DESIGN OF GRAVITY RETAINING WALLS

By

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NOTATION

C	Cohesion of soil in front of retaining wall, kN/m^2
c_a	Adhesion force, kN/m^2
K_2	Coefficient of passive soil pressure.
M	Moment
P_a	Active thrust, kg
P_h	Horizontal thrust, kg
P_p	Passive thrust, kg
P_v	Vertical thrust, kg
q	Pressure, kg/m^2
R	Thrust, kg
S_1	Concentrated surcharge, kg
S_2	Uniformly distributed surcharge, kg
$S3$	Triangular surcharge, kg
S	Sum of all surcharges, kg
W	Weight, kg
β	Angle of slope, degrees
δ	Angle of friction at interface, degrees
γ_2	Density of uniformly distributed surcharge, kg/m3
γ_3	Densities of triangular surcharges, kg/m^3
γ_b	Density of the material retained behind the retaining wall, kg/m^3
γ_p	Density of the soil in front of wall, kg/m^3
θ	Angle, degrees
$\sum$	Summation
ϕ	Angle of shearing resistance, degrees
ϕ_p	Angle of internal friction of soil in front of wall, degrees

CONTENTS

GRAVITY RETAINING WALLS

1 INTRODUCTION

The ratio of the soil pressure on the retaining wall to the overburden pressure is known as the coefficient of earth pressure. If the wall is allowed to move forward slightly then the earth pressure on it gradually decreases until it reaches a minimum value. The coefficient of earth pressure is then known as the coefficient of active pressure. If the wall pushes towards the soil, such as pushing against the soil in front, the earth pressure gradually increases until it reaches a maximum value. The coefficient of earth pressure is then known as the coefficient of passive pressure.
In this study, the walls are assumed to be rigid, constructed out of masonry, mass or reinforced concrete. They can fail either by sliding or more usually by overturning. Active soil pressure behind the wall and passive soil pressure in front of the wall are assumed to govern the design. The Surface of soil behind the retaining wall may be horizontal or sloping. Surcharges may be applied as concentrated, uniformly distributed, triangular, trapezoidal or any combination thereof. Trapezoidal surcharges may be analysed as triangular and uniformly distributed surcharges. For simplicity, the soil surface in front of the wall is assumed to be horizontal.

2 ACTIVE SOIL PRESSURE

A procedure to determine the active thrust on a retaining wall is outlined below. Sufficiently accurate values of active thrust, *Pa*, can be obtained by assuming that the slip surface is a plane (Coulomb's method) [1]

2.1 Active wedge

From the geometry of Fig 1, the following relations may be formed

$$AB = \frac{H_b}{\cos\alpha} \tag{1}$$

$$BD = \frac{H_b}{\cos\theta} \tag{2}$$

$$AD = H_b(\tan\alpha + \tan\theta) \tag{3}$$

The weight of wedge, W_b is then,

$$W_b = \frac{1}{2}\gamma_b.AD.H_b \tag{4}$$

2.2 Surcharge

The surcharges, S shown in Fig 1, may be calculated as follows

$$S_2 + S_3 = \gamma_2.AM.AD + \frac{1}{2}\gamma_3 AD^2 \tan\beta \tag{5}$$

$$S = S_1 + S_2 + S_3 \qquad (6)$$

Where,

S_1 is the concentrated surcharge, S_2 is the uniformly distributed surcharge, S_3 is the triangular surcharge and S is the sum of all surcharges.

γ_2 and γ_3 are the densities of the uniformly distributed and the triangular surcharges respectively, and γ_b is the density of the material retained behind the retaining wall.

3 THRUST BEHIND THE WALL

3.1 Active soil thrust behind wall

From Fig 1, the angles of P_a and of R with the horizon are

Angle of $P_a = \delta - \alpha$

Angle of $R = \theta + \phi$

From the equilibrium of forces in Fig 1, the following expressions are derived

$$\sum F_y = 0 = P_a \sin(\delta - \alpha) + C_a \cos\alpha + C_d \cos\theta + R \sin(\theta + \phi) - W_b - S \qquad (7)$$

$$\sum F_x = 0 = P_a \cos(\delta - \alpha) - C_a \sin\alpha + C_d \sin\theta - R\cos(\theta + \phi) \qquad (8)$$

Multiplying equation (8) by $\tan(\theta + \phi)$ then adding it to equation (7), we get

$$\begin{aligned} &P_a \{\sin(\delta - \alpha) + \cos(\theta + \phi)\tan(\theta + \phi)\} + C_a \{\cos\alpha - \sin\alpha \tan(\theta + \phi)\} + \\ &C_d \{\cos\theta + \sin\theta \tan(\theta + \phi)\} - W_b - S = 0 \end{aligned} \qquad (9)$$

Whence,

$$P_a = \frac{W_b + S - C_a \{\cos\alpha - \sin\alpha \tan(\theta + \phi)\} - C_d \{\cos\theta + \sin\theta \tan(\theta + \phi)\}}{\sin(\delta - \alpha) + \cos(\delta - \alpha)\tan(\theta + \phi)} \qquad (10)$$

$$P_H = P_a \cos(\delta - \alpha) \qquad (11)$$

$$P_V = P_a \sin(\delta - \alpha) \qquad (12)$$

3.2 Maximum thrust

While, angles α, β, δ, ϕ *and* ϕ_p are known quantities, θ that produces the maximum active thrust behind the wall remains to be determined. For a vertical wall, horizontal ground surface with no surcharge and homogeneous soil conditions, a minimum value of P_a will occur when $\theta = 45 - \phi / 2$ degrees. By trying a number of different wedges with different values of θ, a maximum value of P_a can then be determined (see Fig 4). This is assumed to be the true value of the active pressure, to be used in design. To calculate P_a for various values of θ by hand [(1)] is tedious, arduous and with a high probability of making mistakes. The author has therefore developed a computer program based on the analytic derivations presented in this study to determine the maximum thrust behind the wall (see Fig 4).

4 PASSIVE SOIL PRESSURE IN FRONT OF WALL

The intensity of passive soil pressure, q_p at depth, h_p ($\beta = 0$) is given by the following equations

3.3 Ignoring soil cohesion [(2)]

$$q_p = \frac{\gamma_p h_p}{K_2} = \frac{1+\sin\phi_p}{1-\sin\phi_p}\gamma_p h_p \tag{13}$$

3.4 Including soil cohesion [(2)]

$$q_p = \frac{\gamma_p h_p}{K_2} + \frac{2C_p}{K_2} = \frac{1+\sin\phi_p}{1-\sin\phi_p}\gamma_p h_p + 2\frac{1+\sin\phi_p}{1-\sin\phi_p}C \tag{14}$$

(Ref. 2 Tables 16 & 17)

Hence, the total horizontal passive thrust, P_p is given by

$$P_p = \frac{1}{2} q_p h_p \tag{15}$$

Where,
ϕ_p , γ_p and C are the angle of internal friction in degrees, the density and the cohesion of soil in front of wall respectively, and K_2 is the coefficient of passive soil pressure.

4 RIGID RETAINING WALLS

4.1 Stability against overturning

5.1.1 Ignoring the soil in front of wall

The contribution of the soil in front of wall to stability is usually ignored [(1)] (P_p=0). From Fig 2, the position, d of the resultant R, is determined by taking moments about the Toe as follows

$$d = \frac{W.a + P_v.e - P_h.b}{W + P_v} \tag{16}$$

If R is within the middle third (soil) or the middle half (rock), the wall is considered safe against overturning. Otherwise a further check on stability must be made to determine the factor of safety against overturning, F, as shown here below [(1)]

$$F = \frac{W.a}{P_h.b - P_v.e} \geq 1.5 \tag{17}$$

5.1.2 Allowing for the soil in front of wall

Should the contribution of the soil in front of wall be considered, i.e. $P_p > 0$, (see Fig 2) then a factor of safety against overturning ≥2 may be assumed and is calculated as follows

$$F = \frac{W.a + \frac{1}{3} P_p . h_p}{P_h . b - P_v . e} \geq 2 \tag{18}$$

5.2 Stability against sliding [(1)]

Resistance to sliding is checked by comparing horizontal thrust to maximum base friction and adhesion that may be developed.

5.2.1 Ignoring soil in front of wall

$$F = \frac{(W + P_v)\tan\delta + c_a . B}{P_h} \geq 1.5 \tag{19}$$

5.2.2 Allowing for soil in front of wall

$$F = \frac{(W + P_v)\tan\delta + c_a . B + P_p}{P_h} \geq 2 \tag{20}$$

Where, c_a and δ are the adhesion and angle of friction along the base of wall.

6 WALL GEOMETRY

From Fig 3, the following expressions may be derived

$$T = B - h_w(\tan\alpha_1 + \tan\alpha_2) \tag{21}$$

$$W_1 = \frac{1}{2}\gamma_w h_w \tan\alpha_1 \tag{22}$$

$$b = \frac{h_b}{3} \qquad and \qquad e = B - \frac{1}{3}h_b \tan\alpha_1 \tag{23}$$

$$W_2 = \frac{1}{2}\gamma_w h_w{}^2 \tan\alpha_2 \tag{24}$$

$$W_3 = \gamma_w h_w T \tag{25}$$

$$W_w = W_1 + W_2 + W_3 \tag{26}$$

Taking moments about the wall exterior toe, we get

$$\sum M = 0 = -W_w . a + \frac{2}{3}W_2 h_w \tan\alpha_2 + W_3\left(\frac{T}{2} + h_w \tan\alpha_2\right) + W_1\left(h_w \tan\alpha_2 + T + \frac{1}{3}h_w \tan\alpha_1\right) \tag{27}$$

Hence,

$$a = \frac{\frac{2}{3}W_2 h_w \tan\alpha_2 + W_3\left(\frac{T}{2} + h_w \tan\alpha_2\right) + W_1\left(\frac{1}{3}h_w \tan\alpha_1 + T + h_w \tan\alpha_2\right)}{W_w} \tag{28}$$

7 WIND LOADING

7.1 INTRODUCTION

The presence of large trees close to the wall raises serious concerns about the destabilizing effect of severe East winds. Such winds produce transverse shearing forces within the cross section of the stems that will be transmitted from the stems to the backfill behind the wall. The influence of wind forces must therefore be added to the horizontal backfill thrust on the retaining wall.

7.2 NOMENCLATURE

A	Cross-sectional area
a	Velocity of sound
C_p	Specific heat at constant pressure
C_v	Specific heat at constant volume
G	Flow per unit area or mass velocity = $\frac{W}{A}$
g	Gravity acceleration given to a unit mass by unit force = 32.174 ft/sec^2
k	Ratio of specific heats = $\frac{C_p}{C_v}$
M	Mach number = $\frac{V}{a}$
$\overline{m}$	Molecular weight
P	Static pressure
$\overline{R}$	Universal gas constant = 1545.32 $\frac{\text{ft} - \text{lb}}{\text{lb} - \text{mole} - {}^\circ\text{Rankin}}$
R	Gas constant = $\frac{\overline{R}}{\overline{m}}$
T	Absolute thermodynamic temperature
V	Velocity
ν	Specific volume
ρ	Density

7.3 THERMODYNAMIC PROPERTIES [3]

Air will be treated as an ideally compressible fluid. The effect of viscosity is therefore neglected. The most important consequence of viscosity is probably skin friction due to drag in the boundary layer.

The equation of state for a unit mass of air as well as for many other gases over a range of states which includes most engineering applications is accurately represented by the relations [5,6]

$$P\nu = RT \tag{29}$$

$$\nu\rho = 1 \tag{30}$$

$$P = \rho RT \tag{31}$$

$$V = M\sqrt{kgRT} \tag{32}$$

$$G = \rho V \tag{33}$$

7.3.1 Mach functions [3, 4]

For adiabatic expansion, where Pv^k =Constant, the following Mach functions are derived

$$\frac{T_0}{T} = 1 + \frac{k-1}{2}M^2 \tag{34}$$

$$\frac{\rho}{\rho_0} = \left(1 + \frac{k-1}{2}M^2\right)^{\frac{1}{k-1}} \tag{35}$$

$$\frac{P_0}{P} = \left(1 + \frac{k-1}{2}M^2\right)^{\frac{k}{k-1}} \tag{36}$$

$$\frac{A}{A^*} = \frac{1}{M}\left[\frac{2+(k-1)M^2}{k+1}\right]^{\frac{k+1}{2(k-1)}} \tag{37}$$

Equation (36) calculates the total stagnation pressure ratio, $\frac{P_0}{P}$ of wind hitting at a solid surface. This equation may be rewritten as

$$P_0 = P\left(1 + \frac{k-1}{2}M^2\right)^{\frac{k}{k-1}} \tag{38}$$

Wherefore, the stagnation partial wind pressure, P_{w0} is given as

$$P_{w0} = P\left\{\left(1 + \frac{k-1}{2}M^2\right)^{\frac{k}{k-1}} - 1\right\} \tag{39}$$

Using proper units of measurements, Equation (39) conform to Table 15.322, reference (5).

7.3.3 Speed of sound [4]

The speed of sound in air at standard conditions is

$$a = \sqrt{kgRT} \tag{40}$$

For k = 1.4, g = 32.2 ft/sec^2, R = 1545.32/28, and T = 520 degrees Fahrenheit absolute, the speed of sound, is determined as

$$a = \sqrt{1.4 * 32.2 * \frac{1545.32}{28} * 520} = 1137\ ft/\sec = 776 \text{ miles/hour} \qquad (41)$$

7.4.3 Wind pressure

Substituting in Equation (39), we get

$$P_{w0} = 10335.23\left[\left\{1 + 0.2\left(\frac{V}{776}\right)^2\right\}^{3.5} - 1\right] \qquad (42)$$

where, V is the wind velocity in miles/hour and P_{w0} is the wind stagnation pressure in kg/m^2.

7.5 WIND FORCE

The trees in question are too tall to allow making accurate measurement of the wind loaded cross sectional areas. Only a visual estimate from the ground is possible. The parish church vicar, Rev Derek Owen and I conferred about the matter and estimated the vertical gross area of the tree to be in the vicinity of 20 m^2. The branches are scarce and scruffy with large areas of empty spaces in between. Since the leaves are flexible and offer negligible stagnation pressure their area may therefore be ignored. Hence, the ratio of stagnation area to the gross area is estimated to be about 10%.

A trial assumption of a wind speed of 82 miles/hour is assumed. This wind speed produces a horizontal force, F_{w0} as follows

$$F_{wo} = P_{w0} * A = 10335.23\left[\left\{1 + 0.2\left(\frac{82}{776}\right)^2\right\}^{3.5} - 1\right] * \frac{20}{10} = 162.02\ kg \qquad (43)$$

RETAINING WALLS COMPUTER SOFTWARE
for
DOS & Windows

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8.1 INTRODUCTION

RETAIN program was developed to design and investigate gravity retaining walls. Based on the formulations presented in this study, a user-friendly computer program is developed to determine the forces acting on retaining walls and to design safe and stable structures that resist such forces. The amount of computation is enormous, but with the help of this program and powerful computers the task becomes simple, easy and reliable.

8.2 SCOPE OF PROGRAM

Here below is a brief description of the most prominent capabilities of RETAIN software

a) Determination of the maximum active soil thrust behind retaining walls.
b) Determination of the passive soil thrust in front of retaining walls.
c) Plotting thrusts of wedges of failure vs. various angles of failure.
d) Designing gravity retaining walls that resist all the forces resulting from active soil thrusts and concentrated, uniformly distributed, trapezoidal and triangular surcharges.
e) Determination of gravity walls resistance to overturning and sliding.
f) Plotting to scale the designed retaining walls and the wedges of failure.

8.3 PROGRAMMING LANGUAGES

The programming language of the original programs was Hewlett-Packard Rocky Mountain BASIC 3.0 for HP9000 Series 200 Workstations. The programming language of the present development is HP BASIC for Windows and HP BASIC PLUS.

8.4 SYSTEM REQUIREMENTS

This program can run under DOS 5.0 or above and under Windows +95 environments. At least 16 Mbytes of memory would be required to run it. The program will run with a monochrome, 16-colour, 256-colour or 24-bit display driver, but a 256-colour display driver is recommended. COLOR MAP, functions only with 256-color display driver. 17" monitors or larger are recommended for best results. The program can send screen dumps to any graphic printer supported by Windows.

8.5 RUNNING THE PROGRAM

Before running the program, make sure that the computer complies with the limitations stated under SYSTEM REQUIREMENTS mentioned above. The user must strictly heed the guiding instructions displayed on the screen by the program. The program can run from drive C or any other drive specified by the user. If drive A is specified then a diskette with sufficient free space should remain inserted in drive A during the entire performance of the program.

8.6 EXAMPLE OF PROGRAM APPLICATION

An illustrative example of the application of the program for the design of a gravity retaining wall is presented here below. The collapsed wall located at the West Side of St. Denis Church cemetery, Llanishen, Chepstow Monmouthshire is selected for this demonstration. Actual measurements to obtain the design data were taken at the damaged wall. The chosen units of measurement are kilograms, kilonewtons and meters, abbreviated as kg, kN and m respectively.

8.7 INPUT OF DATA

RETAIN Program displays on the screen at proper intervals all the data input forms that are then duly filled by the user with the required information. Corrections of the data input can be made at all times. Output Table 1 lists the following design data that were used in this demonstration.

Soil behind the retaining wall	
Friction factor at wall interface, degrees	30
Internal angle of shearing resistance, degrees	30
Density of retained material, kg/m^3	1600
Depth, m	2.85
Slope of soil-wall interface with the vertical, degrees	8
Soil in front of wall	(Ignored)
Surcharges	
Triangular surcharge slope with horizon, degrees	10
Concentrated load (tree), kg (.23 m radius x 15 m high)	2000
Trial wind velocity, miles/hour	82
Masonry retaining wall	
Base width, m	1.00
Height, m	3.85
Density, kg/m^3	2100
Top width, m	0.46

8.8 PROGRAM OUTPUT

Fig 1 Forces acting on an active wedge
Fig 2 Forces acting on rigid retaining wall
Fig 3 Geometry of retaining wall
Table 1 Design data
Table 2 Checking for wall stability
Fig 4 Thrust, vs. angle of failure
Fig 5 Retaining wall and active wedge

Printing the output Tables and dumping graphics to printers are available options at all times.

8.9 ANALYSIS OF WALL STABILITY OUTPUT

From Tables 2, we get the following information

8.9.1 Ignoring the surcharge loads of the tree

The wall is just safe. The horizontal backfill thrust is 2471.3 kg. The factor of safety against overturning is then 1.52 (the required factor of safety must be > = 1.50), and the factor of safety against sliding is 1.61 (the required factor of safety must be > = 1.50).

8.9.2 Including the concentrated surcharge weight of the tree

The horizontal backfill thrust is 3491.73 kg. The factor of safety against overturning drops to 1.07 and that of sliding to 1.21. These levels of stability are very dangerous and not acceptable.

8.9.3 Including the effect of wind

Adding the influence of East wind with a speed of 82 miles/hour to that of the concentrated surcharge of the tree raises the backfill horizontal thrust to 3653.75 kg. The factor of safety against overturning drops to 1 and the factor of safety against sliding to just 1.15.

9 CONCLUSION AND RECOMMENDATIONS

Therefore, the critical wind velocity is 82 miles/hour. Any East-wind velocity exceeding 82 miles/hour produces sufficient horizontal force behind the wall to cause its collapse. If this happens other tall trees near the wall perimeter might fall too. Helped by torrential rains, graves near the same perimeter might slide to the adjacent land. The damage would then be tremendous and the cost of repairs would run into thousands of pounds. Therefore, I would recommend the following

a. To fell the two trees in question and removed them away at once.
b. No tree should be planted within 2 meters distance from the face of wall.

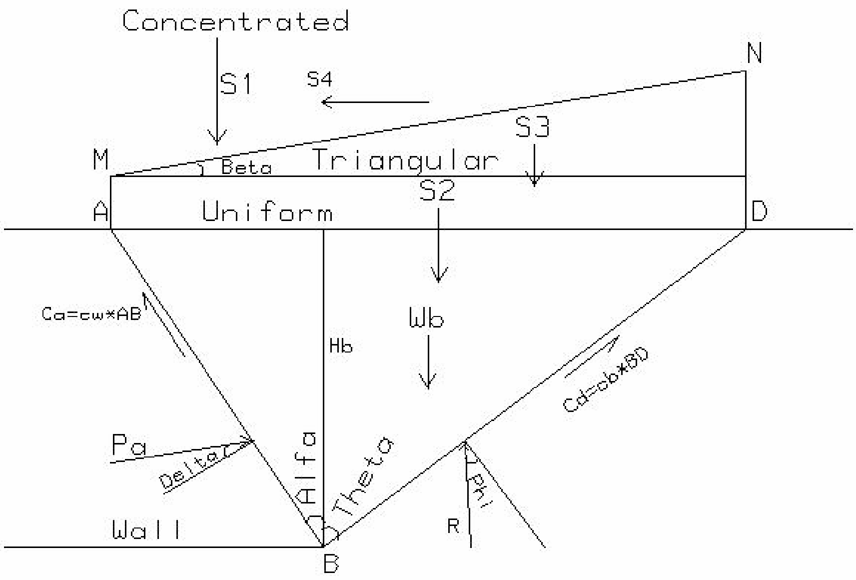


Fig 1 Forces acting on an active wedge
(Coulomb's Method)

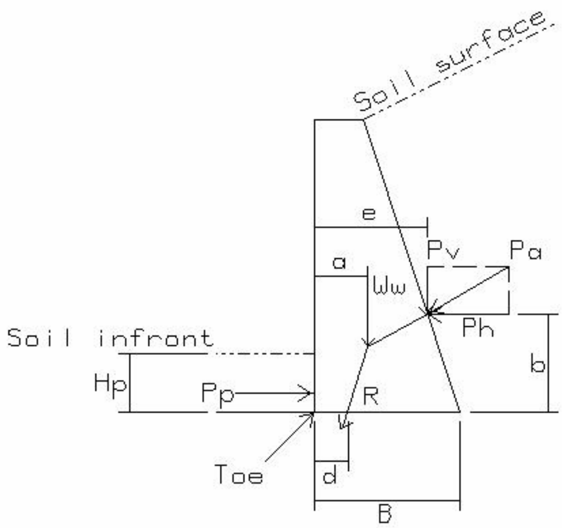


Fig 2 Forces acting on rigid retaining wall

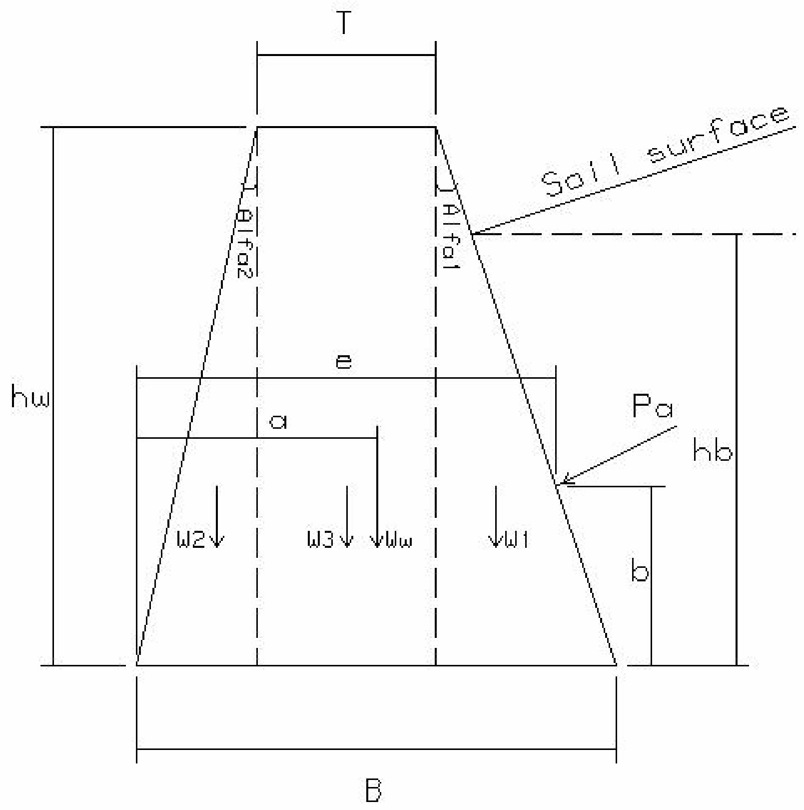


Fig 3 Geometry of Retaining Wall

Ignoring the surcharge loads of the tree

Table 1 Design data

Properties of materials	Units	Values
Backfill properties		
Friction factor, (ref. Table 6-5-1)	deg	30
Adhesion factor, (ref. Table 6-5-1)	kN/m^2	0
Angle of shearing resistance, (ref. Table 6-3-1)	deg	30
Density, (ref. Table 6-1-1)	kg/m^3	1600
Height	m	2.85
Slope angle with the vertical at wall side	deg	8
Properties of soil in front of wall		
height	m	0
Adhesion factor, (ref. Table 6-5-1)	kN/m^2	0
Angle of shearing resistance, (ref. Table 6-3-1)	deg	0
Density, (ref. Table 6-1-1)	kN/m^3	0
Surcharge		
Triangular surcharge slope angle with horizon	deg	10
Triangular surcharge density	kg/m^3	1600
Uniform surcharge height	m	0
Uniformly distributed surcharge density	kg/m^3	0
Concentrated surcharge force	kg	0
Horizontal surcharge force	kg	162.02
Wall perameters		
Slope of interior wall face with the vertical	deg	8
Slope of wall exterior face with the vertical	deg	0
Base width	m	1
Height	m	3.85
Top width	m	.45892
Adhesion factor at wall interface	kN/m^2	0
Adhesion factor at wall foundations	kN/m^2	0
Density of wall construction material	kg/m^3	2100

Date: 23 Jan 2010

Table 2 Checking for wall stability

Wall stability characteristics	Values	Limits
Maximum active backfill thrust (see Fig 4), kg	2665.38	
Components of maximum backfill thrust		
1. In the horizontal direction, kg	2633.32	
2. in the vertival direction, kg	998.47	
Active wedge weight at max. thrust, kg	5070.48	
Wall weight, kg	5897.68	
Active wedge dimensions at maximum backfill thrust		
1. Angle of plane of failure with the vertical, deg	32.61	
2. Wedge plane of failure length, m	3.38336	
3. Wall side backfill plane length, m	2.87801	
4. Wedge horizontal surface length, m	2.22389	
Abscissa of wall center of gravity from toe, m	.381452	
Ignoring the effect of soil in front, Position of resultant force from wall toe, m	.08892	.333 S .5 R
Ignoring the effect of soil in front, Factor of safety against overturning	1.37	>=1.5 S >=2 R
Allowing for soil in front Factor of safety against over turning Soil in front of wall is ignored	NONE	
Factor of safety against wall sliding (ignoring soil in front of wall) Soil in front of wall is ignored	1.51 NONE	>=1.5

S Indicates that the retained material is soil
R Indicates that the retained material is rock
! If the position of the resultant force from the toe is within the middle third for soil or the middle half for rock, the factor of safety against overturning may be ignored

Date: 23 Jan 2010

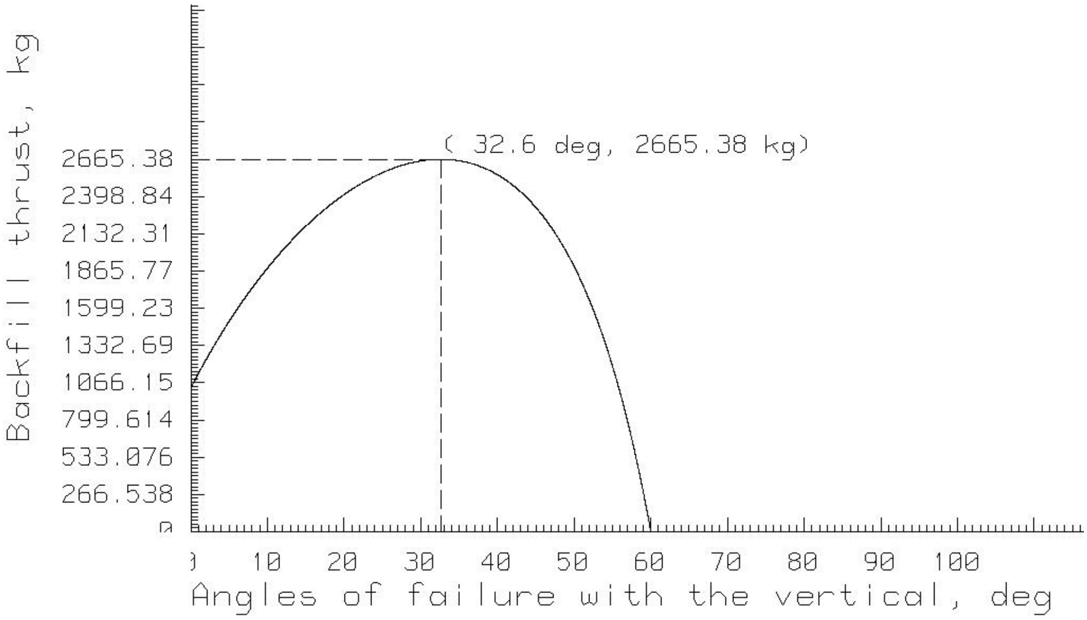
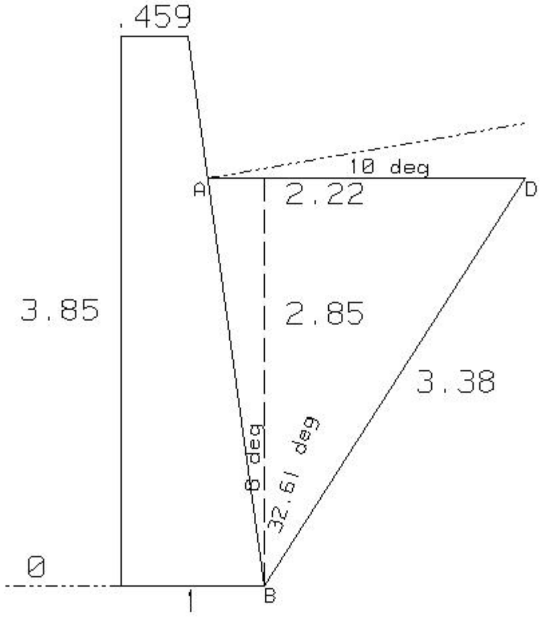


Fig 4 Thrust vs angles of failure



All dimensions are in meters

Fig 5 Retaining wall & active wedge

Including the concentrated surcharge weight of the tree

Table 1 Design data

Properties of materials	Units	Values
Backfill properties		
Friction factor, (ref. Table 6-5-1)	deg	30
Adhesion factor, (ref. Table 6-5-1)	kN/m^2	0
Angle of shearing resistance, (ref. Table 6-3-1)	deg	30
Density, (ref. Table 6-1-1)	kg/m^3	1600
Height	m	2.85
Slope angle with the vertical at wall side	deg	8
Properties of soil in front of wall		
height	m	0
Adhesion factor, (ref. Table 6-5-1)	kN/m^2	0
Angle of shearing resistance, (ref. Table 6-3-1)	deg	0
Density, (ref. Table 6-1-1)	kN/m^3	0
Surcharge		
Triangular surcharge slope angle with horizon	deg	10
Triangular surcharge density	kg/m^3	1600
Uniform surcharge height	m	0
Uniformly distributed surcharge density	kg/m^3	0
Concentrated surcharge force	kg	2000
Horizontal surcharge force	kg	162.02
Wall perameters		
Slope of interior wall face with the vertical	deg	8
Slope of wall exterior face with the vertical	deg	0
Base width	m	1
Height	m	3.85
Top width	m	.45892
Adhesion factor at wall interface	kN/m^2	0
Adhesion factor at wall foundations	kN/m^2	0
Density of wall construction material	kg/m^3	2100

Date: 22 Jan 2010

Table 2 Checking for wall stability

Wall stability characteristics	Values	Limits
Maximum active backfill thrust (see Fig 4), kg	3765.96	
Components of maximum backfill thrust		
1. In the horizontal direction, kg	3653.75	
2. in the vertival direction, kg	1410.75	
Active wedge weight at max. thrust, kg	3418	
Wall weight, kg	5897.68	
Active wedge dimensions at maximum backfill thrust		
1. Angle of plane of failure with the vertical, deg	21.08	
2. Wedge plane of failure length, m	3.0544	
3. Wall side backfill plane length, m	2.87801	
4. Wedge horizontal surface length, m	1.49912	
Abscissa of wall center of gravity from toe, m	.381452	
Ignoring the effect of soil in front, Position of resultant force from wall toe, m	.0001387	.333 S .5 R
Ignoring the effect of soil in front, Factor of safety against overturning	1	>=1.5 S >=2 R
Allowing for soil in front Factor of safety against over turning Soil in front of wall is ignored	NONE	
Factor of safety against wall sliding (ignoring soil in front of wall) Soil in front of wall is ignored	1.15 NONE	>=1.5

S Indicates that the retained material is soil
R Indicates that the retained material is rock
! If the position of the resultant force from the toe is within the middle third for soil or the middle half for rock, the factor of safety against overturning may be ignored

Date: 22 Jan 2010

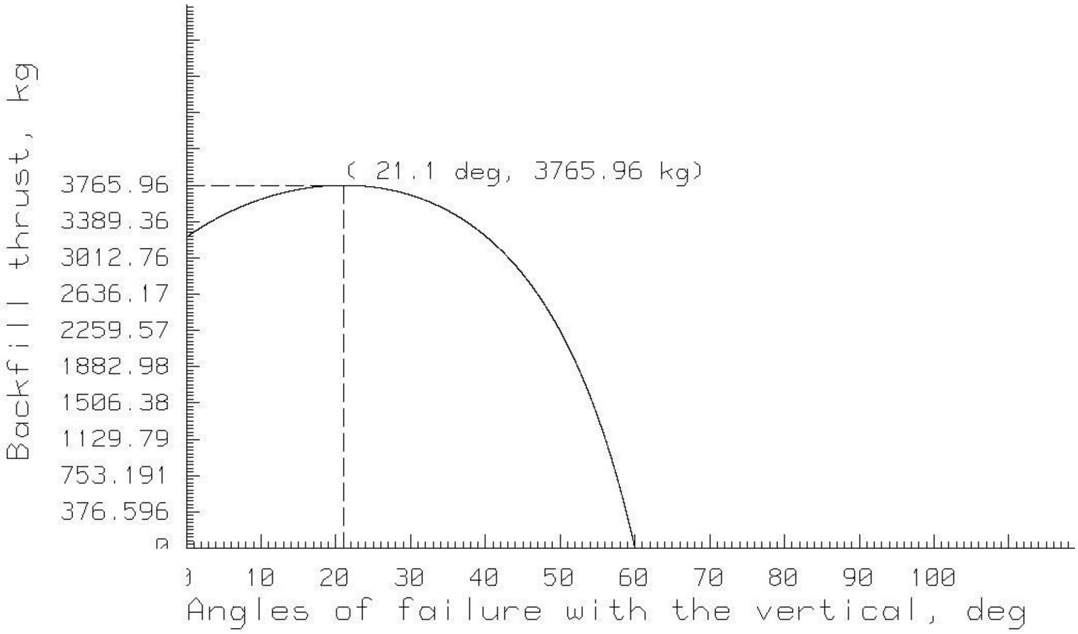
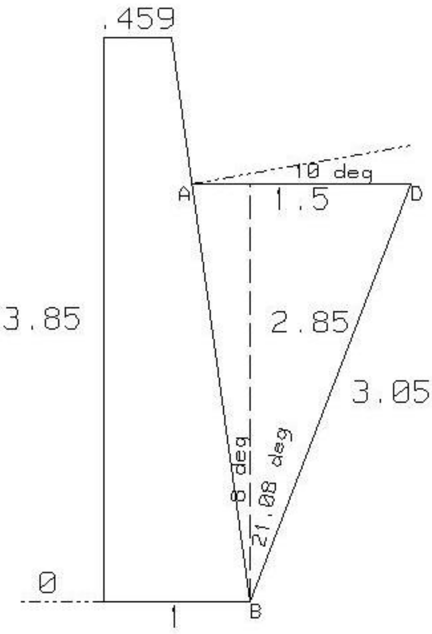


Fig 4 Thrust vs angles of failure



All dimensions are in meters

Fig 5 Retaining wall & active wedge

10 REFERENCES

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