A Comparative Study on Enhancing the Factor of Safety for Retaining Walls Against Failure by the Use of Reinforcement Strips with Soil Mass

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Abstract - *The application of the reinforcing elements technology in soil mass improves safety with a very cost-effective and reliable method. In this research, we used the analytical method of limit equilibrium to check the total internal and exterior stability performance of retaining walls with seven alternative height models by numerical calculation. The major goal of this study is to compare the factor of safety against failure (pullout, strip breaking, bearing capacity, overturning, sliding, etc.) in reinforced and unreinforced models derived by using numerical analysis, to validate the most realistic. The results from the parametric and comparative studies have provided us with a lot of knowledge about the internal and external stability of reinforced earth retaining walls. In this study, galvanized steel strips are engaged as metallic components in the reinforced soil. Here, we investigate serviceability through internal stability to boost the wall's service life and factor of safety against overturning, sliding, and bearing capacity failure.*

Key Words: Retaining wall, Factor of safety, Stability, sliding, Bearing capacity, overturning, Metallic Element, Reinforced Earth, Galvanized Steel Strips Etc.

1.0 INTRODUCTION

Due to its multifunctional working area, simplicity of construction, and affordable construction using operable technologies, the reinforced earth structure approach has had widespread use in civil and geotechnical engineering practice during the last two decades [1][2]. The earth is straightened by the reinforcement, which increases the soil's strength and bearing capacity while also lowering settlement. It also reduces the soil mass's liquefaction tendency [1]. Reinforcement in soil mass is a technique that involves introducing structural materials such as granular piles or blocks, lime/cement mixed soil, metallic bars or strips, synthetic sheet, grids, weir meshes, cells, and so on to enhance the physical and mechanical characteristics of the soil.

The study found that integrating two different strength-characteristic materials, such as reinforcement and soil, resulted in greater strength like Ferro-cement concrete. The system combines the long-term durability of steel with the compressive strength that short-term durability of soil [1][3]. As a result, friction and excellent adhesion establish surface contact between the soil and the reinforcement during mobilization. Soil reinforcement using metal strips, grids, or mesh is now a tried-and-true way of improving the state of the ground [4].

In addition, anchoring and soil nailing is needed to improve the soil's viability [5]. Subsequently, the contribution of reinforced earth or soil mass is influenced by internal environments such as metal quality and temperature and external surroundings such as construction, applied load, and climate conditions [4]. Because of its adaptability, cost-utility, and ease of construction, the reinforced earth technology is more anchoring [1]. Generally, reinforced earth techniques are effective in municipal areas where land availability is proscribed, and construction occurs with minimum traffic disturbance [5].

2.0 Basic concept

By nature, soil has a low tensile strength but a high compressive strength that is only limited by the soil's ability to tolerate applied shear pressures. Integrating soil reinforcement has the purpose of absorbing tensile loads, or shear stresses, and so reducing the loads that might otherwise cause the soil to fail in shear or deform excessively. Even when soil is subjected to compressive stress, tensile tensions can develop inside the soil mass.

[Figure 01] demonstrates a sample of dry granular soil constrained by an externally applied compressive stress of $\mathbf{S_3}$ and loaded by compressive stress of $\mathbf{S_1}$, where $\mathbf{S_1}$ would be greater than $\mathbf{S_3}$. For this loading situation, it is found that the sample that is not reinforced would experience axial compression, $\mathbf{E_v}$ due to $\mathbf{S_1}$ and lateral expansion $\mathbf{E_h}$ **[see Figure-1]**. As a result, this lateral expansion will be linked to the production of lateral tensile strains within the soil mass. When reinforcement is added to the soil, the corresponding deformations are $\mathbf{E_{vr}}$ and $\mathbf{E_{hr}}$ **[see figure-2]**. When identical external stresses are imposed, the axial **($\mathbf{E_{vr}}$)** and lateral expansion **($\mathbf{E_{hr}}$)** are found to be relatively lower than $\mathbf{E_v}$ and $\mathbf{E_h}$, respectively. Because of an internal interaction between the soil and the reinforcement, the magnitude of deformations is reduced.

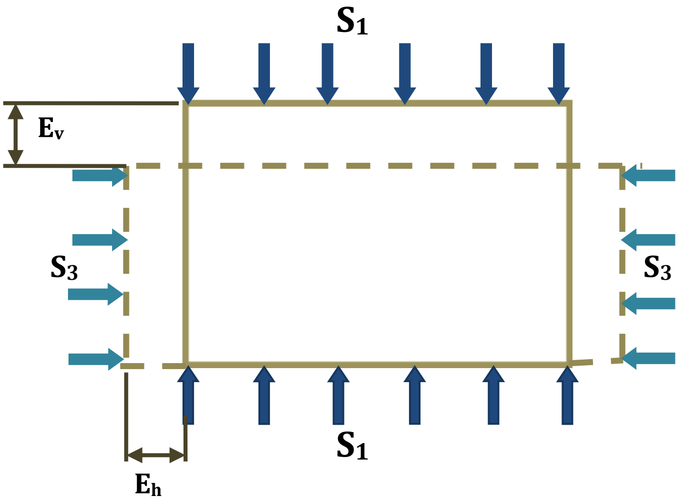


Figure-1: Unreinforced soil sample

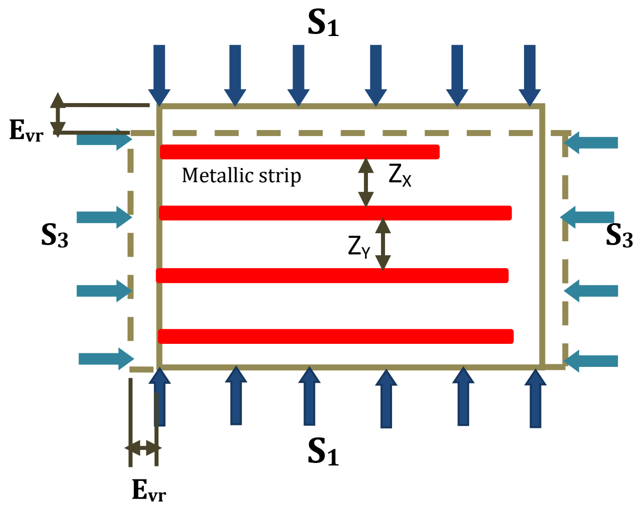
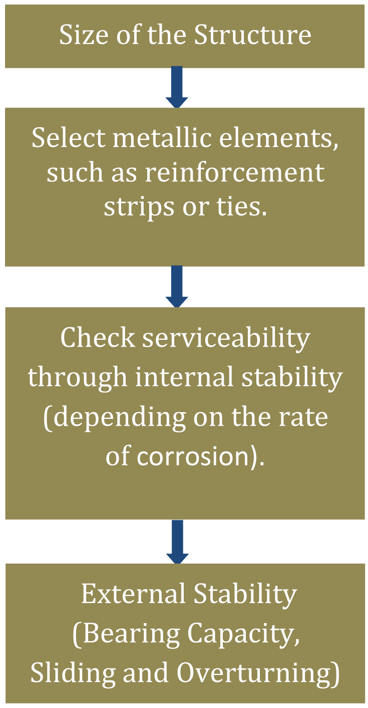


Figure-2: Reinforced soil sample
(E_{vr}< E_v and E_{hr}<E_h)

Unreinforced case: When applied shear stress reaches the soil's shear strength, general shear failure of the unreinforced soil occurs. **(Figure-1)** In continuation when an unreinforced soil is constrained by a constant stress S_3 and the magnitude of S_1 is gradually raised, the soil is subjected to a steadily rising shear stress, which is nearly half of difference between **S_1 and S_3.**

Reinforced case: **(Figure-1)** If the soil is reinforced, extra confining stress **ΔS_3** is created by the interaction between the soil and the reinforcement. So a larger value of **S_1** is needed to cause destruction. This is due to the fact that increments of **S_1** generate increments of **S_3**, which results in relatively low increases in the applied shear stress, which is relatively half of the **S_1 and [S_3+ ΔS_3].** So, **ΔS_3** plays a crucial role in this case. It causes increased service life of the structures against failure.

2.1 Work Flow Diagram



3.0 Metallic Strips Size

The major of the reinforcement strips are usually metal and made of galvanized steel. To enhance the friction between the metal and the soil mass, these strips are simple or include many protrusions, such as ribs or gloves. The width of (b) these strips is larger than their thickness (t), making them flexible and linear (Usually, the range within t<20-40mm and b= 6-80 mm. The typical rate of corrosion of galvanized steel strips, according to Banquet and Lee (1975), is between 0.025 and 0.050 mm/yr. As a result, the rate of corrosion must be included into the reinforcing design.

Generally the breadth is equal to or greater than two times of the thickness.

$$2 \geq \frac{b}{t}$$

b= Breadth of the Strips
t= Thickness of the Strips
$t_{actual} = t_{design} + r$ (rate of corrosion)

> FS (overturning) = 3, FS (sliding) = 3, and FS (bearing capacity failure) = 3 to 5 are recommended as minimum values.

4.0 Numerical Analysis

4.1 Design Procedure

Internal Stability-

Internal stability is mainly subjected to the height of the wall, the characteristics of the soil mass with frictional angle, soil reinforcement interaction, and the size of metallic strips.

a. Reinforcement strip force (Q) per unit length of the retaining wall.

$Q = S_a Z_x Z_y$

Where,

Q = strips breakout force.

S_a= active earth pressure of soil mass

Z_x= lateral spacing of strips.

Z_y= vertical spacing of strips.

b. The factor of safety against strip breaking (FS_b) 2.5 to 3 is generally recommended for strips at all layers.

$FS_b = \frac{btfy}{Q}$

Where,

b= width of each strip.

t = thickness of each Strip.

f_y= yield strength of the reinforcement strip.

Here, the thickness of the strip can be determined by the (a) and (b) equations.

$t = \frac{QFS(b)}{bfy}$

$t_{actual} = t_{design} + r$ (rate of corrosion)

Consequently, the maximum frictional force (F_f) for a strip would be obtained at a depth of "d" and it is-

$F_f = 2LebfS'v\tan\varphi'k$

Where,

$\varphi'k$=frictional angle between soil and reinforcement strip interaction.

d= at that distances, where the strips are placed at full depth.

c. As a result, the aspect of safety(FS_p) against strip pullout would be obtained

$FS_p = \frac{Ff}{Q}$

d. Subsequently, the full strip of length can be found here by the following equation, which is equal to the effective length (Le) plus the length (L_{ran}) within the Rankin failure zone. Where, Effective length,

$L_e = \frac{QFS(p)}{2bfS'v\tan\varphi'k}$ and

The length(Lr_{an}) within the Rankin failure zone,

$L_{ran} = \frac{H-d}{\tan\left(45+\frac{\varphi'o}{2}\right)}$ Where,

$\varphi'o$ =frictional angle of granular backfill soil

$S'v$ = effective vertical pressure at a depth of "d".

and H=Height of the retaining wall.

4.2 External Stability-

External stability is mainly subjected to the height of the wall, the characteristics of the foundation soil layer with ultimate bearing *capacity,* effective stress of the soil mass, and the length of metallic strips.

a. Factor of safety in case of a bearing failure-

General bearing capacity equation(Meyerhof's)

$q_{ult} = CN_C + 0.5(Y_2 L N_Y)$

$FS_{(bearing)} = \frac{q_{ult}}{q_{max}}$

With surcharge

$q_{max} = Y_1 H + S_{sur}$

Without surcharge

$q_{max} = Y_1 H$ [related to total height, H]

q_{ult} =Ultimate bearing capacity of foundation soil·

C= Cohesion

S_{sur}= stress due to surcharge

Y_2= unit weight of in-situ soil(Foundation)

Y_1= unit weight of backfill material (Granular)

N_C, N_Y= Meyerhof's bearing capacity factor correspond to the foundation soil friction angle $\varphi'f$

$\varphi'f$ = friction angle of in-situ soil(Foundation)

$S'v$ = effective vertical stress at a depth of "H".

a. **b. Factor of safety against overturning**

The check for overturning can be done by using the following equation:

$$FS_{(overturning)} = \frac{\text{Ultimate resisting moment capacity}}{\text{Overturning moment per unit length}}$$

The overturning moment is determined as the moment established by the horizontal loads in relation to the base's most-bottom-left corner.

Overturning moment

$M_O = F_a X$

X = arm distance

$= \frac{H}{2}$ [Surcharge]

$= \frac{H}{3}$ [Non-surcharge]

For any horizontal load, the lever arm distance will be. When a non-surcharge load is present, one-third of the wall height from the bottom of the base to the surface level is employed. When a surcharge load is present, one-half of the wall height from the bottom of the base to the surface level is used.

F_a= Active force

$= \frac{1}{2}\gamma_1 \text{ Ka } H^2$

Resisting moment

$M_r = \sum P_n Z_n$

= Area of an active loading zone

$Z = \frac{L}{2}$

c. Factor of safety against sliding

The following equation can be used to check for sliding:

$$FS_{(sliding)} = \frac{\sum Pn\ tank\ \ \varphi'o}{Fa} \ [k = 2/3]$$

4.3 Wall properties

Properties of the granular backfill:

$\phi'_0 = 35^0$

$\gamma_1 = 17\ kN/m^3$

Properties of in-situ (Foundation) soil:

$\varphi' f = 26^0$

$\Upsilon_2 = 16.5\ KN/m^3$

$C = 30\ KN/m^2$

Galvanizing steel reinforcement:

Width of the strip, b = 60mm

$Z_x = 0.6m$ center - to – center

$Z_y = 1.0m$ center - to – center

Steel Strength Properties for elements with nominal thickness *t* ≤ 40 mm.

EN10025-2 Hot rolled products -Non-alloy structural steels S235

$fy = 235000\ KN/m^2$

$\varphi' k = 22^0$

$N_C = 22.25$

$N_\Upsilon = 12.54$

Required $FS_{(b)} = 3$,

Required $FS_{(p)} = 3$

Table -1: Factor of safety against failure in breaking, bearing, overturning and sliding

Height of the wall(m)	$FS_{(breaking)}$	$FS_{(bearing\ capacity)}$	$FS_{(Overturning)}$	$FS_{(Sliding)}$	Comment
5	3.07	23.76	64	7.95	Safe
7.5	2.50	16.66	33.42	5.75	Safe
10	2.50	13.10	21.80	4.64	Safe
15	2.250	9.95	14.285	3.75	Only unsafe for strip breaking
20	2.150	8.075	10	3.15	Only unsafe for strip breaking
30	1.945	6.59	7.72	2.76	Not safe against breaking and sliding
40	1.919	5.86	6.68	2.57	Not safe against breaking and sliding

= safe

= not safe

Chart -1: $FS_{(breaking)}$ vs Wall height

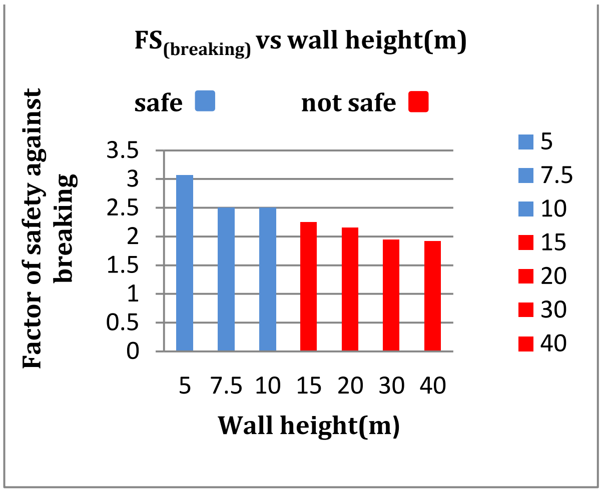


Chart -2: $FS_{(bearing\ capacity)}$ vs Wall height(m)

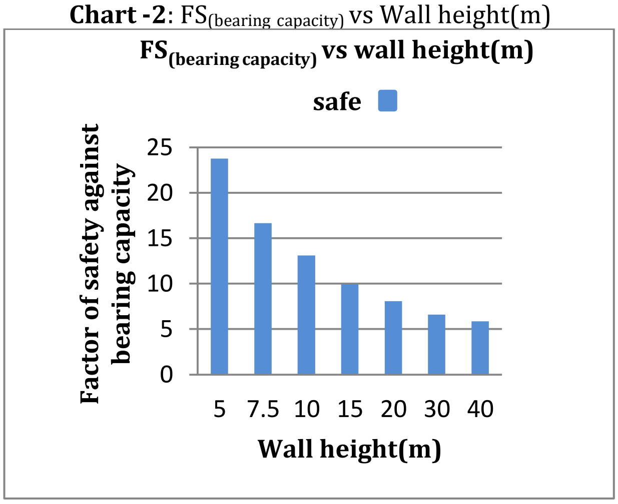


Chart -3: $FS_{(overturning)}$ vs Wall height(m)

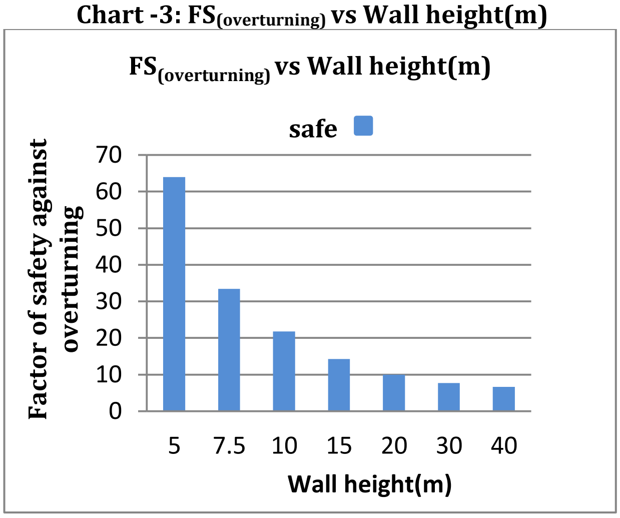
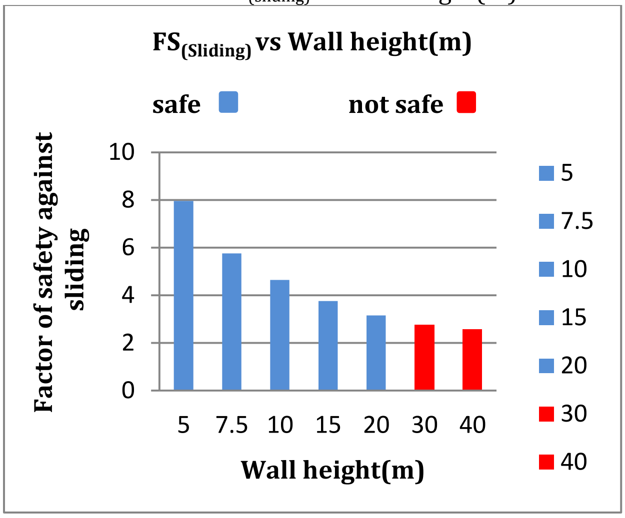


Chart -4: $FS_{(sliding)}$ vs Wall height(m)



5. CONCLUSIONS

In this study, we investigated the behavior of the retaining wall when the soil mass is reinforced by metallic strips and also analyzed the factors of safety against failure, such as strip breakout, bearing capacity, overturning, and sliding. It is observed that the factor of safety against these failures is surprisingly improved, not only that it also increases the service life of the retaining wall. Here we investigated, from small to large, seven different heights of the wall. The factor of safety against strip breaking (FSb) of 2.5 to 3, overturning of 3, sliding of 3, and bearing capacity of 3 to 5 is recommended as minimum values for unreinforced soil. As can be seen, when galvanized steel strips are employed as metallic components in the soil mass, friction and efficient adhesion are established by the interaction between the soil and the reinforcement. As a result, axial and lateral expansion occurred at relatively lower than unreinforced soil.

1. In the numerical analysis, different wall heights, i.e., 5,7.5, 10, 15, 20, 30, and 40 m, are used in the investigation. To check the serviceability of these walls at the same properties at different heights, we found the factor of safety against strip breaking is safe for 5,7.5, and 10 m walls, but other walls are not safe because of their safety value against strip breaking is below 2.5. So, the width and thickness of the strips have to be increased to keep the other walls safe. Therefore, here we have to look at the financial matter. Therefore, it is important to make sure that the reinforcements we use to extend the service life of the wall are adequate.
2. To check the external stability of these walls, the factors of safety against bearing capacity, overturning, and sliding are considerably higher than the recommended value of 3 to 5. But on the other hand, only the 30m and 40m walls failed in sliding. Here, the height of the wall is significantly responsible for this predicament. But for all this, reinforcement strips should be used according to design, and the backfill soil must be granular. Hence, sufficient reinforcement lengths lead to a stable retaining wall, and on the contrary, excessive reinforcement amounts reduce economic efficiency.

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