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Reinforced Soil - Steep Faced Embankments

by

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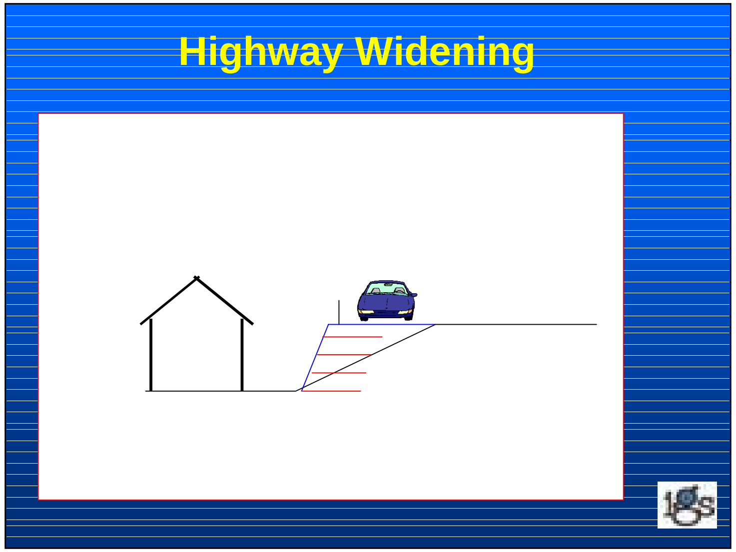
LECTURE OUTLINE

- Application areas and general introduction
- Types of geosynthetics and fill material used
- Review of design methods
- Examples of installation of geosynthetics
- Examples of completed structures

1. Application areas and general introduction

This part of the lecture discusses when and where one might use the technique of reinforced soil for steep slopes and the advantages. The definition of a "steep slope" for the purposes of this lecture is anything up to 70°. The normal application areas of reinforced soil steep slopes are:

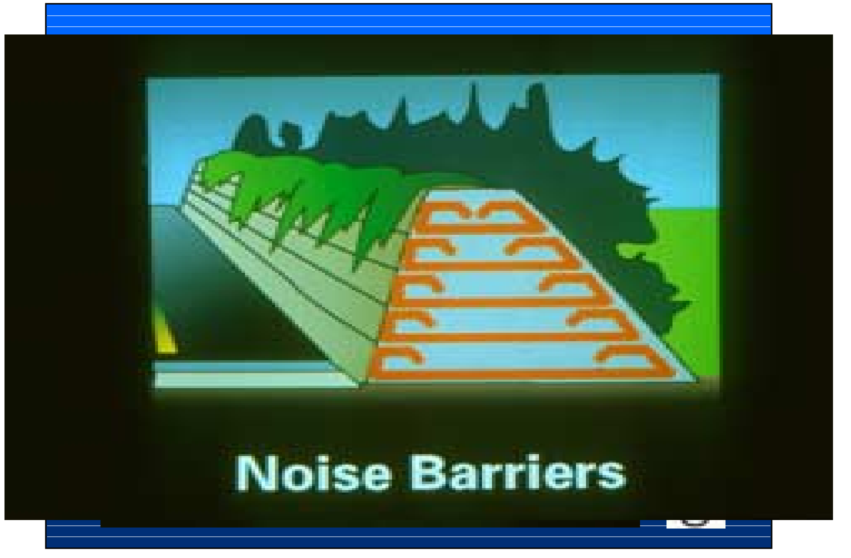
where landtake for a new embankment may be limited or prohibitively expensive



where motorway widening is required, or steepening of an existing slope to make more room at the crest

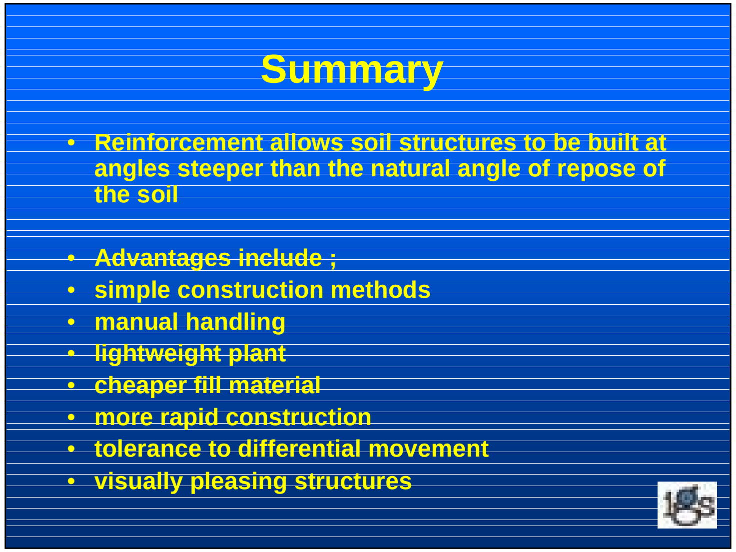
at bridge abutments (but generally only small bridges, or temporary works)

slip repairs after a slope failure



noise bunds, screens

for construction on marginal land, where a relatively poor foundation soil exists and/or where "less-than-perfect" local fill material is available cheaply. (But only providing some degree of differential settlement is acceptable - usually the case)



In summary, anywhere where there is a requirement for a relatively cheap retaining structure or landscaping at a steeper angle than the soil would normally be able to stand. The advantages over traditional retaining wall alternatives are normally that construction costs may be minimised due to simple construction methods, utilising mostly manual labour and light plant, cheaper materials, and quicker construction times. Also that the end-product is generally more visually acceptable structure.

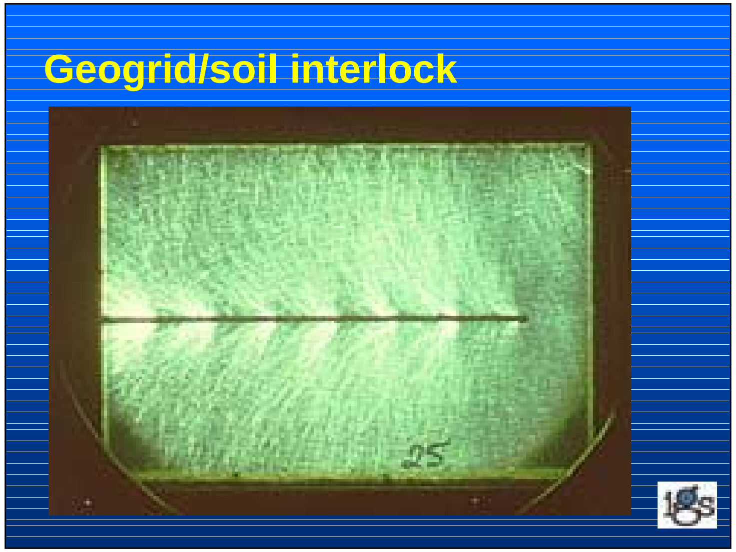
2. Types of geosynthetics and fill material used

Reinforced soil systems consist of planar reinforcements arranged in horizontal planes in the fill soil to resist outward movement of the reinforced soil mass. This part of the lecture presents the various types of geosynthetic reinforcement and fill materials which might normally be used.

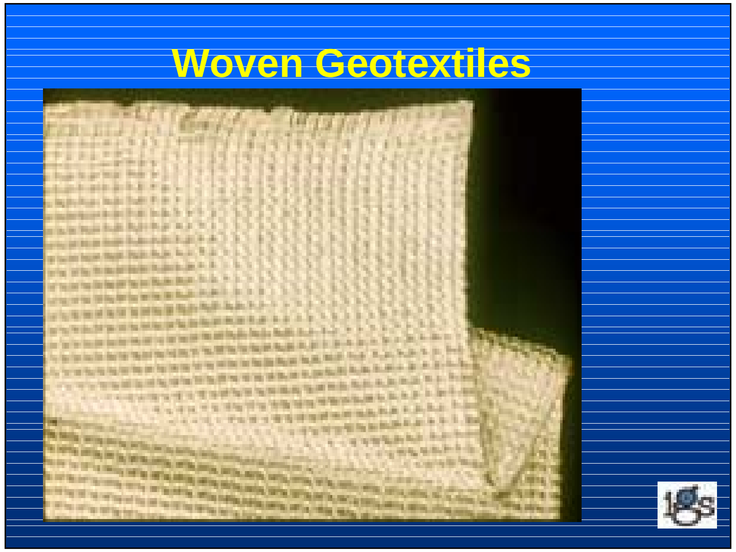
Geosynthetic reinforcement

Geogrids:

Geogrids transfer stress to the soil through passive soil resistance on the grid's transverse members and through friction between the soil and the geogrid's horizontal surfaces.



Because of the "interlock" action achieved, geogrids will generally have superior pull-out capacities to other geosynthetics. Normally uniaxial grids are used with the primary, reinforcing direction laid perpendicular to the line of the wall. Biaxial grids are sometimes used as secondary reinforcement layers near the front face.

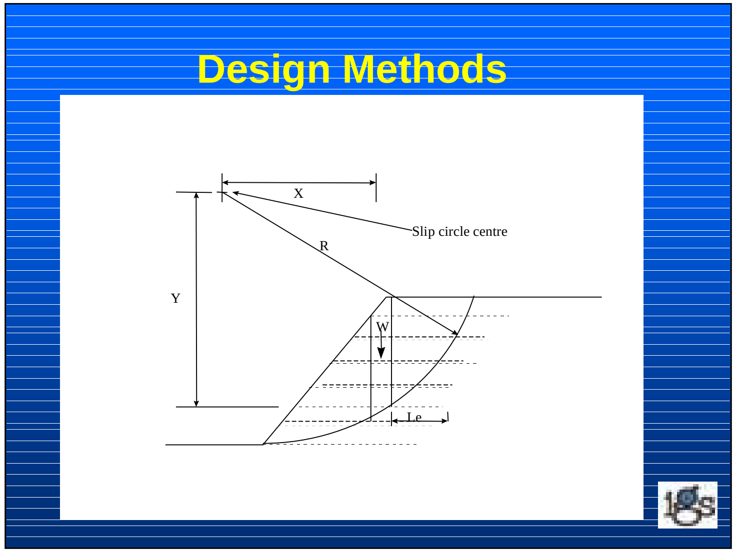


Geotextiles:

Geotextiles transfer stress to the soil through friction. There are two general types of geotextile, woven

and non-woven. Typically only woven geotextiles are used in steep faced embankments as reinforcement because of their higher strengths. However, non-woven geotextiles are being increasingly used for smaller and/or temporary structures. Despite being typically weaker, non-wovens benefit from superior in-plane drainage and isotropic strength. They are also sometimes used as vegetation fabrics on the front face, and also as secondary reinforcement layers near the front face.

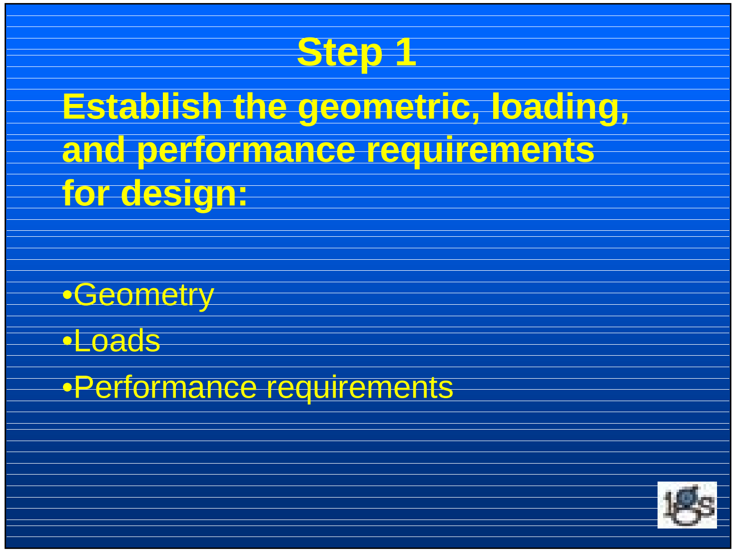
Any soil meeting the requirements for embankment construction can be used in a reinforced slope system. Lower-quality soil than would conventionally be used in unreinforced slope construction can also be used; however, a higher-quality material offers less durability concerns to the reinforcement and is easier to handle, place, and compact, which tends to speed up construction, and would be less sensitive to unforeseen sources of water. Four broad categories of acceptable fill material are :



3. Review of design methods

The overall design requirements for reinforced slopes are similar to those for unreinforced slopes: the factor of safety must be adequate for both short-term and long-term conditions and for all possible modes of failure, checking both internal and external stability. Reinforced Soil slopes are usually analysed using limit equilibrium methods. A circular or 2-part wedge-type potential failure surface is assumed, and driving and resisting forces or moments are compared. Ideally this is performed using a conventional slope stability computer program modified to account for the stabilising effect of reinforcement. Reinforcement layers intersecting the potential failure surface are assumed to increase the resisting force or moment.

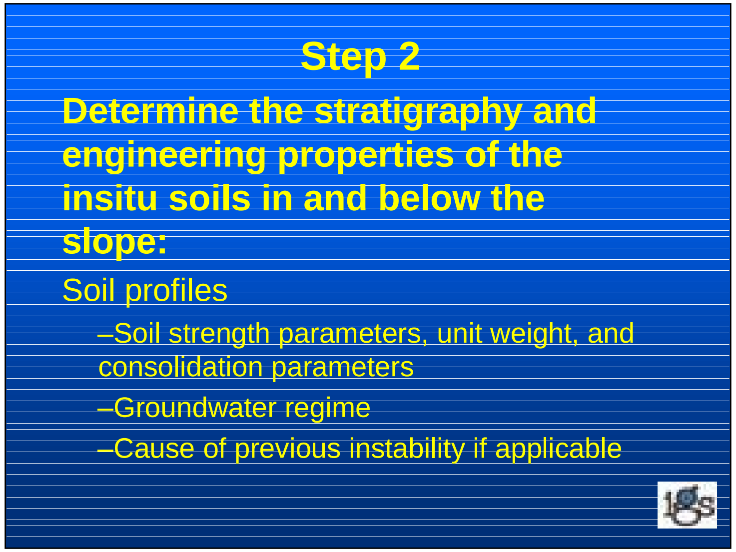
In USA, the FHWA method is perhaps the most authoritative and recommends eight basic steps for the design of a reinforced soil slope, summarised as follows. Design practise in UK is similar, being based on documents such as HA68/94 and BS8006. Some other countries have their own national systems.



Geometry This includes slope height and slope angle. Multi-part slopes are allowable.

Loads These include surcharge, seismic loading, traffic loading.

Performance requirements These include desired factors of safety for external and internal stability (typically 1.3 to 1.5 in terms of peak soil strength, depending on whether temporary/permanent slope, consequences of failure etc), for dynamic loading (typically 1.1) and also includes settlement criteria.



Determine soil profiles at every 30 to 60m along the slope, deep enough to evaluate a potential deep-seated failure (typically to a depth of 2H)

Determine soil strength parameters, unit weight, and consolidation parameters for each layer

Locate groundwater table and/or likely piezometric surfaces and/or representative ru value

For slope repairs, identify cause of instability and locate previous failure surface.

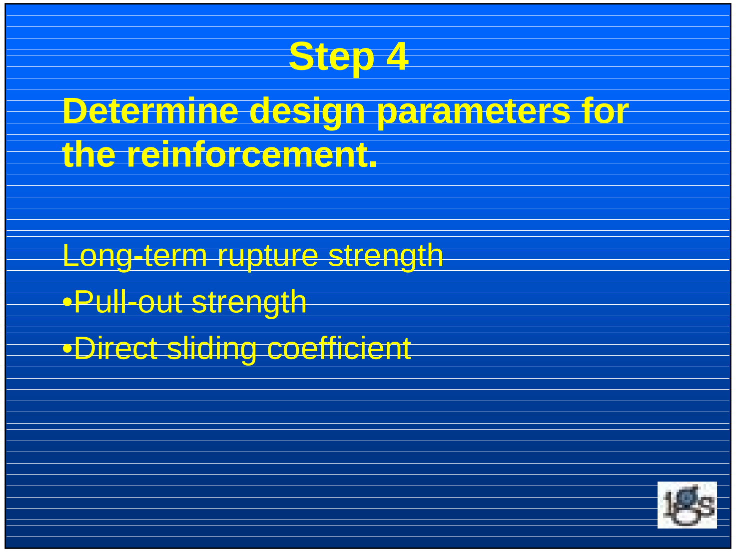
Step 3 Determine the engineering properties of the fill material to be used, and if different, the fill behind the reinforced zone:

l Gradings (FHWA recommend max size of up to 100mm, and no more than 50% passing 75m sieve) and plasticity (FHWA recommend PI £ 20%)

l Compaction characteristics (FHWA recommend not less than 95% max dry density and OMC ± 2%) and placement requirements (FHWA recommend max layer thicknesses of 200mm for cohesive soils and 300mm for granular soils).

l Shear strength parameters in terms of total stress and effective stress. For the latter, ideally do 300mm direct shear box drained tests to large displacement.

l Chemical composition of soil. Primarily pH and oxidation agents.



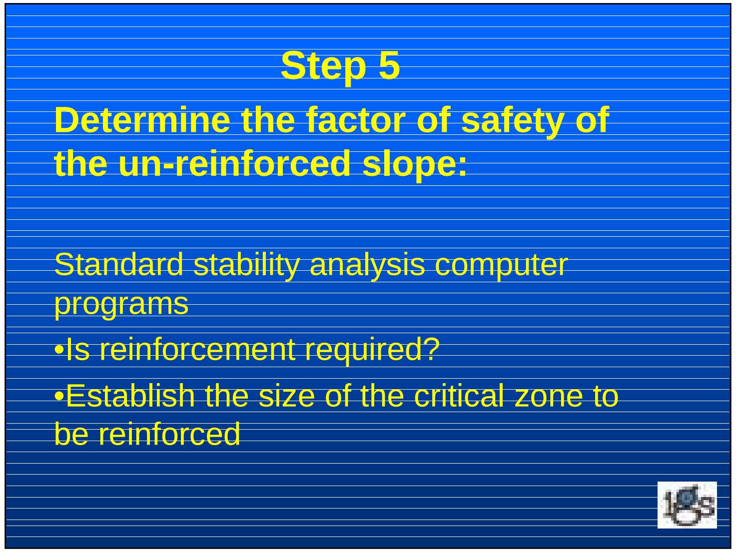
Step 4

Determine design parameters for the reinforcement. (The tensile capacity of a reinforcement layer is the minimum of its long-term rupture strength and its pullout resistance):

Long-term rupture strength. This should be based on the characteristic strength of the material for the required design life and design temperature, factored for installation damage and its durability under the design conditions.

Pull-out strength. This is calculated from the effective overburden stress and the interface friction factor between the reinforcement and the soil. (FHWA recommend using FS = 1.5 for granular soils and FS = 2 for cohesive soils, with a minimum embedment length, Le = 1m). Remember that pull-out resistance has to be checked on *both* sides of the potential failure surface.

Direct sliding coefficient. This is not always the same as the interface friction factor for pull-out purposes, especially for geogrids.

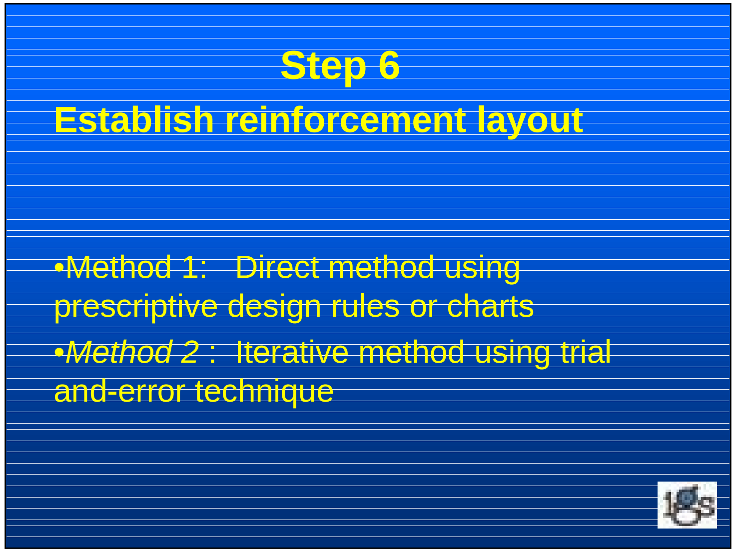


Step 5 Determine the factor of safety of the unreinforced slope:

Use standard stability analysis computer programs

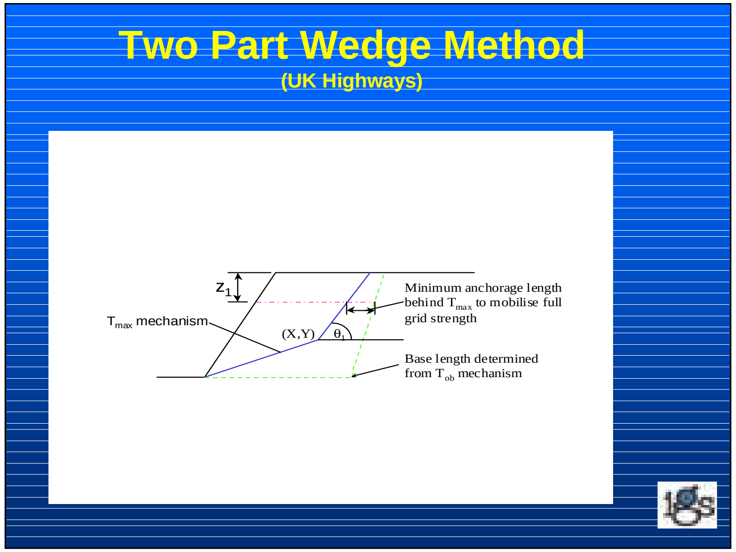
Is reinforcement required?

If so, **establish the size of the critical zone to be reinforced**. (In the FHWA method this is done by examining the full range of potential failure surfaces with FS's less than or equal to the slope's target FS, then draw an envelope around the back of all these mechanisms



Step 6

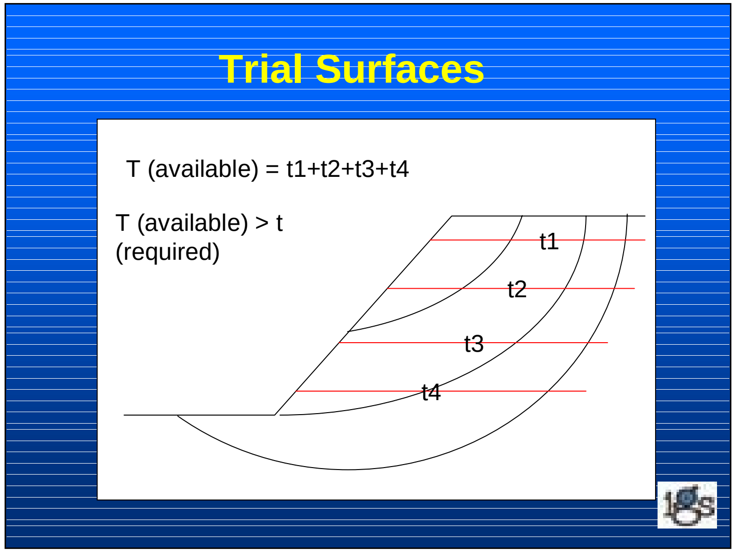
Design Reinforcement to provide for a stable slope. There are 2 fundamentally different ways to do this. The first is *directly* by a prescriptive design method. The second is to do it *iteratively* by a trial and-error method. Often both are necessary, the first method being used to arrive at an initial layout, which is then adjusted and improved by the second method. The principal difference between the 2 methods is that two different designers should arrive at identical solutions via the first method, but will arrive at two different solutions via the second method.



An example of a direct prescriptive method is that recommended in the UK Highway Agency's Advice Note HA68/94. The method is based on the 2 part wedge mechanism. The designer has to find the 2-part wedge mechanism sliding along the base of the reinforced soil zone which just meets the target FS without any reinforcement (the T_{ob} mechanism). This defines the width of the reinforcement zone at its base. Next the designer has to find the 2-part wedge mechanism which requires the maximum amount of reinforcement force (the T_{max} mechanism)

The T_{max} mechanism determines the number of layers of reinforcement that will be needed. The vertical spacing of the layers is then controlled by a fixed equation which sets them at spacings which decrease parabolically with depth. The length of the top reinforcement layer has to stick out beyond the T_{max} mechanism by the correct pull-out length. Then the length of each subsequent layer runs to an imaginary line which joins the end of the first layer to the back of the T_{ob} mechanism

Software programs exist such as *GCG-ReActiv* which can be used to do this type of design automatically for basic slope geometries and on the assumption that the underlying foundation soils are competent bearing materials. The direct method recommended by the US FHWA is similar to the HA68/94 method, but has a different rule for vertical spacing which results in either fixed vertical spacings, or groups of fixed vertical spacings.



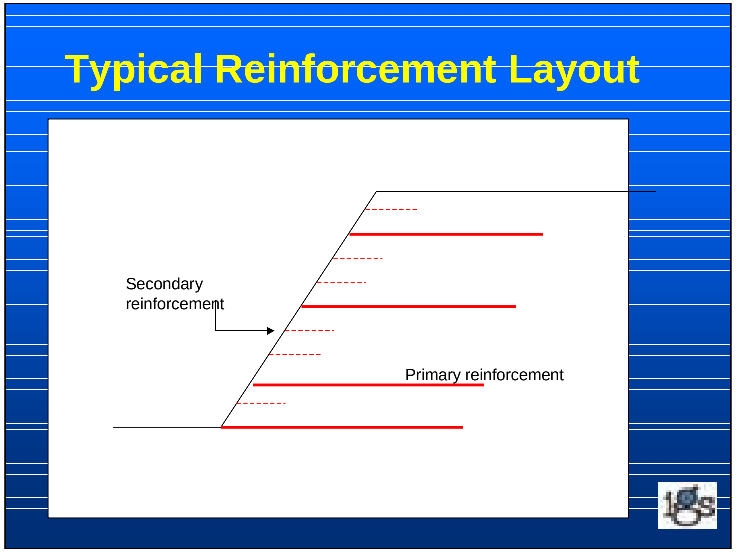
The iterative, trial-and-error method requires the designer to first provide an initial trial layout of reinforcement, and simple design charts or one of the direct design methods above can be used as a good starting point for this. Using both circular arc and sliding wedge methods, the designer then has to consider failure through the toe, through the face at various elevations, and deep seated below the toe. The aim is to check, for every conceivable type of failure surface, that the design layout satisfies the following simple rule:

$$T_{available} > T_{required}$$

If it doesn't, then the design layout has to be adjusted accordingly and the process repeated until a satisfactory design is arrived at iteratively.

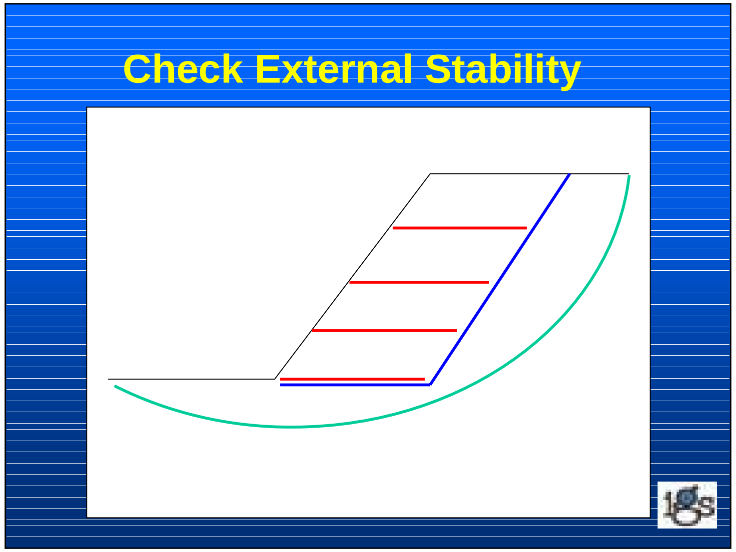
The designer will find that the most economical design is often governed by the local constraints, which will not be the same for each site. The most economic design is not necessarily always the one which uses the least amount of reinforcement. The overall dimension of the reinforced zone can be a controlling factor when excavation is involved.

Design measures which allow ease of construction at the expense of extra reinforcement can also be cost effective.



In both methods above, short lengths of intermediate reinforcement layers are often added to maintain a maximum vertical spacing of 600mm or so for face stability and compaction quality

For slopes with front face angles steeper than about 45°, special additional measures will need to be taken if vegetation is to be established. This can involve proprietary methods utilising special front face vegetation fabrics, incorporating sods of topsoil directly behind the front face, hydroseeding and a program of irrigation. Careful consideration should be given to this part of the design at the earliest design stage; it will be the only part of the structure seen by the client and the public, if the design is successful!



Step 7

Check external stability

If this has not already been done in the above step, this should now be done to check for:

•direct sliding

•deep-seated overall instability

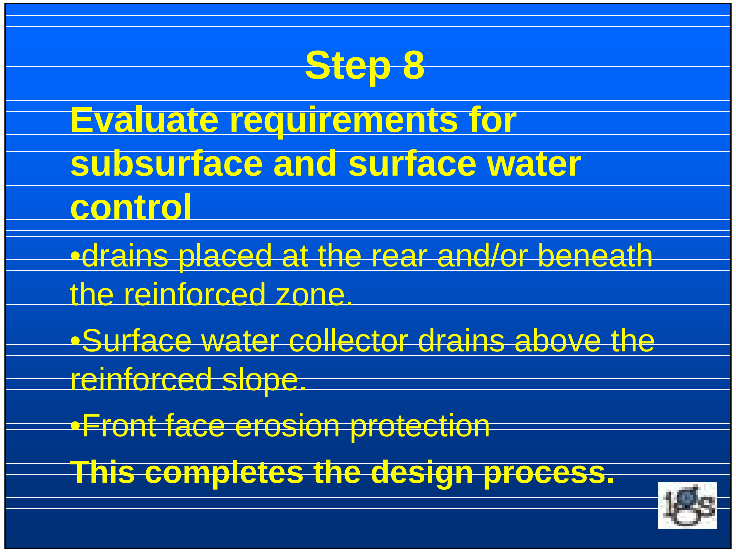
•local bearing capacity failure at the toe

•compound failure surfaces, which involve mechanisms which pass both through the reinforcement zone and the underlying material and/or the fill material behind the reinforcement zone.

•excessive settlement, using ordinary geotechnical engineering procedures.

•dynamic stability

Short term as well as long term stability should be checked.



Step 8

Evaluate requirements for subsurface and surface water control

•For **subsurface water control**, drains typically need to be placed at the rear and/or beneath the reinforced zone.

•**Surface water** control is typically achieved by collector drains above the reinforced slope.

•**Erosion protection** is typically provided by vegetation and/or synthetic permanent erosion control mats.

This completes the design process.

4. **Examples of installation of geosynthetics**

The following sequence is normally adopted during construction of reinforced soil slopes:

Site preparation. This includes clearing and grubbing the site, preparing a level subgrade, and proofrolling.

•Place and compact backfill on reinforcement . Fill is normally placed using a front-end loader operating on at least 150mm of previously placed fill. Lighter compaction equipment is appropriate near the face.
•Compaction control. The water content and fill density will normally need to be controlled within 2% of optimum moisture content and within 95% of maximum dry density.

Face construction. For slope angles steeper than 45° wrap around front face construction is normally required. The reinforcement is turned up at the face and returned typically 1m to 1.2m into the embankment below the next reinforcement layer. Temporary formwork is normally required to support the front face during this operation. For geogrids, a geotextile may be required inside the face to retain the fill material.

Continue with successive layers and drainage as required.

Examples of completed structures

After vegetation has become established.

Bridge Abutment

Geotextile wrap round face

Green faced steep slope