Lecture 34

Design of embankments on soft soil using geosynthetics

Prof. G L Sivakumar Babu
Department of Civil Engineering
Indian Institute of Science
Bangalore 560012
Email: gls@civil.iisc.ernet.in

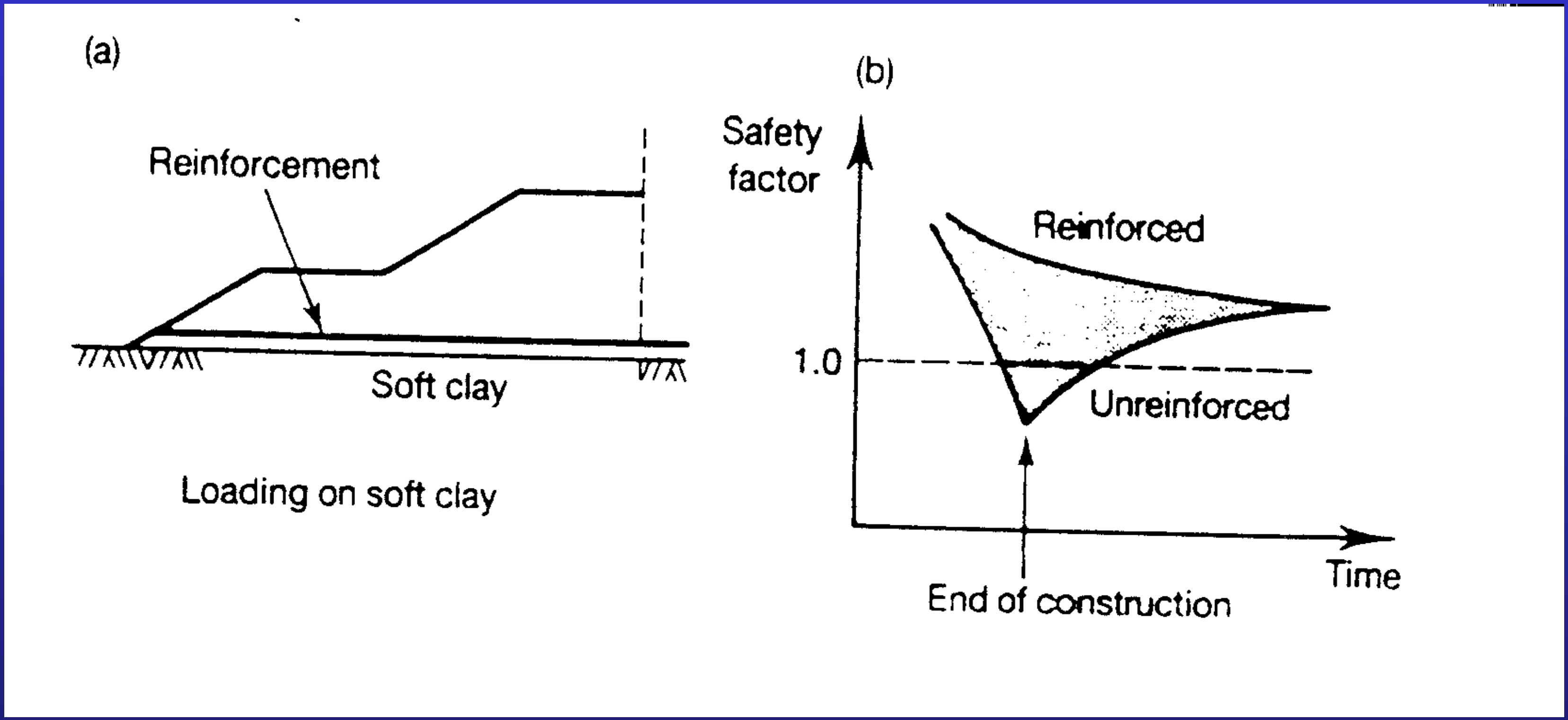
- INTRODUCTION
- MODES OF FAILURE
- STABILITY CONDITION
- DESIGN EXAMPLE

Introduction

Soft soils are characterized by poor shear strength, high compressibility and low permeability.

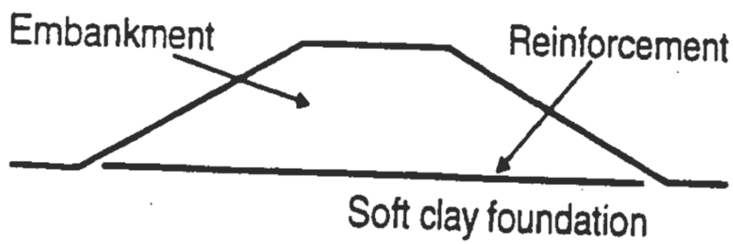
The reinforcement /confinement effect from geotextiles/ geogrids/ geocells is useful. It

- Improves embankment stability
- Permits controlled construction over soft soils
- Ensures more uniform settlement of embankment
- Results in cost effective solutions

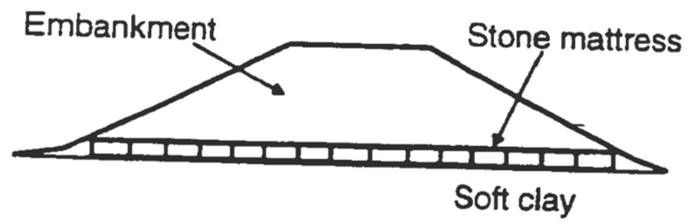


Effect of reinforcement on embankment stability

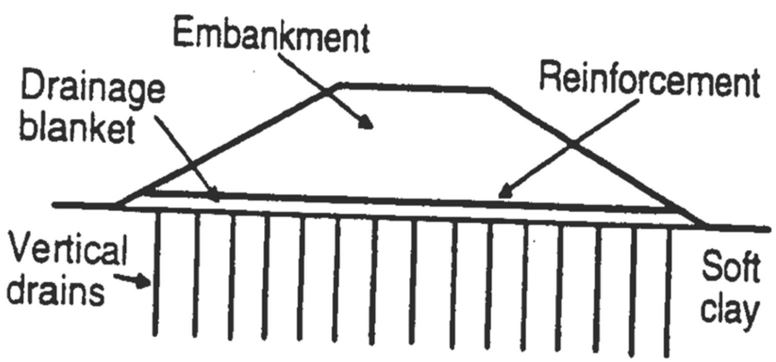
Different types of applications



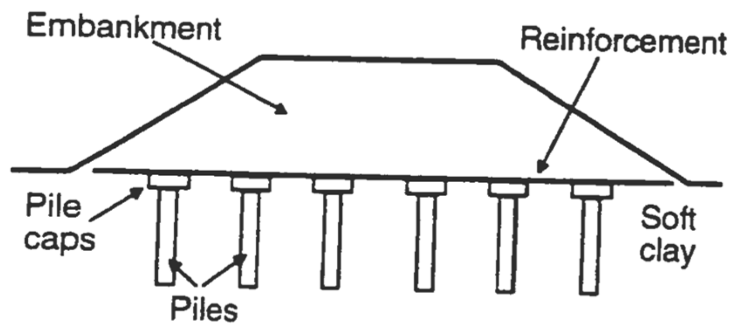
a) Basal reinforcement beneath embankment



c) Basal mattress reinforcement



b) Basal reinforcement with vertical drains



Piled embankment with basal reinforcement

Example of Basal Reinforcement Using Geogrids

- High tensile strength is required to maintain stability and prevent failure
- As the foundation shear stress increases the required geosynthetic tensile force reduces

Analysis and Design

- **Established geotechnical and stability methods used**
- **Three main failure mechanisms considered**
  - Rotational Stability
  - Lateral Sliding
  - Bearing Capacity

Modes of Failure

Internal stability

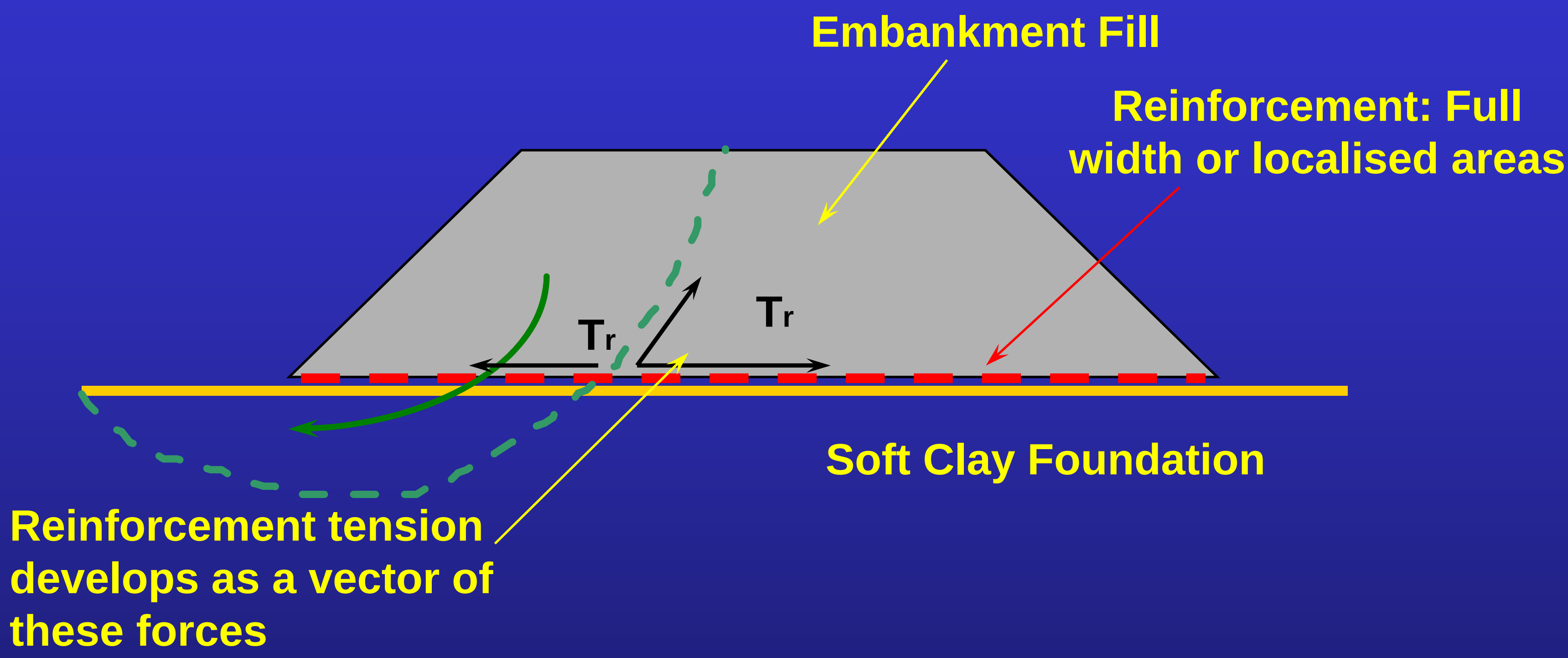
- Direct sliding at the soil-reinforcement interface

Overall stability

- Slippage across the foundation surface

- Stability in the foundation

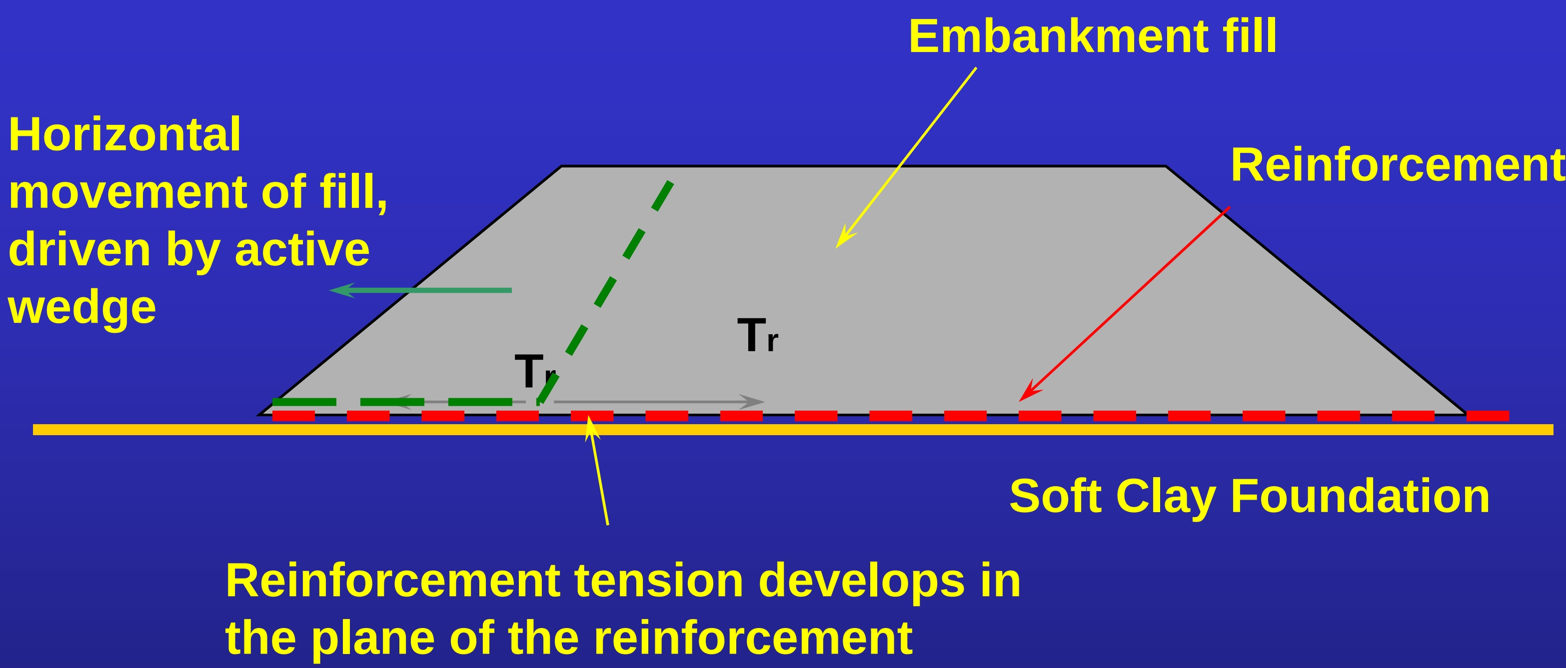
Rotational Stability



Common form of analysis:

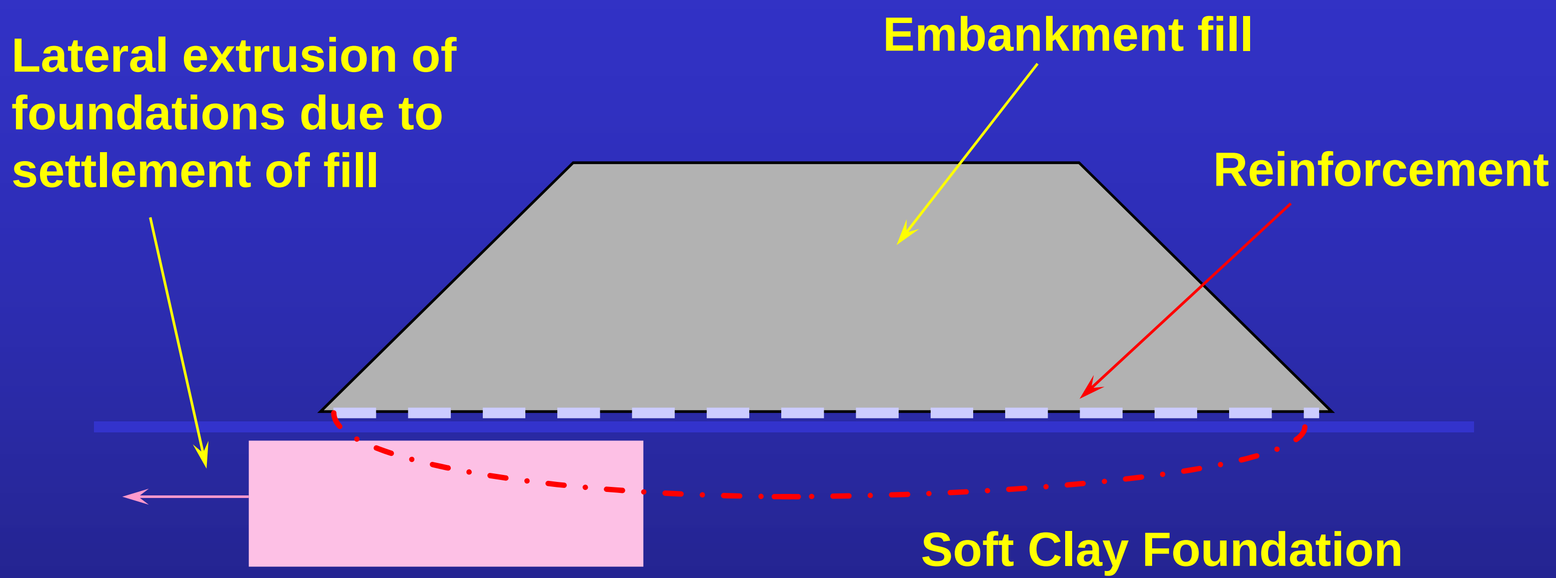
- Simplified Bishop Method for circular surfaces
- Failure can be deep seated or shallow

Lateral Sliding



- Resistance to lateral sliding determined from active driving force
- Geosynthetics/soil interface should be obtained from testing

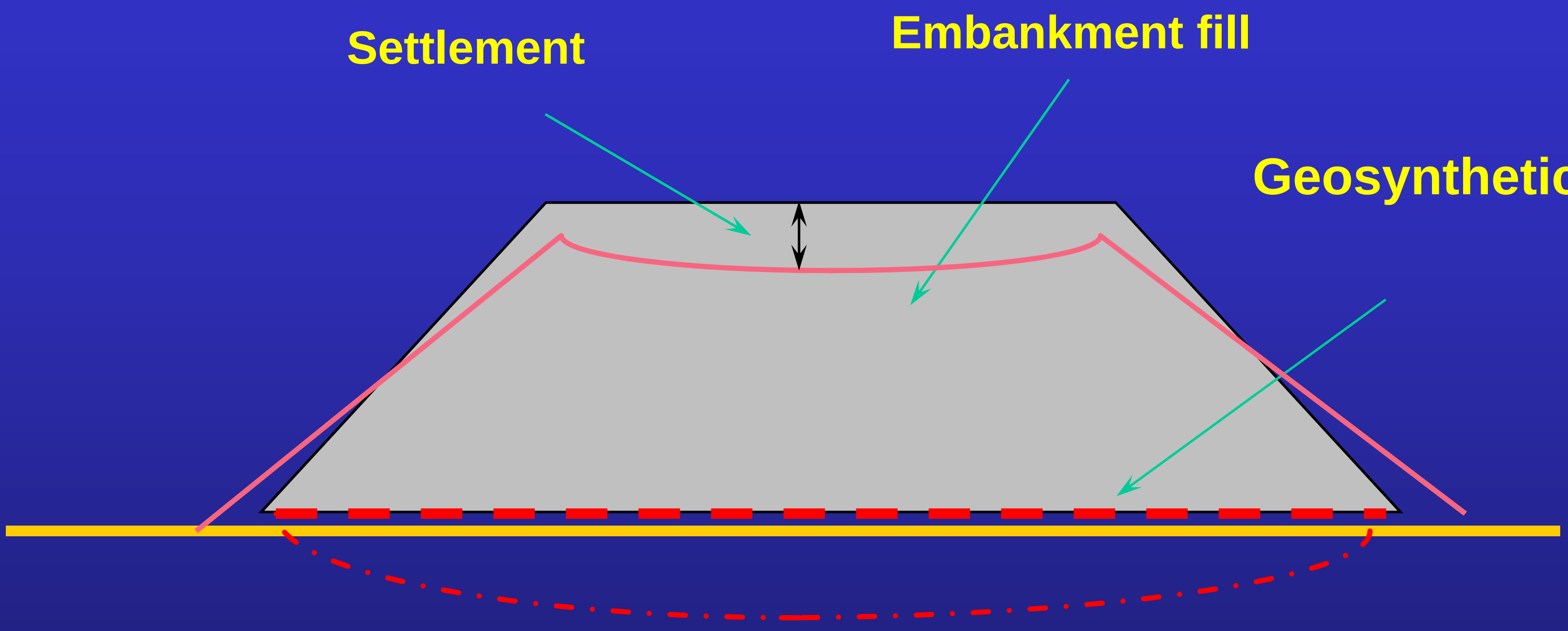
Foundation Extrusion



The solution to this mode of failure is to reduce the settlement by making the base stiffer (Geocell mattress)

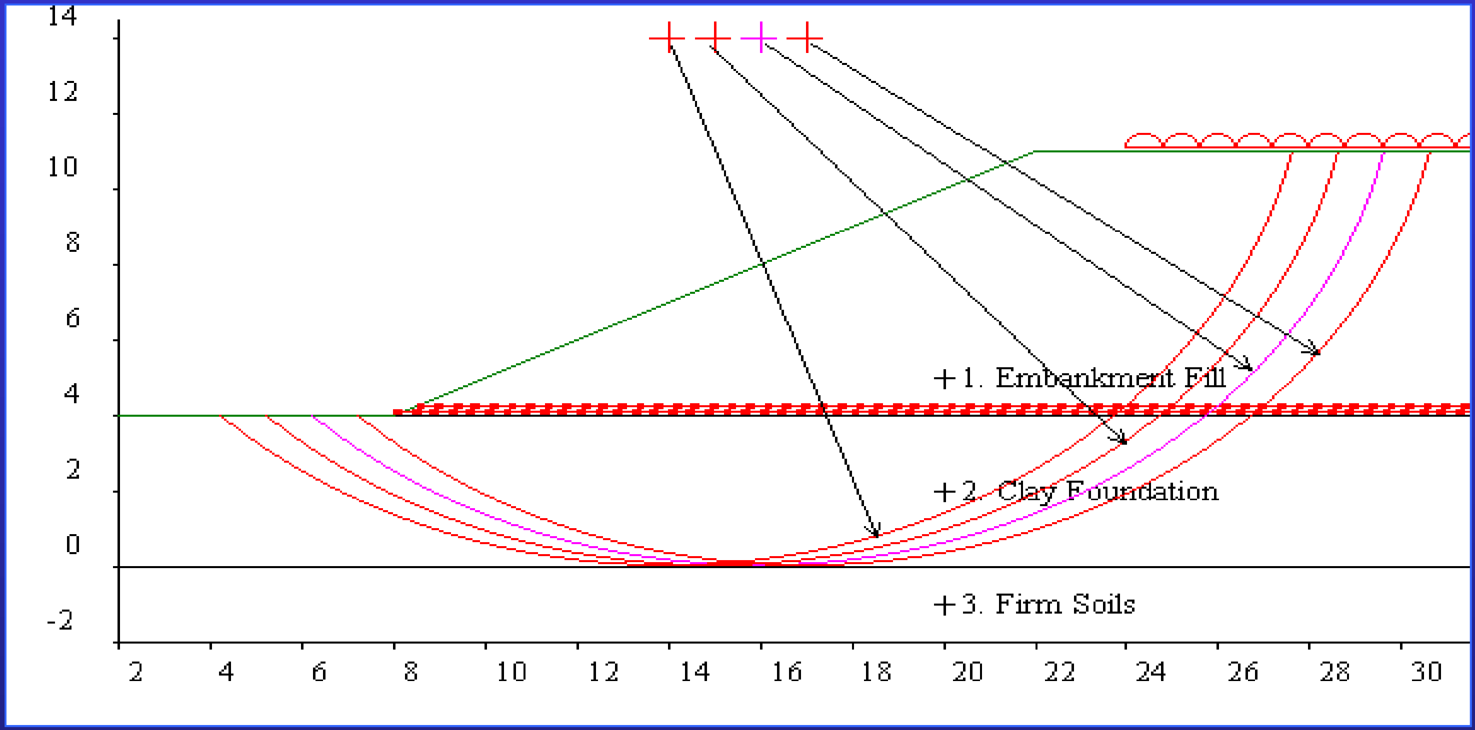
- **If soft soil thickness > embankment base width, a bearing capacity analysis will be required**
- **If soft soil layer thickness < than the embankment base foundation width extrusion occurs at the toe.**

Serviceability Limit States



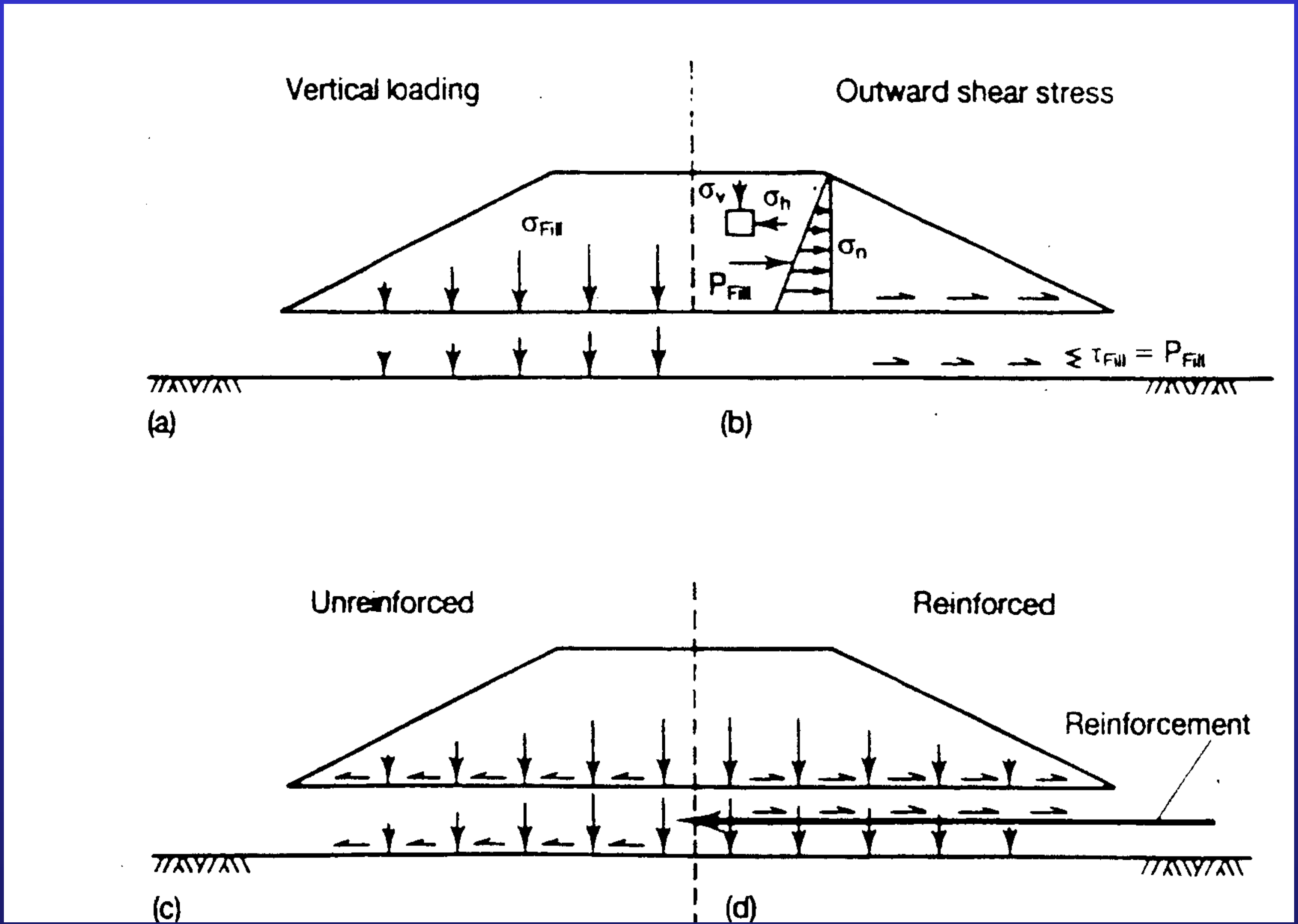
- Both ultimate limit state and serviceability to be considered

Failure Surface



- Stiff Reinforcement may alter the failure surface shape
- Computer programs can consider non-circular failure surfaces

- Two idealised distributions are possible, depending on the nature of soil profile.
  - 1) uniform variation of undrained shear strength with depth
    - Soft soil is of limited depth
  - 2) increase of shear strength with depth
    - Soft soil extends to larger depths compared to height of embankment



Forces acting in embankment

- Two types of loads need to be considered for equilibrium

  - Vertical loading

  - Outward directed lateral force P_{fill}

- To prevent the lateral spreading of the embankment, horizontal stresses within the fill must be balanced by shear reactions at the base.

  - In an unreinforced embankment, the lateral thrust P_{fill} in transferred to the foundation,

  - whereas if reinforcement is present, some of the thrust is carried by the reinforcement itself

•Internal Stability

•Inclusion of reinforcement in soil can allow preferential direct sliding to occur along the surface of the reinforcement layer. Slippage results if the available resistance at the interface is not sufficient to support the lateral thrust from the fill.

•Direct sliding resistance at interface = $\alpha_{ds} \tan\phi_d \times \gamma \, n \, H^2/2$

•Active thrust from the fill (P_{fill}) = $k_{ad} \left(\gamma H^2/2 + q H \right)$

•From equilibrium conditions,

$$n > \frac{K_{ad}}{\alpha_{ds} \tan \varphi_d} \left(1 + \frac{2q}{\gamma H} \right)$$

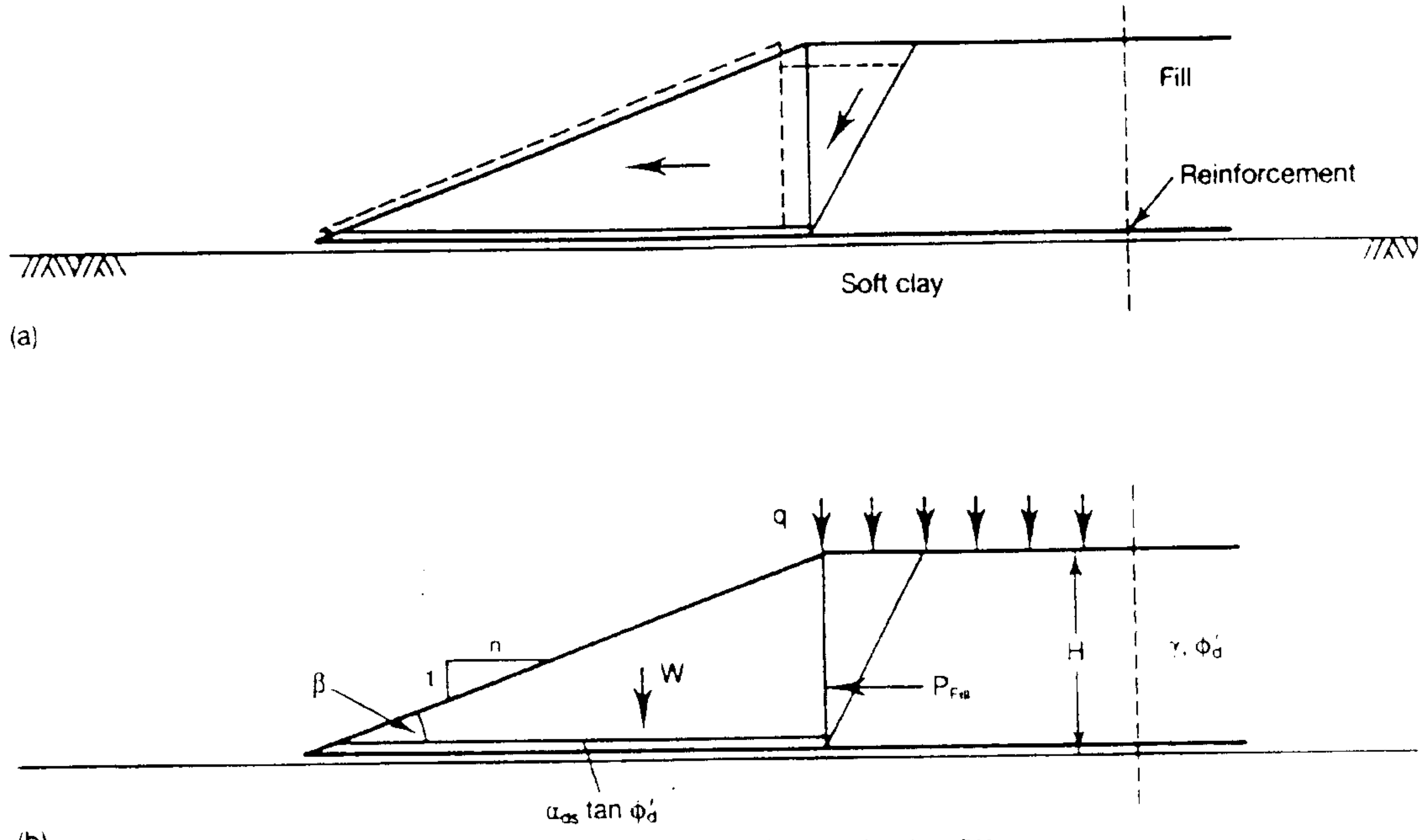


Fig.3. Internal stability: direct sliding failure in the fill

•Direct sliding failure in the fill
•(internal stability)

•Overall Stability

•Needs to be considered in terms of

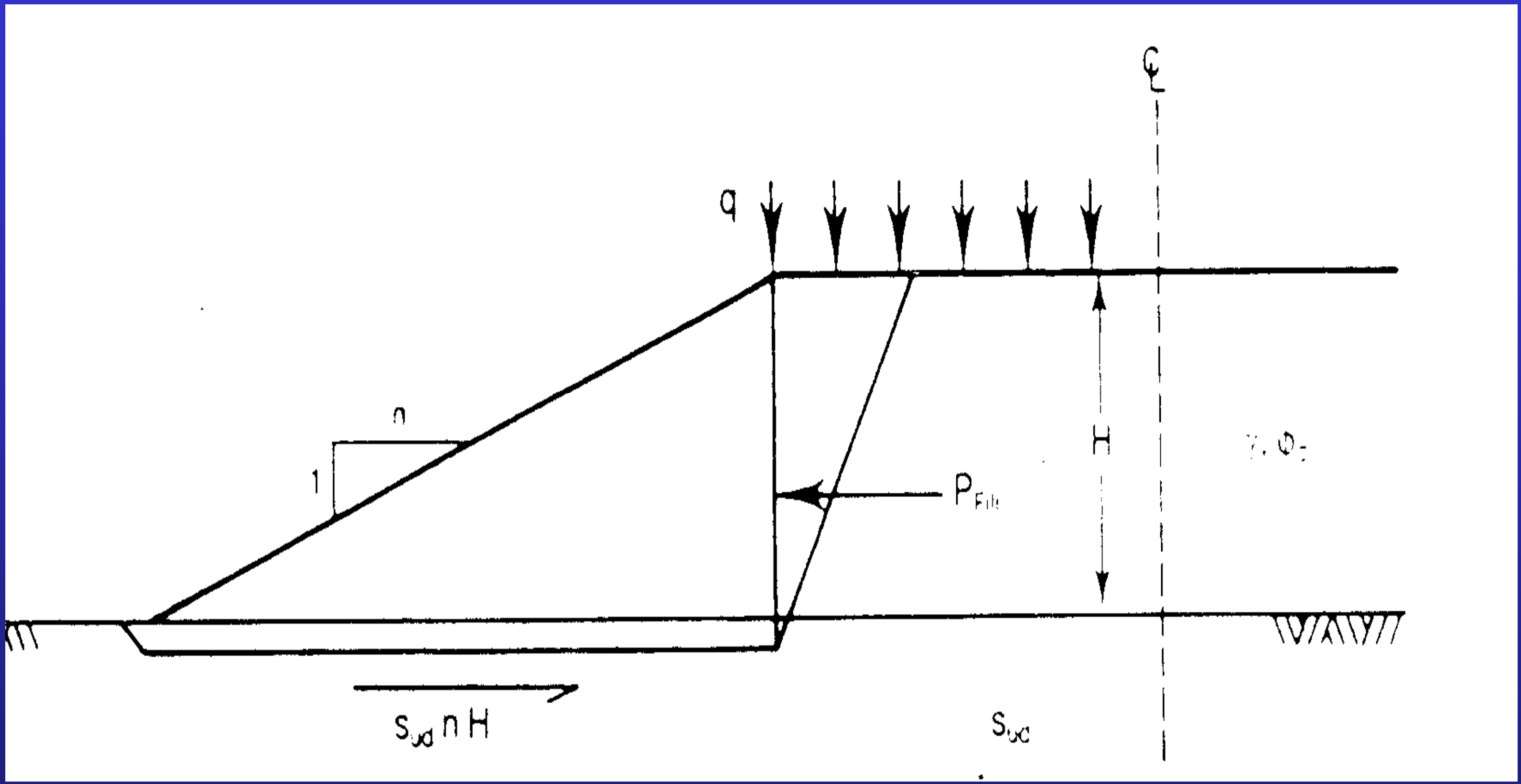
- •Slippage across the foundation surface

- •Stability in the foundation

•Slippage sliding or slippage could occur across the surface of soft clay, in an unreinforced zone, close to reinforcement location or if there is breaking of reinforcement member.

•Hence, for equilibrium conditions,

$$n > \frac{K_{ad}}{S_{ud}\,H}\,\gamma H\left(1 + \frac{2q}{\gamma H}\right)$$



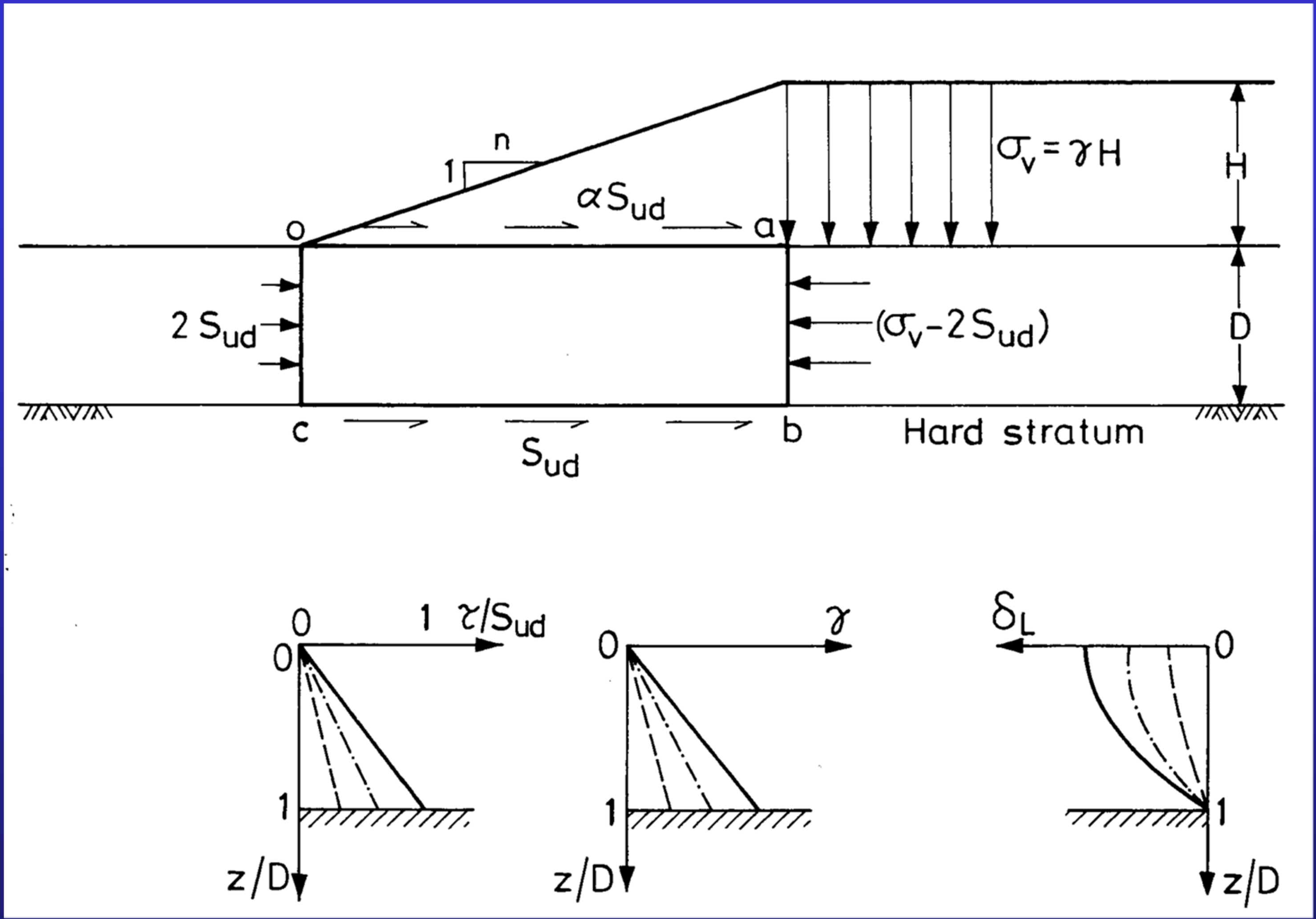
•**Slippage across the foundation**

•Stability in the foundation

•Vertical embankment loading causes an increase in the vertical stress in the foundation soil and a corresponding increase in the horizontal stress. The lateral stress developed eventually causes the foundation soil to get displaced laterally beneath the embankment side slope.

•Consider a zone of soft clay beneath the embankment side slope.

•Vertical stress $\sigma_v = \gamma H$ acts uniformly and that the principal axis of stress on either side of the block *oabc* are horizontal and vertical. The soil block *oabc* experiences a net horizontal stress (σ_v-2S_{ud}) on *ab* and 2S_{ud} on *oc*.



Stability of the foundation

- For the case, where there are no outward or inward shear stresses acting on the tip of soil block (*oa*) $\alpha = 0$.

- The lateral sliding of the soil block is resisted by the available shear strength on the horizontal plane,
- ($n\ S_{ud} \times H$). Hence,

- $$nH.\ S_{ud} = (\sigma_v - 2\ S_{ud})\ D - 2\ S_{ud}\ \ D\ \sigma_v - 4\ S_{ud}\ D$$

$$n = \frac{\gamma D}{S_{ud}} - \frac{4D}{H} \quad \text{or} \quad H = \frac{4D}{\dfrac{\gamma D}{S_{ud}} - n}$$

•Deformation in the foundation

•The load Induces lateral deformation in the foundation soil which is also dependent on the extensibility of the reinforcement

- Max lateral displacement = $\delta n = \gamma_{max}$ D / 2
- = τ_{max} D / 2G

- where γ_{max} = max shear strain and
- τ_{max} = max shear stress
- (S_u, Shear strength of the soil)

•Influence of reinforcement extensibility

•Mobilization of shear stress at the interface is an important factor in the efficiency of the reinforced embankments. The shear stress could mobilize inward, outward or become nil, depending on the extensibility of the reinforcement, shear strength of the soil and the loading conditions.

•Three possibilities are denoted as follows;

- (b) (a) = – 1, full outward shear stress
- = 0, zero shear stress
- (c) = 1, full inward shear stress

•Relationships

•The following relationships hold good for the embankment on foundation of uniform undrained shear strength, S_{ud} and limited depth D.

•1. Embankment height

$$H = \frac{4D}{\left\{ \gamma \, D/S_{ud} - (1+\alpha)\, n \right\}}$$

•2. Factor of safety in a reinforced embankment

$$FS = \frac{S_u}{\gamma \, H}\left(4 + (1+\alpha)\frac{nH}{D}\right)$$

- 3. **Lateral deflection at the ground surface**

$$\delta_h = \frac{S_{ud} D}{2G}(1-\alpha)$$

- 4. **Maximum reinforcement to provide the stability is**

$$P_R = \gamma H^2 \left(\frac{\alpha n D}{4D + (1+\alpha) nH} + \frac{K_{ad}}{2} \right)$$

- where

$$K_{ad} = \frac{1 - \sin \varphi_d}{1 + \sin \varphi_d}$$

- 5. **In the case of unreinforced embankment,**

$$FS = \frac{S_u}{\gamma H} \left(\frac{8D + 2nH}{2D + K_{ad} H} \right)$$

Example Problem

An embankment of 200m length and 4m height road embankment with a crest width of 15m needs to be constructed over soft clay of 4m depth (S_u=15kN/m^2, constant with depth). The embankment is constructed rapidly in one stage. End of construction stability needs to be ensured.

Granular fill in the nearly area (γ_d = 20kN/m^3) is used (ϕ_{cv} = 33^0). Targeted FS = 1.3

•Step 1:

$$FS = \frac{S_u}{\gamma H}\left\{\left[4 + (1+\alpha)\right]\frac{nH}{D}\right\}$$

•Use H= 4.5 m to take of settlement in calculations, though the design height is 4 m

$$1.3 = \frac{15}{20 \times 4.5}\left\{\left[4 + (1+\alpha)\right]\frac{n \times 4.5}{4}\right\}$$

•$\Rightarrow$ 7.8 = 4 + (1+α) 1.125n $\Rightarrow$ 3.38 = (1+α) n

•For α = 0, n = 3.38

• α = 0.5, n = 2.25

• α = 1.0, n = 1.69

•Step 2: •Unreinforced case FS

$$FS = \frac{15}{20 \times 4.5}\left\{\frac{8 \times 4 + 2n \times 4.5}{2 \times 4 + 0.294 \times 4.5}\right\}$$

•For	n	FS	
•	1.69	0.84	
•	2.25	0.94	< <u>1.3</u>
•	3.38	1.12	

•Step 3: •The reinforcement force is given by

$$P_R = \gamma H^2 \left(\frac{\alpha n D}{4D + (1+\alpha) n H} + \frac{K_{ad}}{2} \right)$$

- Substitution of quantities leads to
- = 117.97 kN/m for α = 0.5
- = 59.54 kN/m for α = 0.0

•Required stiffness = J_{req} = $P_{req}/\in_{all}$, $\in_{all}$ = 10%

•J_{req} for α = 0.5 J = 1180 kN/m

• α = 0.0 J = 595 kN/m

•Step 4:

•In order to mobilise design shearing resistance S_{ud}, some shearing strain γ (or γ_{max}) is nearly which is of the order of 10% for soft clay.

•The shear modulus in given by G = 1/γ and using

•We get,

$$\delta_h = \frac{S_{ud} D}{2G}(1-\alpha)$$

•δ_h = 200mm for α = 0.0

•δ_h = 100mm for α = 0.5

•Shows that the higher reinforcement will reduce the lateral displacement

•Geosynthetics are available with index strength in the range of 200 to 400 kN/m

•Step 5 :

•The index strength is to be corrected for loading period (equal to 90% of consolidation) and for temperature corresponding to ground conditions (t = 20^0C) under these conditions, manufacturers data shows that at the end of 90% consolidation (time = 2.5 years) the reference strength is 60% of design strength.

An allowance for compaction of damage is given in the form of f_d = 1.2, besides an allowance of f_{env} = 1.1 for environmental degradation

Hence for index strength of P_{index} = 200 kN/m

Reference strength	**0.6 x 200**	**= 120**
Field strength	**120/1.2 x 1.1**	**= 91**
Design strength	**91/1.3**	**= 70**
Secant Stiffness	**70/0.1**	**= 700 kN/m**

10% in the strain for rupture of the reinforcement

The required strength is 1180 kN/m

for α = 0.5 and 595 kN/m for α = 0.

Hence the considered materials will serve the function of reinforcement

Concluding Remarks

The use of geosynthetics in improving the stability and reduce the settlements in the case of embankments on soft soils, in the construction of loading platforms, preventing the influence of voids in the foundation medium have been beneficial in the ground improvement.

Thank you