REINFORCED SOIL

- The term reinforced soil refers to a soil that has been strengthened by placement of reinforcing material within the soil mass in the form of strip, bars, sheets or grids (meshes).
- When load is applied to the soil mass, these materials resist tensile stresses which develop within the soil mass in a manner which is similar to that of bar reinforcement in concrete.
- However there are a few differences in reinforcement of soil vis-à-vis reinforcement of concrete, namely

i. Reinforcement in soil interacts with the soil through friction, adhesion or passive/bearing resistance, whereas reinforcement in concrete interacts with concrete through a cementations bond,

ii. Reinforcement in soil can be metallic (e.g. steel strips) or non-metallic (e.g. geotextiles) whereas reinforcement in concrete is usually metallic (steel roads), and

iii. Reinforcement in soil is not designed to withstand compressive stresses whereas reinforcement in concrete can always do so.

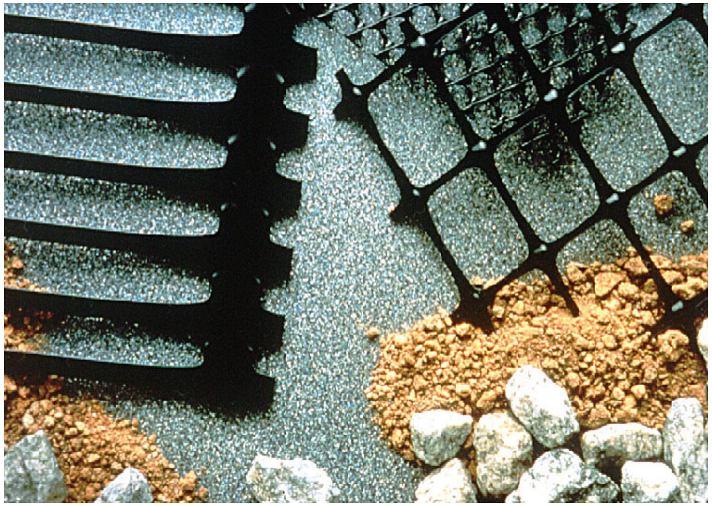
- Reinforcement elements can be installed in soils by two methods,
  - One by placing them in horizontal layers during earth filling operations at pre-specified spacing and
  - The other by inserting the reinforcement elements into an existing soil mass as per a predetermined pattern.
- Reinforcing elements that can be placed during construction are strips, sheets or grids.
  - Strips are linear elements, usually made of steels having thickness of about 5 to 15mm, width 50 to 100mm and length of several meters.
  - Sheet reinforcements are made of woven or non-woven geotextiles and having the appearance of a thick cloth

Woven or Knitted Geotextiles

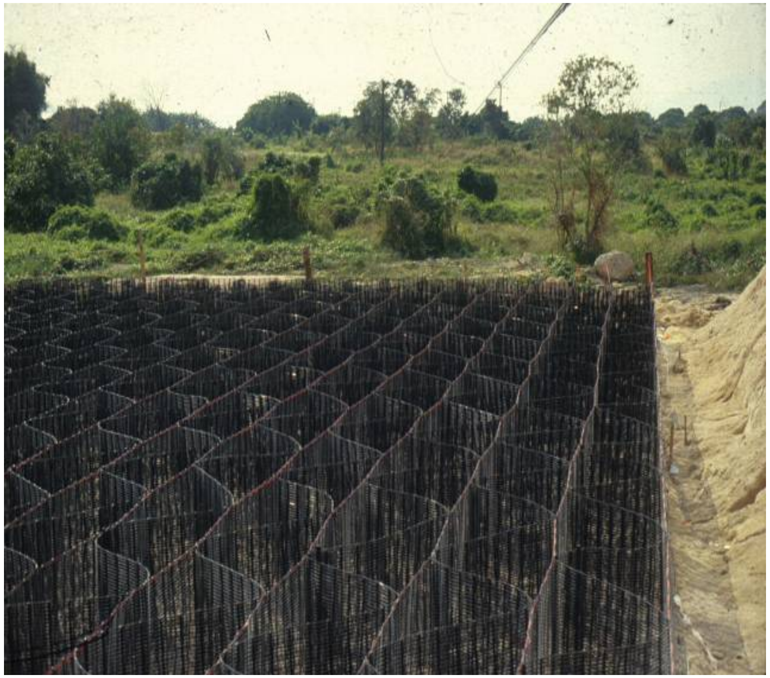
Nonwoven

Geomembranes

Geogrids



Geocell Landfill Access Road



Filling takes place from one edge, once an area is filled, delivery trucks can run on the surface of the geocell.

Lateral extensions in the geocell were less than 1% and the mattress acted as a ‘stiff’ foundation.

The Geocell mattress consists of transverse grids with a triangular honeycomb structure formed by interlacing other sheets of uniaxial geogrid into the mesh

- Grids are mesh-like reinforcing elements having apertures of 50 to200mm. They may be made of steel wires, such as welded mesh, or of polymeric material in which case they are referred to as geogrids.
- (Geotextiles and geogrids are examples of geosynthetics)

- Reinforcing elements that can be inserted into existing soil mass by drive or drill place- grout are in the shape of rigid bars, rods or pipes and are referred as soil nails.
  - Steel bars, rods or tubes used have diameters of 20 to 70mm. They are either placed on the soil or, when used as soil nails , they are driven into the soil. They can also be grouted after insertion in predrilled holes of diameter 100-150mm.

Reinforcement- soil interaction

- The effectiveness of a reinforcing element embedded in soil is governed by the following factors:

i. The capacity of the element to withstand tensile stresses, i.e., its tensile strength,

ii. The amount of extension exhibited by the element under tensile stress, and

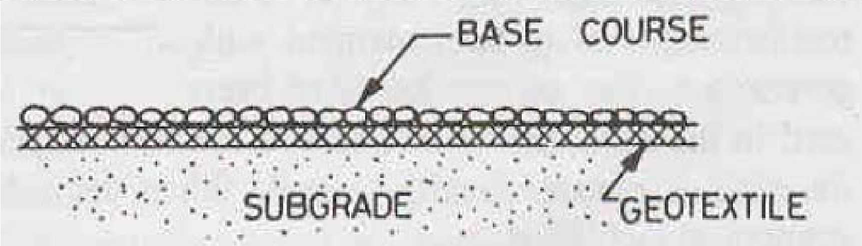
iii. The shearing resistance (adherence) between the reinforcing and the surrounding soil i.e., the maximum stress that can be resisted by the soil-reinforcement interface before the reinforcement slip away from the soil.

- When the tensile strength of an element is low, it can break or yield and become ineffective.
- If the tensile strength is adequate but its extension under stress is high, then the soil may show large movement (settlement or lateral bulging) because of inadequate stiffness of the soil-reinforcement system.
- If the reinforcement element is sufficiently strong and rigid but there is inadequate adherence between the soil and the reinforcement, then relative movement can occur, making the reinforcement ineffective.

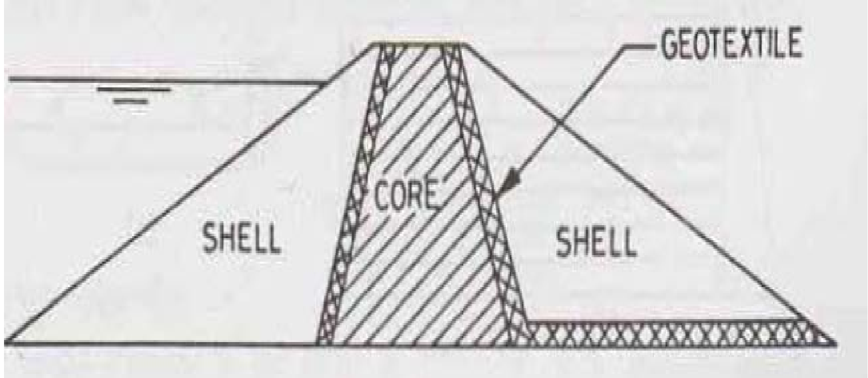
- Amongst metal strips, geogrids and geotextiles,
  - metal reinforcement exhibit the highest tensile strength and the least extensibility,
  - whereas geogrids offer the highest soil-reinforcement shearing resistance per unit surface area. Hence these two types of reinforcements are used widely.

- Geotextile are adopted as reinforcement when the requirement of low extensibility are not very high and when these are also required to perform other functions simultaneously, such as facilitate drainage, separation, or filtration.

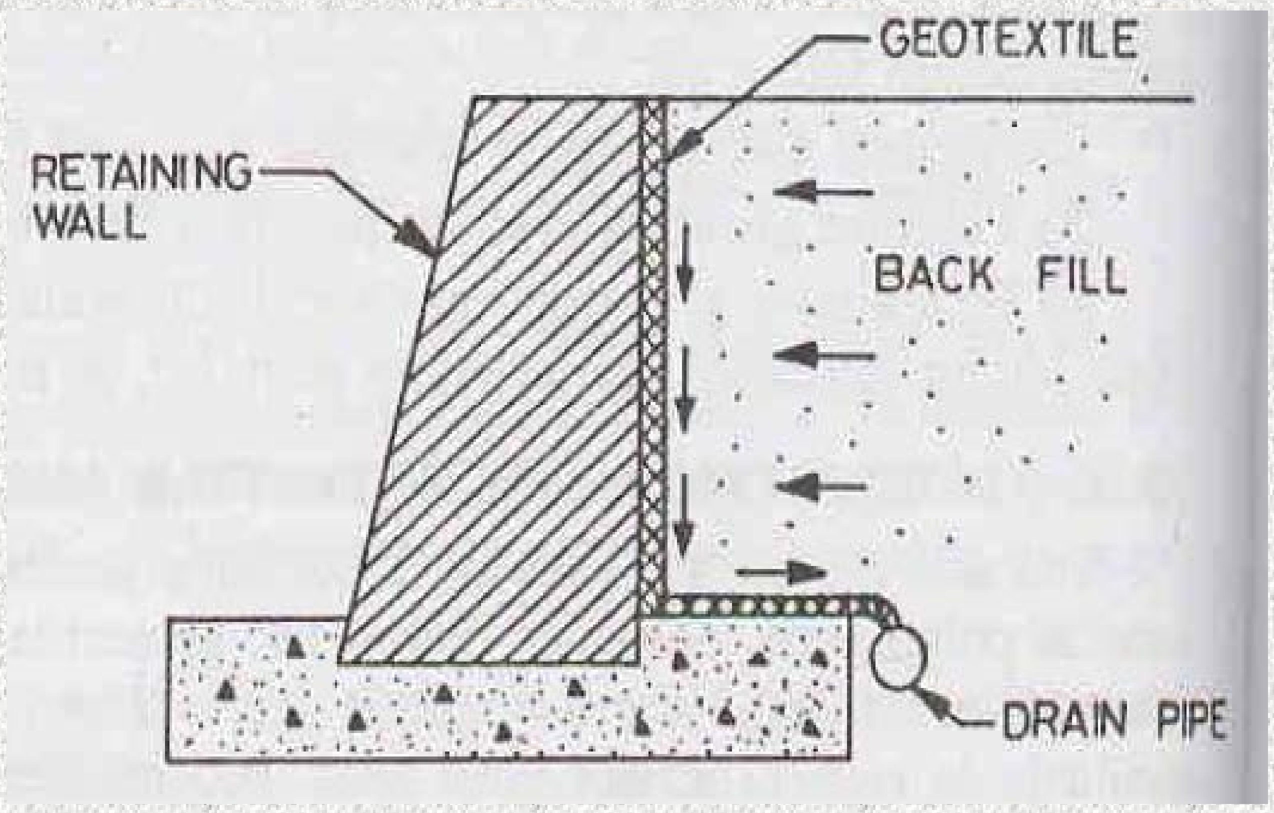
Geotextiles as separators: Geotextiles are commonly used as separators between two layers of soils having a large difference in particle sizes to prevent migration of small-size particles into the voids of large-size particles



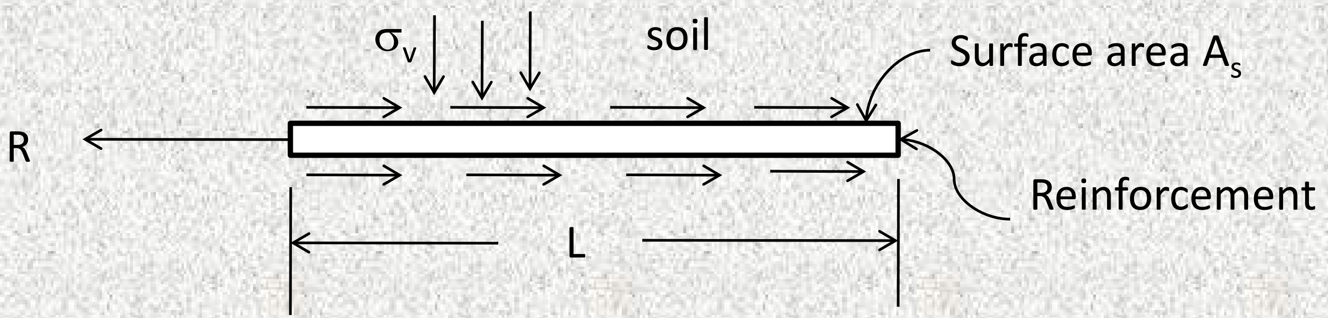
Geotextile as Filter: It is the usual practice to provide a properly graded filter to prevent the movement of soil particles due to seepage forces.



- **Geotextile as Drain**: A drain is used to convey water safely from one place to the other. As the geotextiles are pervious, they themselves function as a drain.



- The mechanism by which shearing resistance is developed at the interface between soil and strips or bars or sheets is similar to that by which skin friction develops between soil and pile surface by adhesion and friction.



Strips, Bars, Sheets

- Pull out force , $R = (C_a + \sigma_v \tan\delta)A_s$
- Where C_a= adhesion $=\alpha C$, (usually estimated as a fraction of the cohesion intercept, C.

δ friction angle between soil and reinforcement material ($\tan\delta$ usually varies between $1/2\tan\phi$ to $\tan\phi$)

σ_v= overburden stress

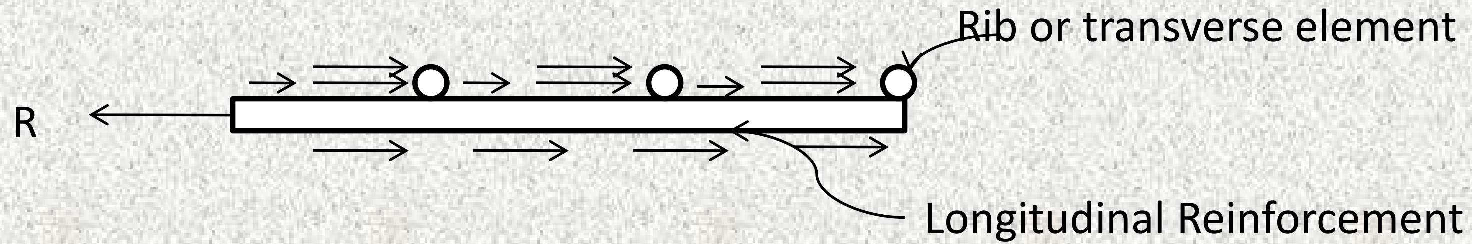
As = surface area = 2bL for strips of width b

= πdL for bars of diameter d

= 2L x 1 for sheets

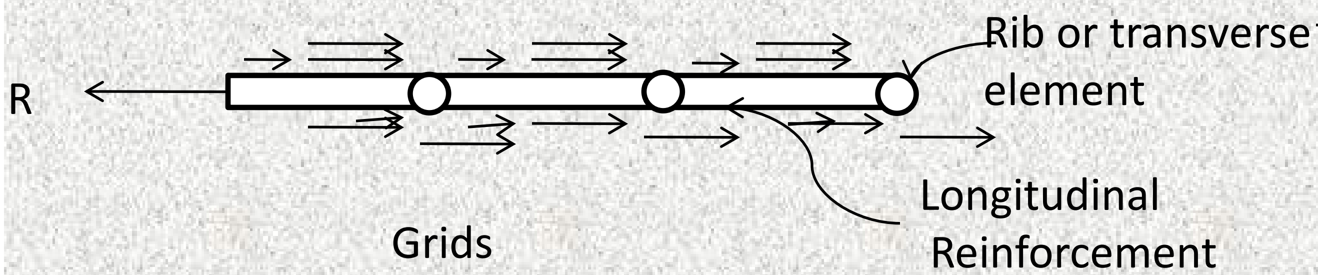
L = length of reinforcement

- For the case of strips with ribs or transverse elements as shown in Figure below buried in dense sand, δ values can be higher than ϕ by as much as 100 percent.

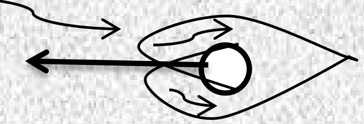


Ribbed strips

- The mechanism by which grids or geogrids develop their shear resistance is different from that of strips, bars and sheets.
- When the aperture of the mesh or geogrid is very small, it is possible that the soil may become clogged in the aperture and the mesh or grid will then behave like a sheet.
- However, when the aperture is large, as is usually the case, the transverse elements of grid develop passive resistance or bearing resistance offered by the soil which fills the aperture.
- The pull out resistance is thus postulated to be a sum of the friction-adhesion resistance along the longitudinal elements that are parallel to the direction of pull and the bearing capacity type of resistance along the transverse elements that are perpendicular to the direction of pull



Grids



Bearing mechanism

$$R = C_a + \sigma_v \tan\delta)A_s + (cN_c + qN_q + 1/2\ \gamma\ d\ N_\gamma)*A_b *n$$

where A_b = bearing area of each transverse element

n = number of transverse element

d= diameter (or thickness) of the transverse element

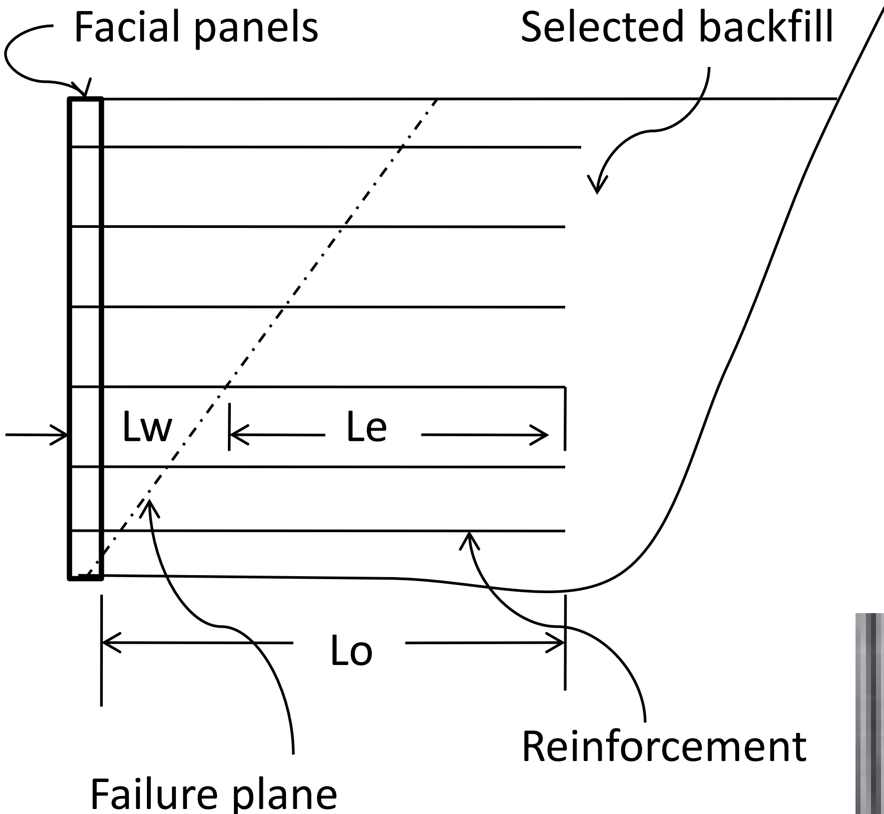
- A_b is taken as the projected area bearing (d*1)where 1 is the unit width of the reinforcement.
- The N_γ term is neglected due to the very small value of ‘d’

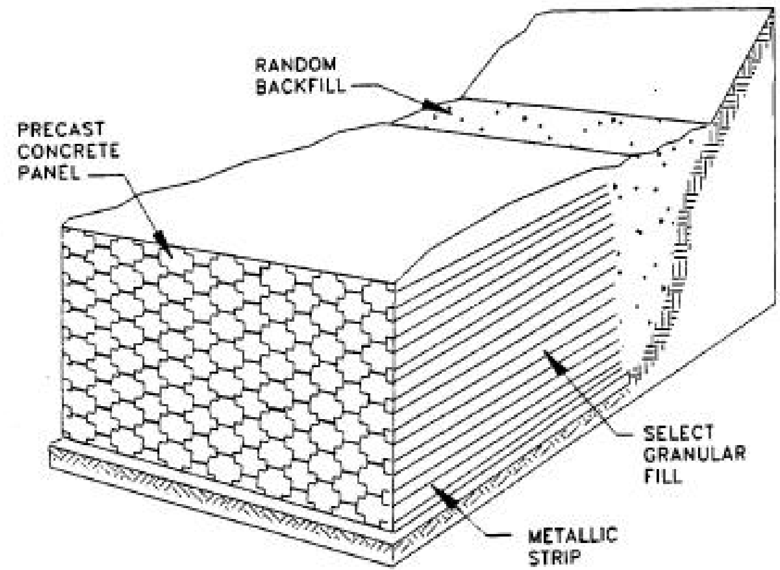
Applications of reinforced soils

- soil reinforcements are used in construction of
  - earth structures with steep or vertical sides
  - bridge abutments
  - highway embankments in hilly regions
  - steep or vertical cuts in open excavations
  - stabilization of unstable slopes
  - unpaved roads on soft soils and
  - embankments on soft soil

Reinforced soil structures with vertical faces

- A structure of reinforced soil with vertical faces often called reinforced earth wall.
- Reinforced soil retaining walls consist of three main elements:
  - soil,
  - reinforcement and
  - Facing
- The soil used as a backfill in such construction is granular soil with less than 15 percent fines to enable development of large friction between the reinforcement and the soil.
- The most often used reinforcement is steel strips since they have large tensile strength as well as low extensibility.
- The facing usually comprises of pre-fabricated concrete or steel panels joined together by an interlocking arrangements.





Reinforced Earth Wall

- Construction takes place from bottom upwards and the reinforcement is placed sequentially as layers of soils are compacted, one after the other.
- Care has to be taken during construction to ensure that the reinforcement is not damaged and that facing panels are neither displaced nor tilted by the compacting equipment.
- The analysis and design of a reinforced earth wall involves two steps

i. A check of the external stability
ii. A check of the internal stability

- External stability assumes that the reinforced earth wall is internally stable i.e., the reinforced zone behaves like a cemented block of soil.

- The stability of the block is checked externally against
    - sliding,
    - overturning,
    - bearing capacity failure and
    - deep-seated slip failure
- The procedure is the same as in the case of gravity retaining walls with the difference that the reinforced soil block replaces the gravity wall.

- Internal stability analysis requires a check on
    i. Whether the reinforcement will rupture at any location
    ii. Whether the reinforcement will slip away from the soil.
- For this purpose it is necessary to utilize an earth pressure theory
    - to determine the lateral earth pressure that will develop and
    - Identify the likely plane of failure

- Once, the failure plane is identified, the internal stability is analyzed as follows:

i. Assume likely magnitudes for the vertical and horizontal spacings of the reinforced elements. (For sheets, grids and geo-grids, horizontal spacing is taken as unity)

ii. Determine the lateral earth pressure and the horizontal force, F, to be resisted by each reinforcing element at different depth.

- F at depth, d_i, is equal to the lateral earth pressure acting at that depth multiplied by the area over which it acts

$$F = \sigma_h H_i B$$

- where $\sigma_h = Ka\, \sigma_v$, $\sigma_v = \gamma_i d_i$

  H_i = vertical spacing of the reinforcement

  B = horizontal spacing of the reinforcement

- This horizontal force is equal to the tension developed in the reinforcement , T_d, that is $T_d = F$.

iii. Check that rupture does not occur by ensuring that the safety factor against rupture is greater than 1.5

$$SF = \frac{T_y}{T_d} = \frac{\sigma_y A_s}{T_d} \geq 1.5$$

where T_y = yield tensile force in the reinforcement

σ_y = yield tensile strength in the reinforcement

A_s = cross-sectional area of reinforcement

iv. Check that slippage does not occur by ensuring that the length of reinforcement in the stable soil mass , L_e, is sufficient to resist the tension T_d with a safety factor of greater than 2.0

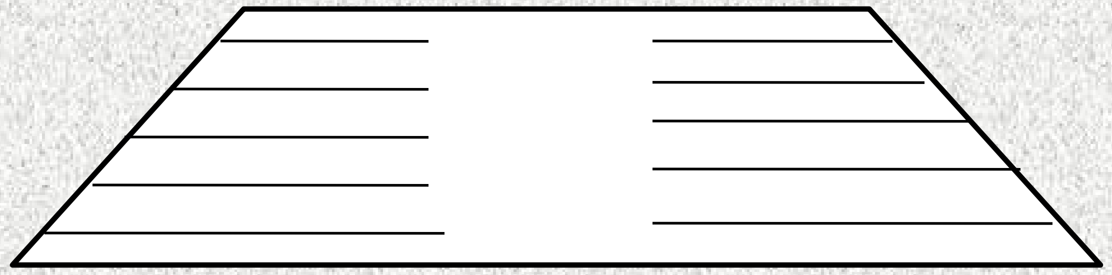
$$SF = \frac{R}{T_d} \geq 2$$

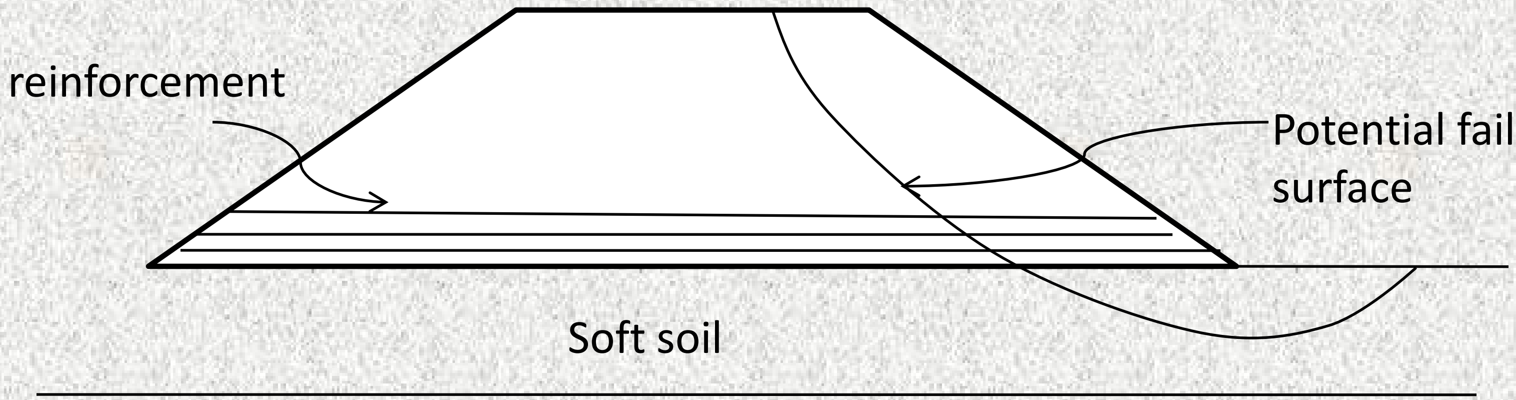
where R = pullout force that is developed along the reinforcement-soil interface for length L_e.

- The overall length $L_o = L_w + L_e$ for each reinforcement .
- Usually a constant L_o is adopted for all elements of the reinforced soil zone equal to the maximum value obtained amongst the strips.

Reinforced soil embankments

- Reinforcements is employed in embankments so as to be able to use steeper slopes and reduces the quantity of earthwork and to increase the stability of embankments resting on soft soil





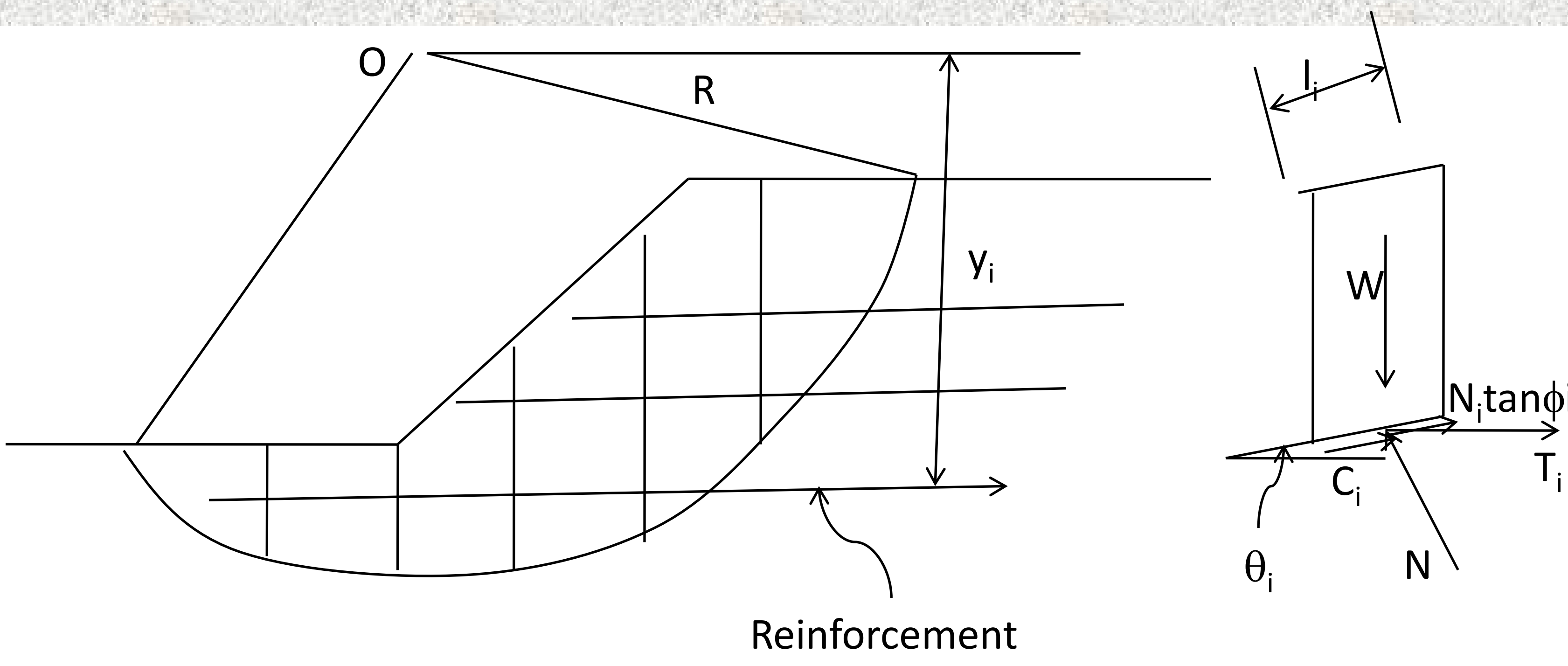
- For steep slopes when the angle with the horizontal exceeds 45^0, special measures have to be adopted for protection of the slope surface against erosion. These may be take the form of placing concrete panels, blocks and gabions on the surface of the slope.
- Reinforced soil slopes that are steeper than 70^0 to the horizontal are considered to be reinforced earth walls and designed as such.
- The stability of a reinforced earth slope is analyzed in the same manner as that for a soil slope with modification that a horizontal force T_i, corresponding to the tension in each reinforcement, is introduced in the analysis.
- The safety factor, is evaluated as the sum of the resting moment divided by the sum of the driving moment as follows:
- $$SF = \frac{(\sum_{i=1}^{n} c_i l_i + W_i \cos\theta_i \tan\phi_i)R + \sum T_i y_i)}{\sum_{i=1}^{n}(W_i \sin\theta_i)R}$$

- For the undrained case, with ϕ_i=0 and c_i = Su the above equation reduces to

$$SF = \frac{S_u(L_{arc})R + \sum_{i=1}^{n} T_i y_i}{WX}$$

- where L_{arc} = the length of the curved failure surface, and

  X= the horizontal distance from the center of rotation to the centroid of the unstable mass, with weight W.



Open excavation using soil nails

- Vertical or steeply inclined cuts can be made for open excavations using rigid soil nails as reinforcement. Such cuts are also referred to as nailed soil walls.
- Nailed soil walls are constructed from top to bottom, in steps, as excavation proceeds incrementally.
- Soil nails may be driven or drilled-placed-grouted .
- The facing of such walls is usually in the form of a wire-mesh reinforced shotcrete panels, although metal plates and other types of panels have also been used.
- Soil nails are installed at an inclination of 20 to 25degrees to the horizontal near the ground surface so as to avoid intercepting underground utilities and the inclination reduced to 10 to 15 degrees as we go deeper into the cut.

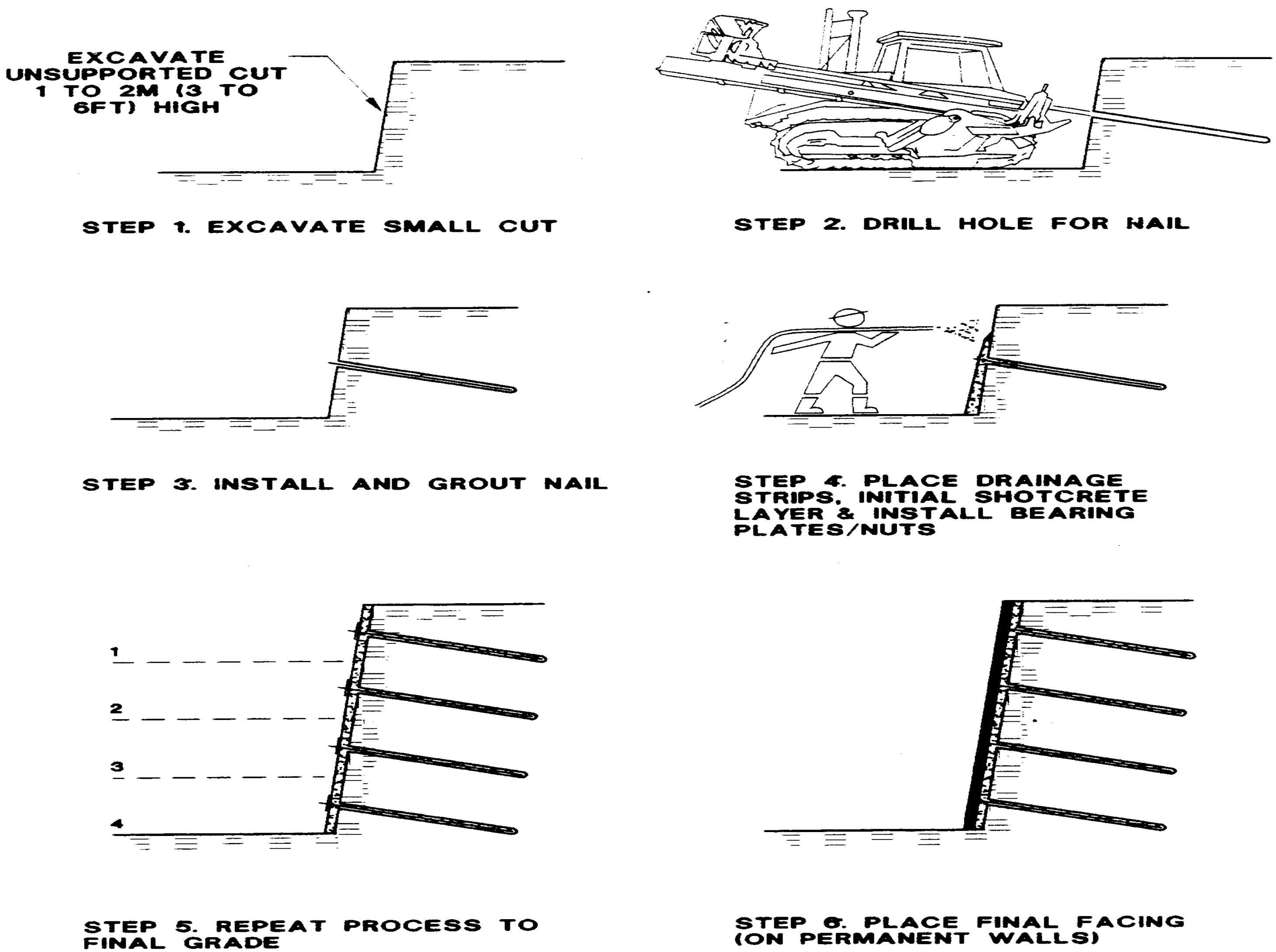


Figure 1. Typical Nail Wall Construction Sequence.

Reinforcement of soils beneath of unpaved roads

- When the surface soil, known as subgrade, consist of soft soil, unpaved roads are made of stone aggregate placed directly on the soil.
- The thickness of stone aggregate can be reduced by placing a geotextile or a geogrid reinforcement on the interface between the subgrade soil and the stone aggregate.
- The influence of the reinforcement is to improve the performance of the unpaved road by a mix of three mechanisms:

i. By increasing the subgrade strength,

ii. By increasing the lateral spread of the stress which is transferred through the aggregate thereby decreasing its intensity, and

iii. By decreasing the depth of rutting due to its tensioned-membrane effect.

Geotextile

Geotextile

Reinforcement of soils beneath foundations

- Soils having low bearing capacity can be reinforced beneath shallow footing to increase the bearing capacity.
- The reinforcement has to be designed to withstand rupture and slippage.
- Placement of reinforcement beneath footings requires excavation of the soil and backfilling in layers with careful placement of reinforcement and proper compaction of soil.
- Since the excavation of soil is necessary in all such cases, the economics of backfilling with reinforced soil has to be compared with that of backfilling with a better soil or with stabilized soil.
- One reinforcement system which has been observed to be useful for embankment on soft soil is the geocell matter system.
- Such mattresses, which can typically be 1m high, improve the performance of the foundation soil by increasing the bearing capacity and by reducing settlements and lateral extrusion of the foundation soil.
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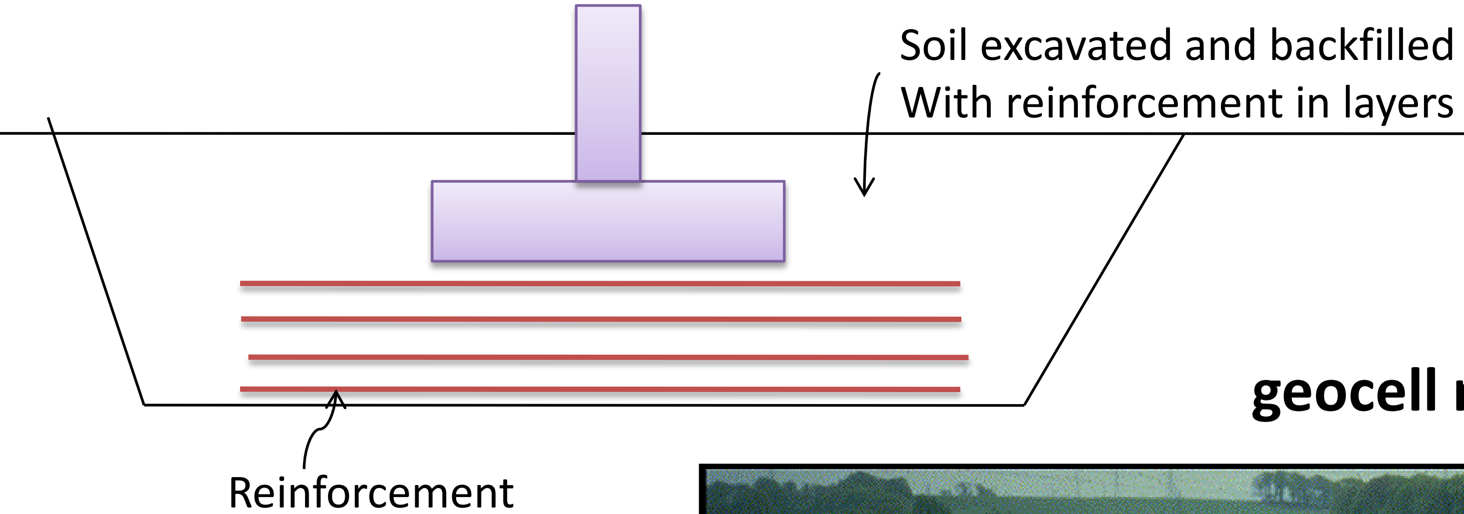

geocell matter system.