Lecture 30

SLOPE STABILITY IMPROVEMENT

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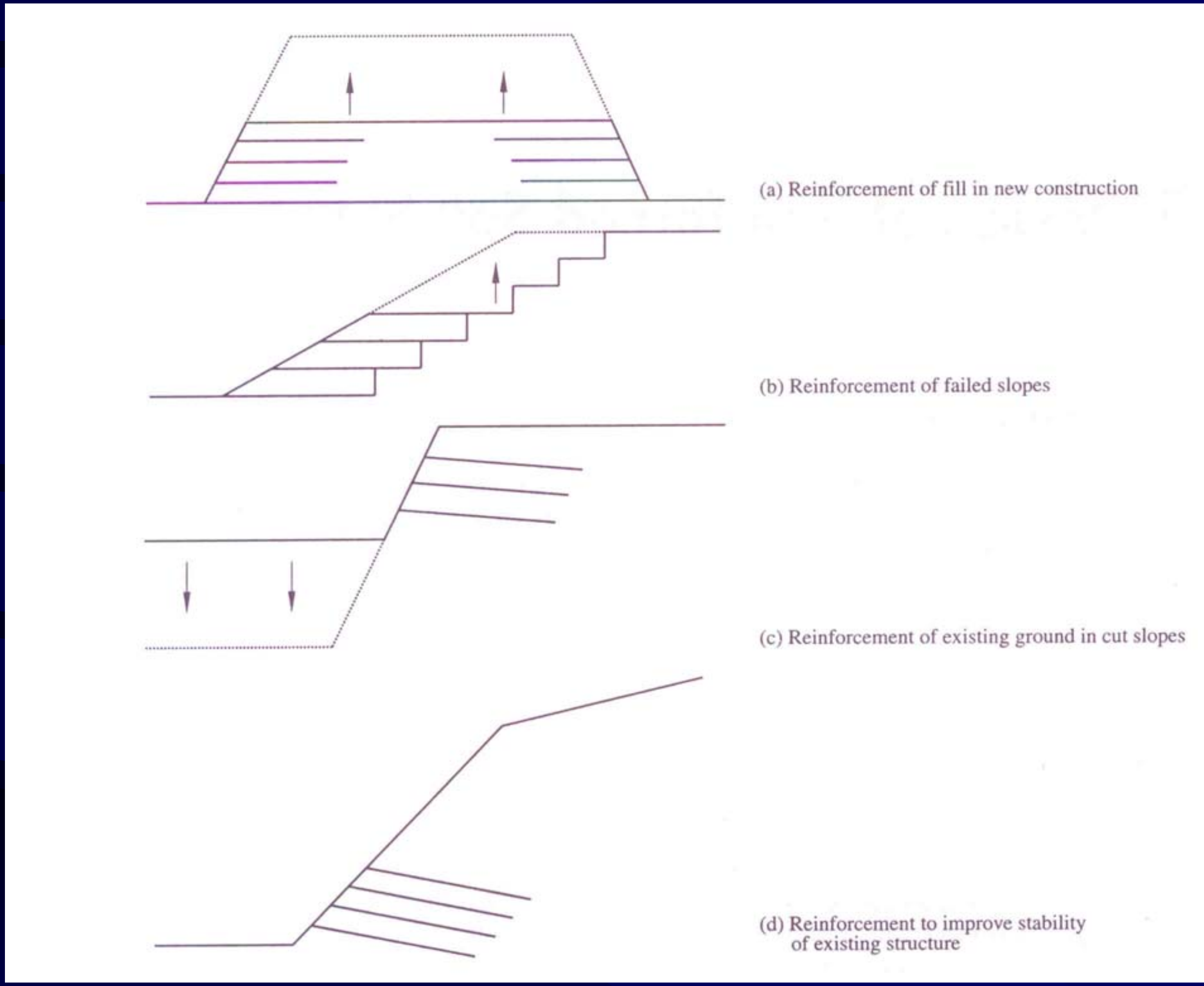
Design of Reinforced Soil Slopes

- Introduction
- Definition of parameters
- Design values for parameters
- Steps for design
- Example

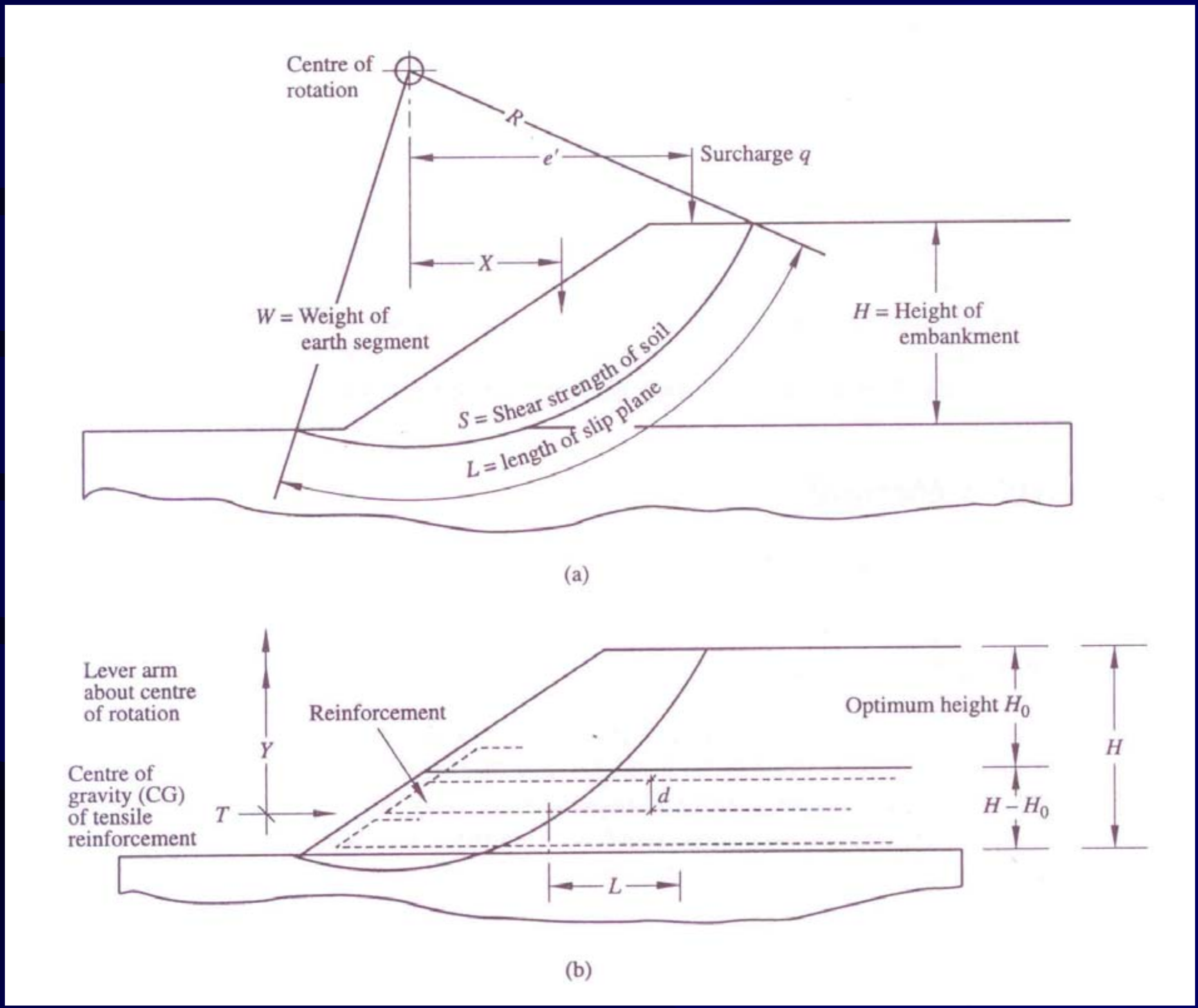
Introduction

BS 8006 (1995) indicates that reinforcement of slopes is possible for a number of applications. They are

- reinforcement of a fill in new construction
- reinforcement of failed slopes
- reinforcement of existing ground in cut slopes
- reinforcement of an existing cut or fill slope which is marginally stable.



Applications of reinforced soil slopes

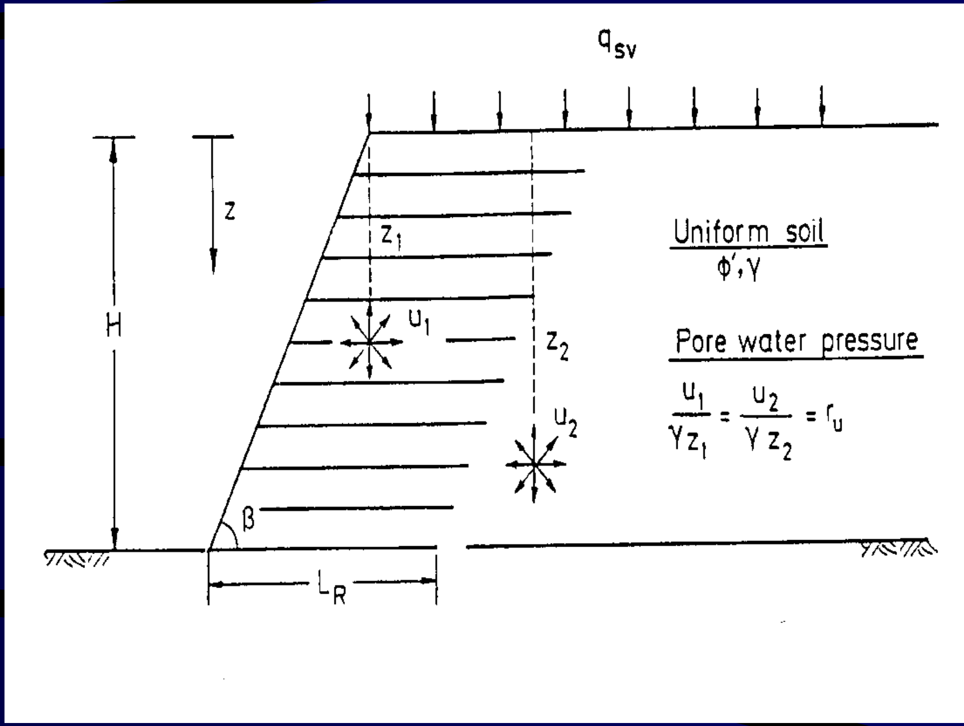


Unreinforced slope and reinforced slope

Approaches for design are based on

Limit equilibrium methods for slopes assuming suitable mechanism of failure such as circular, logarithmic spiral, wedge, two part wedge etc.. Jewell, 1989, Leschinsky and Bodecker 1989)

Design earth pressure coefficient approach



Parameters

- Slope angle
- Large strain friction angle
- Pore water pressure coefficient
- Bond coefficient
- Direct sliding coefficient

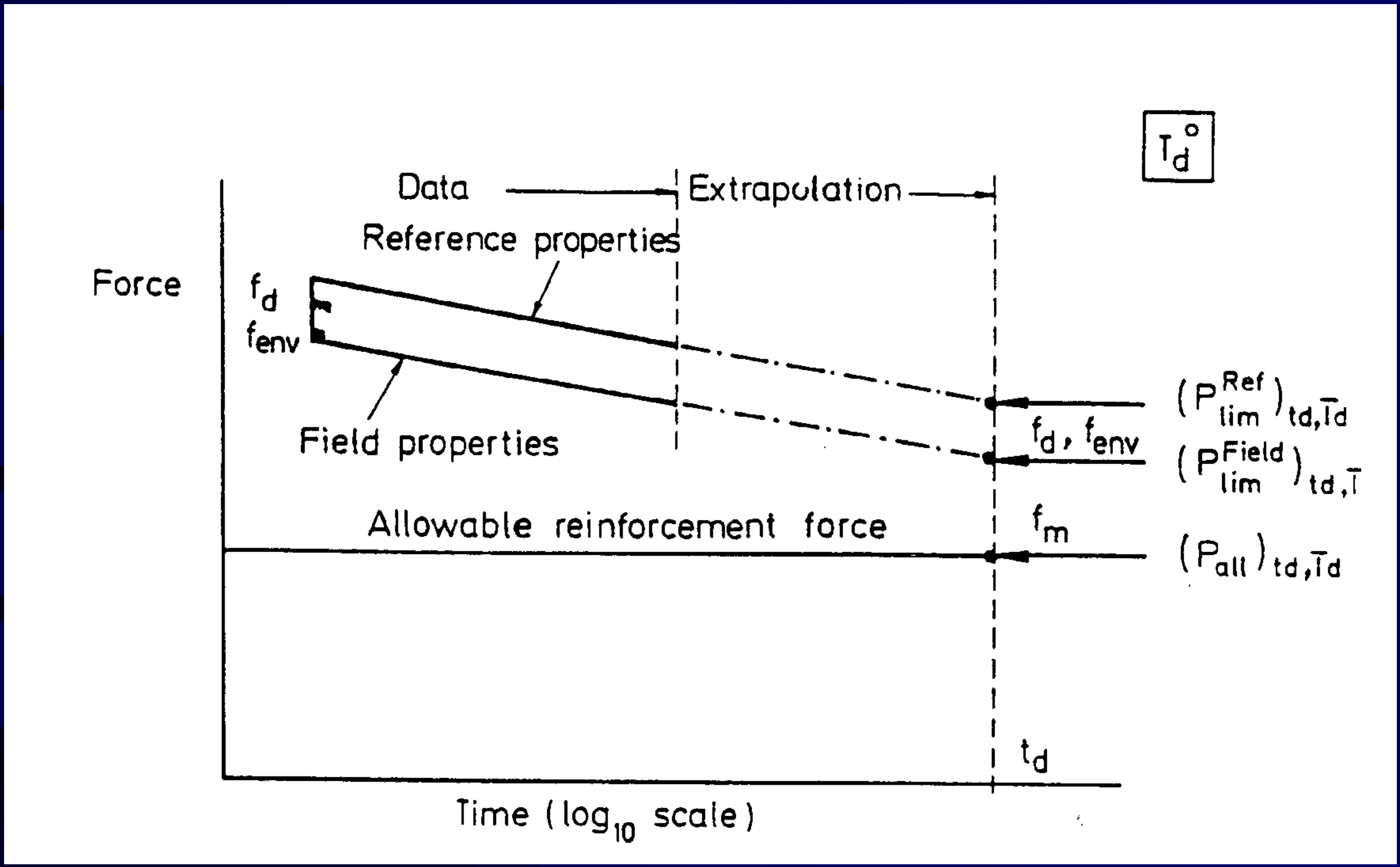
Soil Properties

Design value for the soil shearing resistance is $\phi'_d = \phi'_{cs}$

Range for granular fills is $\phi_{cs} = 30^0$ to 35^0, and for low plastic clay fill $\phi_{cs} = 20^0$ to 25^0

Maximum expected unit weight for the soil is $\gamma_d = \gamma_{max}$ (good compaction is necessary)

Suitable pore pressure coefficient



Reinforcement strength properties with time

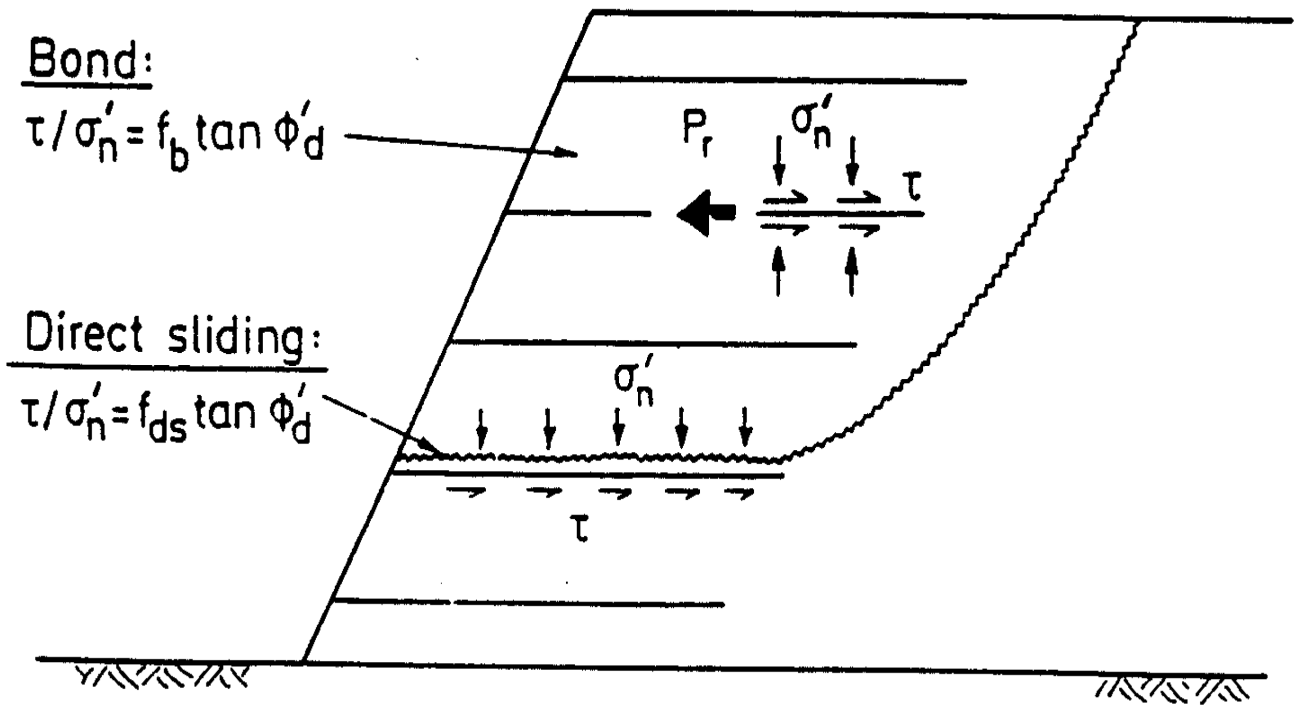
Reinforcement Properties

The *allowable force* P_{all} in the reinforcement must be selected to allow for conditions in the ground, at the end of the design life and at the design temperature.

Partial safety factors

Mechanical damage	f_d	minimum	1.1
		maximum	1.6
Environmental effects	f_{env}	minimum	1.1
Material factor	f_m	no extrapolation	1.3
		extrapolation 1 $\log_{10}$ cycle	1.5
		extrapolation 2 $\log_{10}$ cycle	2.2

Overall factor 1.2



Bond and sliding coefficients

Interaction Parameters

Direct sliding coefficient

The *direct sliding coefficient* f_{ds} is a measure of shearing resistance $f_{ds} \tan \phi'$ for preferential sliding across the surface of a reinforcement layer.

Bond coefficient

The *bond coefficient* for reinforcement materials is due to bond through *shear* on plane reinforcement surface areas as well as bearing and depends on the proportions of the grid and on the shearing resistance of the soil

Basis of Design

For an economical and balanced equilibrium in a steep slope, basis of design is the calculation of the distribution of the *maximum required stress* to be supplied by the reinforcement for equilibrium in the soil. A suitable provision of reinforcement can then be made with sufficient strength and spacing so that the *minimum available stress* (from the reinforcement) exceeds the *maximum required stress* (for equilibrium in the soil) at every depth in the slope, thereby satisfying local and overall equilibrium.

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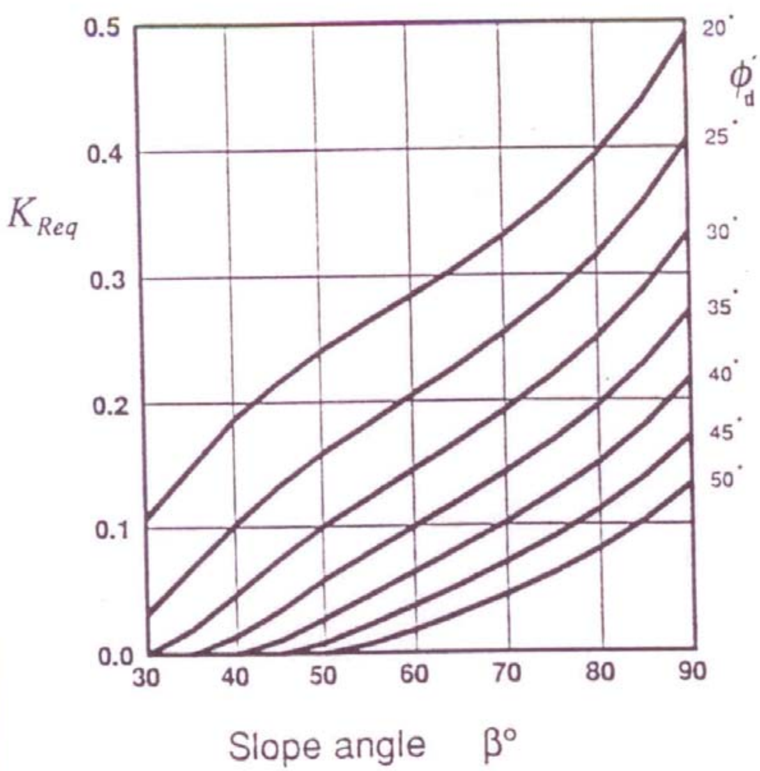
Minimum Required Force K_{Req}



Minimum reinforcement length:

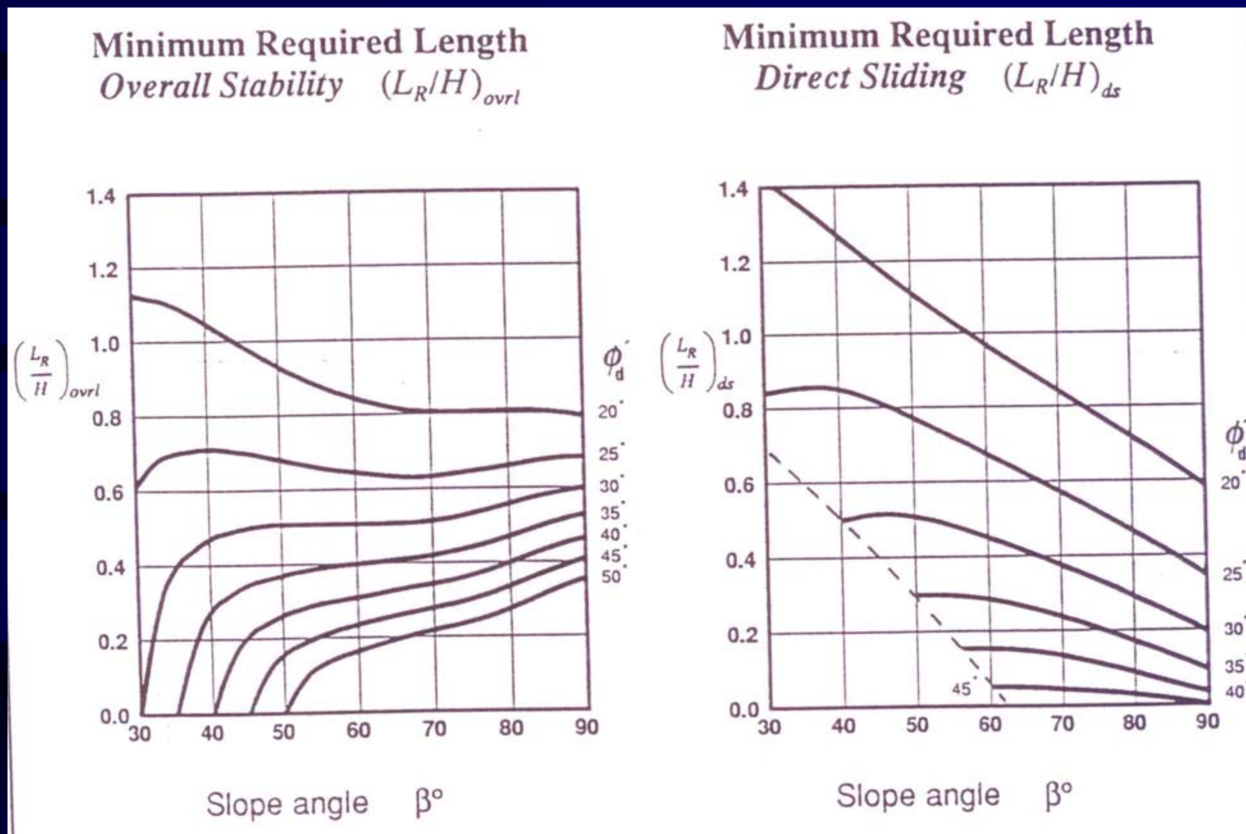
(1) The minimum length at the crest of the slope is that required for *overall stability*.

(2) The minimum length at the base of the slope is the greater of that required for *overall stability* and to prevent *direct sliding*.

(3) Where reinforcement of constant length is to be used select the greater length required to satisfy equilibrium at the base of the slope, (2) above.

(4) Where *direct sliding* governs the required reinforcement length at the base of the slope it is permissible to reduce the length uniformly from L_{ds} at the base of the slope to L_{ovrl} at the crest of the slope.

Jewell's chart for Minimum required force (Pore pressure coefficient r_u=0)


Minimum Required Length
Overall Stability $(L_R/H)_{ovrl}$
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
$\left(\frac{L_R}{H}\right)_{ovrl}$
30
40
50
60
70
80
90
ϕ'_d
20°
25°
30°
35°
40°
45°
50°
Slope angle β°
Minimum Required Length
Direct Sliding $(L_R/H)_{ds}$
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
$\left(\frac{L_R}{H}\right)_{ds}$
30
40
50
60
70
80
90
ϕ'_d
20°
25°
30°
35°
40°
45°
Slope angle β°

Values from the Charts

The first figure in the chart gives an earth pressure coefficient K_{req} from which the *required reinforcement force* for equilibrium is calculated

The second two figures in the chart gives the minimum *required reinforcement length* L_R/H

The minimum required reinforcement length satisfies both *internal* and *overall* stability requirements, and prevents *direct sliding* through the reinforced block

Steps for Simplified Design

(I) Values from the charts

(2) Envelope of maximum required stress in the soil

(3) Locus of minimum available stress from the reinforcement

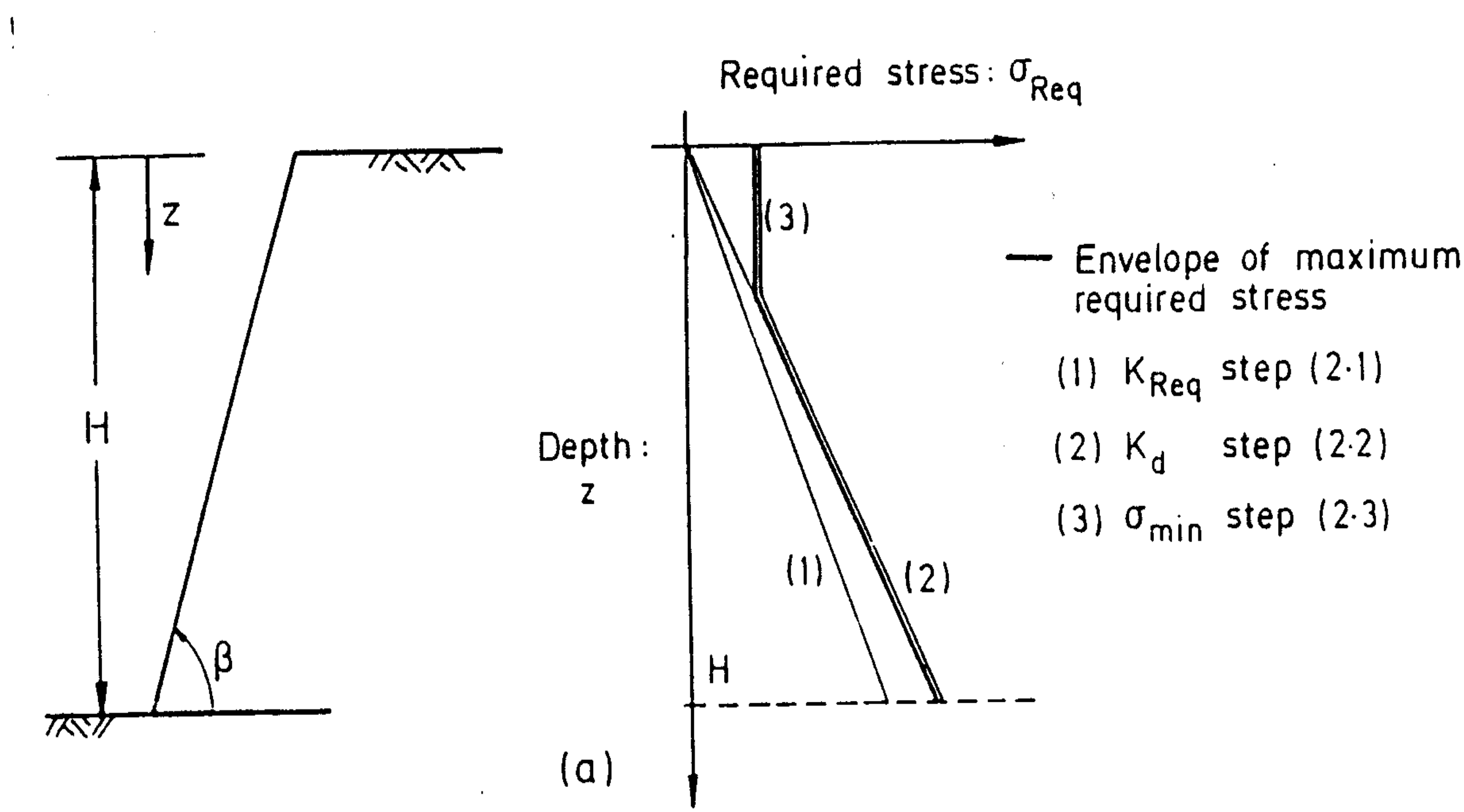
(4) Allowance for uniform vertical surcharge

Envelope of maximum required stress in the soil

The basic required stress for equilibrium is determined from the depth below the slope crest z and the required earth pressure coefficient K_{req}

$\sigma_{Req} = \gamma_d \, z \, K_{req}$

- Calculate the bond allowance, $(1 – L_B/L_R)$, and increase the design earth pressure coefficient
- Calculate the critical depth to determine the minimum required stress at the crest of the slope
- Make allowances for surcharge, compaction and other forces



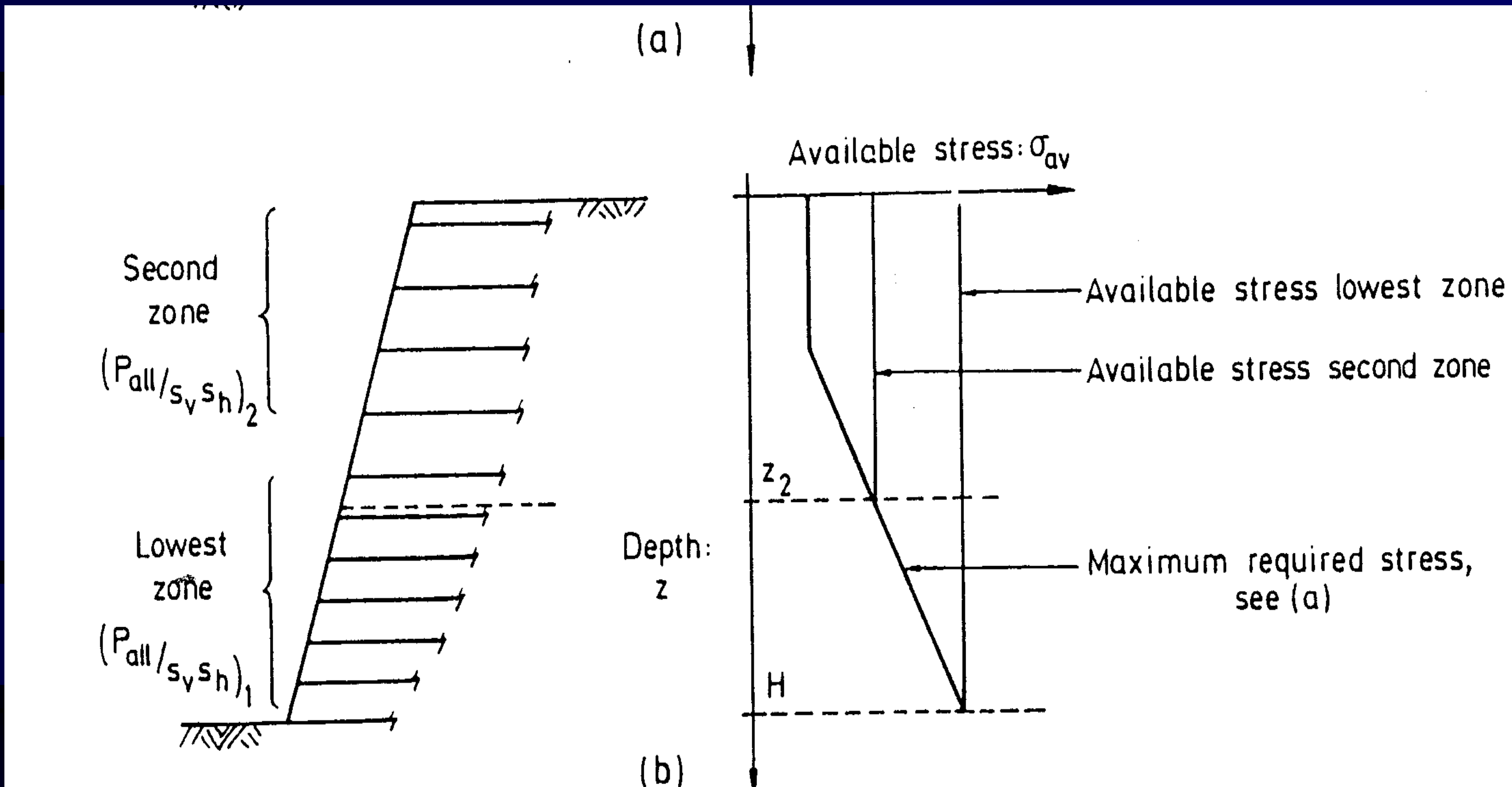
Envelope of maximum required stress in the soil

Locus of minimum available stress from the reinforcement

Devise a reinforcement layout so that the minimum available stress at every depth z exceeds the envelope of maximum required stress calculated

The available stress, $\sigma_{av} = P_{all}/(S_v x S_h)$, depends both on the reinforcement force and spacing

Either or both of these may be changed at different elevations in the slope



Locus of minimum available stress from the reinforcement

Design Example

A 8m high slope with an angle $\beta = 80^o$, and with a 15m wide crest is needed for an environmental protection scheme. A granular fill is available on site. Design values $\gamma_d = 21$ kN/m^3 and $\phi = 31^o$

Design assuming zero surcharge and pore water pressure, $q_{sv} = 0$ kN/m^2 and $(\gamma_u)_d = 0$. The required design life is 60 years, giving the design conditions $t_d = 60$ years and $T_d = 20^oC$

Reinforcement grids with Index strengths in the range 110 kN/m to 35 kN/m are available. The coefficient of skin friction for these grids is $f_{sf} = 0.6$, and they all have a similar geometry with $\alpha_s = 0.4$ and $S/\alpha_b B = 20$

Design a suitable reinforcement layout

Characteristic strength of the reinforcement grids

(t_d = 60 years and T_d = 20º)

Index strength	Ref. strength	Field strength	Allowable force
110	66	50	33
80	48	36	24
55	33	25	16.5
35	21	16	10.5

Notes : Characteristic Index and Reference strength from manufacturer

Field strength for degradation f_d = 1.2 and f_{env} = 1.1
Material factor f_m = 1.5 for 1 $\log_{10}$ cycle of extrapolation

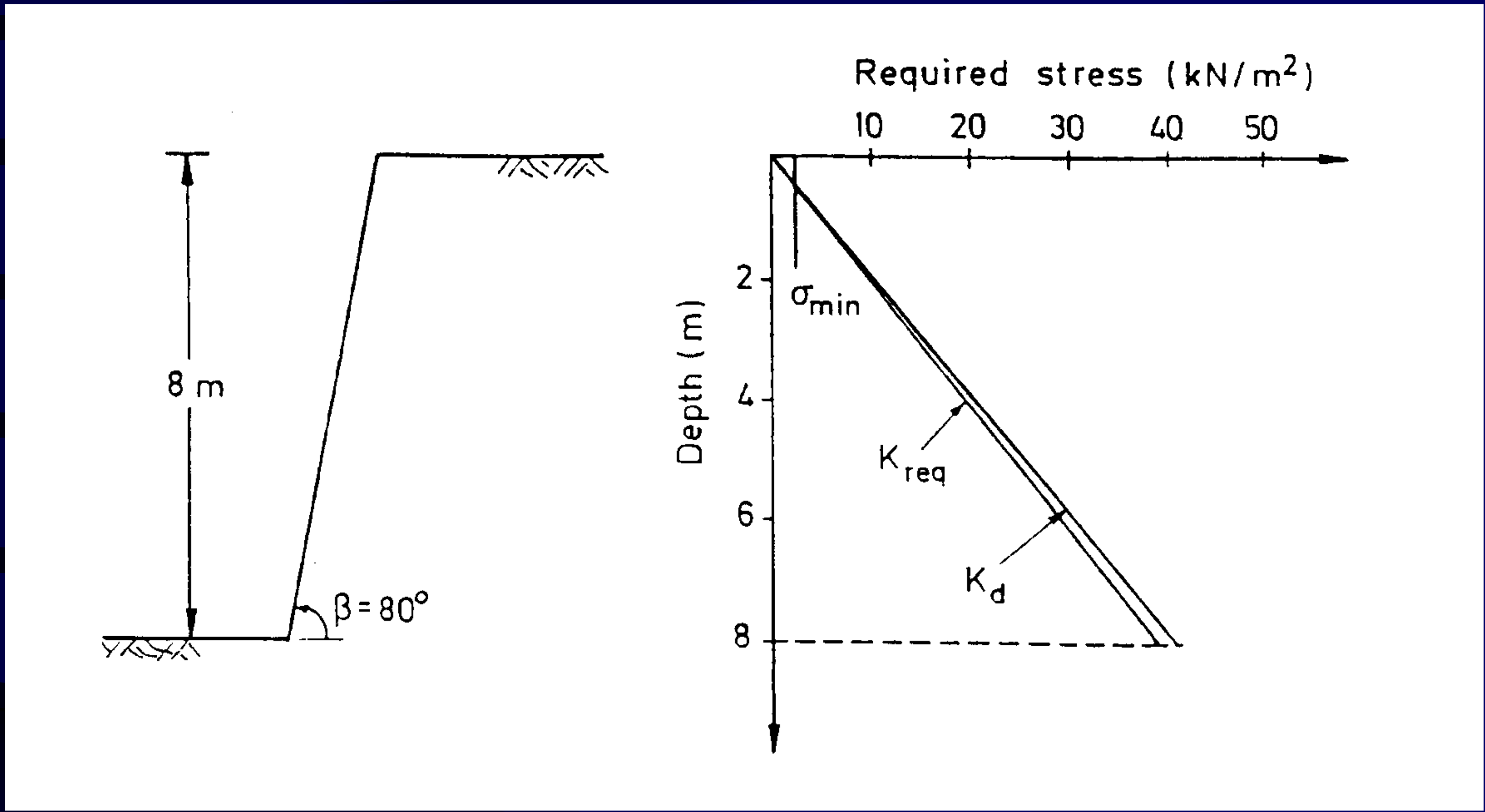
Design Steps

Obtain the basic required earth pressure coefficient K_{Req} = 0.23 and the required reinforcement lengths $(L_R/H)_{ovrl}$ = 0.53 and $(L_R/H)_{ds}$ = 0.28 from the charts for the design values $(r_u)_d = 0$, $\beta = 80^o$ and $\phi = 31^o$

As $(L_R/H)_{ovrl} \geq (L_R/H)_{ds}$, the minimum required reinforcement length has a constant value $L_R = 0.53 \times 8 = 4.3$m

For a constant spacing s_v = 0.5 m throughout the slope, the maximum required stress at the base of the slope is $\sigma_{Req} = K_{Req}\,\gamma_d H$ = 39 kN/m^2. Grid reinforcement with an index strength 80 kN/m is selected for the lowest reinforcement zone as it provides a minimum available stress σ_{av} = 24/0.5 = 48 kN/m^2. Consider bond allowance $(1 – L_B/L_R)$ = 0.94. This gives the design earth pressure coefficient K_d = 0.23/0.94 = 0.24

For L_B/L_R = 0.06, the minimum required stress is σ_{min} = 2.2 kN/m^2



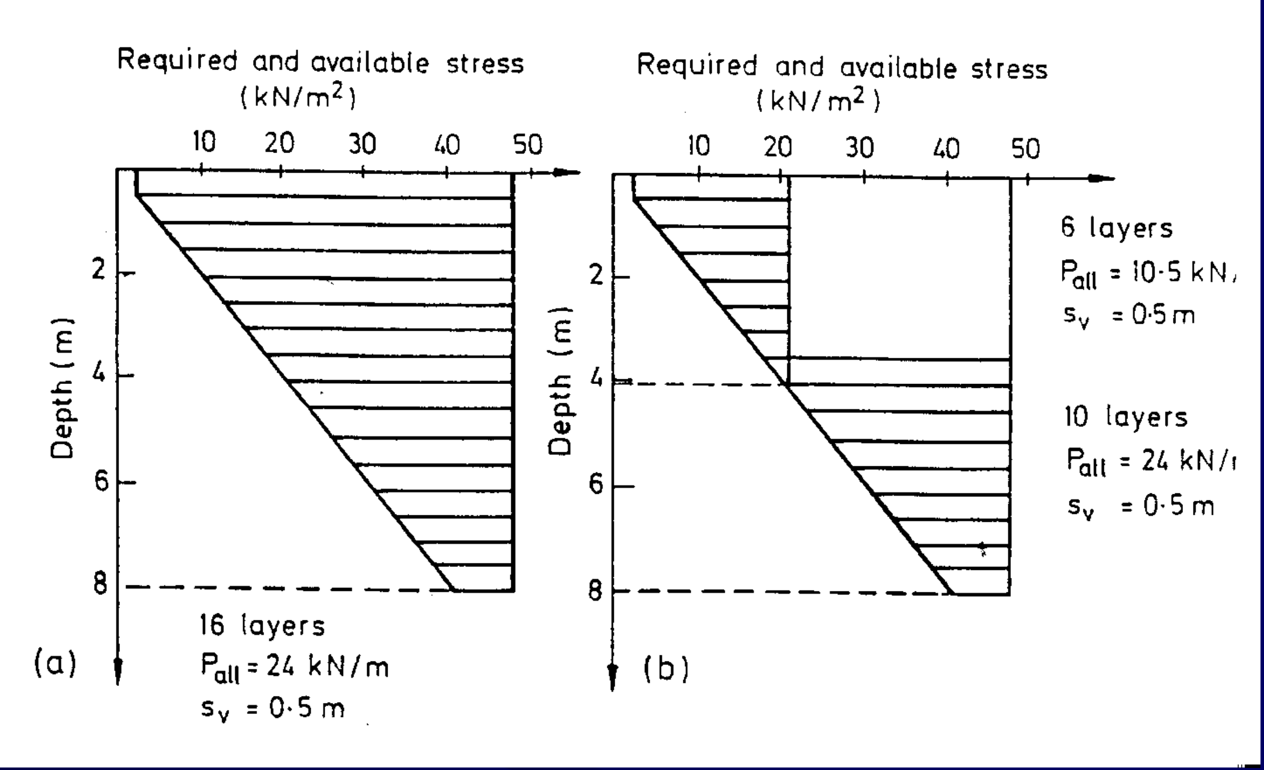
Envelope of maximum required stress

Alternative Designs

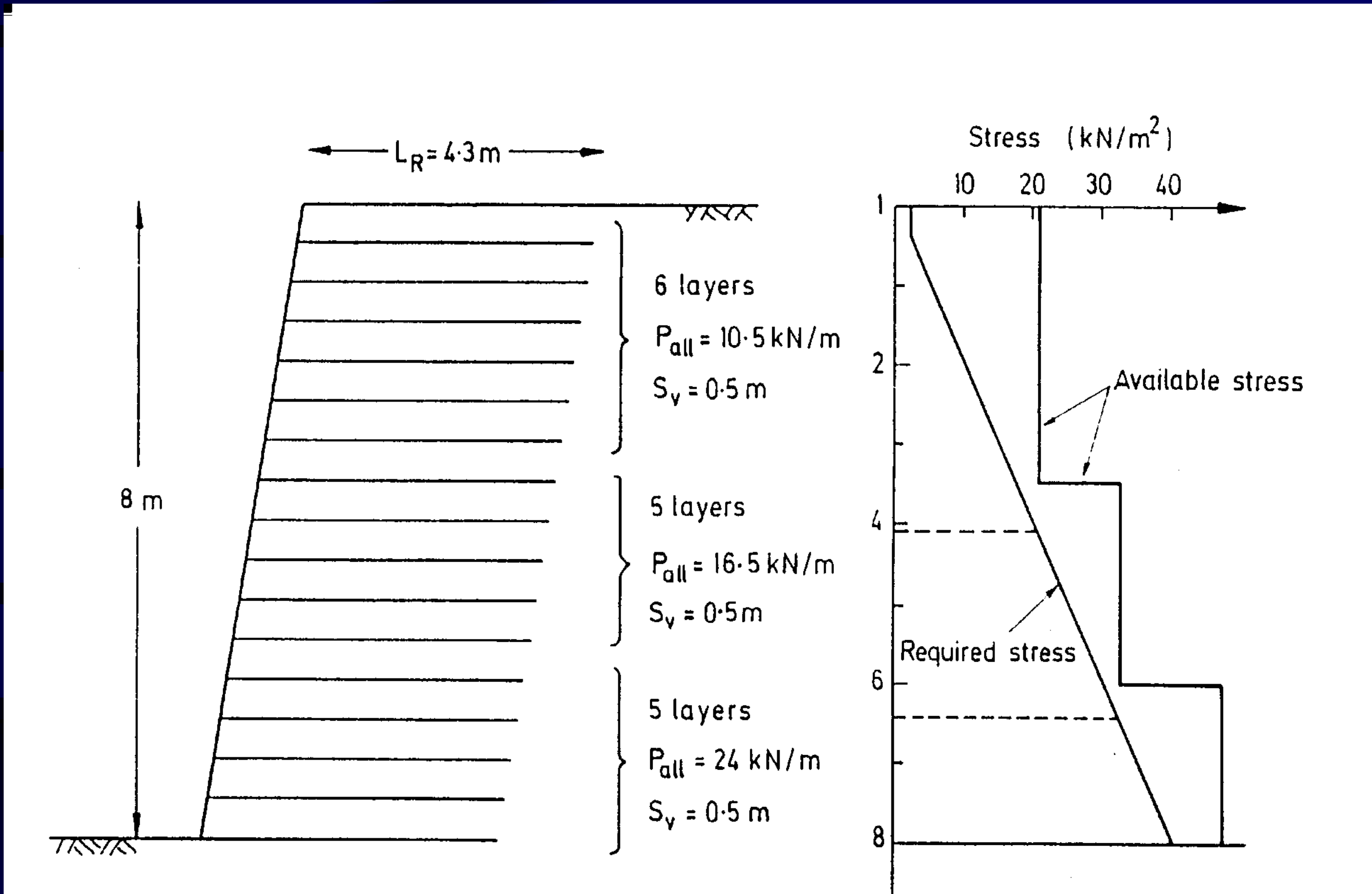
For single spacing arrangement with s_v = 0.5 m and P_{all} = 24 kN/m n = 8/0.5 = 16 layers are required

For excess available stress, choose the weakest grid with $(P_{all})_2$ = 10.5 kN/m. With s_v = 0.5 m this grid can provide an available stress $(\sigma_{av})_2$ = 21 kN/m^2 which is acceptable above a depth z_2 = 21/(0.24x21) = 4.1 m below the crest. This enables the top 6 layers of reinforcement grid to be replaced

Use of intermediate grid with P_{all} = 16.5 kN/m can reduce further the excess available stress in the slope. For this grid, σ_{av} = 33 kN/m^2 which is permissible above a depth z = 6.45 m below the slope crest



Plot of required and available stresses



Optimized layout

Reinforcement Design Summary

Index strength kN/m	Design 1 Layers	Design 2 Layers	Design 3 Layers
80	16	10	5
55			5
35		6	6

Relative unit cost:

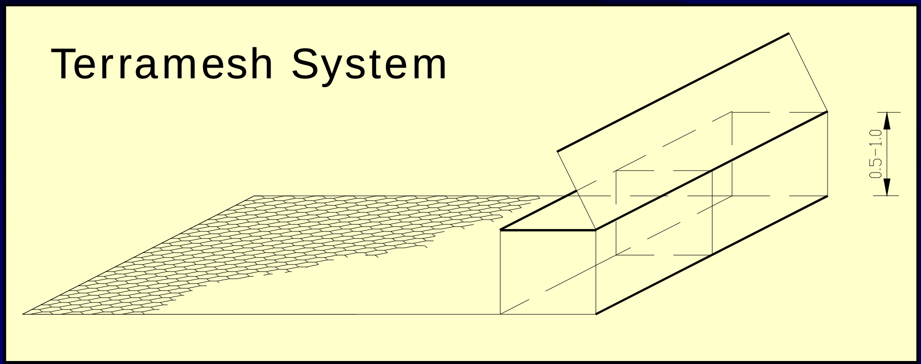
	80	68	63

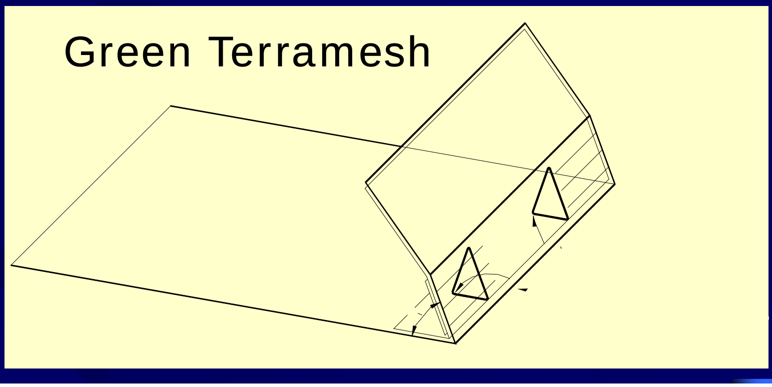
Saving over design1:

	0%	15%	21%

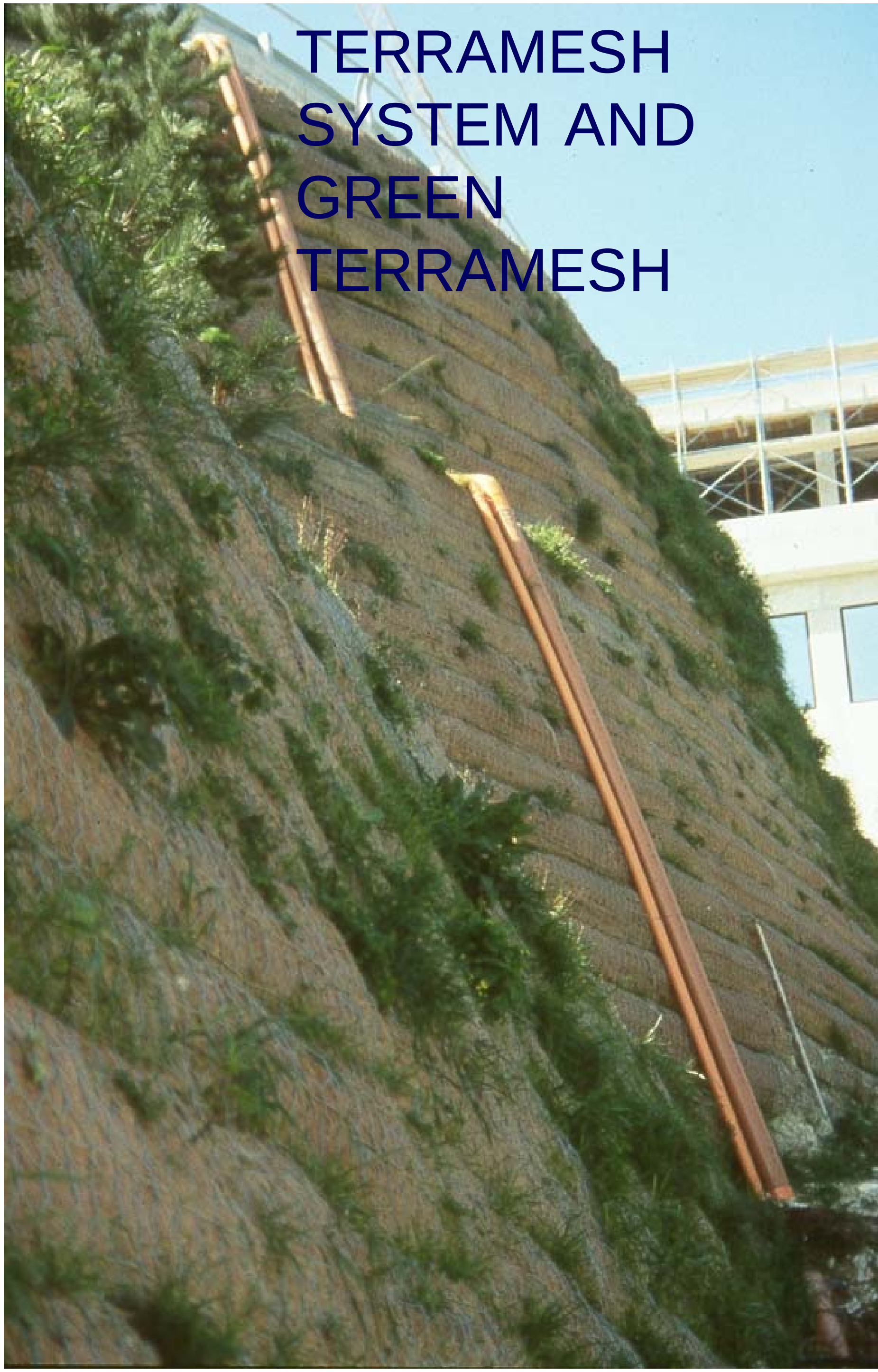
Note: Relative unit costs are 5, 4 and 3 respectively

COMBINATION OF TMS AND GTS





TERRAMESH SYSTEM AND GREEN TERRAMESH



MACCAFERRI

Vegetation Growth

Vegetation Growth

Case Study:

Carretera PR184, km 18 DTOP de Guayama, Puerto Rico

Engineer: Jose Abrams, Director of Guayama DTOP

Contractor: DTOP

Date of construction: February 1999



Case Study:

Castries to Cul De Sac Highway, Santa Lucia, West Indies

Engineer: Halcrow - UK

Date of construction:

March 1997 - June 1998

Conclusions

Reinforcement of slopes is a viable technique to increase the stability of slopes and the design philosophy can also be used to design soil nailing layout based on the required forces for maintaining stability.

Thank you