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Vegetation for stability and green facing

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ABSTRACT: Vegetation may be used on a slope to help resist shallow slip failure or simply to improve the aesthetic appearance. A method of including the effects of the vegetation in conventional stability analysis is presented and reference made to a demonstration site on the M20 motorway. The problems associated with maintaining a green face for aesthetic purposes are discussed in relation to current Codes of Practice for steep slopes. A number of successful case histories are recorded and conclusions drawn for future establishment of green faces.

1. INTRODUCTION

Vegetation may be established to contribute additional strength to the soil mass within a slope or retaining structure or it may be used simply for aesthetic reasons to give an acceptable green appearance to a finished slope or structure.

In this paper the use of vegetation to assist stability is described with reference to a current demonstration site on the M20 motorway near Maidstone.

The recommendations for green facings to walls and slopes as given in the recently published Code of Practice for Strengthened/ Reinforced soils and other Fills are reviewed and problems associated with the construction and maintenance of the green face are discussed with reference to case studies.

2. CONTRIBUTION OF VEGETATION TO SLOPE STABILITY

The use of vegetation to limit surface erosion is well recognised. The possible contribution of vegetation to resist deeper instability within a soil slope is also of interest to engineers. The CIRIA publication on "Use of Vegetation in Civil Engineering" (1990) focused attention on how the selection of appropriate vegetation could be of benefit to the slope designer.

The various influences of vegetation on a soil slope are illustrated in Figure 1. These influences may be incorporated into routine stability analysis by taking the basic simple stability equation (Greenwood 1983):

$$F = \frac{\sum\left[c'b\sec\alpha + (W - ub)\cos\alpha\tan\phi'\right]}{\sum W\sin\alpha}$$

This simple equation provides a reasonable estimate of the factor of safety for most situations and is readily adapted for inclusion of the reinforcement forces, T kN/m, acting at an angle θ to the slip surface.(Greenwood 1986): ie

$$F = \sum\left[c'b\sec\alpha + \left[(W-ub)\cos\alpha + T\sin\theta\right]\tan\phi' + T\cos\theta\right]$$

The roots of vegetation will act in a similar way to provide soil reinforcement. The simple stability equation may therefore be adapted to include the reinforcement and other effects of vegetation as follows (Greenwood in Coppins & Richards 1990):

$$F = \frac{\sum\{(c' + c'_R)b\sec\alpha + [((W + Sw) - (u - u_v)b)\cos\alpha - D\sin(\alpha - \beta) + T\sin\theta]\tan\phi' + T\cos\theta\}}{\sum[(W + Sw)\sin\alpha + D\cos(\alpha - \beta)]}$$

The contribution of vegetation to the stability of soil slopes is being further investigated by a current CIRIA research project supported by the Highways Agency and Department of the Environment (Coppin, Greenwood, Morgan and Churcher 1994).

For conventional non-reinforced highway slopes typically constructed at side slopes of less than 1 horizontal in 2 vertical it is likely that vegetation will play an increasing role in reducing the risk of shallow slope failure.

For steeper slopes, up to 70°, and walls (70 - 90° to the horizontal) the consequences of failure are often more severe in terms of risk to life and property. Consequently designers will introduce geotextile or geogrid reinforcement or a form of soil nailing/anchorage to be sure of providing an adequate factor of safety against failure. Vegetation is generally required only for aesthetic reasons although it may help to resist surface erosion.

3. BS 8006 RECOMMENDATIONS

The recently published Code of Practice for Strengthened/Reinforced Soils and Other Fills, BS 8006 states (paragraph 6.7.1) that for reinforced soil walls and abutments the facing must be robust, durable and able to fulfill its function during the life of the structure. This will generally tend to preclude the use of vegetated facing except perhaps in planting troughs which do not affect the structural integrity. The tight tolerances stated in BS 8006 (Table 23 reproduced as Figure 2) are difficult to achieve in practice for hard facing and are unlikely to be achieved with any soft vegetated facing.

For steep slopes (> 70°) BS 8006 states (Section 7.6) that "it is usually difficult to establish permanent vegetation to cover the exposed face. A permanent facing will therefore usually be necessary to prevent erosion and ensure face stability"

For shallower slopes (< 70°) BS 8006 states that "it is usually possible to establish vegetation. However this may take some time to develop. It is therefore essential to provide short term protection against erosion and to provide an environment where appropriate vegetation becomes established."

In Section 9.2.5.3 of BS 8006 a number of design options are presented for soft facing of reinforced slopes between 45° and 70° to the horizontal. These include:

a) Turf laid behind wraparound reinforcement

b) Pre seeded mulch mat against the face of wraparound facing

c) Brush layering of live, unrooted cuttings of hardy shrubs such as willows

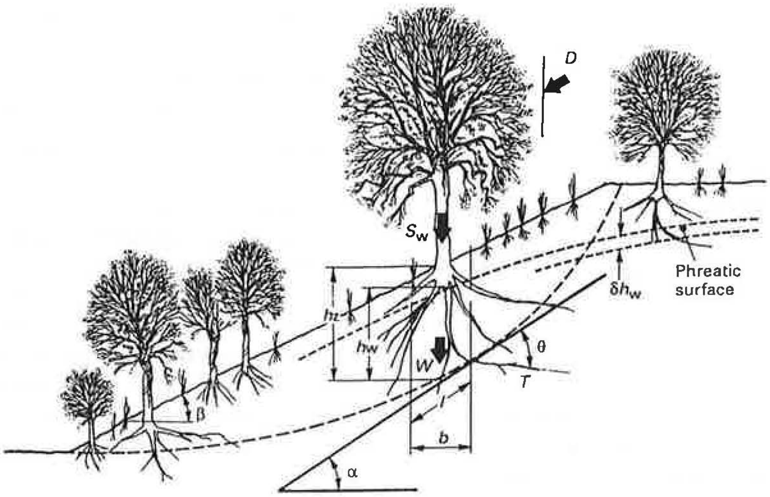
It advises that topsoil fertilizers and soil conditioners are placed in the adjacent 150 to 300 mm of fill. The Code emphasises that in all cases it should be ensured that the vegetation has access to enough water to survive.

4. UK EXPERIENCE

The importance of the advice offered in BS 8006 regarding access to water has been emphasised by problems encountered in the UK following two dry summers. Barker (1996) noted problems with vegetation on steepened slopes on the M25 motorway where deterioration has occurred with time rather than improvement as hoped. Barker listed the following factors affecting the establishment and maintenance of the vegetation:

Wrong or inappropriate:

- design or layouts



Parameters applied in slope stability analysis

W — Total weight of soil slice, kN/m^2

c', ϕ' — Effective strength parameters at slip surface

l — Length of slip surface with slice, m (b sec α)

u — Pore-water pressure at slip surface, kN/m^2 ($\gamma_w h_w$)

Due to vegetation:

u_v — Decrease in pore-water pressure to evapotranspiration by vegetation at slip surface, kN/m^2 (2)

c'_R — Enhanced effective soil cohesion due to root matrix reinforcement by vegetation along slip surface, kN/m^2

c'_s — Enhanced effective soil cohesion due to soil suction due to evapotranspiration by vegetation at slip surface, kN/m^2 (2)

S_w — Surcharge due to weight of vegetation, kN/m

D — Wind loading force parallel to slope, kN/m

T — Tensile root force acting at base of slice, kN/m (assumed angle between roots and slip surface, θ)

h_z — Vertical height of surface of soil layer above slip plane, m

h_w — Vertical height of phreatic surface or water table above slip surface, m

Figure 1 The influences of vegetation on a soil slope (from Coppin and Richards 1990)

Location of plane of structure	**Tolerance ± 50 mm**
Verticality	± 5 mm per metre height (i.e. ± 40 mm per 8 m)
Bulging (vertical) and bowing (horizontal)	± 20 mm in 4.5 m template
Steps at joints	± 10 mm
Alignment along top (horizontal)	± 15 mm from reference alignment

Figure 2 Usually accepted tolerances for facings of retaining walls and abutments (reference BS 8006)

- soils in face or main body of wall
- plant types and species
- system components inhibiting face plant growth
- time of construction
- aftercare practices - failure to irrigate, excessive irrigation, failure to fertilise, failure to correct excess soil pH
- maintenance - failure to or excessive clipping, pruning and coppicing

Lack of:

- soil moisture due to steep face inclination (low interception and high run-off), face orientation (south and west are worst), exposure at crests, interception by vegetation growing higher on face
- heat due to shade and exposure to cold wind

Excess of:

- moisture due to exposure to heavy rainfall
- heat due to face orientation (south and west are worst)

Failure to

- prevent excessive soil compaction
- prevent or cure plant diseases or pests

Many of these problems can be overcome and Figure 3 records some UK examples where vegetation has thrived on steeper slopes over a number of years.

It is generally found that slopes steeper than 60^o are more prone to vegetation loss due primarily to the lack of direct rainfall. If natural vegetation is an important aesthetic requirement of a design and if space permits, slightly shallower slopes at say 45-60^o to the horizontal are likely to have a greater chance of remaining green. Records indicate that slopes constructed in the cooler weather climates of Northern England and Scotland are more likely to stay green.

5. CONCLUDING REMARKS

For the future, designers and client organisations must give more attention to the factors listed by Barker. The local environment and available soils for the construction of each slope should be carefully considered. For example vegetation on motorway slopes is often subject to pollutants or stresses due to salt spray, exhaust gases and buffeting from trucks. Locally available topsoils must be checked for high levels of contaminants which will inhibit growth. The maintenance regime is likely to be an important element of the design if vegetation is not to decline after the first season of growth.

The inclusion of irrigation pipes is sometimes seen as a necessary design feature. Perhaps more thought can be given to collecting and directing natural rainfall to the required locations and retention of the moisture to sustain vegetation through dry periods.

Other options worthy of further study include the use of couch type grasses which may be more resistant to adverse soil and environmental conditions and the use of creeping plants such as Russian Vines which can cover the slope face from basal rooting systems. There is however an inherent danger in introducing plant species which might spread to adjoining land with undesirable consequences.

Research must continue with the engineer and plant specialist working together to determine the best species, planting and maintenance regimes to maximise the chance of survival and minimise the level of on-going maintenance required.

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Project	Client	Construction Date (approx)	Height (m)	Slope (^{0})	Embankment (E) or Cutting (C)	Face Construction	Comments
M74 Gretna	Scottish Office	1992	6	60	E	Tensar grid wrapped around turf lining and topsoil	Benefit of cooler wetter climate
A9 Dunblane	Babtie Group	1990	5.5	60	E	Tensar grid wrapped around turf lining and topsoil	Benefit of cooler wetter climate
Buck Mills Cliff Stabilisation	Devon County Council	1990	20	70-80	C	Enkamat 7020 and Fortrac 35 geogrid secured to duckbill anchors	
Sandown Bay Cliff Stabilisation	South Wight Borough Council	1990	40	80	C	Enkamat S pegged to cliff face, sprayed with sticky Erodofix emulsion. Seed mixture and friable soil added by absailers. Other sections used Enka N33 turf with irrigation system for dry weather	
Lhanbryde (Elgin)	Grampian Regional Council	1995	4	78	E	Living Willow (Greenwall) frame with earth core	Irrigation pipes included
Dumfries	Safeway	1993	4	78	E	Living Willow (Greenwall) frame with earth core	Irrigation pipes included
M25 J.10-11	Highways Agency	1994	4.5	60	E	"Textomur" mesh form system - vegetation geotextile and low maintenance seed mix	Some browning during winter replaced by new seasons growth (consistent with low maintenance mix)
Kimbolton Butts Bridge Abutments	Cambridgeshire County Council	1992	3	60	E	"Textomur" mesh form system - vegetation geotextile and low maintenance seed mix	Few of the man made pollutants and stresses associated with highway slopes
Marchwood Southampton	DWS, UK	1994	5	71.5	E	Tenax TT301 SAMP wrapped around fine sand infill and green polypropylene matting	Artificial grass avoids problems

Figure 3 Examples of Steepened Slopes Demonstrating "Green" Faces

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