

Report on strengthened/reinforced soils and other fills

Sols et autres remblais compactés

Bodenverfestigungen

Foreword

This Published Document has been prepared under the direction of the Civil Engineering and Building Structures Standards Committee.

There has been an increasing use of soil reinforcement techniques in Britain over the past decade for a variety of applications from vertical walls and abutments through reinforced slopes to reinforced foundations. The modern impetus for the use of such techniques stems from the development of reinforced soil techniques for walls, abutments and near vertical slopes some 25 years ago, generally using metallic reinforcement, usually with modular concrete facing units. The development of the use of synthetic materials in the form of geotextiles in the civil engineering industry has been accompanied by their introduction into reinforced soil applications.

Reinforced soil techniques are now used extensively for a range of design lives and service requirements but are still in an active stage of development, particularly as far as the use of synthetics is concerned. It was felt that the absence of a British Standard covering the technique was preventing its wider development within the UK and possibly holding back British firms from competing successfully abroad.

BSI Committee CSB/56, which was formed to look into the matter, appointed a drafting contractor to carry out a Stage I Investigatory Report into current practice, with the objective of preparing recommendations on the scope of any code of practice which could be prepared. The route of appointing a drafting contractor was chosen in view of the perceived urgency in issuing a code of practice, if indeed the Stage I work would confirm that adequate practice exists.

Based on the findings of the Investigatory Report, it was decided to proceed with the preparation of a code of practice on the subject. This Published Document, which preceeds the publication of the code, is itself based on the findings of the Investigatory Report and its purpose is to provide information in support of the code.

It is hoped to publish the code within a few years.

The full list of the organizations who took part in the work of the Technical Committee is given on the back cover.

The Chairman of the committee was Mr N Paine and the following were responsible for the drafting of the Published Document.

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0 Introduction

The increasing realization by the civil engineering industry of the usefulness of the technique of reinforcing soils or other fills by the inclusion of materials of various types has stimulated a study of current practice, with a view to the drafting of a British Standard code of practice. This document summarizes the work performed to date and provides information on the proposed contents of the code.

Reinforced soil in its widest definition is a composite material comprising the soil itself and reinforcing elements acting in tension and/or shear. In this Published Document, the term 'soil' is taken to include suitable fills, except where otherwise stated. The soil to be reinforced can be imported or in-situ, and the reinforcing elements are metals or plastics, working essentially in tension. An analogy to the behaviour of reinforced concrete can be drawn.

Reinforced soil can be used in a number of applications, e.g. vertical walls, steep slopes and abutments. In these forms it is often more appropriate than conventional methods of soil retention, whether for temporary or permanent structures. In particular, when used over poor ground, its inherent flexibility compared with classical structures can avoid the need for piled foundations or other ground treatments. It can be applied as excavation progresses in the case of in-situ structures. Various applications for repair or raising of slopes are also possible.

Another distinct application is in the form of foundation reinforcement, usually to embankment structures over poor ground, or, potentially, to light industrial structures. Various techniques are possible, depending upon the particular ground conditions, either using a basal reinforcement at the interface between the embankment and the foundation strata, or a mattress structure combining cells of reinforcing material with granular fill, or by constructing a reinforced soil raft.

In the United Kingdom the only officially published design standard is the Department of Transport Technical Memorandum BE 3/78 'Reinforced Earth Retaining Walls and Bridge Abutments for Embankments'. This Technical Memorandum is written for very specific applications and a specific design life. Other designs have used proprietary methods.

A number of design methods have been used for slopes and for foundation applications. It is considered essential that design methods are unified as much as possible, and that in the proposed code, recommendations are given for consistent approaches throughout the whole range of applications. In order to complete the design guidelines, recommendations are needed on the assessment of the materials and their behaviour in the environment and on construction practice. Each of these items should be related to the end-use requirements of the structure concerned.

In view of this, and in particular because of the advent of new materials for use as the reinforcing medium and the desirability of being able to use a range of fill

materials, the need for development of a code of practice was identified. Although the use of reinforced soils is still developing, it was recognized that significant advantages would accrue from the production of the code within a relatively short time. A drafting contractor was appointed to prepare state of practice papers on behalf of BSI Technical Committee CSB/56 and to make recommendations on the contents of a code of practice.

The recommended contents of the proposed code include a section on the concepts and fundamental principles of reinforced soil and in which types of soil, fill and reinforcement will be described and classified and relevant testing requirements, standards and specifications will be referenced. A further section of the code will relate more specifically to design, construction and maintenance of structures. This section will include a review of all the environmental aspects that need to be taken into account. Particular consideration will be given to the designer's end-use requirements, such as design life and consequences of failure.

Finally, emphasis is given to the importance of quality control. Where appropriate quality assurance programmes are available, their usefulness to the practice of soil reinforcement is referenced.

This Published Document provides a brief review of design guidelines to be adopted in the code, and of the present views on the utilization of various types of material.

1 Scope

This Published Document provides a summary of the key findings of the Investigatory Report into current practice in design, specification, construction and maintenance of reinforced soil structures enhanced in strength by the inclusion of metals, plastics (polymers, glass reinforced) and tensile materials of varying extensibilities. For the purpose of this study the term 'soils' is deemed to include other fills such as waste products from mining or other industries.

The purpose of the Investigatory Report was to identify current practice and make recommendations on the contents of a new code of practice. This Published Document includes an outline of the recommendations made.

The Investigatory Report was prepared on behalf of BSI Technical Committee CSB/56, with whom it was discussed in detail. However, a great deal of information that was collected on behalf of the Technical Committee was provided on the understanding that it was to remain confidential to the committee. This Published Document therefore does not provide detailed notes of discussions, but does incorporate the conclusions.

NOTE. The titles of the publications referred to in this Published Document are listed on the inside back cover.

2 What is reinforced soil?

Reinforced soil is a composite of soil and tensile or shear resistant inclusions which function through the agency of direct soil-reinforcement interaction to produce a material having a performance superior to that of soil alone. Any system designed to exclude this interaction, or any system which aims to improve the soil by means of a chemical action or by utilizing compression members, is not regarded as reinforced soil for the purposes of this Published Document.

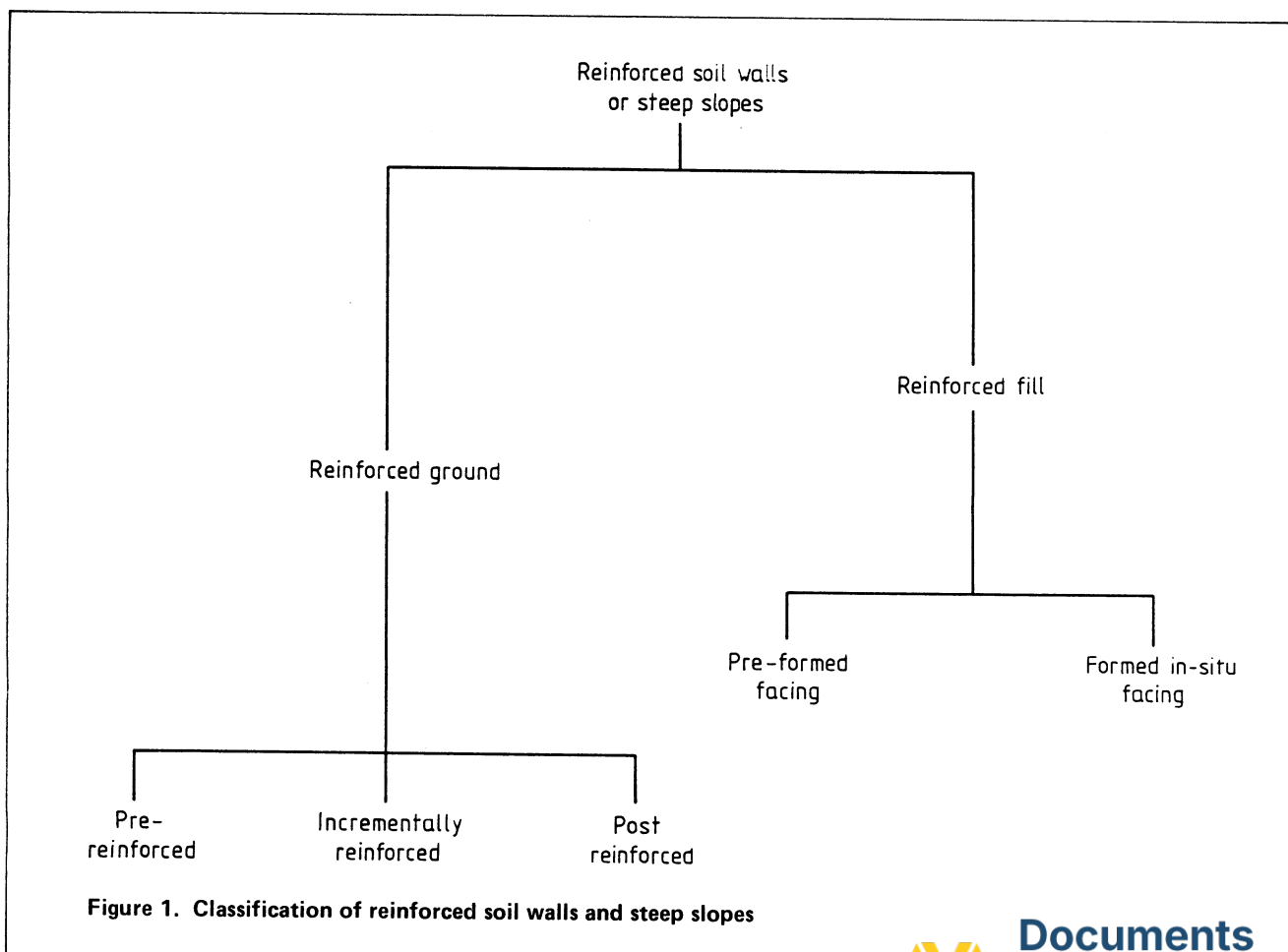
It is useful to consider two general classes of reinforced soil, as depicted in figure 1, with particular reference to walls and steep slopes on competent foundations.

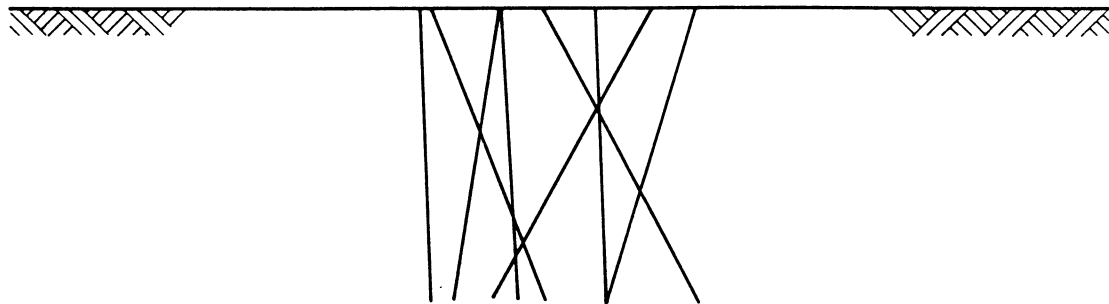
Reinforced ground is in-situ material into which reinforcement is introduced. The pre-reinforcement of the ground can be effected by installing a network of small diameter piles to form a strengthened mass, and subsequently excavating the adjacent ground, as shown in figure 2. During construction an incremental technique can be used, for example by introducing soil nails into the ground as excavation proceeds (see figure 3). Vertical or steep sided cuttings which may become unstable may be post-reinforced using soil nailing.

Fill structures, i.e. steep embankments, walls, etc., are generally reinforced as they are constructed, with the incorporation of strips, bars, sheets, grids or filaments. Reinforcement may be used in layers to reinforce the fill structure itself (see figure 4), or it may be placed at the base of a fill structure to provide tensile strength along the interface with the foundation soils. In the former case, the fill is usually faced. Preformed facing units are usually employed for permanent vertical structures, and are normally partial height panels which also act as a climbing formwork. Full height panels have also been used. Formed in-situ soft facings are by necessity partial height, and construction using this technique may require the use of temporary formwork. These 'soft facings' usually comprise geotextile fabrics or geogrids, and they may be enhanced by a finish such as shotcrete, masonry or preformed units that do not provide a structural function.

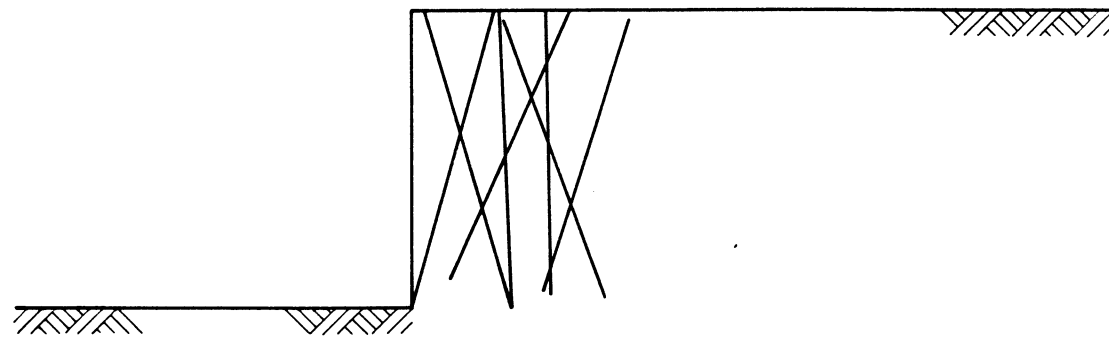
A technique that may be analogous to soil reinforcement when applied to natural or man-made slopes is vegetation, where the roots of trees, shrubs or grasses may be considered to reinforce the upper soil layers.

The proportion of reinforcing elements required in the composite material is very small. Typically in fills, the proportion is between 0.05 % by volume for metallic strip reinforcement and filament elements and about 0.5 % by volume for layered geotextile sheets.



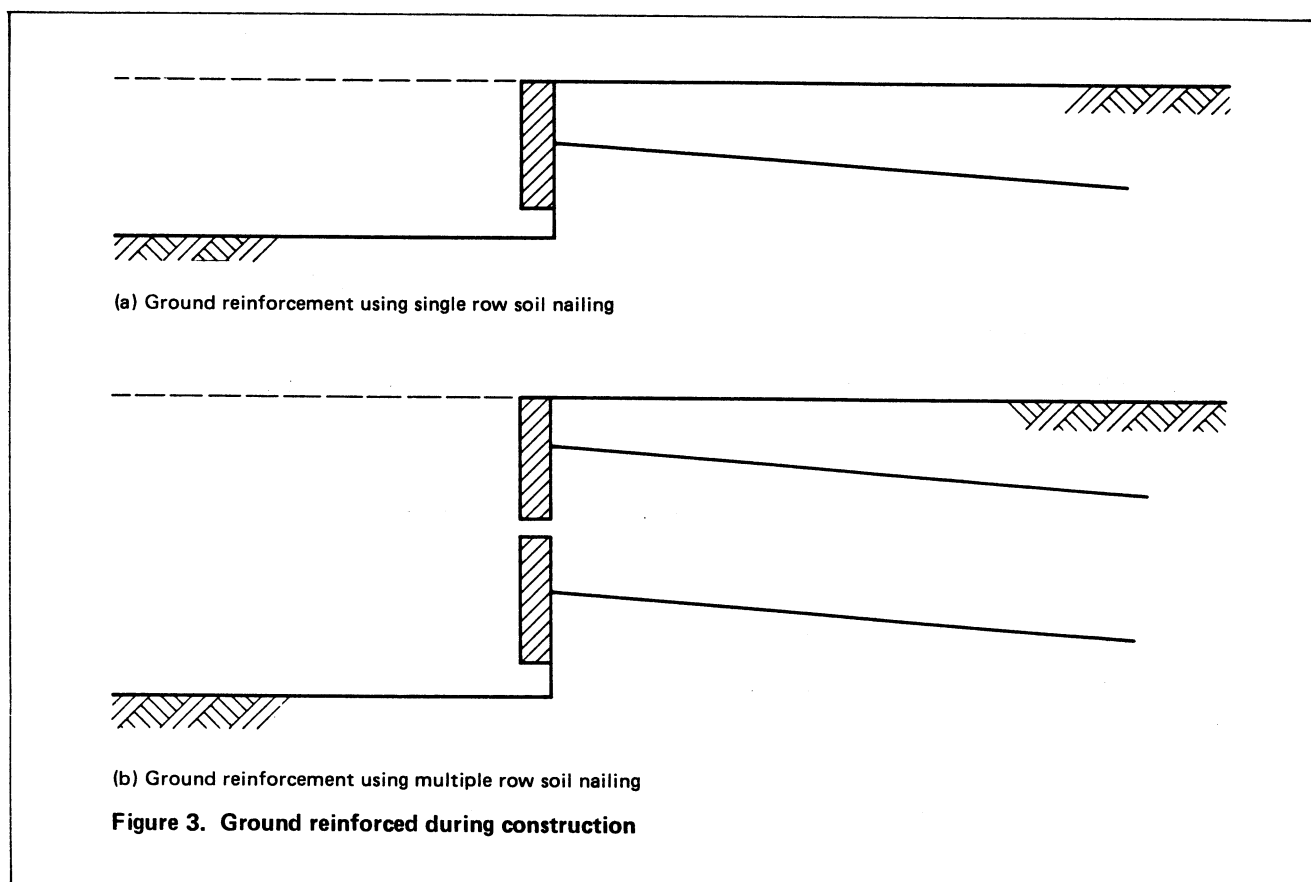


(a) Installation of reinforcement prior to excavation



(b) Ground retained by reticulated pile wall

Figure 2. Ground reinforced prior to construction



3 Why is reinforced soil useful?

Reinforced soil may be used in a variety of applications to replace conventional structures, to reduce land take or to build flexible structures over poor or soft foundation materials.

Reinforced soil walls are commonly used for some form of soil retention. An example is shown in figure 4, where a vertical face constructed without reinforcement would fail in time, depending upon the value of the soil parameters. However, if the soil in the region of the face is reinforced, it will form a stable mass which can support the unreinforced soil behind it. The same principle applies to reinforced slopes constructed to an angle steeper than their angle of internal friction.

The advantage of a reinforced fill retaining structure over a reinforced concrete wall is that the inherent resilience and flexibility of the composite enables construction to progress with a minimum of treatment of the foundation soils where subsequent movements are likely. In addition there is less need to excavate outside the toe of the wall as compared to a reinforced concrete cantilever wall, and this may reduce the working space requirements.

Using a similar configuration in cutting, where soil nailing is employed, reduces yet further the working space requirements.

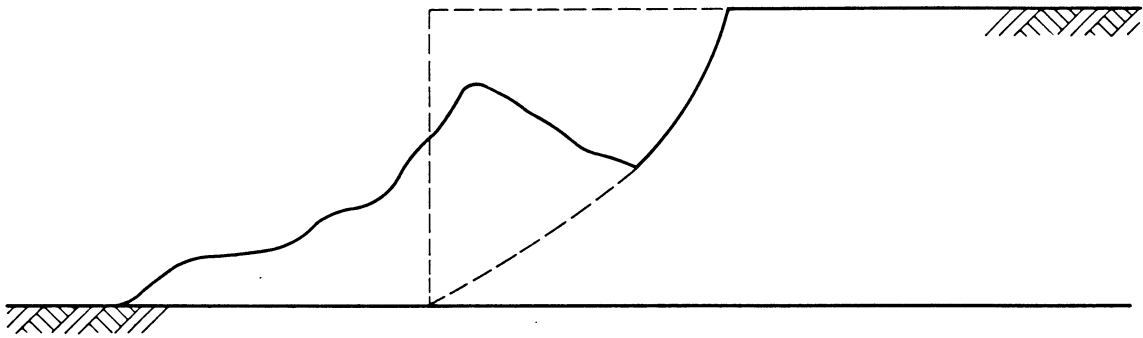
Reinforced soil embankments on competent foundations are used to provide steep side slopes and thus reduce land take.

Reinforcing techniques for the foundation of flexible structures are useful in assisting rapid construction over poor foundation strata where conventional construction could result in failure, as illustrated in figure 5. In such uses they, incidentally, act as a temporary reinforcement to support construction traffic.

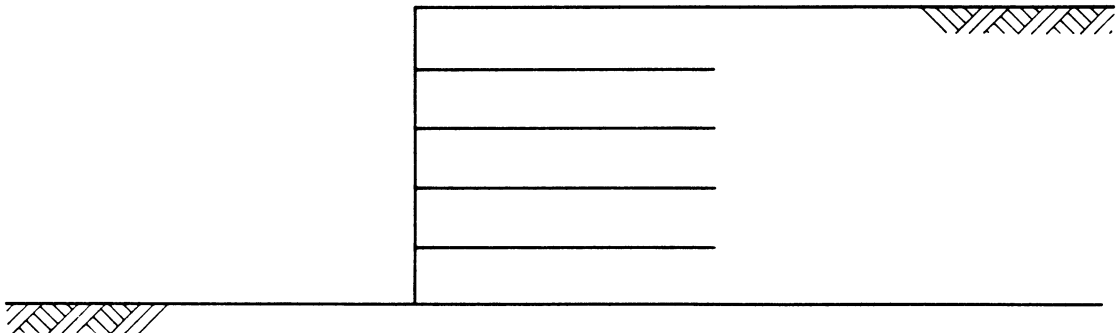
Reinforced soil involves the use of preformed components and so construction times are often much shorter than for conventional structures. Many reinforced soil techniques involve the use of easily transported materials which facilitate construction in remote areas or locations with difficult access.

Generally, therefore, reinforced soil is useful because it is a relatively straightforward construction technique, once experience has been gained in its use. The finished product provides a strong composite that can accommodate a certain amount of movement.

As new materials, particularly the various synthetic reinforcements, and new construction techniques develop, more economical structures and novel uses will undoubtedly result.

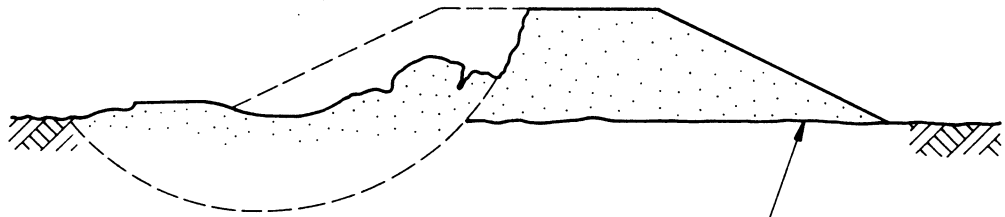


(a) Without reinforcement



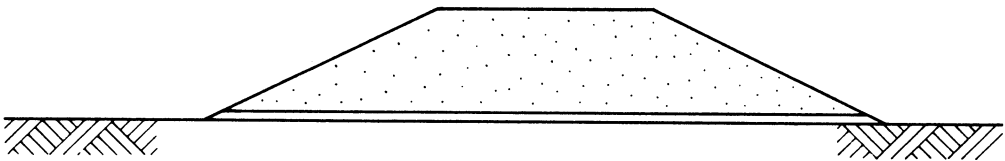
(b) With reinforcement

Figure 4. Reinforced soil walls



(a) Without reinforcement

Soft clay foundation



(b) With basal reinforcement

Figure 5. Short term stability of basal reinforced embankment

4 Basic principles

The behaviour of reinforced soil is essentially a function of the stress distribution and interaction between the reinforcement and the soil. There is some similarity to the principle of reinforced concrete, in that the reinforced mass may be considered a composite material with improved properties, particularly in tension, compared with the soil or concrete alone.

The influence of reinforcement in the soil may be illustrated by considering a simple, hypothetical, model. Figure 6(a) shows an element within a soil mass (in general it will be a plane strain condition), which is subjected to a uniform vertical stress. As a consequence of this stress, the element is deformed and mobilizes a stabilizing horizontal stress in the soil; the magnitude of this stabilizing stress is directly related to the lateral deformation of the element.

If the same element of soil is reinforced (see figure 6(b)), the interaction between the soil and the reinforcement results in a tensile restraining force within the reinforcement. This tensile force, combining with the induced horizontal stress in the soil, maintains the equilibrium of the element. The effect of the reinforcement on the stability of the element is primarily a function of the lateral strain, reinforcement stiffness and soil type. Hence the objective of reinforcing soil is to transfer the majority of the horizontal confining stress into the reinforcement to create a stable soil mass. This behaviour was first described by Vidal (1963).

Although the direct stresses acting in conventional soil structures are compressive, one set of principal strains may exhibit tensile strain increments. A simple example of this is the active wedge of soil behind a conventional retaining wall where the horizontal soil strain increments would be tensile if the active case were allowed to develop from a fully propped condition (see figure 7). If sufficiently strong and axially stiff reinforcement is installed in the soil to align with the tensile strain directions, then a tensile strain, and therefore tensile force, will be transmitted from the soil to the reinforcement. The method by which forces and strains are transmitted from the soil to the reinforcement is effectively soil-reinforcement friction (or adhesion in the case of undrained loading of clays). Since axially stiff reinforcement is used, this limits the magnitude of tensile strain in the soil and thereby reinforces it.

Early design principles considered the horizontal equilibrium of a reinforced wall. Two approaches were explored (Schlosser and Vidal 1969):

- (a) Coulomb wedge method;
- (b) Rankine method.

Using the notation shown in figure 8, both approaches approximate to the following equations for the maximum tensile force per metre run T_m in the bottom layer:

$$T_m = K_a \gamma H S_v \dots\dots\dots (1)$$

where

K_a is the coefficient of active earth pressure of fill in the wall;

γ is the unit weight of the fill;

H is the total height of the reinforced wall;

S_v is the vertical spacing of the reinforcement layers.

or more generally:

$$T_m = K_a \sigma_v' S_v \dots\dots\dots (2)$$

where

K_a is the coefficient of active earth pressure of fill in the wall;

σ_v' is the effective vertical pressure due to the fill in the wall;

S_v is the vertical spacing of the reinforcement layers.

These first analyses were extended to take into account the effects of the horizontal thrust generated by the fill behind the reinforced soil wall. In figure 9(a), the backfill is considered to impose a horizontal thrust P_a at one third the height of the wall. Two alternative stress distributions were considered: the trapezoidal stress distribution, (see figure 9(c)) and that proposed by Meyerhof, (see figure 9(d)) (Schlosser and Vidal 1969).

For walls where the height approximately equals the length of the reinforcement and good-quality granular backfill is used, the methods predict maximum vertical stresses, near the face of the wall, which are some 25 % and 10 %, respectively, greater than the vertical overburden pressure, (see figure 9(b)).

These principles describe the mechanism of bond between the reinforcement and the fill. Observations on the performance of full-scale walls have provided information on the distribution of the tensile force along metallic reinforcing strips and the mechanisms involved (Schlosser and Long 1974).

When the tensile force in a reinforcement is measured, it is found to vary along the length of the reinforcement. This is illustrated for a vertical wall in figure 10. It follows from this that the shear stress, τ , which transmits forces between the soil and the reinforcement, also varies along the length of the reinforcement. Indeed, as can be seen in figure 10, the shear stress actually changes direction between one end, (in the restraint zone) and the other end (in the active zone). The relationship between reinforcement tension and soil-reinforcement shear stress can be deduced from figure 11 which shows an incremental length of reinforcement of unit width and length $d/$.