REINFORCED EARTH: PRINCIPLES AND APPLICATIONS IN ENGINEERING CONSTRUCTION

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Abstract

Reinforced earth is a material formed by combining earth and reinforcement material. The reinforced soil is obtained by placing extensible or inextensible materials such as metallic strips or polymeric reinforcement within the soil to obtain the requisite properties. The reinforcement enables the soil mass to resist tension in a way which the earth alone could not. The source of this resistance to tension is the internal friction of soil, because the stresses that are created within the mass are transferred from soil to the reinforcement strips by friction. Reinforcement of soil is practiced to improve the mechanical properties of the soil being reinforced by the inclusion of structural elements. The reinforcement improves the earth by increasing the bearing capacity of the soil. It also reduces the liquefaction behavior of the soil. Reinforced earth is not complex to achieve. The components of reinforced earth are soil, skin and reinforcing material. The reinforcing material may include steel, concrete, glass, planks etc. Reinforced earth has so many applications in construction work. Some of the applications include its use in stabilization of soil, construction of retaining walls, bridge abutments for highways, industrial and mining structures.

Keywords: Reinforcement, Reinforced earth.

1.0 Introduction

An internally stabilized system such as reinforced earth involves reinforcements installed within and extending beyond the potential failure mass. Reinforced earth is a material formed by combining earth and reinforcement. The reinforcement comprises of reinforcing elements which is in the form of strips set at certain intervals disposed in horizontal layers. On the facing of the structure, a certain type of boundary or skin is required to retain the earth particles that are not in contact with reinforced strips. A reinforced soil mass is somewhat analogous to reinforced concrete in that the mechanical properties of the mass are improved by reinforcement placed parallel to the principal strain direction to compensate for soil's lack of tensile resistance. The improved tensile properties are a result of the interaction between the reinforcement and the soil. The concept of combining two materials of different strengths characteristics to form a composite material of greater strength is quite familiar. The reinforced concrete constructions are examples for such composite materials. It combines the high tensile strength of steel with the high compressive, but relatively low tensile strength of concrete. Likewise, soils which have little, if any tensile strength can also be strengthened by the inclusion of materials with high tensile strength. This mobilization of tensile strength is obtained by surface interaction between the soil and the reinforcement through friction and adhesion. The reinforced soil is obtained by placing extensible or inextensible materials such as metallic strips or polymeric reinforcement within the soil to obtain the requisite properties

(Nand K. 2005). Soil reinforcement through metallic strips, grids or meshes and polymeric strips sheets is now a well-developed and widely accepted technique of earth improvement.

Typical early uses of earth reinforcement include use of branches of tree etc. to support tracks over marshy areas and to build hutments. Structures are also built by insects and birds using mud and leaves. These are all familiar sights even today. This kind of principle is also used in building parts of Great Wall of China and the Babylonian temples. In the 19th century Passel used tree branches to reinforce back fills in order to reduce the earth pressure and thereby economize the retaining walls. Textile material was perhaps first used in road construction in South Carolina in the early 1930s. The first use of woven synthetic fabrics for erosion control was made in 1958 by Barrett (Nand K. 2005).

The use of reinforced earth technique is primarily due to its versatility, cost effectiveness and ease of construction. The reinforced earth technique is particularly useful in urban locations where availability of land is minimal and construction is required to take place with minimum disturbance traffic.

The construction of reinforced earth structure has become wide spread in Geotechnical engineering practice in the last two decades owing to their ease of construction and economy compared to those of conventional methods. Reinforcement of soil, is practiced to improve the mechanical properties of the soil being reinforced by the inclusion of structural element such as granular piles, lime/cement mixed soil, metallic bars or strips, synthetic sheet, grids, cells etc.

2.0 Principles

Soil has an inherently low tensile strength but a high compressive strength. An objective of incorporating soil reinforcement is to absorb tensile loads or shear stresses within the structure. In absence of the reinforcement, structure my fail in shear or by excess of the deformation. When an axial load is applied to the reinforced soil, it generates an axial compressive strain and lateral tensile strain this is illustrated by model in Figure 1 . If the reinforcement has an axial tensile stiffness greater than that of the soil, then lateral movements of the soil will only occur if soil can move relative to the reinforcement (Nand K. 2005). Movement of the soil, relative to the reinforcement, will generate shear stresses at the soil/ reinforcement interface, these shear stresses are redistributed back into the soil in the form of internal confining stress. Due to this, the strain within the reinforced soil mass is less than the strain in unreinforced soil for the same amount of stresses, this is indicated in Fig 1 where $\delta hr < \delta h$. and $\delta vr < \delta v$, provided the surface of the reinforcement is sufficiently rough to prevent the relatively movement and the axial tensile stiffness of reinforcement is more than that of soil.

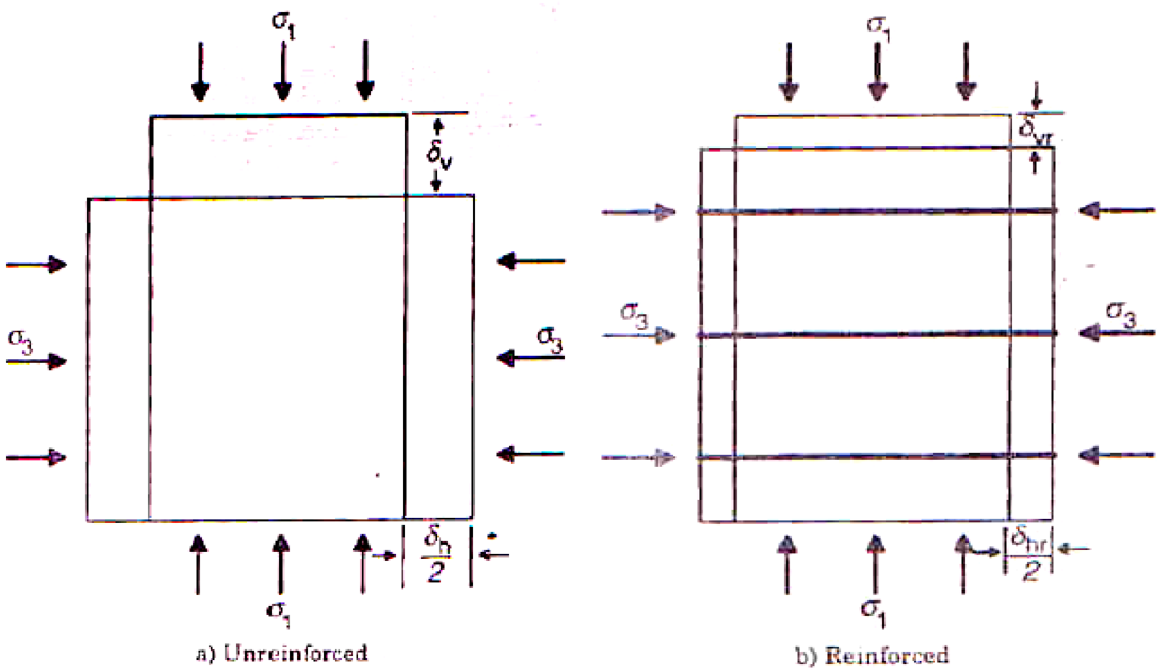


Fig 1: Effect of reinforcement on a soil element (Nand, K. 2005)

2.1 Soil Reinforcing principles in Walls and Slopes

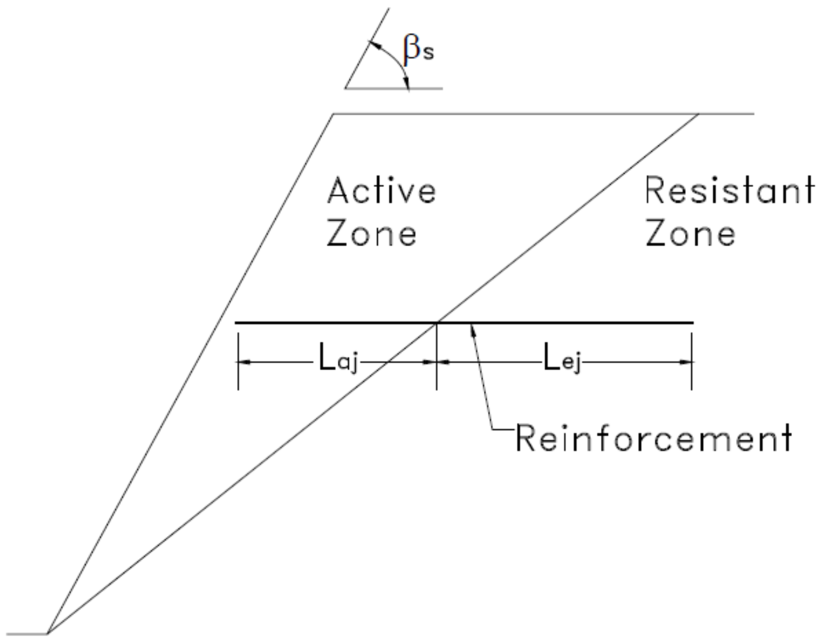


Fig 2: Principle in walls and slopes. (Nand, K. 2005)

The figure above shows a steep slope in a dry cohesion less soil with a face inclined at ‘ βs’ to the horizontal, where βs is greater than the internal angle of shearing resistance. Without the benefit of soil reinforcement the slope would collapse, however by the incorporation of suitable soil reinforcement the slope may be rendered stable. Investigation of the basic reinforcing mechanism reveals that the soil in the slope comprises two distinct zones, viz. active-zone and the resistant zone as shown in the figure. Without reinforcement the active zone is unstable and tends to move outwards and downwards with respect to the resistant zone. If soil reinforcement is installed across the active and resistant zones it can serve to stabilize the active zone. The figure shows a single layer of reinforcement with a length Laj embedded in the active zone and length Lej embedded in the resistant zone. A practical reinforcement layout would contain multiple layers of reinforcement. However, the single layer shown in the figure is adequate to illustrate the basic mechanisms involved. The embedded length of Lej should be sufficient enough to mobilize enough bond strength between the soil and reinforcement to resist the disturbing force caused by active zone. The tensile strength of the reinforcement is not constant but it decreases towards the free end of Lej and it is zero at the end (Nand, K. 2005).

Flexible reinforcement is incorporated in fill during construction. Consequently, the layers of reinforcement are horizontal. Flexible reinforcement is also inserted into cut sections during construction (in the form of soil nails) at inclinations close to the horizontal. This inclination is convenient since it coincides with the general inclination of the tensile strength developed in the soil in the active zone.

2.2 Soil reinforcement interaction

For soil reinforcement interaction to be effective reinforcement is required to absorb strains which would otherwise cause failure. In this context an ultimate state of collapse in terms of interaction with the soil and reinforcement can be caused by rapture of reinforcement or failure of bond between soil and reinforcement. In serviceability, limit state occurs when deformation occurs beyond serviceable limit or strain within the reinforcement exceed prescribed limit.

If the soil is cohesion less the bond resistance will be friction and will depend upon surface roughness and soil. If soil is cohesive the bond stress will be adhesive. In case of grid reinforcement the bond stress will be governed by the shear strength of the soil and roughness of the reinforcement.

Having absorbed load it is necessary for the reinforcement to sustain this load during the design life without rupture or without suffering time dependent deformation which might give rise to serviceability limit. To maximize the tensile load capacity the flexible reinforcement are install horizontally to coincide with the principle tensile strain. The axial forces absorbed by the reinforcement are statically determinate.

2.3 Soil properties required to be taken into consideration

The soil property required to be taken into consideration are effective shear strength parameter ‘c’ and ‘ϕ’ which are obtained by taking into consideration pore pressure within the soil. However shear strength of fill or soil incorporating multiple layer of reinforcement.
In wall and slope, load imposed on the soil reinforcement will increase if positive pore water pressure is allowed to develop. The development of adverse pore pressure in reinforcement fill wall can be prevented by providing appropriate drainage. In case the development of pore

water pressure is unavoidable in water front construction increased reinforcement is required to be considered. In addition to physical interaction of soil and reinforcement electrochemical interaction is also required to be considered for design life to assess the durability.

2.4 Stress Transfer Mechanism

Stresses are transferred between soil and reinforcement by friction (fig 3a) and/or passive resistance (fig 3b) depending on reinforcement geometry:

Friction develops at locations where there is a relative shear displacement and corresponding shear stress between soil and reinforcement surface. Reinforcing elements where friction is important should be aligned with the direction of soil reinforcement relative movement.

Passive resistance occurs through the development of bearing type stresses on "transverse" reinforcement surfaces normal to the direction of soil reinforcement relative movement. Passive resistance is generally considered to be the primary interaction for rigid geogrids, bar mat, and wire mesh reinforcements. The transverse ridges on "ribbed" strip reinforcement also provide some passive resistance.

The contribution of each transfer mechanism for a particular reinforcement will depend on the roughness of the surface (skin friction), normal effective stress, grid opening dimensions, thickness of the transverse members, and elongation characteristics of the reinforcement. Equally important for interaction development are the soil characteristics, including grain size, grain size distribution, particle shape, density, water content, cohesion, and stiffness.

2.5 Mode of Reinforcement Action

The primary function of reinforcements is to restrain soil deformations. In so doing, stresses are transferred from the soil to the reinforcement. These stresses are carried by the reinforcement in two ways: in tension or in shear and bending.

Tension is the most common mode of action of tensile reinforcements. All "longitudinal" reinforcing elements (i.e., reinforcing elements aligned in the direction of soil extension) are generally subjected to high tensile stresses. (U.S department of transport 2001).

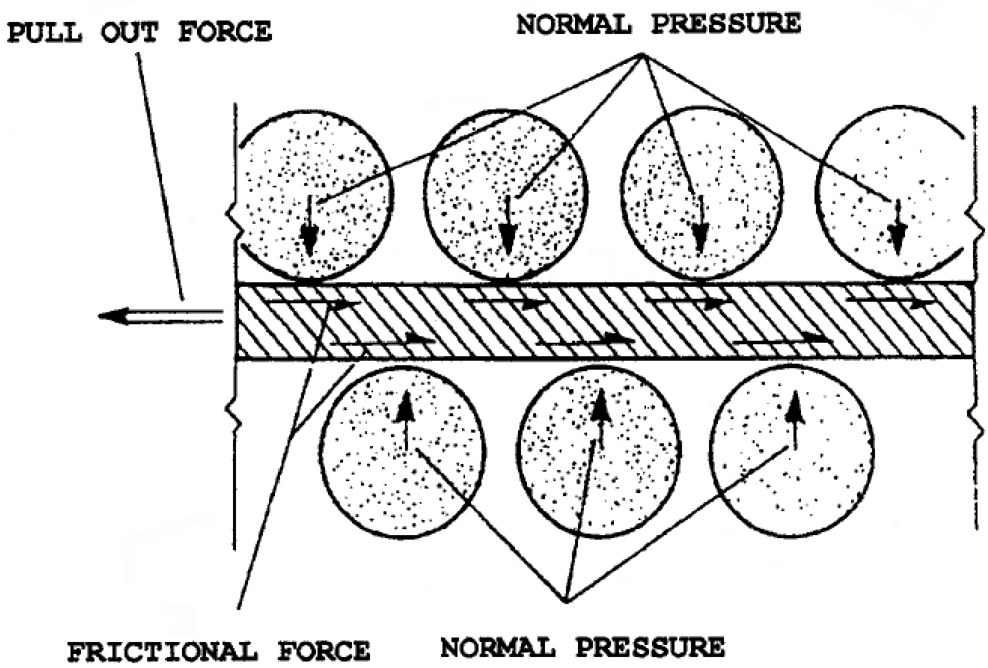


Fig 3A: Frictional stress transfer between soil and reinforcement surface.

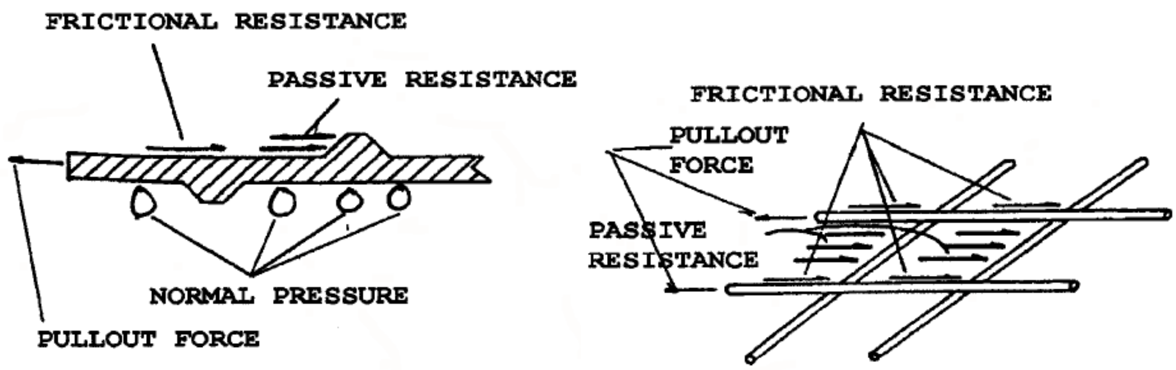


Fig 3B: soil passive (bearing) resistance on reinforcement surface.

Fig 3: Stress transfer mechanisms for soil reinforcement (U.S department of transport 2001)

2.6 Reinforcement Geometry

Soil reinforcement can take a variety of forms, some of which are shown in the Figure below. Grids meshes and strips can be metallic or polymeric whilst sheet reinforcement takes the form of polymeric geotextiles. Anchored earth fill employs multiple layers of flexible steel bars or polymeric materials, which are shaped, at the end remote from the face of the wall, to form an anchor. When used as soil nails, steel bars have a simple circular cross section.

Sheet reinforcement and polymeric grids are generally installed full width, such that each meter length of face is associated with a 1m width of reinforcement, and so, in a multiplayer system, the total stabilizing force developed by the reinforcement is a function of the number of layers of reinforcement and their vertical spacing. Strip reinforcement, including wide strips of metallic or polymeric grid, are not placed full width

Consequently, the total stabilizing force developed by such reinforcement will be a function of the number of reinforcement elements and both their horizontal and vertical spacing. The total length of each reinforcing element will influence the overall geometry of the reinforced mass and this in turn will influence external stability. For example, in the case of a reinforced fill wall, the length of the reinforcing elements at the base of the wall determine the width of the base of the wall and therefore affect the performance of the reinforced mass with respect to forward sliding on the base, bearing, tilting, settlement and overall stability.

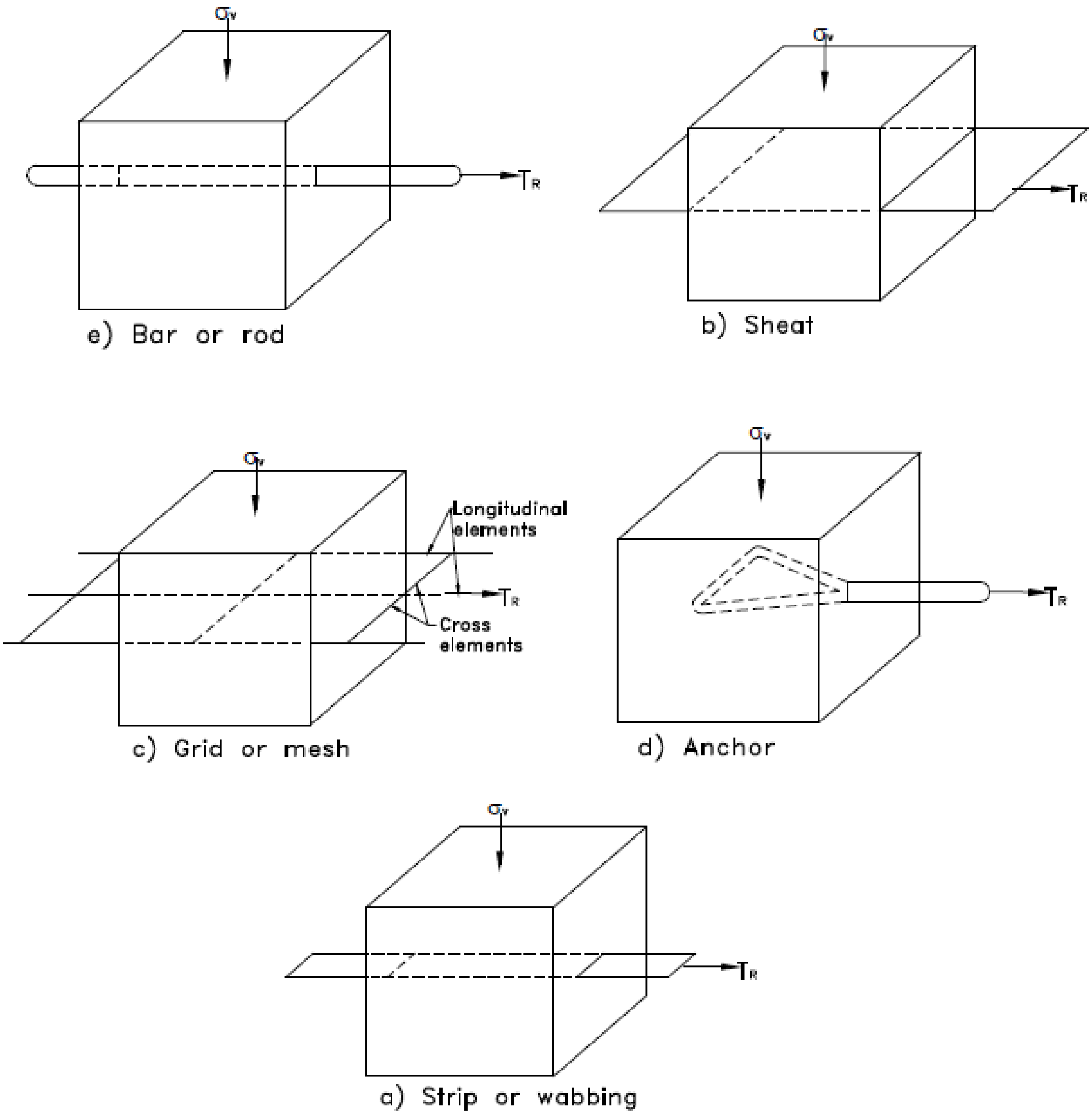


Fig 4: Forms of reinforcement. (Nand, K. 2005)

3.0 Materials and construction of reinforced earth

Reinforced earth structure consists of three main components shown in the figure below, namely

- Reinforcing element
- Soil back fill
- Facing element

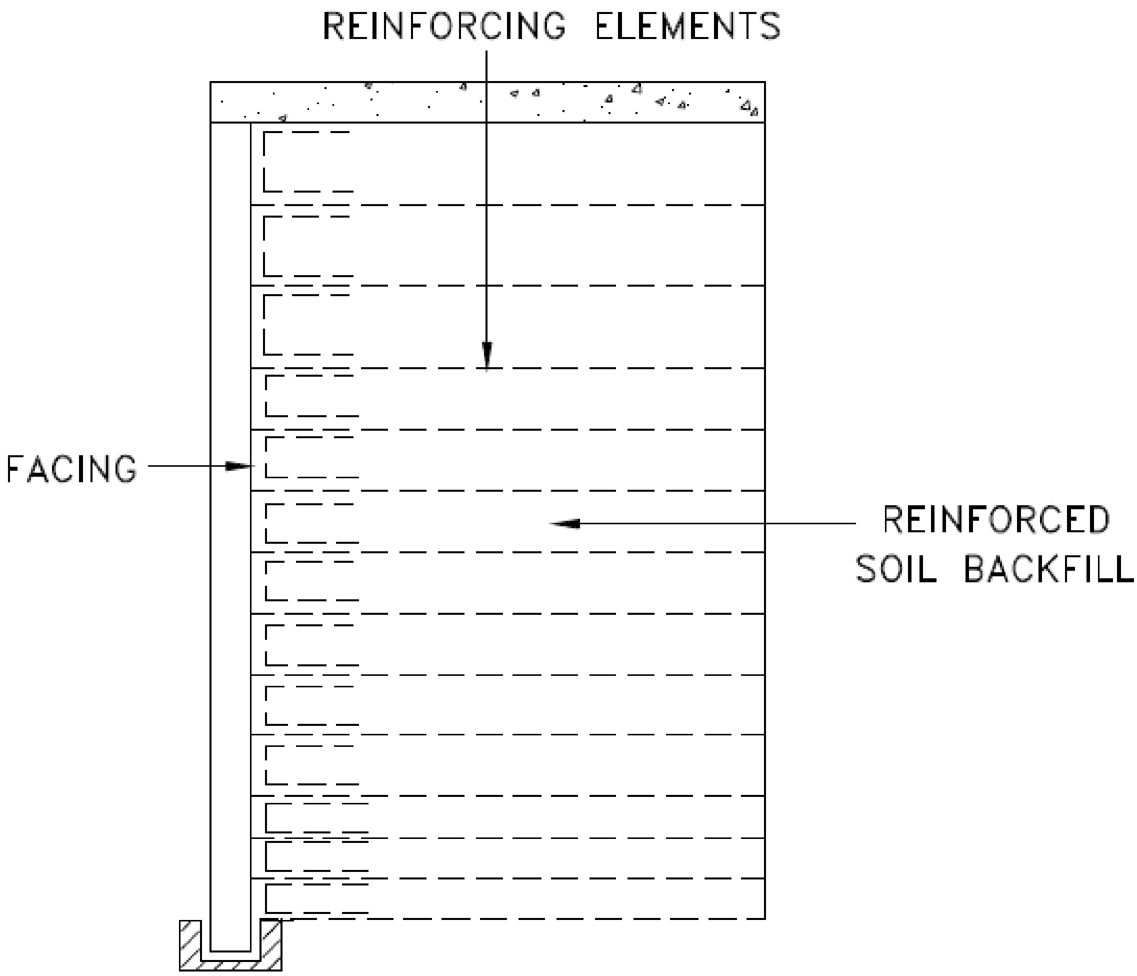


Fig 5: Components of reinforced earth structure (Nand, K. 2005).

3.1 Description of reinforcing element

A variety of materials can be used as reinforcing materials .Those that have been used successfully include steel, concrete, glass fibre, wood, rubber, aluminium and thermoplastics. Reinforcement may take the form of strips, grids, anchors & sheet material, chains planks, rope, vegetation and combinations of these or other material forms.

3.2 Types of reinforcing materials

3.2.1 Strips

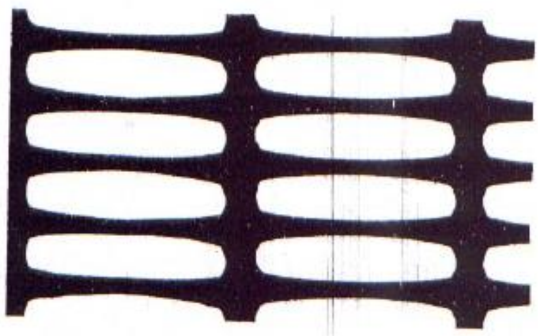
These are flexible linear element normally having their breadth, 'b' greater than their thickness, 't'. Dimensions vary with application and structure, but are usually within the range t = 3-5 mm, b = 5-100 mm. The most common strips are metals. The form of stainless, galvanized or coated steel strips being either plain or having several protrusions such as ribs or gloves to increase the friction between the reinforcement and the fill. Strips can also be formed from aluminium, copper, polymers and glass fibre reinforced plastic (GRP). Reed and bamboo reinforcements are normally categorized as strips, as are chains.

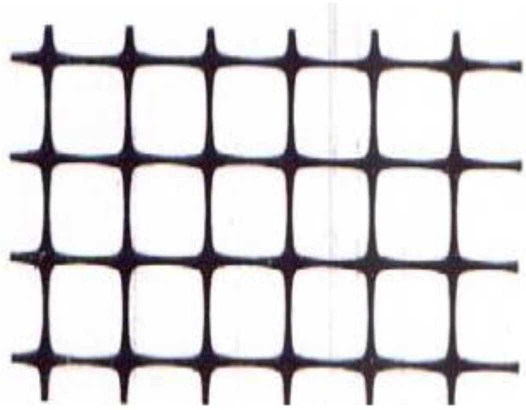
3.2.2 Planks

Similar to strips except that their form of construction makes them stiff. Planks can be formed from timber, reinforced concrete or prestressed concrete. The dimensions of concrete planks vary; however, reinforcements with a thickness, 't' = 100 mm and breadth, b= 200–300 mm have been used. They have to be handled with care as they can be susceptible to cracking.

3.2.3 Grids and Geogrids

Reinforcing elements formed from transverse and longitudinal members, in which the transverse members run parallel to the face or free edge of the structure and behave as abutments or anchors as shown in the figure below. The main purpose is to retain the transverse members in position. Since the transverse members act as an abutment or anchor they need to be stiff relative to their length. The longitudinal members may be flexible having a high modulus of elasticity not susceptible to creep. The pitch of the longitudinal members, pL is determined by their load-carrying capacity and the stiffness of the transverse element. The pitch of the transverse elements, pT depends upon the internal stability of the structure under consideration. A surplus of longitudinal and transverse elements is of no consequence provided the soil or fill can interlock with the grid. Mono and Bi Oriented grid are shown in Fig 6.





Monooriented Geogrid Bi – oriented Geogrid

Fig 6: Geogrid

The most important properties of geogrid are its tensile strength, tensile modulus and interface shear strength.

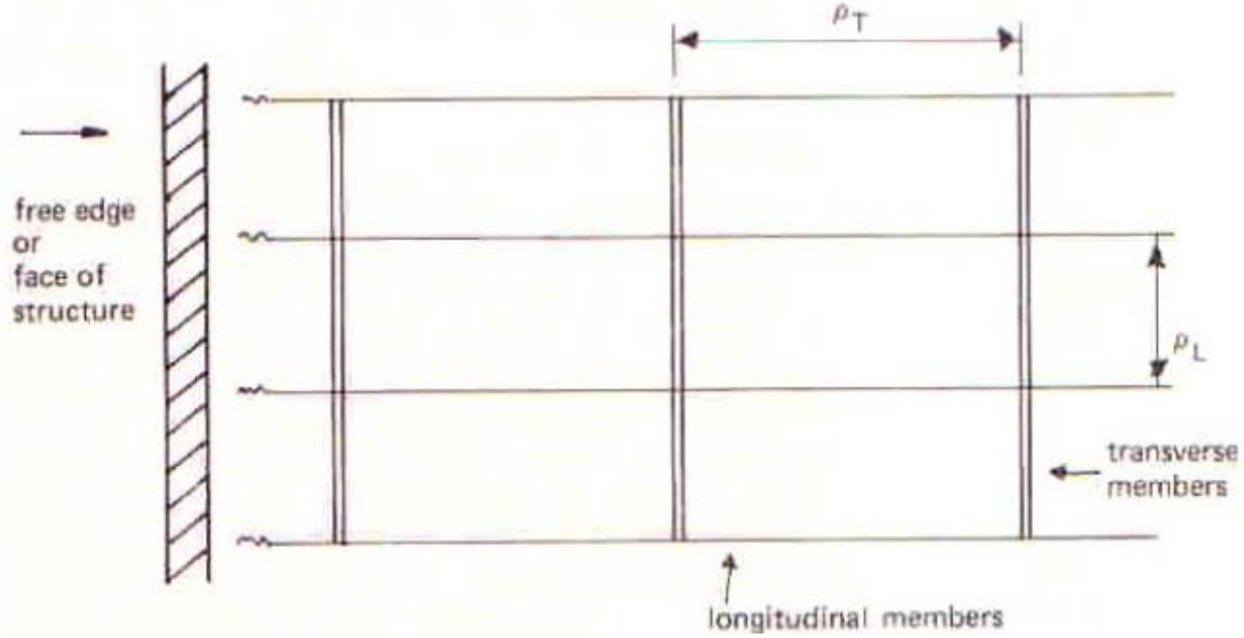


Fig 7: Geogrid behavior as abutments and anchors (Nand, K. 2005).

Grids can be formed from steel in the form of plain or galvanized weldmesh, or from expanded metal. Grids formed from polymers are known as "Geogrids" and are normally in the form of an expanded proprietary plastic product.

3.2.4 Sheet Reinforcement

May be formed from metal such as galvanized steel sheet, fabric (textile) or expanded metal not meeting the criteria for a grid.

3.2.5 Nailing

Earth may be protected by geosynthetics with earth nailing.

3.2.6 Anchors

Flexible linear elements having one or more pronounced protrusions or distortions which act as abutments or anchors in the fill or soil. They may be formed from steel, rope, plastic (textile) or combinations of materials such as webbing and tyres, steel and tyres, or steel and concrete

Fig 8: Anchors

3.2.7 Composite Reinforcement

Reinforcement can be in the form of combinations of materials and material forms such as sheets and strips, grid and strips and anchors, depending on the requirements.

In reinforcement with polymers, polymeric joints are required. Polymeric reinforcement joints are subdivided into prefabricated joints and joints made during execution of the works. A number of different jointing systems are in use. Joints in geotextiles should normally be sewn where load transference is needed. For polymeric meshes or grid a bodkin may be employed. A Bodkin joint is an effective method of joining some polymeric grid reinforcement.

3.3 Description of Soil Backfill

The fill material for reinforced earth structures shall be preferably cohesion-less and it should have an angle of on interface friction between the compacted fill and the reinforcing element of not less than 30, measured. The soil should be predominantly coarse grained; not more than 10 percent of the particles shall pass 75 micron sieve. The soil should have properties such that the salts in the soil should not react chemically or electrically with the reinforcing element in an adverse manner. A wide variety of fill types can be used with the grids including crushed rock, gravel, industrial slag, pulverized fuel ash and clay, but fill particles greater than 125 mm should be avoided.

3.4 Description of Facing Element

Facings may be 'hard' or 'soft' and are selected to retain fill material, prevent local slumping and erosion of steeply sloping faces, and to suit environmental requirements.

The facing shall comprise of one of following:

- Reinforced concrete slabs
- Plain cement concrete form fill hollow block (precast)
- Masonry construction, rubble facia
- Other proprietary and patented proven system

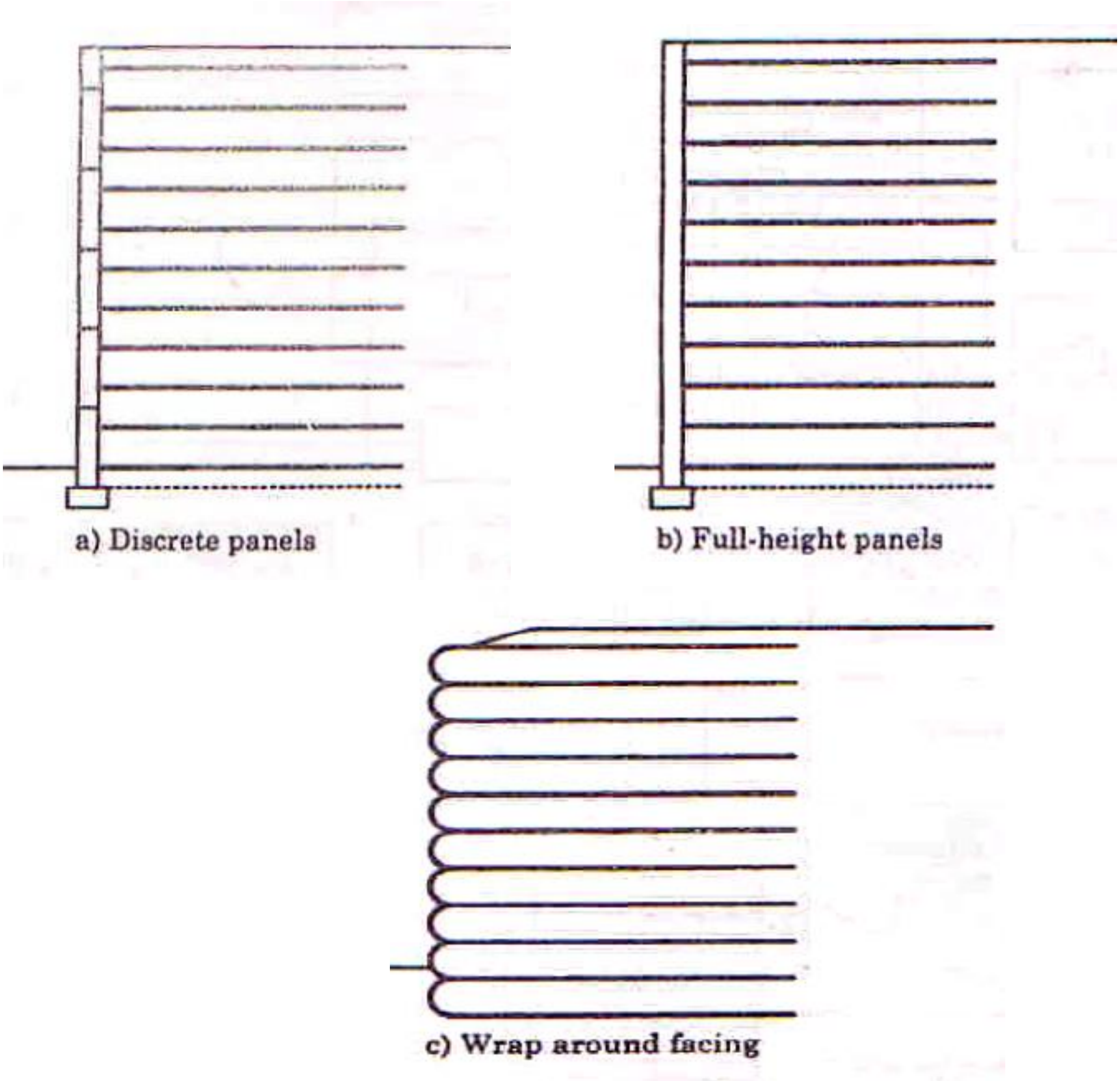


Fig 9: Common facing used (DiMaggio, J. 1988)

3.4.1 Hard facings

Facing may consist of concrete, steel sheet, steel grids or mashes, timber, proprietary materials or combination of these. They should conform to the appropriate material standard and should be sized by normal design procedures using the appropriate standard.
Interlocking concrete blocks, grout filled bags or Gabions can provide a substantial facing. Some of this facing is shown in Figure below.

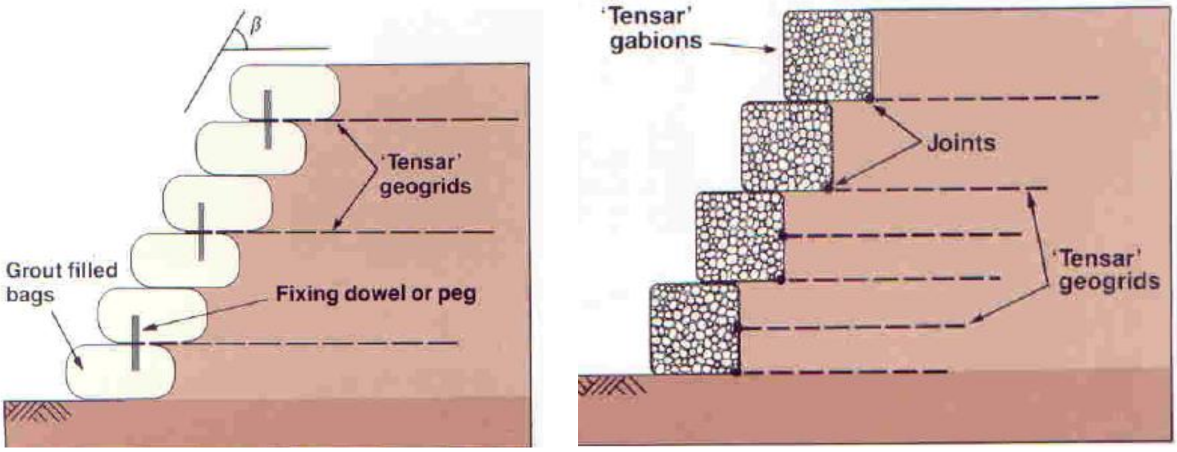
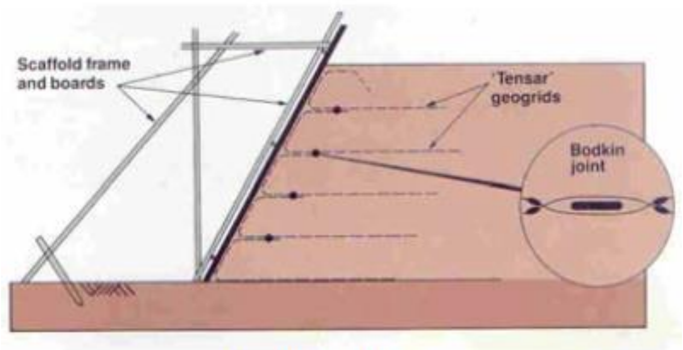


Fig 10: Hard facing (Nand K. 2005).

3.4.2 Soft Facings

Generally, external temporary formwork is erected to support the face during the construction of steep slopes (>45^0). It can take the form of a lightweight system of scaffold tubes and boards or consist of some form of 'climbing' shutter. The grids are turned up the face of the framework and returned into the embankment directly below the next reinforcement layer. The two grids are connected using a high density polyethylene bodkin. The soft facing is shown in Figure below.



Scaffold frame

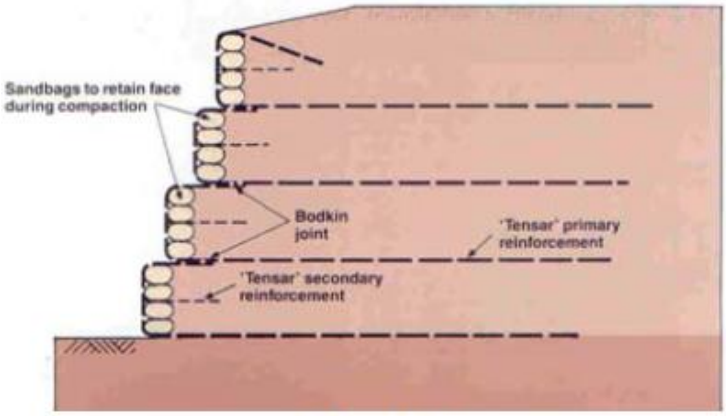


Fig 11: Soft facing (Nand K. 2005)

Turf and topsoil can be placed on the fill side of the grid reinforcement as it is turned up the face of the slope to create a natural and aesthetic appearance.

Where the vertical spacing of the main reinforcement is greater than 500mm, biaxial grid reinforcement is used as intermediate secondary reinforcement to provide local stability at the face of the slope.

3.5 Fasteners between the Facing and Reinforcing Elements

Fasteners are used to make a connection between the reinforcement and the facing and take the form of dowels, rods, hexagon headed screws and nuts and bolts and may consist one of the following materials:

- Plain steel
- Coated steel
- Galvanized steel
- Stainless steel
- Polymers

The choice of material used to form the fastener should be compatible with the design life of the structure.

3.6 Construction

By nature, reinforced soil is a combination of structural engineering and geotechnics. The structural engineering takes care of the limit state design where as the geotechnics takes care of the geotechnical parameters. Limit state is deemed to be reached when the following happens;

a) collapse or major damage
b) deformation in excess of acceptable limit
c) Other forms of distress or minor damage which could shorten the expected life of the structure.

In the design of reinforced earth structure two main criteria are used to develop the dimensions and layout, they are external stability and internal stability. The external stability considers the structure as a whole and check the stability for sliding, overturning, bearing capacity, deep stability, tilt and slip (Babu G.L, 2012). External stability can be achieved using two methods which include the tie back wedge method and the coherent gravity method.

Internal stability covers the internal mechanism (tension and pullout failure) within the structure, arrangement and behavior of the reinforcement and backfill. For internal stability, two main failure mechanisms need to be investigated viz; tension failure and pull-out failure.

In a typical construction of reinforced earth wall, the various components are arranged as shown in the figure below.

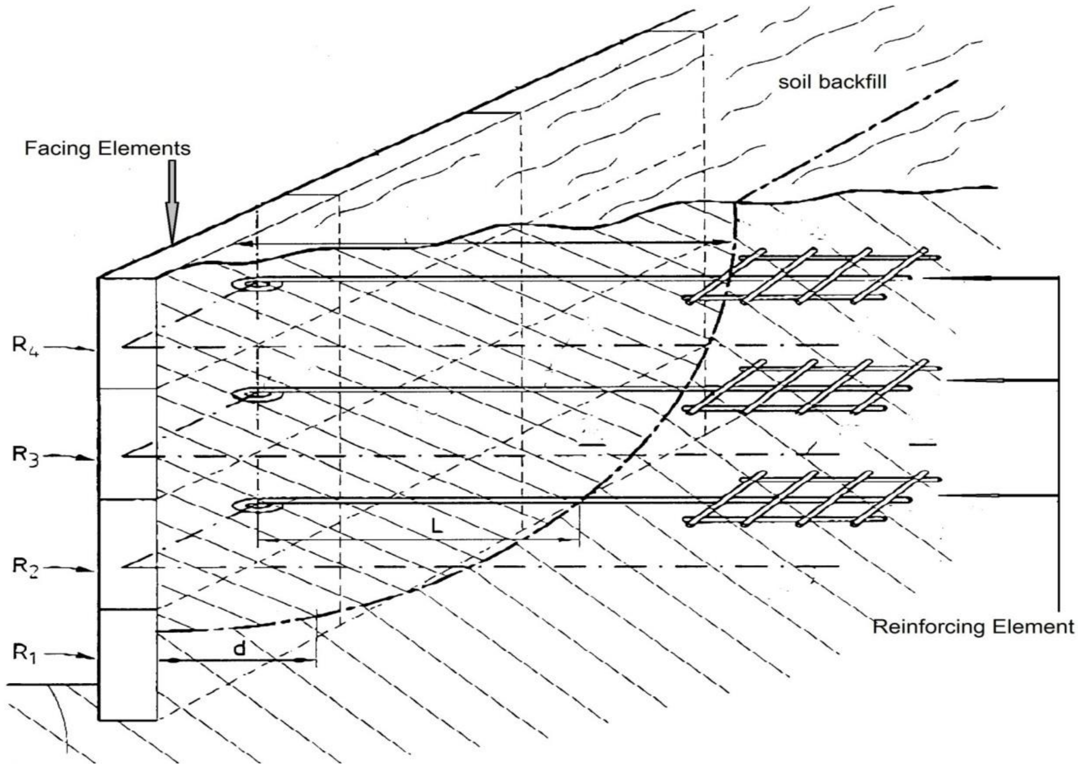


Fig 12: arrangement of the components (Umar, F. 2008).

All the components are arranged accordingly facing element, reinforcing element and soil backfill.

Fig 13: construction of walls (Babu, G.L. 2007).

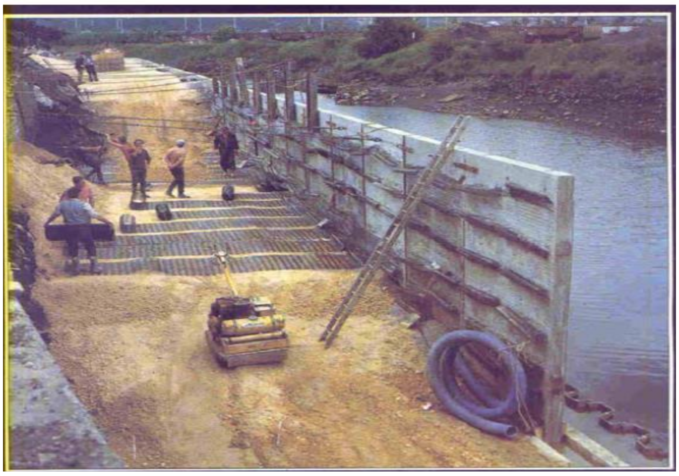


Fig 14: Laying of geogrid (Nand, K.2005).

4.0 Applications of reinforced earth

Reinforced Earth systems can be used to construct retaining walls and bridge abutments for highway and railway applications. The various applications of reinforced earth are shown in the Figure below. Anchoring and soil nailing is also adopted to improve the soil property.

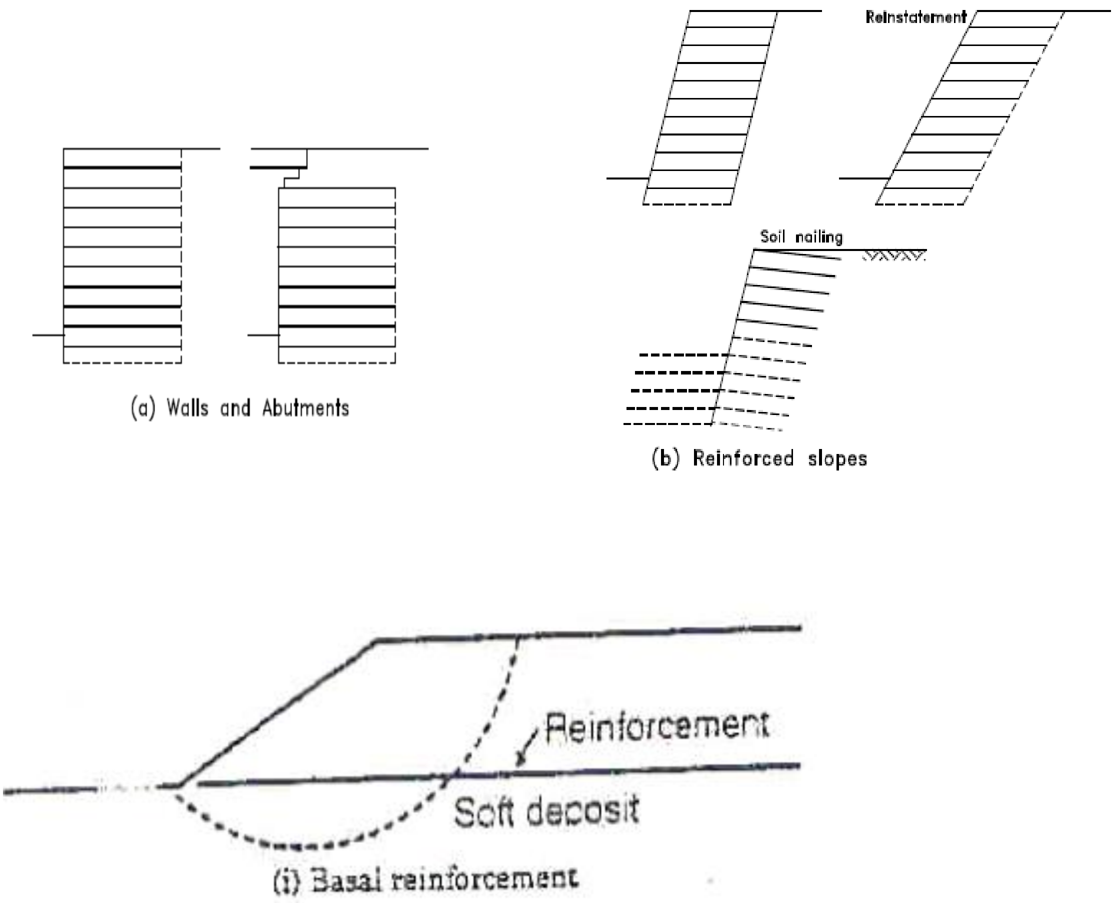


Fig 15: Applications of reinforced earth (Nand, K. 2005)

They can also be used for industrial structures, mining structures and marine structures. Structures can be dismantled and materials can be re-used, thereby providing a truly sustainable solution. Reinforced earth wall has a high seismic stability. This is shown in the figure below which illustrates a wall that withstands the 1995 Kobe earthquake.

Before the earthquake

After the earthquake

Fig 16: Geogrid-reinforced soil wall along JR Kobe line (Babu, G.L. 2007).

High performance during the 1995 Kobe Earthquake of a Reinforced Wall that had been constructed at Tanata validated its high seismic stability.

Reinforced earth is also applied in soil stabilization by increasing the weight bearing capabilities of in-situ subsoil, thereby improving the California bearing ratio of in-situ soil by about 4 to 6 times.

The most common application of reinforced earth is in mechanical stabilized earth wall (MSEW) and Reinforced soil slope (RSS).

MSEW structures are cost-effective alternatives for most applications where reinforced concrete or gravity type walls have traditionally been used to retain soil. These include bridge abutments and wing walls as well as areas where the right-of-way is restricted, such that an embankment or excavation with stable side slopes cannot be constructed. They are particularly suited to economical construction in steep-sided terrain, in ground subject to slope instability, or in areas where foundation soils are poor. MSE walls offer significant technical and cost advantages over conventional reinforced concrete retaining structures at sites with poor foundation conditions. In such cases, the elimination of costs for foundation improvements such as piles and pile caps, that may be required for support of conventional structures, have resulted in cost savings of greater than 50 percent on completed projects (U.S department of transport 2001).

Reinforced slopes are a form of mechanically stabilized earth that incorporate planar reinforcing elements in constructed earth sloped structures with face inclinations of less than 70 degrees. Typically, geosynthetics are used for reinforcement.

There are two primary purposes for using reinforcement in engineered slopes.

- To increase the stability of the slope, particularly if a steeper than *safe* unreinforced slope is desirable or after a failure has occurred
- To provide improved compaction at the edges of a slope, thus decreasing the tendency for surface sloughing as shown in figure 4b.

The principal purpose for using reinforcement is to construct an RSS embankment at an angle steeper than could otherwise be safely constructed with the same soil. The increase in stability allows for construction of steepened slopes on firm foundations for new highways and as replacements for flatter unreinforced slopes and retaining walls (U.S department of transport 1999).

5.0 Summary and Conclusion

Soil reinforcement through metallic strips, grids or meshes and polymeric strips sheets is now a well-developed and widely accepted technique of earth improvement. The use of reinforced earth technique is primarily due to its versatility, cost effectiveness and ease of construction. Soil has an inherently low tensile strength but a high compressive strength. The strain within the reinforced soil mass is less than the strain in unreinforced soil for the same amount of stresses. When an axial load is applied to the reinforced soil, it generates an axial compressive strain and lateral tensile strain. A variety of materials can be used as reinforcing element, e.g. steel, concrete, and wood, rubber, aluminum, thermoplastics. Reinforcement materials may take different forms which include strips, grids, anchors and sheet material, plank, nailing, composite reinforcement or a combination of these materials.

In the design of reinforced earth structure two main criteria are used to develop the dimensions and layout, they are external stability and internal stability.
The external stability considers the structure as a whole and checks the stability for sliding, overturning, tilt and slip. Internal stability covers the internal mechanism (tension and pullout failure) within the structure, arrangement and behavior of the reinforcement and backfill.

Some of the applications of reinforced earth include its use in stabilization of the soil by increasing the California bearing ratio of the soil. It can also be used to construct retaining walls and bridge abutments for highway and railway applications. It is applied in control of erosion. The most common application of reinforced earth is in mechanical stabilized earth wall (MSEW) and Reinforced soil slope (RSS). MSEW can be used in reinforced soil containment dikes which is economical and can also result in savings of land because a vertical face can be used, which reduces construction time. Reinforced soil slope increases the stability of a slope to prevent failure. It also provides improved compaction at the edges of a slope, thus decreasing the tendency for surface sloughing.

References

- Andrawes, K.Z., McGown, A., and Murray, R. T., (1986), "The Load-Strain-Time Behavior of Geotextiles and Geogrids," Proceedings of the Third International Conference on Geotextiles, Vienna, Austria, pp. 707-712

- Babu, G.L., (2007) "Reinforced soil retaining walls design and construction". Lecture 31, Indian institute of science. Bangalore 560012.

- Bastick, M., Schlosser, F., Amar, S., and Canepa, Y., "Monitoring of a Prototype Reinforced Earth Wall with Short Strips," to be published in the Proc. of the 12th ICSMFE, Rio de Janeiro, (1989).

- Bush, D.I., (1990), "Variation of Long-Term Design Strength of Geosynthetics in Temperatures up to 40o C", Proceedings of the Fourth International Conference on Geotextiles, Geomembranes, and Related Products, The Hague, Netherlands, pp. 673-676.

- Cheney, R.S., "Permanent Ground Anchors," Federal Highway Administration Report No. FHWA-DP-68-1R, November, (1984).

- Christopher, B.R., and Holtz, R.D., "Geotextile Design and Construction Guidelines Manual," Federal Highway Administration, Washington, DC, (1988). 279

- Den Hoedt, G., Voskamp, W., van den Heuvel, C.J.M., (1994), "Creep and Time-to-Rupture of Polyester Geogrids at Elevated Temperatures," Proceedings of the Fifth International Conference on Geotextiles, Geomembranes, and Related Products, Singapore, pp. 11251130.

- DiMaggio, J., "Mechanically Stabilized Earth: walls and Slopes", Internal Memo Federal Highway Administration, Washington, D.C., (1988).

- Elias, V., and Juran, I., "Soil Nailing", Report to Federal Highway Administration, Washington, D.C., (1988).

- Helwany, B., Wu, J.T.H., (1992), "A Generalized Creep Model for Geosynthetics," International Symposium on Earth Reinforcement Practice, Japan, pp.

- Jewell, R.A. and Greenwood, J.H., (1988), "Long-Term Strength and Safety in Steep Soil Slopes Reinforced by Polymer Materials", Geotextiles and Geomembranes, Vol. 7, Nos. 1 and 2, pp. 81-118.

- Jewell, R.A., Milligan, G.W., Sarsby, R.W., and Dubois, D., "Interaction Between Soil and Geogrids", Proc. Symp. on Polymer Grid Reinforcement in Civil Engineering, Science and Engineering Research Council and Netlon, Ltd., March, (1984).

- Juran, I., Beech, J., and Delaure, E., "Experimental study of the Behavior of Nailed Soil Retaining Structures on Reduced Scale Models," Proc., Int. Symp. on In-situ Soil and Rock Reinforcements, Paris, (1984).

- Koerner, R.M., (1990), "Determination of the Long-Term Design Strength of Stiff Geogrids," GRI Standard Practice GG4(a).

- McGown, A., Paine, N., and DuBois, D.D., (1984), "Use of Geogrid Properties in Limit Equilibrium Analysis", Proceedings of the Symposium on Polymer Grid Reinforcement in Civil Engineering, Paper No. 1.4, pp. 1-5.

- Murray, R. T., McGown, A., (1988), "Assessment of the Time Dependent Behavior of Geotextiles for Reinforced Soil Applications," Durability of Geotextiles RILEM, Chapman and Hall.

- Nand, K. (2005). Concept and design of reinforced earth structures. Report no.GE: R-73

- Popelar, C. H., Kenner, V.H., and Wooster, J.P., (1991), "An Accelerated Method for Establishing the Long-Term Performance of Polyethylene Gas Pipe Materials," Polymer Engineering and Science, Vol. 31, pp. 1693-1700.

- Segrestin, P., Bastic, M.J., Seismic Design of Reinforced Earth Retaining Walls: The Contribution of Fini te Element Analysis," Proc. of the Int. Symp. On Theory and Practice of Earth Reinforcement, Kyushu, Japan, Oct, (1988).

- Terre Armee Internationale, Finite Element Study of Reinforced Earth Structures, Rosalie, Internal Report, (1983).

- U.S department of transport (1990) Reinforced soil structures FHWA-RD-89-043

- U.S department of transport (2001),Mechanically stabilized earth walls and reinforced soil slopes design and construction guidelines.FHWA-NHI-00-043

- Umar, F. 2008, Reinforced earth and Reinforced earth structures

- Weatherby, D.E., "Tiebacks", Report No. FHWA/RD-82/047, Federal Highway Administration, Washington, D.C., (1982)