Economical Design of Reinforced Earth Retaining Wall

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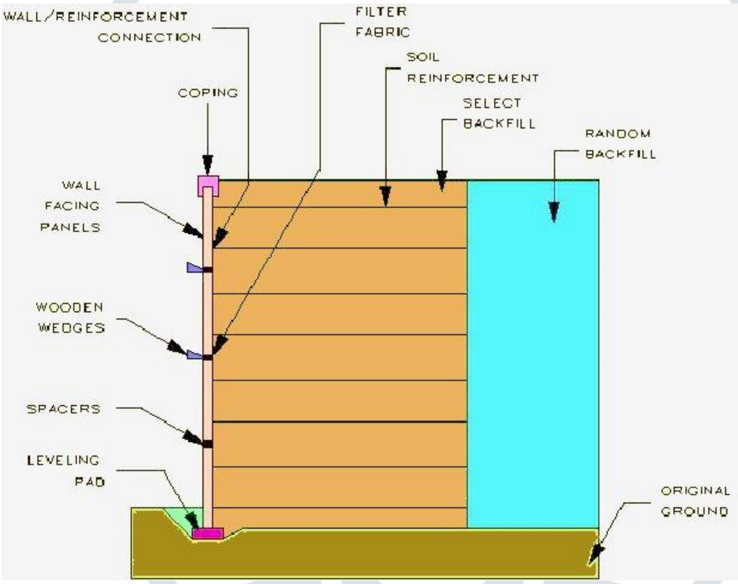
ABSTRACT

In this paper various analysis and design methods were proposed for reasonable design of reinforced earth retaining wall. Limit equilibrium analysis is mostly used to decide the safety factor for failure of retaining wall. This design method shows different results according to differences for assumptions and application of safety factor because equilibrium for stresses and moment is analyzed assuming stress condition and shape of active failure plane and pullout resistance of geosynthetic reinforcements. Therefore for analysis of the internal and external stability two methods are consider i.e. by Modified Rankin's, Clayton & Wood. Comparing the external and internal stability it is found that Clayton and Woods, shown intermediate result while Modified Rankin's method shows most conservative results and easy to understand.

INTRODUCTION

Reinforced earth structures that function as Retaining wall and for stabilizing earth slope can offer a cost advantage compared condition that, generally, reinforced earth structure do not required special foundation, often being built directly on natural ground settlement or wall deflection occur, provided that movement are not excessive. The design of reinforced structure require consideration of effective life of material used for reinforcing. Metals that experience only limited corrosion or no degradable fabrics are preferred.



The following is a list of terms that will be used in the study for reference.

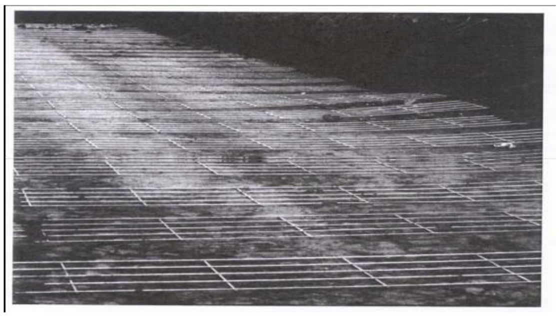
Coping

The coping is used to tie in the top of the wall panels and to provide a pleasing finish to the wall top. It can be cast-in-place or prefabricated segments.

Extensible Reinforcement

Polymeric reinforcement materials (exhibits creep characteristics under stress).

The soil reinforcement for Retained Earth structures comprises welded wire mesh manufactured from cold drawn steel wire. The individual soil reinforcing elements are referred to either as reinforcing mesh or bar mats. Each bar mat consists of a series of longitudinal and transverse wires, which are fusion welded at the intersections to form a long, narrow mesh element.



Filter Fabric

A geotextile filter fabric is used to cover the joint between panels. It is placed on the backside of the panels. This keeps the soil from being eroded through the joints and allows any excess water to flow out. Joint materials comprise either foam strips or high-density polyethylene (HDPE) waffle-type bearing pads and filter fabric. If foam is specified, the foam strips are pushed into all joints from the rear of the panels. It is not necessary to use both foam and filter fabric. The primary purpose of bearing pads is to maintain a consistent joint width and avoid direct concrete- o concrete contact. Bearing pads also serve to reduce the axial stiffness of the wall facing, thereby minimizing the amount of axial load transferred to the panels as the backfill compresses under its own weight.

Leveling Pad

The leveling pad is a non-reinforced concrete pad used to provide a level, consistent surface at the proper grade to place the panels.

Random Backfill

Random backfill is the backfill that is allowed in normal embankment construction.

Select Backfill

Ideally, the backfill in a reinforced soil structure should consist of well-graded granular material compacted to a high density for maximum strength and minimum compressibility. The preferred particle size range for reinforced soil is a well-drained, well-graded granular material, providing long-term durability, stability during construction and possessing good electrochemical properties. In the typical stress range associated with reinforced soil structures, well-graded granular materials behave elastically, and post-construction movements associated with internal yielding are rare. Fine-grained soils are normally poorly drained and effective stress transfer between soil and reinforcement may not be immediate. Such soils also often exhibit time-dependent behavior, thereby increasing the risk of post construction movement.

Soil Reinforcement

Soil reinforcement holds the wall facing panels in position and provides reinforcement for the soil. The soil reinforcement can be strips, grids, or mesh. The reinforcement can be made of steel (inextensible materials) or polymers (extensible materials).

Spacers

Wall panel spacers are typically ribbed elastomeric or polymeric pads. They are inserted between panels to help provide the proper spacing. Proper spacing keeps the panels from having point contact and spalling the concrete.

Wall Facing Panel

At a free boundary of a reinforced earth structure it is necessary to provide some form of barrier so that the soil is contained. Wall Facing panels or panels are used to hold the soil in position at the face of the wall. The panels are typically concrete but they can be metal, wood, block, mesh or other material. Retained Earth wall panels are available in three basic geometric shapes: 5-feet (1.5m) high hexagonal panels; 5-feet (1.5m) square panels; and rectangular panels 10 feet (3.05m) wide and 5 feet (1.5m) high.

The concrete block usually present passing holes, which are filled with soil when installed, increasing in this way the weight of the block and allowing the weight. The concrete block usually present passing holes, which are filled with soil when installed, increasing in this way the weight of the block and allowing the anchorage of Geogrids. The face of the blocks may be curved for better aesthetical finishing. The block is self stable by gravity without soil pressure.

Wall/Reinforcement Connection

This is where the connection is made between the wall facing panel and the soil reinforcing.

Wooden Wedges

Wooden wedges are used to help hold the panels at the correct batter during the filling operation. The wooden wedges should be made from hard wood (such as oak, maple or ash).

Advantages:

The Reinforced Earth system provides a number of significant advantages:

- The resistance and stability of the composite structure provides significant load-bearing capacity against both static and dynamic loads.
- The durability of the materials is well documented and the safety of the structures is unrivalled.
- The ease and speed of construction are significant advantages in reducing overall cost.
- The technology provides solutions to complex cases and often proves to be the best answer to circumstances such as restricted right-of-way, unstable natural slopes, marginal foundation conditions and large settlements.
- The variety of facings can meet all architectural requirements.

Disadvantages:

- Corrosion of metallic reinforcement occurs and must be assessed on a project basis by determining the potential aggressiveness of the soil. Special coatings such as galvanized zinc and resin-bonded epoxy are used with a sacrificial thickness of steel added in the design to give the required service life.
- Although polymeric reinforcement is a robust material, some allowance must be made for decrease in strength due to abrasion during construction. This will vary with the type of reinforcement material.
- Different polymers have different creep characteristics. Allowable loads in the grid should be selected based on allowable deformations, as well as the results of creep tests (10,000 hour).
- Excavation behind the reinforced earth wall is restricted.

TECHNICAL BENEFITS

The benefits of reinforced soil may be considered in terms of both technical benefits and economic benefits. The former arise when the design provides for an improvement in the technical performance of the structure. The latter may accrue as a result of a technical benefit, or as a result of a lower cost solution.

The major technical benefits associated with reinforced soil are:

- The presence of reinforcement in the soil helps to reduce the forces in the soil which cause failure and helps also to increase the forces in the soil which resist failure.
- Design needs no longer be dominated solely by the shearing resistance of the available soils. For example, soil slopes can be steepened, if required, by the inclusion of reinforcement, or unexpectedly poor ground can be strengthened.

BASIS FOR DESIGN

The design of reinforced walls and abutments follows the principles involved in conventional earth retaining structures, however, reinforced soil structures required additional consideration with regards to soil reinforcement interaction. For convenience analysis is usually considered in two parts covering external and internal stability. External stability covers the basic stability of the reinforced soil structure as a unit, while internal stability covers all areas relating to internal behavior mechanisms, consideration of the stress with in the structure, arrangement and behavior of the reinforcements and backfill properties.

There are two methods currently used for the design of reinforced soil structures, which as referred to as the tie back wedge method and coherent gravity method. The tie back wedge method follows basic design principles currently employed for classical or anchored retaining walls. It has evolved from the use of all forms of permitted reinforcements. The coherent gravity method is based on the monitored behavior of structures using extensible reinforcements and has evolved over a number of year from observations on a large number of structures, corroborated by theoretical analysis. Design is usually based upon the assumption of a two dimensional plane strain condition.

GENERAL

In this the initial design is carried out determining the length of the reinforcement and the number of layers of reinforcement. This design follows the external stability and internal stability criteria of tie-back wedge method. Prior to considering external stability the overall geometry of the wall should be selected. Considering either the external or the internal stability may require the dimensions of the structure to be increased from the initial size. The initial dimensions of the structure should not be less than the minimum specified in table 1, unless it can be satisfactorily demonstrated by previous experience that smaller value are adequate. The geometrical size of the structure should be based upon a concept of mechanical height, H, which is defined as the vertical distance from the toe of the structure

Table 1 Dimensions of the walls

Structure Type	Minimum reinforcement length.
Walls with normal retaining function	0.7 H (3 m. minimum)
Bridge abutments	The greater of 0.6H + 2m or 7m.
Trapezoidal walls and abutments	0.7 H for reinforcements in top half of structure 0.4 H for reinforcements in bottom half of structure or 3 m. minimum.
Stepped walls and abutments	0.7 m in top half of structure.
Wall subjected to low thrust from retained fill such as negative back slope or embedded walls.	0.6 m or 3m minimums.
Low height walls i.e. less than 1.5 m.	Subject to particular considerations.

DESIGN OF REINFORCEMENT

The design of reinforced soil wall is required to full fill the following.

- External stability
- Internal stability

The external stability analysis of reinforced wall is carried out analogous to gravity retaining wall design. In this the portion with reinforcement layer and soil layers (i.e. reinforced soil zone) is considered as a monolithic rigid block and checked for different failures against sliding, overturning, and bearing capacity. The fig. 1 shows the schematic representation of forces due to backfill beneath the reinforced soil zone, due to own weight and due surcharge.

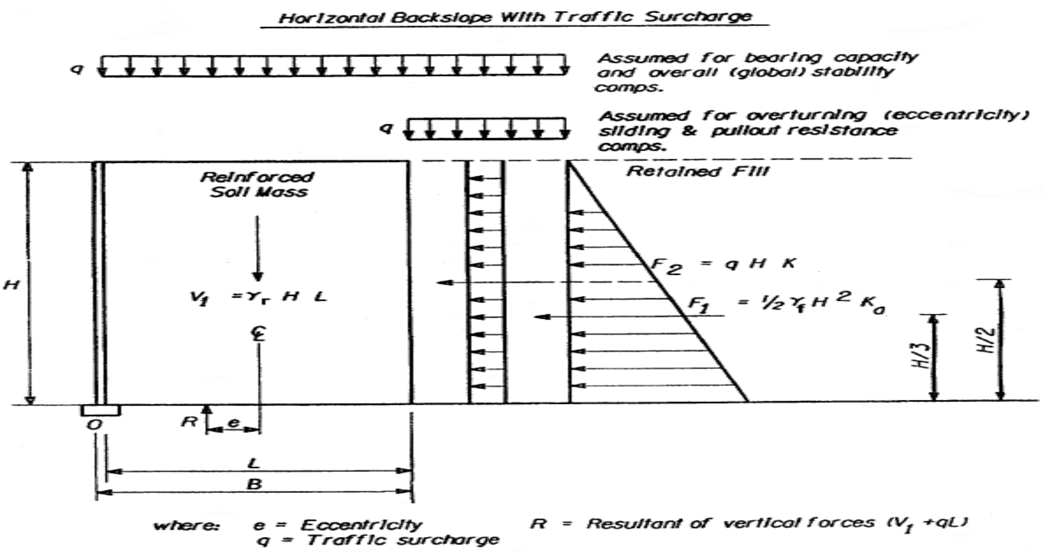


Fig. 1 Forces For External Stability Calculations of Reinforced Soil Wall

The tie–back wedge method for internal stability is used to determine the number of layers and strength of the reinforcement layer by assuming a fix vertical spacing between the reinforcement layers. The maximum tension mobilized in (case of planner reinforcement) the reinforcement is calculated at each layer as shown in the fig. 2. It is assumed that the maximum tension in the respective reinforcement layer is mobilized at the point where it cuts the Rankin's failure plane. The calculated maximum tensile force is checked with the design strength of reinforcement layer provided at particular reinforcement layer. Similarly the adequacy of the bond length is checked for the assumed spacing and as specified minimum bond lengths are mentioned as per requirement.

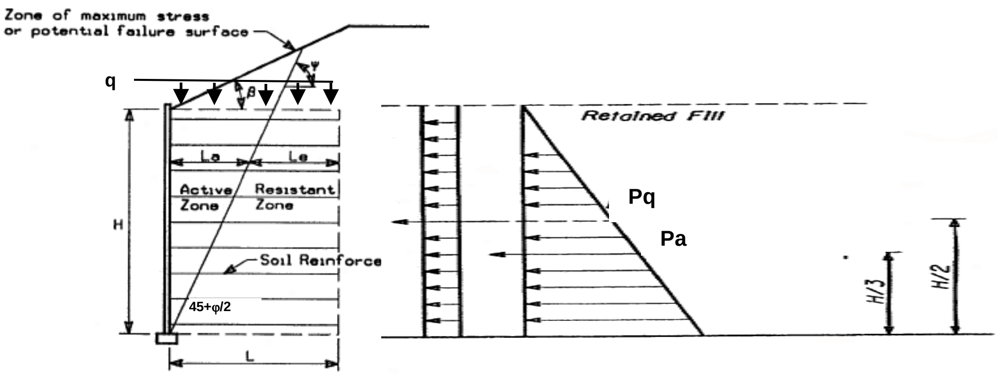


Fig 2 Internal stability Forces used for calculations of reinforced soil wall

i) Sliding failure: The stability against forward sliding of the structure at the interface between the reinforced fill and the subsoil should be considered. The resistance to movement should be based upon the properties of either the subsoil or the reinforced fill, whichever is the weaker. This is because the coefficient of friction will generally be lower between the soil and reinforcement than soil on soil and consideration should be given to sliding on or between any reinforcement layers used at the base of the structure.
ii) Overturning: Overturning is initiated by the thrust of the reinforced backfill, causing the reinforced block to topple forward as shown in fig. 2 .The factor of safety is calculated from overturning and restoring moment above the toe of the wall.
iii) Bearing failure: bearing failure is occurs if the maximum vertical stress is exerted by the reinforced soil block exceeds the bearing capacity of the underlying soil as shown in fig. 3 normal practice is to estimate the vertical distribution on the base of the wall and compare this with the allowable bearing pressure, for a uniform wall with surcharge, and assuming trapezoidal pressure distribution.
Allowable bearing pressure may be taken from foundation codes (e.g. BS 8004) or estimated using bearing capacity theory with factor more than 2. If bearing capacity is inadequate, the designed may consider using a reinforced slab under the wall.

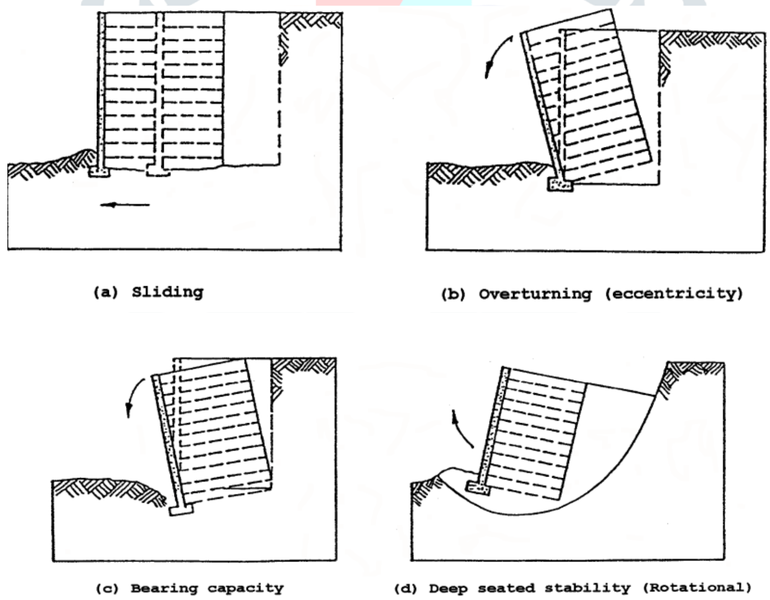


Fig. 3 Mechanism of overall failure in reinforced soil walls (a) outward sliding. (b) Over turning (c) Base failure (b) over burning (c) deep seated failure

INTERNAL STABILITY

The internal stability of the reinforced zone must be checked with respect to the mechanism shown in fig. 4
i) Tension failure It is checked for each layer taking in to account the self weight of the fill, Uniform surcharge, vertical and horizontal line loads on the crest. And bending moment caused by external loading.
ii) Pullout failure It is checked by considering both the pullout capacity of each layers, and the equilibrium of planner wedge mechanism through the reinforced zone. For each layer, bond length beyond the point of maximum tension are assessed. Bond or anchorage length beyond the critical wedge must be sufficient to prevent pullout.

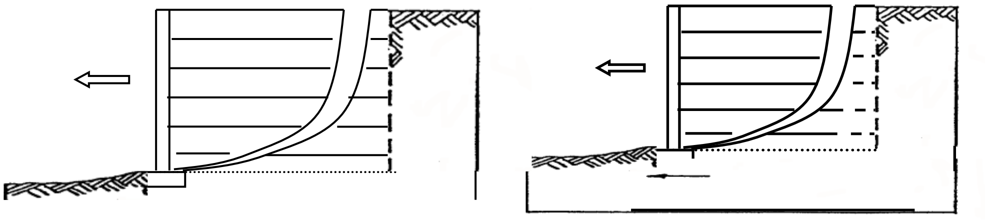


Fig. 4 Mechanism of internal failure in reinforced soil walls
(a) Tension failure (b) Pullout failure

VIDAL'S METHOD
The earth retaining wall was first introduced in the 1960,s by H. Vidal of France with the concept of reinforced earth.

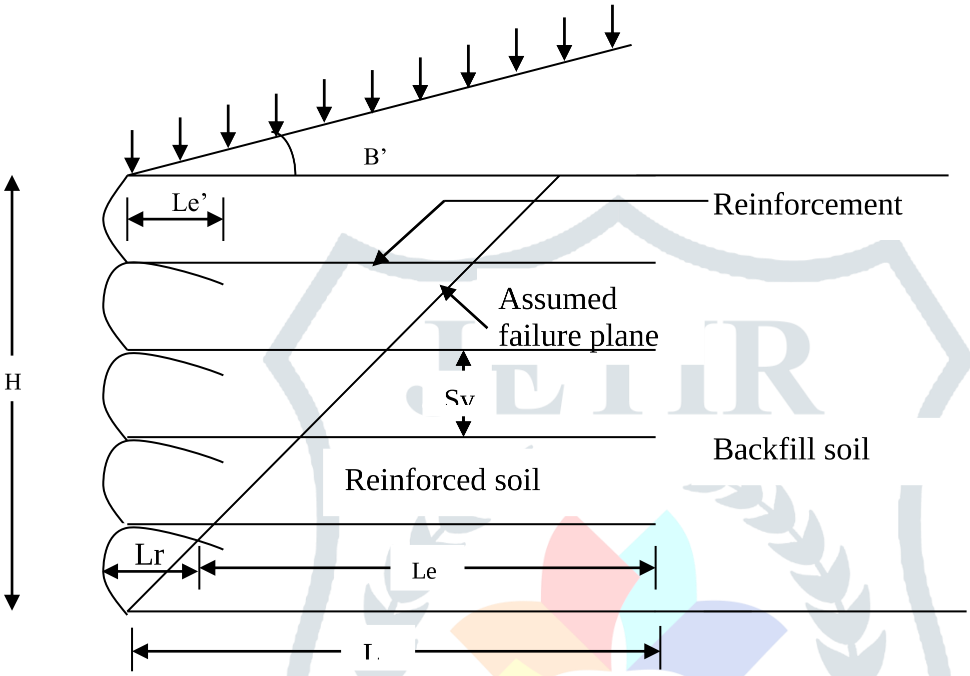


Fig. 5 Details of reinforced earth retaining wall

EXTERNAL STABILITY
The check for external stability and the calculation of the length of the reinforcement as follows.
With the help of backfill soil properties, total active earth pressure acting on retaining wall is calculated using the equation.

$P_h = Pa + Pq$

$P_h = \gamma_b \; H \; Ka + Ka \; q$

Where,

$K_a = \tan^2 (45 - \phi_b /2)$

1) The factor of safety against sliding is the ratio of resisting force and the total active force. And checked against the minimum value of 1.5.

$$FS_{(SL)} = \frac{\text{Re}\,sisting.force}{Total.ActiveForce} \geq 1.5$$

Now the resisting force is calculated by taking the initial value of the length of the reinforcement by using following equation

$F_r = [Ca + ((W+Pa \sin \delta)/3) \times \tan \delta] \times 3$

$Pa = Pa \times \cos \delta$

Where,

F_r = Resisting force
L = Length of the reinforcement
Ca = Cohesion in foundation soil = 0.8 c
δ = Angle of wall friction = 2/3 $\varnothing_r$

$$FS = \frac{[Ca + ((W+Pa \sin \delta)/3) \times \tan \delta] \times 3}{Pa \times \cos \delta} \geq 1.5$$

2) The factor of safety against overturning is calculated as the ratio of stabilizing moment and overturning moment this value is checked against a minimum value of 3.0

$$FS = \frac{\text{Stabilizing Moment}}{\text{Overturning Moment}} \geq 3$$

The stabilizing and overturning moments are calculated using the following equation.

$M_s = W \times (L/2) + Pa \times \sin\delta$

Where, $W = L \times H \times \gamma r$

$M_o = Pa \times \cos\delta \times (L/3)$

3) The factor of safety against bearing pressure is calculated as the ratio of bearing capacity of the foundation and bearing pressure.

$$FS = \frac{\text{Bearing capacity of foundation}}{\text{Bearing Pressure}}$$

Or, Safe bearing capacity of foundation soil > Bearing pressure

The bearing pressure is calculated by the following equation.

$Bp = \gamma_r .H + q$

INTERNAL STABILITY

1) The factor of safety against rupture is calculated as the ratio of the allowable tensile strength of the reinforcement and the maximum tensile strength of the reinforcement and the maximum tensile force calculated, and checked against a minimum value of 1.5.

$$FS = \frac{\tau_{all}}{\tau_{max}}$$

Knowing the length of bars required, the check for internal stability and the calculation of number of bars proceed as follows.

The maximum tensile force acting on the bottom most layers is calculated by using the following equation.

$T_{max} = \sigma v. Sv$

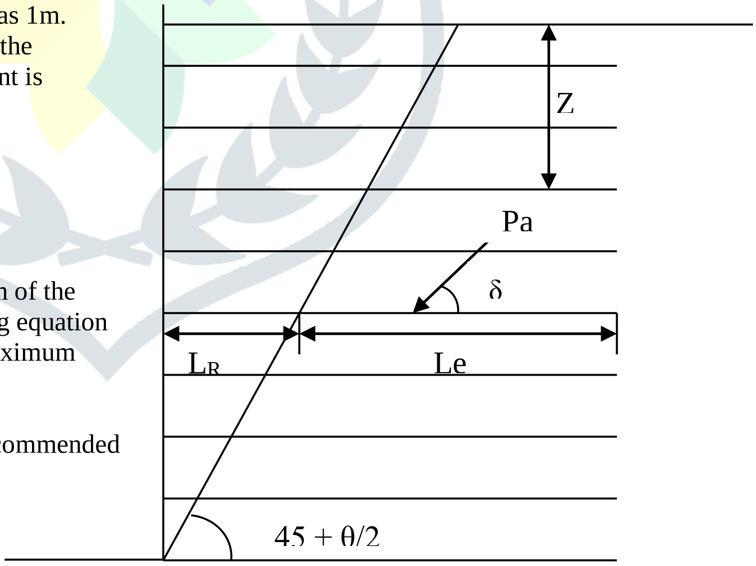
If the check fails, the strength of the reinforcement is increased and the procedure is repeated. The number of bars required for the reinforced soil wall is calculated by dividing the active earth pressure on the wall by allowable strength of the reinforcement.

The minimum effective length is calculated by using the following expression

If the effective length is less than 1m, it has been taken as 1m. If it is greater than 1m. The calculated value is taken as the effective length. The required length of the reinforcement is calculated by using the following equation.

$L_r = (H – Z) \tan (45 – \theta/2)$

$$Le = \frac{Sv \times бh \times FS_g}{2 \times (C+(\gamma r \times Zx \tan\delta)}$$



The total length of the reinforcement is the sum of the effective length and the required length calculated using equation of Lr The length of the reinforcement is taken as the maximum calculated length by external stabilities.

$L = Lr + Le$

Check for overlap length to see if it is less than 1m. Recommended value using the equation.

$$L_o = \frac{Sv \times бh \times FS_g}{4 \times (C+(\gamma r \times Zx \tan\delta)}$$

As Le is maximum than Lo in upper layer.

CLAYTON AND WOOD

External stability

1) The factor of safety against sliding

$$FS = \frac{2\,\mu\,(\gamma \times H + q)}{Ka \times (\gamma \times H + 2xq) \times (H/L)} \geq 2.0$$

Calculate the total active force

$Pa = Ka \times (\gamma \times H + 2xq) \times (H/L)$

Calculate resisting force

$F = 2\ \mu\ (\gamma_r .H + q)$

Where,

μ = Sliding coefficient = minimum of (tan ϕ_b , tan ϕ_r or tan ϕ_r)

2) Factor of safety against overturning

$$FS = \frac{3 \text{ x } (\gamma \text{ x } H + q)}{Ka \text{ x } (\gamma \text{ x } H + 3xq) \text{ x } (H/L)^{\wedge 2}} \geq 2.0$$

The stabilizing moment are calculated as

$Ms = 3\ (\gamma_r .H + q)$

The overturning moment is calculated as

$Mo = Ka \text{ x } (\gamma \text{ x } H + 3xq) \text{ x } (H/L)^{\wedge 2}$

3) The bearing pressure is calculated as

The bearing capacity of soil is BC

$$F.S_{(BC)} = \frac{BC}{BP} \geq 2.0$$

Internal Stability

1) Factor of safety against breaking

$$FS = \frac{\tau_{all}}{\tau_{max}}$$

Maximum tension in reinforcement

Tmax = Ka x Sv x □v

σ_v = $(\gamma \text{ x } Z + q) + Ka\ (\gamma \text{ x } Z + 3 \text{ x } q)\ (Z/L)^{\wedge 2}$

Tall = Allowable strength of reinforcement

2) The Factor of safety against pullout is calculated as

$$FS = \frac{F_p}{P_p}$$

Pullout force is calculated as

$F_p = 2 \text{ x } Le \text{ x } (\gamma_b \text{ x } Z + q)\ f_b \text{ x } \phi_b \text{ x } \tan \phi_r$

$P_p = 2 \text{ x } Be \text{ x } Le \text{ x } (\gamma \text{ x } Z + q) \text{ x } \mu$

Where,

Be = Effective width of reinforcement per unit length of wall

Be = B / Sh

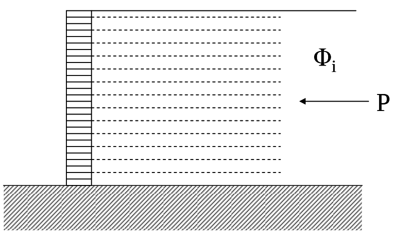
B = width of reinforcement

MODIFIED RANKINE'S METHOD

External stability

Rankine's analysis is the simplest but also the most restrictive. It can only include a horizontal thrust (which is probably not accurate for soil versus soil) so it is modified to include an inclination angle.

1. Horizontal back slope (i.e.β =0)



$Ka = \tan^2(45 - \Phi_i/2)$

Inclination(deg.) = 0º

Vertical wall (i.e. $\omega \cong 0$)

Calculation of active earth pressure due to soil

$Pa = 0.5\gamma_b H^2 Ka$

Calculation of pressure due to surcharge:

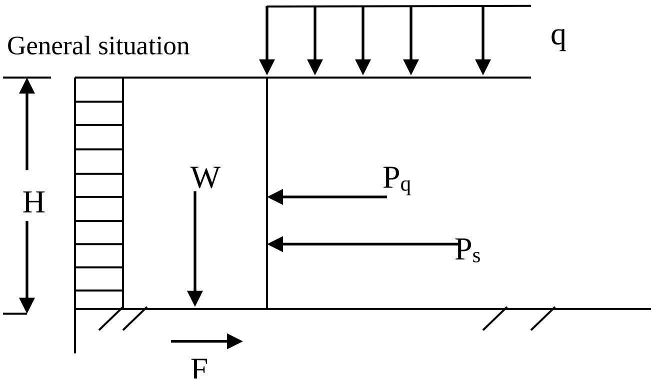
$Pq = q\ H\ Ka$

Calculation of total active pressure acting on the retaining wall

$P_h = Pa + Pq$

In all methods 'P' acts at H/3 above the foundation soil for soil pressure, and H/2 for surcharge pressure.

1) Calculation of sliding against foundation soil or rock General situation



$$FS = \frac{F}{P_h} \geq 1.5$$

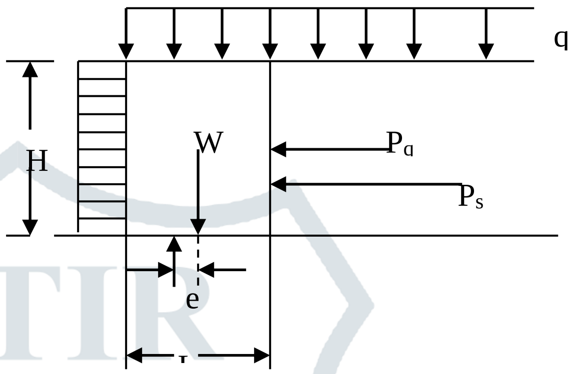
Where, $F = W\mu$

μ = Minimum of (or tan ϕ_p)

W = L x H x γ_r

The calculation method requires the resulting FS to equal or exceed a value of 1.5.

2) Calculation of eccentricity and foundation soil bearing capacity



$$e = \frac{M_{ov}}{W + qL} < \frac{L}{6}$$

Where,

$$M_{ov} = H\left(\frac{P_a}{3} + \frac{P_q}{2}\right)$$

Bearing pressure calculated as

$$BP = \frac{W + qL}{L - 2e}$$

$$Fs = \frac{\text{Bearing capacity, BC}}{\text{Bearing prassure, BP}} \geq 2.0$$

To calculate load eccentricity on the basis of the drainage provided in reinforced soil zone where it interfaces with the foundation soil. This load eccentricity is then used in the calculation of mass bearing pressure (BP), as well as the foundation soil bearing capacity (BC). The result of this ratio is FS- value, which must exceed or equal, either 2.0 or 2.5 using the Modified Rankine's method.

3) Calculation of overturning about the toe of the RER wall

$$FS = \frac{Mr}{M_{ov}} \geq 2.0$$

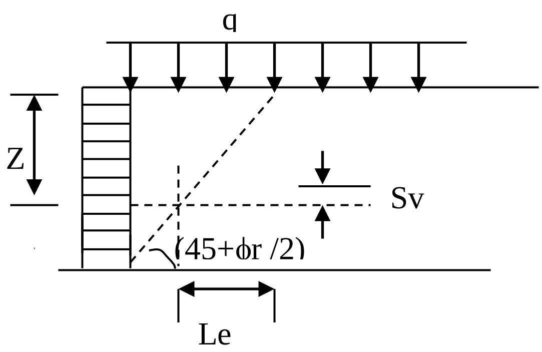
Where, $Mr = \frac{WL}{2}$

$$M_{ov} = H\left(\frac{P_a}{3} + \frac{P_q}{2}\right)$$

The design method used for the calculation of FS – value against overturning of the RER wall mass is about the toe of the wall. It uses the earth pressure at their respective inclinations and locations to obtain the overturning moment. When compared to resulting or stabilizing moment the ratio results in a FS- value. This value must exceed, or equal, 2.0 in modified Rankine's method.

Internal stability

1) Factor of safety against Pullout



$$\frac{2L_e\, C_i\, C_r\, \sigma_v \tan \phi_r}{S_v\, \sigma_h} \geq 1.5$$

$$FS = \frac{Sv\, \sigma_h\, F.S.}{2\,(C + (\gamma_r \times Z + \tan \delta)} \geq 1.5$$

Where,

Le = Embedment length (min 1.0m)

Ci = Interaction coefficient

Cr = Coverage ratio

$\sigma_h = K_{ar}(\gamma z + q)$

ϕr

$K_{ar} = \tan^2 (45 - \quad)$

$\sigma_v = \gamma_r + Z$

2) Factor of safety against Over tension

$$F.S. = \frac{Tz}{\text{Design Strength}}$$

T_{hz} = Tensile force from the height of fill at Z^{th} layer
$T_{hz} = (Ka \times \gamma r \times Z - 2C \times Ka)^{1/2} \times Z$
T_{qz} = Tensile force from uniformly distributed surcharge on top of wall at Z^{th} layer
$T_{qz} = Ka \times q \times Z$
Tz = Maximum tensile force to be resisted by the Z^{th} layer of element at a depth hz
$Tz = T_{hz} + T_{qz}$

PROBLEM STATEMENT

For the comparisons of the three design methodologies given in the previous sections, a practical problem the following segmental retaining wall design example is offered.

Data:
Height of wall (H) = 10.5m
Length of wall (L) = 6.40m
Uniformly Distributed Surcharge (q) = 22.5 kN/m^2
Unit weight of backfill soil (γ_b) = 18 kN /m^3
Unit weight of reinforced earth backfill soil (γ_r) = 20 kN /m^3
Unit weight of foundation soil (γ_f) =18 kN /m^3
Friction angle of Foundation Soil (ϕ_f) = 30°
Friction angle of Backfill Soil (ϕ_b) = 30°
Friction angle of Reinforced Soil (ϕ_r) = 32°
Angle of wall friction (δ) = 2/3 x ϕ_r = 2/3 x 32 = 21.33°
Allowable Geotextile Strength (τ_{all}) = 100 kN/m
Safe Bearing Capacity of soil (SBC) = 400 kN /m^2

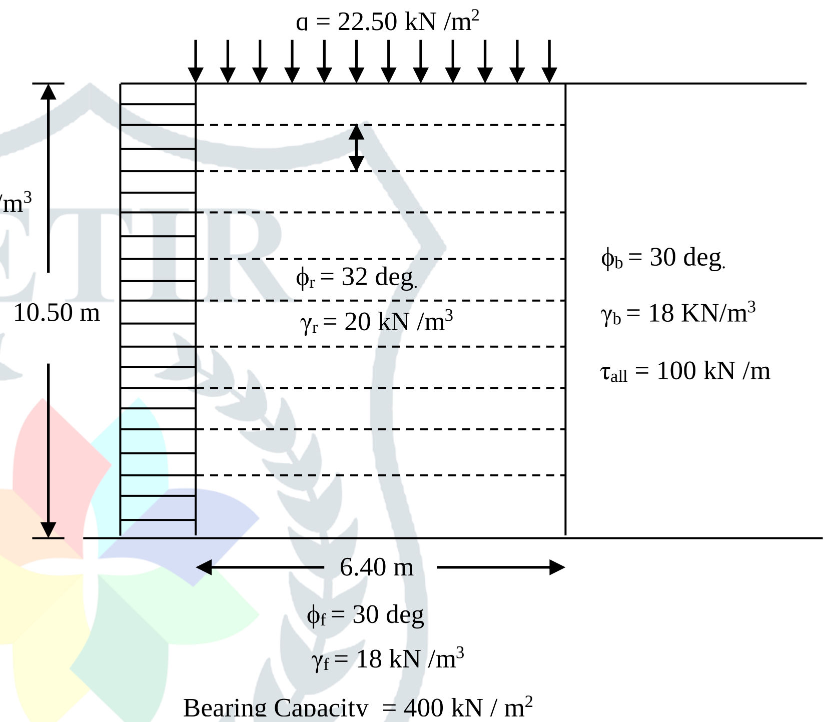


Fig. Reinforced Soil Wall

ANALYSIS BY HENDRY VIDAL'S METHOD: -

<u>External stability</u>

❖ **Coefficient of active earth pressure**

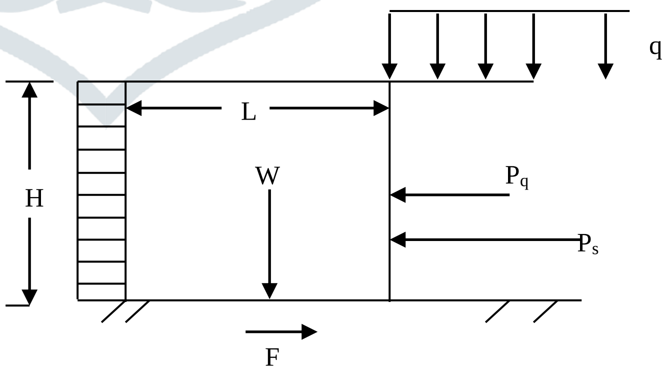
Ka $= \tan^2 (45 - \phi_b /2)$
$= \tan^2 (45 - 30 /2)$
=0.33

Pa = Pressure due to soil

Pa $= 0.5\gamma_b H^2$ Ka
$=0.5 \times 18 \times 10.5^2 \times 0.33$
=327.44 kN /m

Pa x cos δ = 327.44 x cos 21.33°
=305.01

Pa x sin δ = 327.44 x sin 21.33°
=119.10



❖ **Factor of Safety against Overturning**

$$FS = \frac{\text{Stabilizing Moment}}{\text{Overturning Moment}} \geq 3$$

$$\frac{W \times (L/2) + Pa \times \sin\delta}{Pa \times \cos\delta \times (L/3)}$$

$$\frac{1344 \times (6.4/2) + 119.10}{305.01 \times (6.4/3)}$$

= 6.79 > 3

Where,

W = L x H x γr

= 6.4 x 10.5 x 20

= 1344

❖ **Factor of Safety against Sliding**

$$FS = \frac{[Ca + ((W+Pa \sin \delta)/3) \times \tan \delta] \times 3}{Pa \times \cos \delta} \geq 1.5$$

$$= \frac{[0 + ((1344+119.10)/3) \times 0.39] \times 3}{305.01}$$

= 1.85 > 1.5

❖ **Factor of Safety Bearing Pressure**

$$FS = \frac{\text{Bearing capacity of foundation}}{\text{Bearing Pressure}} \geq 1.5$$

FS=Safe bearing capacity of the foundation soil > Bearing pressure

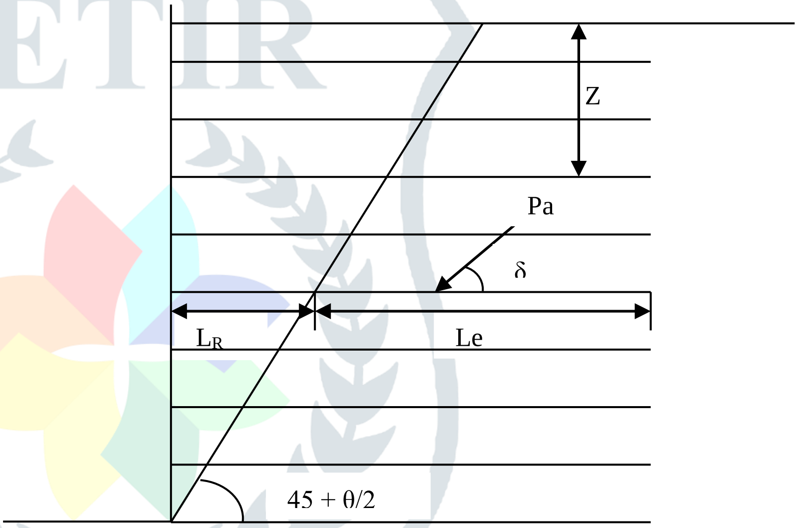
Bp = Bearing Capacity = γ_b x H + q

= 20 x 10.5 + 22.5

= 232.50 < 400 kN /m^2

Internal stability

❖ Factor of safety against pullout failure



L =Total length of reinforcement

L = Lr + Le

Where,

Le = Minimum effective length

$$= \frac{Sv \times бh \times FS_g}{2 \times (C+(\gamma r \times Zx \tan\delta)}$$

Lr = Required length of reinforcement

= (H – Z) tan (45 – θ/2)

Lo = Overlap length

$$= \frac{Sv \times бh \times FS_g}{4 \times (C+(\gamma r \times Zx \tan\delta)}$$

$б_h$ = H

= (Ka x γb x z) + (Ka x q)

FS = Factor of Safety against Pullout

$$= \frac{2(C+ (\gamma r \times Z \times \tan\delta) \times Lo}{Sv \times бh}$$

Table 5.1 Calculation of factor of safety against pullout at various depth

Depth Z (m)	**Coeff. Of Active earth pressure Ka**	**Hori. Stress On Layer $б_h$ (kN /m)**	**Spac-ing Of reinf. Sv (m)**	**Req. length Of reinf. Lr (m)**	**Eff. length Le (m)**	**Min. eff. length Le (min) (m)**	**Total length of reinf. L (m)**	**Over lap length Lo (m)**	**Lo (min)**	**FS**
9.5	0.33	64.50	0.5	0.577	0.326	1.000	1.577	0.163	1.000	4.602
8.5	0.33	58.50	1	1.155	0.661	1.000	2.155	0.330	1.000	2.270
7.5	0.33	52.50	1	1.732	0.672	1.000	2.732	0.336	1.000	2.232
6.5	0.33	46.50	1	2.309	0.687	1.000	3.309	0.343	1.000	2.184
5.5	0.33	40.50	1	2.887	0.707	1.000	3.887	0.354	1.000	2.122
4.5	0.33	34.50	1	3.464	0.736	1.000	4.464	0.368	1.000	2.038
3.5	0.33	28.50	1	4.041	0.782	1.000	5.041	0.391	1.000	1.919
2.5	0.33	22.50	1	4.619	0.864	1.000	5.619	0.432	1.000	1.736
1.5	0.33	16.50	1.5	5.196	1.584	1.000	6.780	0.792	1.000	0.947
0.5	0.33	10.50	1.5	5.774	3.025	1.000	8.798	1.512	1.512	0.750

❖ *Factor of safety against Tension failure*

FS = Factor of Safety against Tension Failure

$$FS = \frac{\tau_{all}}{\tau_{max}}$$

$6v = \gamma r \times Z$

$Tmax = 6v \times Sv$

Table 5.2 Calculation of factor of safety against tension failure at various depths

Depth Z (m)	Spacing of reinforcement Sv(m)	Vertical Stress on Layer 6v	τ_{max}	τ_{all}	FS_p
9.5	0.5	190.00	95.00	100	1.053
8.5	1	170.00	170.00	100	0.588
7.5	1	150.00	150.00	100	0.667
6.5	1	130.00	130.00	100	0.769
5.5	1	110.00	110.00	100	0.909
4.5	1	90.00	90.00	100	1.111
3.5	1	70.00	70.00	100	1.429
2.5	1	50.00	50.00	100	2.000
1.5	1.5	30.00	45.00	100	2.222
0.5	1.5	10.00	15.00	100	6.667

Table 5.3 Calculation for design strength for desired factor of safety

Depth Z (m)	Spacing of reinforcement Sv(m)	Vertical Stress on Layer 6v	τ_{max}	τ_{all}	FS_p
9.5	0.5	190.00	95.00	142.50	1.50
8.5	1	170.00	170.00	255.00	1.50
7.5	1	150.00	150.00	225.00	1.50
6.5	1	130.00	130.00	195.00	1.50
5.5	1	110.00	110.00	165.00	1.50
4.5	1	90.00	90.00	135.00	1.50
3.5	1	70.00	70.00	105.00	1.50
2.5	1	50.00	50.00	75.00	1.50
1.5	1.5	30.00	45.00	67.50	1.50
0.5	1.5	10.00	15.00	22.50	1.50

ANALYSIS BY CLAYTON & WOOD METHOD: -

External stability

❖ **Factor of safety against Sliding**

$$FS = \frac{2\,\mu\,(\gamma \times H + q)}{Ka \times (\gamma \times H + 2xq) \times (H/L)} \geq 2.0$$

$$FS = \frac{2 \times 0.577 \times (20 \times 10.5 + 22.5)}{0.33\,(20 \times 10.5 + 2 \times 22.5) \times (10.5/6.4)}$$

$= 1.94$

Alternatively, the minimum reinforcement length can be expressed as

$$L_{min} = \frac{F.S._{(slide)} \times Ka\,(\gamma \times H + 2 \times q) \times H}{2 \times \mu\,(\gamma \times H + q)} < L\ (prov.)$$

$$L_{min} = \frac{1.94 \times 0.33(20 \times 10.5 + 2 \times 22.5) \times 10.5}{2 \times 0.577 \times (20 \times 10.5 + 22.5)}$$

L_{min} = 6.38 m < 6.40 m (provided)

- **Factor of safety against Overturning**

$$FS = \frac{3 \times (\gamma \times H + q)}{Ka \times (\gamma \times H + 3xq) \times (H/L)^{2}} \geq 2.0$$

$$FS = \frac{3 \times (20 \times 10.5 + 22.5)}{0.33\,(20 \times 10.5 + 3 \times 22.5) \times (10.5/6.4)^{2}}$$

FS = 2.80 > 2.0

- **Factor of safety against Bearing failure**

The Bearing Pressure is calculated as

$$BP = \frac{(\gamma_r.H.+q)}{\left[1-\left(\frac{K_{ar}(\gamma_r.H.+3q)\left(H/L\right)^2}{3(\gamma_r.H.+q)}\right)\right]}$$

= 361.56 < 400 KN/m^2

Safe Bearing capacity of foundation soil > Bearing capacity of soil

Internal Stability

- **Factor of Safety against Tension failure**

$$FS = \frac{\tau_{all}}{\tau_{max}}$$

σ_v = (γ x Z + q) + Ka (γ x Z + 3 x q) (Z/L)^2

τ_{max} = Ka x Sv x □v

Table 5.4 Calculation of factor of safety against tension failure for various depth

Depth Z (m)	Spacing of reinforcement Sv (m)	Vertical □stress on layer□ □v (kN /m)	Maximum Allowable stress τ_{max} (kN/m)	Allowable stress τ_{all} (kN /m)	FS
9.5	0.5	401.62	66.94	100	1.49
8.5	1	332.14	110.71	100	0.90
7.5	1	272.06	90.69	100	1.10
6.5	1	220.41	73.47	100	1.36
5.5	1	176.20	58.73	100	1.70
4.5	1	102.88	34.29	100	2.17
3.5	1	106.21	35.40	100	2.82
2.5	1	78.48	26.16	100	3.82
1.5	1.5	54.29	27.14	100	3.68
0.5	1.5	32.66	16.33	100	6.12

Table 5.5 Calculation for design strength for desired factor of safety

Depth Z (m)	Spacing of reinforcement Sv (m)	Vertical stress on layer□ □v (kN/m)	Maximum Allowable stress τ_{max} (kN/m)	Allowable stress τ_{all} (kN/m)	FS
9.5	0.5	401.62	66.94	100.41	1.50
8.5	1	332.14	110.71	166.07	1.50
7.5	1	272.06	90.69	136.03	1.50
6.5	1	220.41	73.47	110.20	1.50
5.5	1	176.20	58.73	88.10	1.50
4.5	1	102.88	34.29	51.44	1.50
3.5	1	106.21	35.40	53.10	1.50
2.5	1	78.48	26.16	39.24	1.50
1.5	1.5	54.29	27.14	40.71	1.50
0.5	1.5	32.66	16.33	24.49	1.50

❖ **Factor of Safety against Pullout failure**

$$FS = \frac{F_p}{P_p}$$

Where,

$F_p = 2 \times Le \times (\gamma_b \times Z + q)\, f_b \times \phi_b \times \tan \phi_r$

$P_p = 2 \times Be \times Le \times (\gamma \times Z + q) \times \mu$

$\square_v = (\gamma \times Z + q) + Ka\, (\gamma \times Z + 3 \times q) \times (Z / L)^2$

Le = Embedment length (min 1.0m)

$$= \frac{Sv\ \sigma_h\ F.S.}{2\ (C + (\gamma_r \times Z + \tan \delta)} \geq 1.5$$

Be = Effective Width of reinforcement per unit length of wall = 0.5 m

Table 5.6 Calculation of factor of safety against pullout failure for various depth

Depth Z (m)	Spacing of reinforcement Sv (m)	Horizontal Stress on layer σ_h (kN/m)	Embedd-ed length Le (m)	Pullout Force Fp (kN)	Effective Width of reinforc-ement. Be (m)	Pullout Resistance Pp (kN/m)	F.S.
9.5	0.5	133.87	0.677	241.824	0.5	83.003	2.913
8.5	1	110.71	1.251	219.329	0.5	138.997	1.578
7.5	1	90.69	1.161	196.834	0.5	115.629	1.702
6.5	1	73.47	1.085	189.205	0.5	95.554	1.980
5.5	1	58.73	1.025	155.689	0.5	78.436	1.985
4.5	1	46.15	0.985	127.375	0.5	63.961	1.991
3.5	1	35.40	0.971	103.777	0.5	51.868	2.001
2.5	1	26.16	1.005	84.752	0.5	42.054	2.015
1.5	1.5	18.10	1.737	107.482	0.5	52.663	2.041
0.5	1.5	10.89	3.136	123.443	0.5	58.838	2.098

ANALYSIS BY MODIFIED RANKINE'S METHOD: -

External stability

❖ **Coefficient of active earth pressure**

Ka $= \tan^2 (45 - \phi_b /2)$

$= \tan^2 (45 - 30 /2)$

$=0.33$

$P_h = Pa + Pq$

Where,

P_h = Total active pressure acting on the retaining wall (KN/m),

Pa = Pressure due to soil

Pa $= 0.5\gamma_b\, H^2\, Ka$

$=0.5 \times 18 \times 10.5^2 \times 0.33$

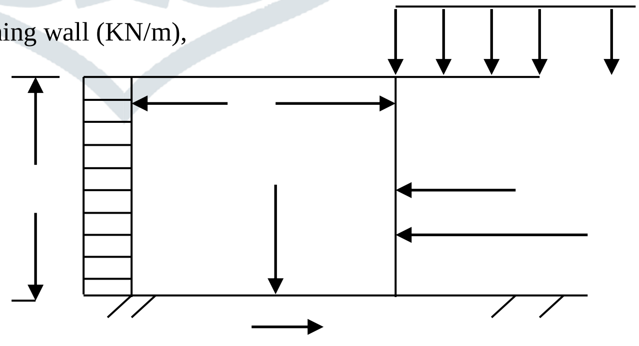
$=327.44$ kN/m

Pq = Pressure due to surcharge:

Pq $= q\, H\, Ka$

$=22.5 \times 10.5 \times 0.33$

$=77.96$ kN/m



In all methods 'P' acts at H/3 above the foundation soil for soil pressure, and H/2 for surcharge pressure.

❖ **Sliding against foundation soil or rock**

$$FS = \frac{F}{P_h} \geq 1.5$$

Where, $F = W\mu$

μ = minimum of ($\tan \phi_f$, $\tan\phi_r$ or $\tan \phi_p$)

= tan 30

=0.577

W $= L \times H \times \gamma_r$

=6.4 x 10.5 x 20
=1344 kN/m

F = 1344 x 0.577
=775.488 KN/m

$$FS = \frac{775.488}{405.40}$$

= 1.91 > 1.5

The calculation method requires the resulting FS to equal or exceed a value of 1.5.

- **Eccentricity and foundation soil bearing capacity**

$$e = \frac{M_{ov}}{W + qL} < \frac{L}{6}$$

Where, $M_{ov} = H \left(\frac{P_a}{3} + \frac{P_q}{2} \right)$

$$M_{ov} = 10.5 \times \left(\frac{327.44}{3} + \frac{77.96}{2} \right)$$

=1555.33

$$e = \frac{1555.33}{1344 + 22.5 \times 6.40} < 6.4 / 6$$

= 1.04 < 1.06

$$Fs = \frac{\text{Bearing capacity, BC}}{\text{Bearing pressure, BP}} \geq 2.0$$

Where BC = 350 kN/m^3

$$BP = \frac{W + qL}{L - 2e}$$

$$BP = \frac{1344 + 22.5 \times 6.40}{6.40 - 22.5 \times 6.40}$$

= 344.44 < 350 kN/m^3

- ***Overturning about the toe of the MSE wall***

$$FS = \frac{Mr}{M_{ov}} \geq 2.0$$

Where, $Mr = \frac{WL}{2}$

$$Mr = \frac{1344 \times 6.40}{2}$$

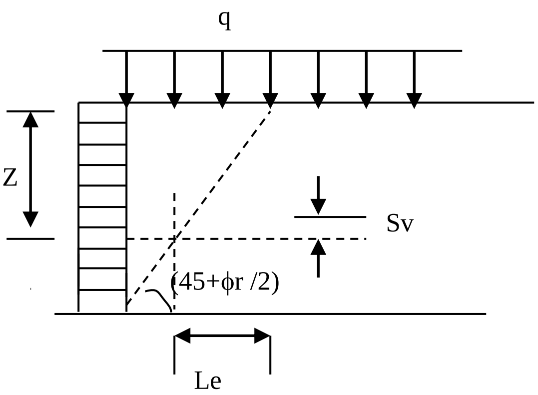
= 4300.8

Where, $M_{ov} = H \left(\frac{P_s}{3} + \frac{P_q}{2} \right)$

M_{ov} = 1555.33 kN/m

$$FS = \frac{43000.8}{1555.333} \geq 2.0$$

$= 2.76 \qquad \geq 2.0$



Internal stability

❖ *Factor of safety against Pullout*

$$FS = \frac{2L_e\, C_i\, C_r\, \sigma_v \tan \phi_r}{S_v\, \sigma_h} \geq 1.5$$

Where,

Le = Embedment length (min 1.0m)

$$= \frac{Sv\, \sigma_h\, F.S.}{2(C + (\gamma_r \times Z + \tan\delta))} \geq 1.5$$

Ci = Interaction coefficient (0.75),

Cr = Coverage ratio (0.8)

$\sigma_h = K_{ar}(\gamma z + q)$

$$K_{ar} = \tan^2\left(45 - \frac{\phi r}{2}\right) = 0.307$$

$\sigma_v = \gamma_r + Z$

Table 5.7 Calculation of factor of safety against pullout failure for various depth

Depth Z (m)	Horizontal Stress on layer σ_h(kN/m)	Spacing of reinforcement Sv (m)	Embeded length Le (m)	Le (min) (m)	Vertical stress on layer σ_v (kNm)	FS
9.5	65.24	0.5	0.330	1.000	190.000	4.368
8.5	59.10	1	0.668	1.000	170.000	2.157
7.5	52.96	1	0.678	1.000	150.000	2.124
6.5	46.82	1	0.692	1.000	130.000	2.082
5.5	40.68	1	0.710	1.000	110.000	2.028
4.5	34.54	1	0.737	1.000	90.000	1.954
3.5	28.40	1	0.779	1.000	70.000	1.848
2.5	22.26	1	0.855	1.000	50.000	1.684
1.5	16.12	1.5	1.548	1.548	30.000	1.440
0.5	9.98	1.5	2.874	2.874	10.000	1.440

❖ **Factor of safety against Over tension**

$$F.S. = \frac{Tz}{\text{Design Strength}}$$

T_{hz} = Tensile force from the height of fill at Z^{th} layer

$T_{hz} = (Ka \times \gamma r \times Z - 2C \times Ka^{1/2}) \times Z$

T_{qz} = Tensile force from uniformly distributed surcharge on top of wall at Z^{th} layer

$T_{qz} = Ka \times q \times Z$

Tz = Maximum tensile force to be resisted by the Z^{th} layer of element at a depth hz

$Tz = T_{hz} + T_{qz}$

Table 5.8 Calculation of factor of safety against over tension for various depth

Depth Z (m)	Spacing Sv (m)	Tensile force for depth Z T_{hz} (kN/m)	Tensile force for surcharge T_{qz} (kN/m)	Max. tensile force T_z (kN/m)	Long Term Design Strength (kN/m)	FS
9.5	0.5	31.089	3.750	34.839	100	2.870
8.5	1	55.512	7.500	63.012	100	1.587
7.5	1	48.845	7.500	56.345	100	1.775
6.5	1	42.179	7.500	49.679	100	2.013
5.5	1	35.512	7.500	43.012	100	2.325
4.5	1	28.845	7.500	36.345	100	2.751
3.5	1	22.179	7.500	29.679	100	3.369
2.5	1	15.512	7.500	23.012	100	4.346
1.5	1.5	13.268	11.250	24.518	100	4.079
0.5	1.5	3.268	11.250	14.518	100	6.888

Table 5.9 Calculation for design strength for desired factor of safety

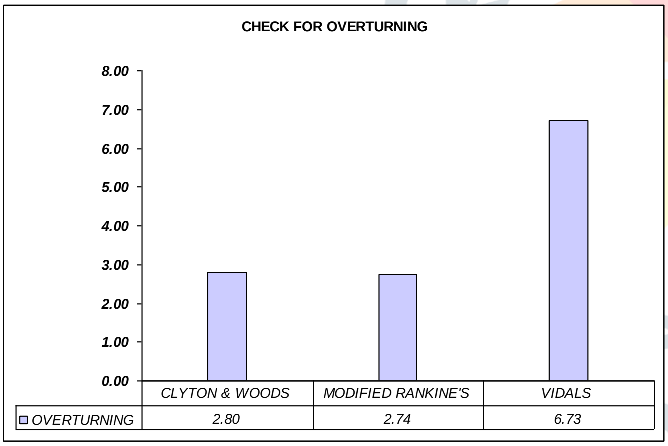
Depth Z (m)	Spacing Sv (m)	Tensile force for depth Z T_{hz} (kN/m)	Tensile force for surcharge T_{qz} (kN/m)	Max. tensile force T_z (kN/m)	Long Term Design Strength (kN/m)	FS
9.5	0.5	31.089	3.750	34.839	52.26	1.50
8.5	1	55.512	7.500	63.012	94.52	1.50
7.5	1	48.845	7.500	56.345	84.52	1.50
6.5	1	42.179	7.500	49.679	74.52	1.50
5.5	1	35.512	7.500	43.012	64.52	1.50
4.5	1	28.845	7.500	36.345	54.52	1.50
3.5	1	22.179	7.500	29.679	44.52	1.50
2.5	1	15.512	7.500	23.012	34.52	1.50
1.5	1.5	13.268	11.250	24.518	36.78	1.50
0.5	1.5	3.268	11.250	14.518	21.78	1.50

RESULT AND DISCUSSION

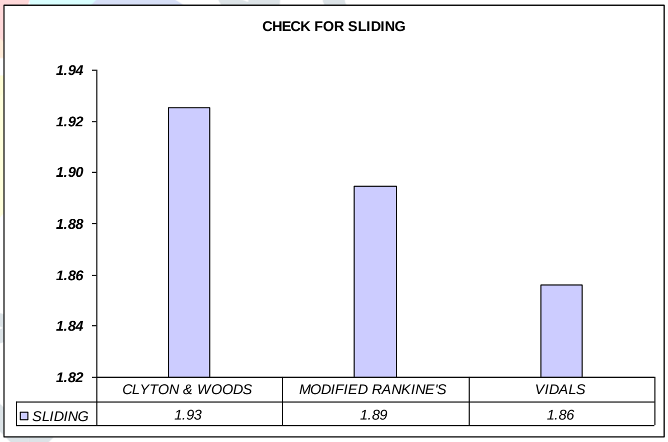
COMPARISION BETWEEN EXTERNAL STABILITY

Checks / Methods used	OVERTURNING	SLIDING	BEARING FAILURE kN/m^2
CLYTON & WOODS	2.80	1.93	481.48
MODIFIED RANKINE'S	2.74	1.89	346.99
VIDALS	6.73	1.86	232.50

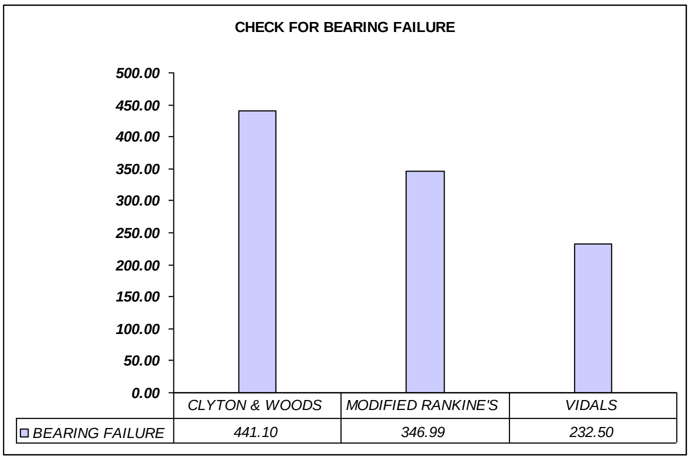
1) Factor of Safety for Overturning



2) Factor of Safety for Sliding



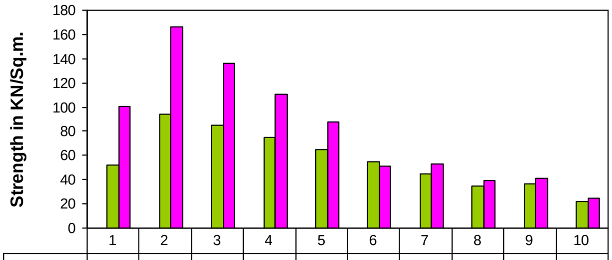
3) Factor of Safety for Bearing Failure



COMPARISION BETWEEN INTERBNAL STABILITY

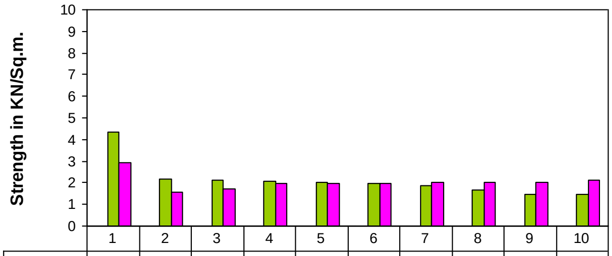
Reinforcement Strength while considering

1)Tension Failure



Depth	9.5	8.5	7.5	6.5	5.5	4.5	3.5	2.5	1.5	0.5
Rankine's	52.26	94.52	84.52	74.52	64.52	54.52	44.52	34.52	36.78	21.78
C & W	100.41	166.07	136.03	110.20	88.10	51.44	53.10	39.24	40.71	24.49

2) Pullout Failure



Depth	9.5	8.5	7.5	6.5	5.5	4.5	3.5	2.5	1.5	0.5
Rankine's	4.37	2.16	2.12	2.08	2.03	1.95	1.85	1.68	1.44	1.44
C & W	2.91	1.58	1.70	1.98	1.98	1.99	2.00	2.02	2.04	2.10

DISCUSSION

The Vidal's method is a preliminary method and modifications done in this further called as Modified Rankin's method. Therefore for comparison of internal and external stability consider two methods only i.e. by Modified Rankin's, Clayton & Wood.

Considering external stability, in the Modified Rankin's method is lower values in its factor of safety for overturning, sliding and bearing failure, the Clayton & Wood method has higher values for overturning, sliding and bearing failure. Therefore for external stability considers Clayton & Wood is the moderate method (i.e. higher factor of safety).

Considering internal stability for tension failure when desired factor of safety considered then the maximum design tensile strength required at various depth 'Z' from top can be calculated. This tensile strength when compared with Modified Rankin's method and Clayton & Woods method then it is found that required tensile strength at various depths in Modified Rankin's method is less as compared to Clayton & Woods method. And for pullout failure reinforcement tensile strength required at various depths in Rankin's method is less than Clayton & Woods method. Hence, as considering both failures it is found that Rankin's method is cheaper as compared to Clayton & Woods method.

CONCLUSION

1) Now a days segmental retaining walls are preferred more than conventional retaining wall.
2) This growth is justified on the basis of excellent performance, easy construction and overall low cost.
3) Comparing for the external an internal stability it is found that Clayton and Woods, shown intermediate result while Modified Rankin's method shows most conservative results
4) It can also concluded that the Modified Rankin's Method is the most conservative method and easy to understand.
5) The design of Rankin's method is more economical.
6) So, Rankin's Method is most commonly used in India for the design of Reinforced earth retaining walls.

REFERENCES

1. Geotextile and geomembranes- Geosynthetic and reinforced segmental retaining walls by Robert M. Korner, Te- Yang soong.
2. Installation Manual – The Reinforced earth company
3. Design with Geotextile reinforcement Earth retaining wall by VIDALS
4. Earth Pressure and Earth Retaining Structures By Clayton and Woods
5. Soil Mechanics And Foundation Engineering by K. R. Arora.
6. Earth pressure and earth retaining structure by Clayton and Woods.
7. Modern Geotechnical Engineering (Third Edition) by Alam Singh.
8. Dr.Kasmalkar B.J., Foundation Engineering, Vidyarthi Griha Prakashan,Pune.
9. Brahma S.P., Foundation Engineering, Tata McGraw-Hill Book Co., New Delhi.
10. Bowles Joseph V., Foundation Analysis and Design.
11. Foundation Design by Wayne C. Teng.
12. IRC: -1966, "Standard Specification and Code of Practice for Road Bridges (section-II) Loads and Stresses", Bureau of Indian Standards, New Delhi.
13. Sinha S.N., Reinforced Concrete Design, Tata McGraw-Hill Book Co., New Delhi.
14. Nayak Narayan V., Foundation Design Manual, Dhanpat Rai Publications, New Delhi.