that one should invariably carry out sensitivity studies using the programme, before arriving at your final optimal design.

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