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Review Article

A Comparative Study to Improve Service Ability by Enhancing the Safety Margin of Retaining Walls by Incorporating Metallic Strips or Geotextiles with Soil Mass

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Abstract *- The use of non-biodegradable and reinforcing materials in soil mass enhances safety with a highly cost-effective and dependable method. In this study, we used the limit equilibrium analytical technique to numerically determine the total internal and external stability performance of retaining walls using seven different height models. The reinforcement allows the soil mass to withstand strain in ways that the earth could not alone. Because stresses formed within the mass are transmitted from the soil to the reinforcing strips through friction, the internal friction of the soil is the source of this tension resistance. The parametric and comparative investigations yielded a wealth of information concerning the internal and exterior stability of reinforced earth-retaining walls. In this study, galvanized steel strips and geotextiles are engaged as reinforced elements in the reinforced soil. We demonstrated the energy difference between these two sorts of components. In this paper, we look at serviceability through internal stability to enhance the wall's service life and factor of safety against overturning, sliding and bearing capacity failure. The major goal of this study is to compare the factor of safety against failure (pullout, strip breaking, bearing capacity, overturning, sliding, and so on) between reinforced and unreinforced models generated using numerical analysis to see which is more constructive. After numerical analysis, we found that the value of the factor of safety increased significantly in all types of failures. Not only that, but we also find out which is more reliable between strips and fabrics.*

Keywords - *Retaining wall, Factor of safety, Stability, Sliding, Bearing capacity, Serviceability, Galvanized steel strips, Geotextiles.*

1. Introduction

Reinforced earth structure techniques have been extensively used in civil and geotechnical engineering practice over the last couple of decades because of their multifunctional working area, ease of construction, and inexpensive construction employing operable technologies[1]. Reinforced earth in designing and building foundations and earth-retaining structures is a relatively new phenomenon. The reinforcement straightens the ground, increasing its strength and bearing capacity while minimizing settlement [2]. It also lowers the liquefaction propensity of the soil bulk [2]. Strengthening soil mass is a technique for improving soil's physical and mechanical properties by introducing reinforcing elements. So, reinforced earth is a composite material formed of earth that has been strengthened by tensile elements such as steel rebar or strips, nonbiodegradable textiles (geofextiles), geogrids, and so on[1]. The study shows that exterior and interior stability are the two most important factors reinforced earth walls that define total service life. Exterior stability assesses the structure's overall stability for sliding, overturning, tilting,

and sliding. The internal mechanisms (tension and pullout failure) within the structure, as and behavior of the filler material and backfill are to as internal stability. The basic concept of strengthening soil is not new. It dates back several centuries. The concept of systematic analysis and design was established by H.Vidal, a French engineer, in 1966. The French Road Study Laboratory has conducted considerable research on the practicality and benefits of using reinforced earth as a construction material. H. Vidal and DERRICK I. PRICE published an extensive document on reinforced earth in 1969 and1975[4-5]. In 1972, the first reinforced-earth retaining wall with metal strips as reinforcement was built in southern California.

The overall rotational and global stability of the reinforced soil mass has to be checked using slope stability procedures as described in BS EN 1997-1:2004,11.5.1. Reinforced soil fill comprises many layers of flexible steel bars or polymeric fabrics. The overall geometry of the reinforced soil is determined by the total length of each reinforcing element, which affects external stability. The stabilizing force of the reinforcement is related to the number of layers and their vertical spacing[6-8]. As a result, the total stabilizing force is generated by the number of reinforcing elements as well as their horizontal and vertical spacing. In this study, we used the limit equilibrium analytical technique to numerically determine the total internal and external stability performance of retaining walls using seven different height models[7]. The favorable benefits of soil reinforcement result from (a) improved tensile strength of the soil and (b) the shear resistance developed from friction at the soil-reinforcement interfaces, and the main goals can be demonstrated in two ways: a) developed safety factor against failure and b) demonstrate improved bearing capacity against failure by incorporating reinforcing elements (metallic strips and geotextiles).

2. Concept

The analysis found that combining two distinct strength characteristic components, reinforcing elements and soil, resulted in a stronger composite material, similar to Ferocement concrete. The technique incorporates the longterm durability of steel with the high compressive strength of the soil. Soil has low tensile strength by nature but has a high compressive strength capacity to withstand applied shear stresses. When the soil mass is subjected to compressive stress, tensile tensions might occur. In the reinforced soil, soil with reinforcement reduces tensile loads that might otherwise cause the soil to fail in shear or deform excessively by absorbing tensile pressures or shear stresses. Friction and/or passive resistance are used to transmit stresses between the soil and the reinforcement, depending on the geometry of the reinforcement. Because the flexible elements have a frictional interaction with the soil, which resists the shear stresses in the soil mass. The shear stress at the soil-reinforcement contact causes strains in the reinforcement and mobilizes a tensile force in the reinforcement. If the tensile force exceeds the reinforcement's tensile capacity, rupture occurs, resulting in tensile failure. A slide is more possible if the deformations are large or the contact is smooth. We can understand better through Fig. 2.

2.1. Principles

[Figure 01] depicts a dry granular soil sample limited by $б_3$ external compressive stress and loaded by $б_1$ compressive stress, where $б_1$ is greater than $б_3$. In this loading scenario, the sample that is not reinforced will suffer vertical compression, $Є_v$ due to $б_1$, and lateral expansion, $Є_h$ in this loading scenario [see Fig-1]. The development of lateral tensile stresses within the soil mass will be connected to this lateral expansion. The comparable deformations that occur when reinforcing elements are applied under the tension zone to the soil are $Є_{vr}$ and $Є_{hr}$ [see figure-2]. It is found that when equal external forces are applied, the axial ($Є_{vr}$) and lateral expansion ($Є_{hr}$) are shown to be much less than $Є_v$ and $Є_h$.

2.2. Unreinforced Case [Fig. 1]

General shear failure of unreinforced soil happens when applied shear stress exceeds the soil's shear strength. (Figure 1) When an unreinforced soil is constrained by a constant stress $б_3$ and the magnitude of $б_1$ is progressively increased, the soil is subjected to a constantly rising shear stress that is roughly half of the difference between $б_1$and $б_3$.

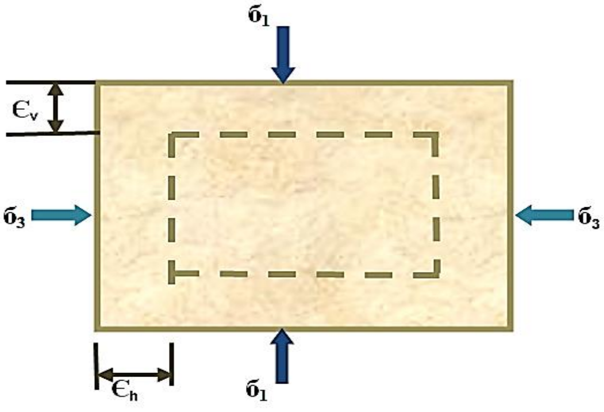

Fig. 1 Deformed shape of the unreinforced soil mass

2.3. Reinforced Case [Fig. 2]

If the soil is reinforced, the interaction between the soil and the reinforcement creates additional confining stress $Δб_3$. To induce destruction, a greater value of $б_1$ is required. This is because increments of $б_1$ generate increments of $б_3$, resulting in minor increases in the applied shear stress, which is half of the $б_1$ and [$б_3$+ $Δб3$] increments. So, $Δб_3$ plays vital role in this case. It causes increased service life of the structures against failure.

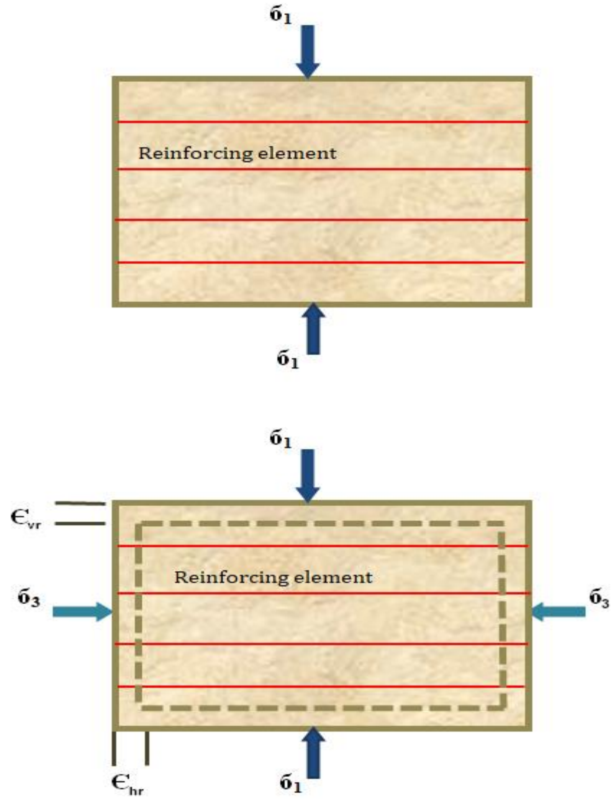

Fig. 2 Deformed shape reinforced soil sample ($E_{vr}<E_v$ and $E_{hr}<E_h$)

3. Work Flow Diagram

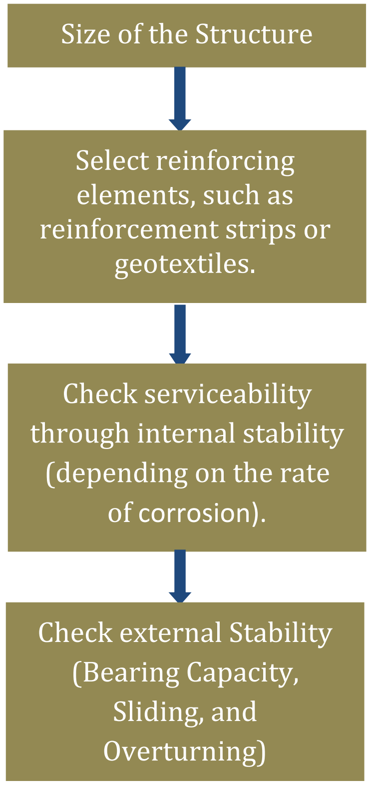

Fig. 3 Workflow diagram

4. Components of Reinforced Soil

Any reinforced soil construction has three essential components. These are:

- soil,
- reinforcing element, and
- a facing.

4.1. Soil Properties

Minimum specification of cohesive fill

- It must be granular and cohesion-free with a particle size of no more than 125 mm and no excessive silt or clay.
- The plasticity index should be within 6.
- Not more than 10% of the particles must pass through a 75-micron sieve.
- The earth reinforcement coefficient of friction must be more than or equal to 0.4.
- The moisture content of the soil must be suitable for compaction.

Backfill materials

4.2. Reinforcing Elements

In the study, we have worked with two types of material

- Metallic Strips
- Nonbiodegradable fabrics(Geotextiles)

Table 1. Minimum specification of select fill

Sieve size	% of passing
6"	100
3"	75-100
No. 200	0-25
Percentage passing No. 200 is greater than25 percent, and not more than 15% of particles smaller than 75μm and ϕ < 30°(Boyd,1980). Y_{max}= 18.67 kN/m^3 Y_{min}= 15.57 kN/m^3 by B.S. Brown and Poulos[8]	

4.2.1. Metallic Strips

When a soil mass is subjected to vertical stress ($б_1$), it experiences vertical compression (E_v) as well as lateral deformation (E_h). If reinforcing elements are added to the soil in horizontal layers, the soil element will be restrained against deformation, which acts as a lateral force. The overall geometry of the reinforced soil is determined by the total length (L) of each reinforcing element, which affects external stability. The geometrical size the determined by the physical height, H, which is defined as the vertical distance from the structure's toe. The length (L) of reinforcement is divided into two zones, Lo and Le, which run the length of the reinforcement (Nand, K. 2005)[9]. If the entire length of the reinforcement is limited to Lo, then load transfer from soil to reinforcement in the active zone will not prevent it from collapsing. The reinforcement extends a length into's of the resistive zone to accomplish this behavior. Load is transferred from the reinforcement to the soil via the soil/reinforcement connection mechanism as long as the reinforcement has sufficient tensile strength to support tensile loads received from the active zone. The tensile stress on the reinforcement along L is not constant but falls further from the slope face as the load is shed into the soil.

The initial length of the reinforcement should not be less than the minimum specified in Table 2 unless it can be satisfactorily demonstrated by previous experience that lesser values are sufficient.

The majority of the reinforcing strips are normally metal and constructed of galvanized steel. These strips are basic or include multiple protrusions, such as ribs or gloves, to increase friction between the metal and the soil mass. These are flexible linear components with a breadth "b" greater than their thickness "t." The dimensions vary according to the application and construction, but they are commonly between t =3-9 mm and b =40-120 mm. The maximum corrosion rate of the same metals in various soils is 15 to 20 times lower. Marine sand dissolves 150-200 microns of mild or galvanized steel every year and 2-3 microns of Al-Mg alloy strips. Metal reinforcements are employed by adding 0.75-1.25 mm of thickness to galvanize steel and 0.1 to 0.2 mm to stainless steel. So, provision should be made for thickness loss due to corrosion. **)**. The normal corrosion rate of galvanized steel strips is between 0.025 and 0.050 mm/yr. As a result, the reinforcing design must include the corrosion rate.

Table 2. Minimum strip length for wall and abutment

Structure Type	Minimum Reinforcement Length (L)
Normal retaining wall	0.6H to 0.7H
Trapezoidal wall and abutments	The reinforcement length in the upper half of the structure is 0.7H, and the bottom half of the structure is 0.4H.
Stepped wall and abutment	0.7H in the top half of the structure
Negative back slop or embedded wall	0.6H or 3m minimum
H = total height of the structure the lateral spacing of strips = 0.6 to 1m minimum vertical spacing of strips =1m minimum	

In most cases, the breadth is equal to or larger than double 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)

Consequently, the total stabilizing force developed by such reinforcement will function the number of reinforcement elements and their horizontal and vertical spacing.

According to Structural Steel Strength Properties for elements with nominal thickness $t \leq 40$ mm
EN 1993-1-1:2005+AC2:2009 Sections 3.2.1, 3.2.6is used

4.2.2. Nonbiodegradable Fabrics(Geotextiles)

Geotextiles are non-biodegradable fabrics that aren't biodegradable. Since 1970, geotextiles have become more popular in construction across the world. To avoid biodegradation, geotextiles are made of chemically resistant synthetic materials such as polyester, polyethylene, and polypropylene. They're frequently utilized to divide two soil layers with varying particle sizes. Geotextiles come in a variety of thicknesses ranging from 0.25 to 7.5 mm. The most typical geomembranes used today have a thickness of 0.5 mm. However, mass and thickness measurements are taken following AS 3706.1.AOS (apparent opening size), tear, tensile strength, and permeability are the essential performance characteristics for geotextile separation. Geotextiles operate as reinforcing elements in the soil matrix, assisting in creating a more durable structural material. The fabric must also be able to flow freely, retain dirt, and avoid clogging. Puncture resistance, mass, and burst strength are the most significant characteristics of geotextile protection. The ultimate strengths of geotextiles based on the ASTM D4595 standard have been followed.

4.3. Numerical Analysis

This study used the limit equilibrium analytical technique to numerically determine retaining walls' total internal and external stability performance using seven different height models.

4.4. Internal Stability

4.4.1. Reinforcement strips

The height of the wall, the properties of the soil mass with frictional angle, soil reinforcement interaction, length of the reinforcement, and spacing of reinforcement all influence internal stability.

a. Reinforcement strip force (F_{rs}) per unit length of the retaining wall can be determined by-

$$\mathrm{Frs} = \text{б}\mathrm{a}\ \mathrm{ZxZy}$$

Where,
F_{rs}=strips breakout force.
$б_a$= active earth pressure of soil mass
$б\mathrm{a} = \Upsilon 1\mathrm{HK}_a$
Z_x =lateral spacing of strips and
Z_y = vertical spacing of strips.

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

$$\mathrm{FS(br)} = \frac{\mathrm{btfy}}{\mathrm{Frs}}$$

Where,
b = width of each strip.
t = thickness of each strip.
fy = yield strength of the reinforcement strip.
Steel Strength Properties for strips with nominal thickness $t \leq$ 40 mm.
EN10025-2Hot rolled products -Non-alloy structural steels S235
f_y= 235000 KN/ m^2
Hence, the thickness of the strip can be determined by the (a) and (b) equations.

$$\mathrm{t} = \frac{\mathrm{FsrFS(br)}}{\mathrm{bfy}}$$
$$\mathrm{t(actual)} = \mathrm{t(design)} + \mathrm{r(rate\ of\ corrosion)}$$

[Banquet and Lee (1975)]
Consequently, the maximum frictional force (F_f) for a strip can be obtained at a depth of "d," and it is-

$$\mathrm{Ff} = 2\mathrm{Leb}б'\mathrm{vtan}\phi'\ k$$

Where,
$\phi' k$=frictional angle between soil and reinforcement strip interaction.
$б'\mathrm{v}$ =Effective vertical pressure at a depth of "d."
d= the distances where the strips are placed at full depth.

c. Subsequently, the safety(FS_p) aspect against strip pullout can be determined.

$$\mathrm{FSp} = \frac{\mathrm{Ff}}{\mathrm{Frs}}$$

d. Subsequently, the full length of the tie can be found here by the following equation, which is equal to the effective length (Le) plus the length (L_0) within the Rankin failure zone.

Effective length (Le)-

$$\mathrm{Le} = \frac{б\mathrm{a\ ZxZy\ FS(p)}}{2\mathrm{b}б'\mathrm{vtan}\varphi' k}$$

where,
L_e= effective length
$б\mathrm{a} = ϒ1\mathrm{d}K_a$
$б'\mathrm{v} = ϒ1\mathrm{d}$

$L_0 = \frac{\mathrm{H-d}}{\tan\left(45+\frac{\phi' o}{2}\right)}$

Where,
L_0= length within the Rankin failure zone,
$\phi' o$ =frictional angle of granular backfill soil
and H=Height of the retaining wall.
Tie length is the maximum when "d" is the minimum.

4.4.2. Geotextile

a. Active earth pressure (at a Z depth) on the retaining wall.

$б\mathrm{a(tex)} = ϒ1K_a\mathrm{Z}$

b. Allowable tensile strength for retaining wall construction (Koerner,2005) [10]

$$f(\mathrm{all}) = \frac{f(\mathrm{ult})}{\mathrm{RF(id)xRF(cr)xRF(cbr)}}$$

$$f(\mathrm{all}) = \text{Allowable tensile strength}\left(\frac{\mathrm{kN}}{\mathrm{m}}\right)$$

$$f(\mathrm{ult}) = \text{Ultimate tensile strength}\left(\frac{\mathrm{kN}}{\mathrm{m}}\right)$$

RF(id) = Reduction factor for installation damage. =1.1-2.0
RF(cr) = Reduction factor for creep =2.0-4.0 and
RF(cbr) = Reduction factor for chemicaland biological reaction =1.0 -1.5 by (Koerner,2005)

c. Vertical spacing(Zy) of the layers at a depth of z-

$$\mathrm{Zy} = \frac{f(\mathrm{all})}{б\mathrm{a(tex)FS(br)}}$$

FS(br) =1.3-1.6[globally recommended]

d. The whole length of the geotextile may be calculated using the following equation, which is equal to the effective length (Le) plus the length (L0) within the Rankin failure zone.

$$\mathrm{L} = \frac{\mathrm{H-d}}{\tan\left(45+\frac{\phi'0}{2}\right)} + \frac{б\mathrm{a(tex)\ Zy\ FS(p)}}{2б'\mathrm{vtan}\varphi' k}$$

Where,
FS(p) =1.3-1.6[globally recommended]
$\phi' k$=$\frac{2}{3}$of frictional angle of granular backfill soil,$\phi' o$
[Based on published results].
[length is the maximum when "d" is the minimum.]

e. Subsequently, the aspect of lap length, $l_{(lap)}$can be determined by-

$\mathrm{l(lap)} = \frac{б\mathrm{a(tex)\ Zy\ FS(p)}}{24\mathrm{vtan}\varphi' k} \geq 1$[should not be less than 1m]

4.5 External Stability

External stability is influenced by the height of the wall, the properties of the foundation soil layer with ultimate carrying capacity, the effective stress of the soil mass, and the length of the reinforcement. (strips& geotextiles)

a. The factor of safety in the case of bearing failure-

Generally**,** Meyerhof's general bearing capacity equation is used

$$\mathrm{Qult} = \mathrm{CNc} + \frac{1}{2}\mathrm{YfLNY}$$

$$\mathrm{FS(bearing)} = \frac{\mathrm{Qult}}{\mathrm{Qmax}}$$

With surcharge

$$\mathrm{Qmax} = \mathrm{Y1H} + \mathrm{Qsur}$$

Without surcharge

$$\mathrm{Qmax} = \mathrm{Y1H}$$

[related to total height, H]
Qult =Ultimate bearing capacity of foundation soil·
C=Cohesion
Q_{sur}= stress due to surcharge
$ϒ_f$= unit weight of in-situ soil(Foundation)
$ϒ_1$= unit weight of backfill material (Granular)

N_C, N_Y=Meyerhof's bearing capacity factor
correspond to the foundation soil friction angle $\varphi' f$
$\phi' f$ = friction angle of in-situ soil(Foundation)
$\sigma' v$ = effective vertical stress at a depth of "H."

b. The factor of safety against overturning

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

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

Overturning Moment

The overturning moment is calculated as the moment created by the lateral load concerning the most bottom-left corner of the base.

$$Mo = FaX$$

X = arm distance
$= \frac{H}{2}$[Surcharge]
$= \frac{H}{3}$ [Non-surcharge]

The moment arm distance will be the same for any horizontal load. When there is no surcharge load, one-third of the wall height from the bottom of the foundation to the surface level is used. One-half of the wall height from the base to the surface level is used when there is a surcharge load.

F_a= Active force
$Fa = \frac{1}{2} \gamma_1 \, Ka \, H^2$
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:

$$FS_{(sliding)} = \frac{\sum Pn \tan k \phi' o}{Fa} \text{ [k= 2/3)}$$

5. Properties of Walls and Materials

Table 3. Soil and wall properties with the recommended factor of safety against failure

Wall Heights(m)	Soil and reinforcements properties	The factor of Safety against failure(Globally recommended)
7	Properties of the granularbackfill: $\phi'_0 = 36^0$ $\gamma_1 = 17.5$ kN/m^3 Properties of Foundation soil: $\phi' \mathbf{f} = 26^0$ According to Meyerhof's general bearing capacity factor- N_C =22.25 N_Y= 12.54 Y_2= 16.5 KN/ m^3 C =48 KN/ m^2 Galvanizing steel reinforcement: Width of the strip, b = 60mm Rate of corrosion= 25mm/yr And life span=60 yrs Z_x =0.75m center - to – center Z_y =1.0m center - to – center. d= 2,4, 6.8……… $\phi' \mathbf{k} = 20^0$ [min 18^0 according to B.S. Brown and Poulos theory] Geotextiles: d= 0.5, 1.0, 1.5,2.0, 2.5………. $\phi' \mathbf{k} = \frac{\mathbf{2}}{\mathbf{3}} \phi' \mathbf{o} = 24.12^0$ Vertical spacing, Z_y = 0.6m	Metallic strips The factorofsafetyagainst strip breaking, FS (br) =2.5 to 3. The factorofsafetyagainstpullout, FS (p) =2.5 to 3. FS (overturning) = 3, FS (sliding) = 3, and FS (bearing capacity failure) = 3 to 5 are recommended as minimum values. Geotextiles Factorofsafetyagainstsliding, FS($_{br}$) =1.2 to 1.5. $\mathbf{RF(id) = Reduction\ factor\ for\ installation\ damage.}$ =1.1-2.0 $\mathbf{RF(cr) = Reduction\ factor\ for\ creep}$ =2.0-4.0 and $\mathbf{RF(cbr) = Reduction\ factor\ for\ chemical\ and\ biological\ reaction}$ =1.0-1.5 (Koerner,2005)
8		
10		
12		
15		
18		
20		

6. Results

6.1. Metallic Strips

Table 4. Factor of safety against failure in breaking, bearing, overturning, and sliding

Height of the wall(m)	Strip length, L(m) [d= 2, 4, 6….]	FS (breaking) (2.5-3)(Consider corrosion rate)	FS (pullout) (2.5-3)	FS (bearing capacity) (3-5)	FS (Overturning) (2.5-3)	FS (Sliding) (2.5-3)
7	15.95	3.88	3.00	24.92	59.96	7.85
8	16.46	3.77		19.89	48.89	7.08
10	17.48	3.62		18.49	35.29	6.01
12	18.50	3.51		15.98	27.45	5.31
15	20.01	3.41		13.47	20.53	4.59
18	21.56	3.34		11.82	16.57	4.12
20	22.58	3.30		9.76	14.72	3.88

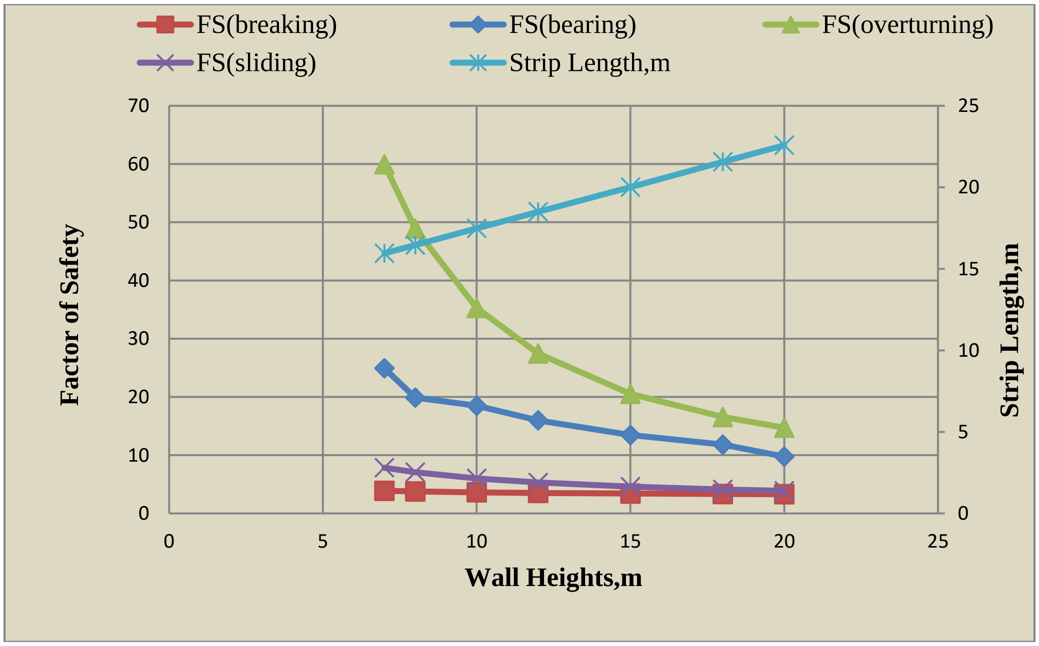

Fig. 4 Wall heights vs. reinforcement length (metallic strips) and factor of safeties

6.2. Geotextiles

Table 5. Factor of safety against failure in breaking, bearing, overturning, and sliding

Height of the wall(m)	length, L(m) [d= 0.5, 1.0, 1.5, 2.0…]	Lap Length, m	FS (pullout) (2.5-3)	FS (bearing capacity) (3-5)	FS (Overturning) (2.5-3)	FS (Sliding) (1.2-1.5)
7	1.53	1m	3	11.73	3.004	1.76
8	2.56			10.64	3.004	1.76
10	3.57			9.11	3.004	1.76
12	5.1			8.1	3.004	1.76
15	6.12			7.08	3.004	1.76
18	7.65			6.41	3.004	1.76
20	9.18			6.06	3.01	1.758

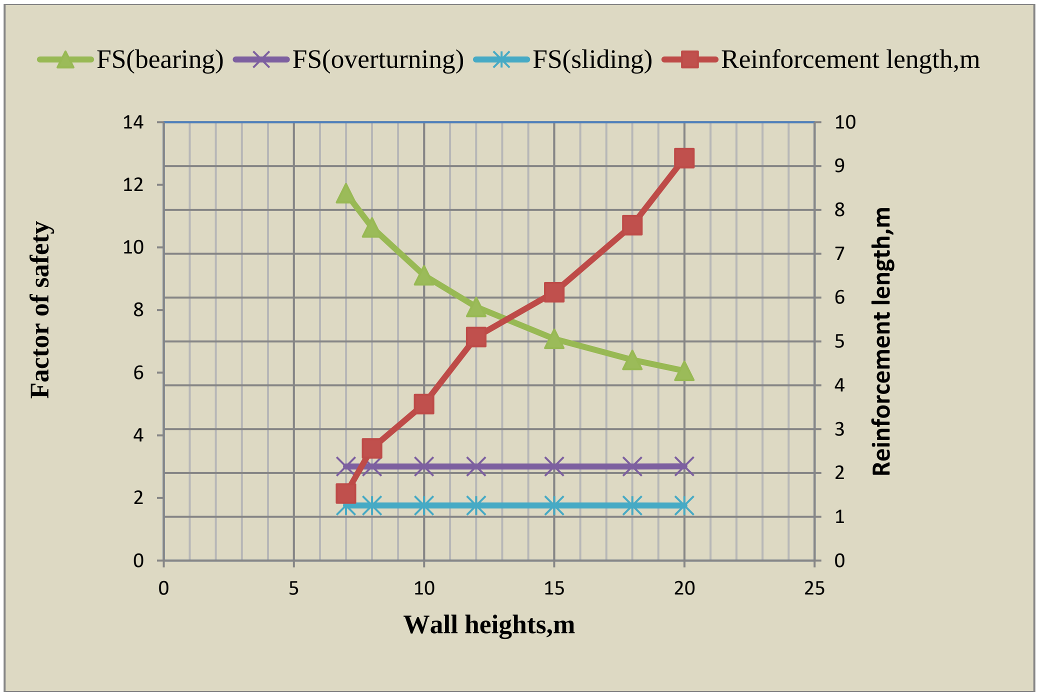

Fig. 5 Wall heights vs. reinforcement length (Geotextiles) and factor of safeties

6.3. Comparative Results Between Metallic Strip and Geotextiles

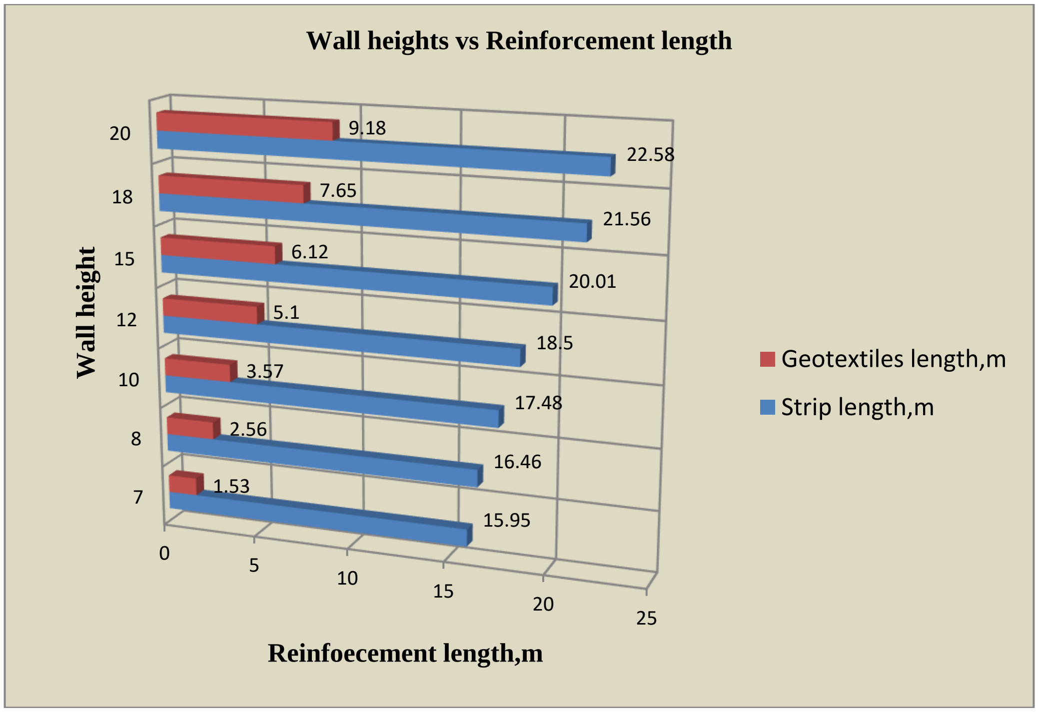

Fig. 6 Wall heights vs.reinforcement length

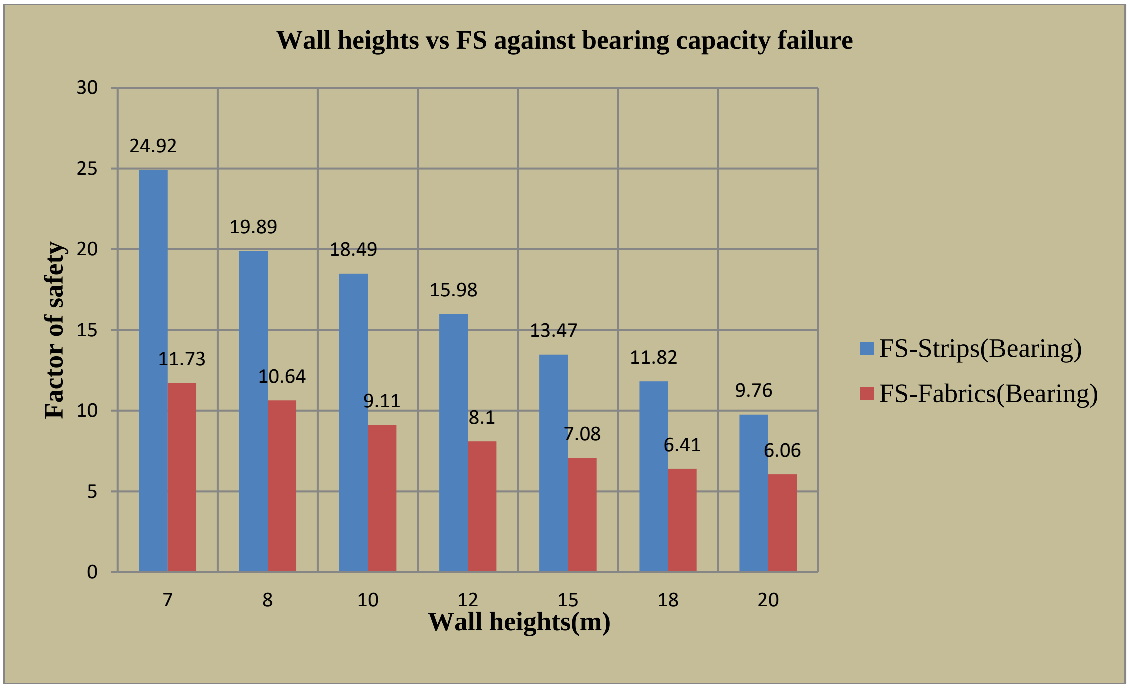

Fig. 7 Wall heights vs. factor of safety against bearing capacity failure

6.4. Remarks from Data Tables

The factor of safety increased as-.

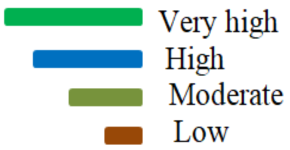

Fig. 8 Evaluation of factor of safeties from the data table

7. Discussion

In this study, external and internal stability are the two key factors utilized in designing reinforced earth structures to determine their proportions and layout. The exterior stability evaluates the stability of the structure as a whole for sliding, overturning, tilting, and sliding. Internal stability refers to the internal mechanisms (breaking and pullout failures) within the structure and the configuration and behavior of the reinforcement and backfill. It has been found that the factor of safety against these failures has significantly improved, not only that the retaining wall's service life has increased also. This analysis evaluated the wall at seven different heights, ranging from modest to high. The soil that is not reinforced should have a 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 globally. It is being shown that when galvanized steel strips are used as metallic components in the soil mass, the contact between the soil and the reinforcement creates friction and efficient adhesion. As a result, axial and lateral expansion rates were lower in reinforced soil than in unreinforced soil.

Different wall heights, namely 7,8, 10, 12, 15, 18, and 20 meters, are employed in the numerical study. It is determined that the factor of safety against failure is safe for all walls at different heights with the same properties but that the use of geotextiles has not raised the factor of safety as much as the metallic strip has. Although the safety factor against bearing failure is significantly increased by using geotextiles in soil mass, even then, in the case of use, we must consider the financial matter, not only the environmental condition and soil properties. As a result, it's critical to ensure that the reinforcements we utilize to extend the wall's service life are enough.

The numerical analysis shows that in the use of reinforcement strips, the factor of safety has increased the most in the case of overturning, with a value of 59.96 found at the 7m height and 14.72 found at the 20m height. In the case of bearing failure, the highest value of FS is found at 24.92 at 7 m height and the lowest at 9.8 at 20 m height. Consequently, the highest value of FS is found at 7.85 at 7 m height and the lowest, at 3.88 at 20 m, in the case of sliding. Considering all this, it can be seen that in the case of all the failures, the value of the factor of safety is higher than the value of the limit equilibrium, which increases the serviceability index of the wall.

In the use of geotextiles, the value of FS has increased the most in bearing capacity failure, and that is 11.73 found at the 7m height and 6.06 found at the 20m height. In contrast to overturning and sliding failure, the value of FS is equal to or slightly higher than the recommended value.

8. Conclusion

In the overall study, to check the external stability of these walls, safety factors against failure of bearing, overturning, and sliding are considerably higher than the recommended value of 3 to 5. But on the other hand, the value of FS gradually decreases as the height of the wall increases with the same properties. The heights of the wall play a vital role in this dilemma. However, reinforcing strips must be utilized in accordance with the design, and the backfill soil must be granular. As a result, appropriate reinforcement lengths result in a sturdy retaining wall but remember that excessive reinforcement quantities diminish economic efficiency also.

References

[1] Shin E. C, Cho S. D, & Lee K. W, “Case Study of Reinforced Earth Wall Failure during Extreme Rainfall,” *Proceeding of TC302 Symposium Osaka 2011: International Symposium on Backwards Problem in Geotechnical Engineering and Monitoring of Geo-Construction,* pp. 146–153, 2011. [Online]. Available: https://repository.kulib.kyotou.ac.jp/dspace/handle/2433/173835

[2] Xiaopeng Guo, Zhang H, and Liangliang Liu, “Planar Geosynthetic-Reinforced Soil Foundations: A Review,” *SN Applied Sciences*, vol. 2, no. 12, 2020. *Crossref,* https://doi.org/10.1007/s42452-020-03930-5

[3] Vijay Kumar, and Dr. Bharat Nagar, “Analysis and Design of Reinforced Earth wall,” *International Journal of Scientific & Engineering Research (IJSER),* vol. 12, no. 4, pp. 281-287, 2021.

[4] Henri Vidal, *The Principle of Reinforced Earth,* 1969. [Online]. Available: http://onlinepubs.trb.org/Onlinepubs/hrr/1969/282/282-001.pdf

[5] Derrick I. Price, “Reinforced Earth,” *Ground Engineering*, no. 3, pp. 19-24, 1975.

[6] Okechukwu S.I, Okeke et al., “Reinforced Earth: Principles and Applications in Engineering Construction,” *International Journal of Advanced Academic Research*, vol. 6, no. 2, pp. 14-33, 2016.

[7] Belabed L, Benyaghla H, and Jarir Yahiaoui, “Internal Stability Analysis of Reinforced Earth Retaining Walls,” *Geotechnical and Geological Engineering*, vol. 29, no. 4, pp. 443-452, 2011. *Crossref*, http://dx.doi.org/10.1007/s10706-011-9390-4

[8] BS. Brown, H.G. Poulos, “Analysis of Full Scale Experimental Reinforced Embankments,” *Proceedings 4th Australia-New Zealand Conference on Geomechanics*, Perth, Western Australia, pp. 183-187, 1984.

[9] Nand Kishore, “Concept and Design of Reinforced Earth Structures,” Report no. GE: R73, 2005.

[10] Braja M.Das, *Principle of Foundation Engineering*, SI; 8th Edition, 2016.

[11] Damians I. P, Bathurst R. J, Josa A, & Lloret A, “Numerical Analysis of an Instrumented Steel-Reinforced Soil Wall,” *International Journal of Geomechanics*, vol. 15, no. 1, pp. 04014037, 2015. *Crossref,* https://doi.org/10.1061/(ASCE)gm.1943-5622.0000394

[12] Richard J. Bathurst, Axel Nernheim, and Tony M. Allen, “Predicted Loads in Steel-Reinforced Soil Walls using the AASHTO Simplified Method,” *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 135, no. 2, pp. 177-184, 2009. *Crossref,* http://dx.doi.org/10.1061/(ASCE)1090-0241(2009)135:2(177)

[13] Imad A. Basheer and Yacoub M. Najjar, “Reliability-Based Design of Reinforced Earth Retaining Walls,” *Transportation Research Record Journal of the Transportation Research Board*, vol. 1526, no. 1, pp. 64-78, 1996. *Crossref*, http://dx.doi.org/10.3141/1526-09

[14] Aqueeb Inamdar, “Global Stability Analysis of Reinforced Earth Wall Using Basal Reinforcement,” *International Journal for Science and Advance Research in Technology,* vol. 6, no. 8, pp. 198-202, 2020. *Crossref*, http://dx.doi.org/10.6084/m9.figshare.12847838

[15] Adnan A. Basma, Samer A. Barakat, and Maher T. Omar, “Reliability-Based Risk Index for the Design of Reinforced Earth Structures,” *Geotechnical and Geological Engineering*, vol. 21, no. 3, pp. 225-242, 2003. *Crossref,* http://dx.doi.org/10.1023/A:1024932408001

[16] Young Je Kim et al., “Behaviour Analysis of Reinforced Soil Retaining Wall According to Laboratory Scale Test,” *Applied Sciences*, vol. 10, no. 3, pp. 1-17, 2020. *Crossref,* https://doi.org/10.3390/app10030901

[17] Michael Dobie, CEng FICE, “Reinforced Soil Retaining Walls - An Outline of Design Methods and Sources of Conservatism,” *Conference: CTAG/CCIGS Seminar on Reinforced Soil Design*, at Wuhan, China, 2013.

[18] Richard J. Bathurst, “Reinforced Soil Retaining Wall Testing Modeling and Design,” *Geoindex –Indian Geotechnical Society, IGC*, Chennai, India, pp. 21-32, 2006.

[19] Kianoosh Hatami, Richard J. Bathurst, and Pasquale Di Pietro, “Static Response of Reinforced Soil Retaining Walls with Nonuniform Reinforcement,” *International Journal of Geomechanics*, vol. 1, no. 4, pp. 477-506, 2001. *Crossref,* https://doi.org/10.1080/15323640108500164

[20] Carlos Vinicius Santos Benjamim, B. S. Bueno and J. G. Zornberg, “Field Monitoring Evaluation of Geotextile-Reinforced Soil-Retaining Walls,” *Geosynthetics International*, vol. 14, no. 2, pp. 100-118, 2007. *Crossref,* http://dx.doi.org/10.1680/gein.2007.14.2.100

[21] Erol Guler, Murat Hamderi, and Mehmet Melih Demirkan, "Numerical Analysis of Reinforced Soil-Retaining Wall Structures with Cohesive and Granular Backfills," *Geosynthetics International*, vol. 14, no. 6, pp. 330-345, 2007. *Crossref,* http://dx.doi.org/10.1680/gein.2007.14.6.330

[22] Richard J. Bathurst, and D.J. Benjamin, "Failure of a Geogrid-Reinforced Soil Wall," *Transportation Research Record Journal of the Transportation Research Board,* 1990.

[23] Ayush Mittal, ShalineeShukla, "Effect of Non-Woven Geotextile and Biaxial Geogrid Reinforcement on the Strength Behaviour of Subgrade Soil," *SSRG International Journal of Civil Engineering,* vol. 5, no. 10, pp. 28-32, 2018. *Crossref,* https://doi.org/10.14445/23488352/IJCE-V5I10P105

[24] R.J. Bathurst, et al., "Performance Testing and Numerical Modeling of Reinforced Soil Retaining Walls," *Conference: Seventh International Geosynthetics Conference,* at Nice, France, 2002.

[25] Safa Hussain, Abid Awn, and Waad Abdulsattar Zakaria, "Behavior of Retaining Wall Founded on Collapsible Soil – A Prototype Laboratory Study," *Diyala Journal of Engineering Sciences*, vol. 7, no. 3, pp. 1-42, 2014. *Crossref,* http://dx.doi.org/10.24237/djes.2014.07301

[26] Moamen E. Abd El Raouf, "The Residual Lateral Earth Pressure on Retaining Wall Due to Vibratory Rollers," *Journal of Al-Azhar University Engineering Sector*, vol. 14, no. 50, pp. 37-46, 2019. *Crossref,* http://dx.doi.org/10.21608/auej.2019.28504