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Lateral earth pressures acting on the facing units of reinforced earth structures

Poussées exercées sur le parement des ouvrages de soutènement en terre armée

Les poussées latérales exercées par le remblai d'un ouvrage de soutènement en terre armée dépendent fortement du degré de compactage à la construction. La plupart des critères utilisés pour le dimensionnement des murs de soutènement, ouvrages en terre armée compris, ne tiennent aucun compte des effets réels des engins de compactage. L'article passe en revue les facteurs qui influencent la génération des poussées latérales dans le remblai armé, et illustre les avantages qu'on pourrait obtenir en appliquant au parement un petit mouvement latéral après compactage. On montre en particulier comment réaliser ce mouvement dans le cas de grands ouvrages.

The majority of modern earth retaining structures are designed in accordance with the classical theories of Coulomb (1976) and Rankine (1857), although it is known that the assumed stress states do not usually reflect field conditions, Casagrande (1973), Jones (1973). Several attempts have been made to introduce improved design theories, but their adoption has not been widespread due in part to the reluctance of designers to incorporate refinements into design which are negated by any one of a number of construction factors outside their control.

The influence of the Coulomb and Rankine theories is deeply entrenched into the design methods proposed for reinforced earth structures, Mamujee (1974), Broms (1978), Juan and Schlosser (1978), although the latter criticise their use and suggest a new method of limit analysis. A notable exception to the use of Coulomb and Rankine stress states is provided by Bassett and Last (1978) who argue that the action of tensile reinforcement is to surpress the natural dilation in areas of tensile strain and to re-arrange this displacement field; arguably this approach may provide the basis for future design methods supplementing those based on Coulomb and Rankine.

In a critical review of the classical theories Terzaghi (1936), has illustrated the physical meaning of the assumptions that have to be made with their use. Adopting this procedure it is worth noting that the development of the Ka Rankine state of stress in a 10m high wall using reinforcement 10m long would require a lateral extension of the reinforced earth mass of approximately 150mm. Movements of this magnitude are not realised in practice. On the other hand the development of the limiting Coulomb pressure is dependent upon the retaining wall being permitted to yield a small distance. In contrast to Rankine's assumptions, this lateral yield of the wall produces only a localised transition from the natural at rest state. However, due to the usual way in which reinforced earth structures are built the possibility of even a small yield of the facing taking place after the backfill has been placed is negligible.

Effects of Compaction.

The preceeding argument suggests that at rest (Ko) pressures should predominate in the backfill and that the designer should be particularly concerned with the lateral earth pressures generated during construction, particularly those caused by the compaction plant. Sowers et al (1957) have shown that residual lateral pressures generated during compaction are significant. This finding has been confirmed by measurements of the earth pressures acting against large retaining walls, Sims et al (1970, 1974), Bridge Abutments, Broms and Ingleson

(1971), Jones and Sims (1975), and Reinforced Earth Walls, Findley (1978). Analytical methods have been proposed to cater for stresses including the use of finite element methods, Aggur and Brown (1974). A recent development has been the introduction of a simple empirical method for use in the design office which shows good agreement with practice, Ingold (1979a).

Studies of the effects of the dynamic loadings of soils are scarce, although it is an accepted principle that shear strain is the primary factor which controls compaction, Youd (1972). Since shear strain is likely to be susceptible to the weight of the compacting plant it follows that the larger plant will produce greater degrees of compaction, a point confirmed in practice, Whiffin (1957). Further, the degree of compaction is dependent upon the number of passes of the roller, D'Appolonia et al (1969) although the effects are progressively less effective with each pass, a point which argues in favour of a method specification. Another point which is usually ignored is that the intensity of lateral soil pressures is dependent upon the presence of end restraints such as abutment wing walls, the shape of the fill wedge and the direction of the roller (the pressure wave normal to a roller is completely different to that acting in the perpendicular direction, only if the fill is compacted using a regular criss-cross pattern will an isotropic value of lateral stress $Ko = \sigma_h/\sigma_v$ be developed). The compaction of the fill in a reinforced structure is usually accomplished using a roller running in a direction predominantly parallel to the face of the structure. As a result residual lateral pressures parallel to the face of a wall are likely to be considerably higher than those parallel to the reinforcement.

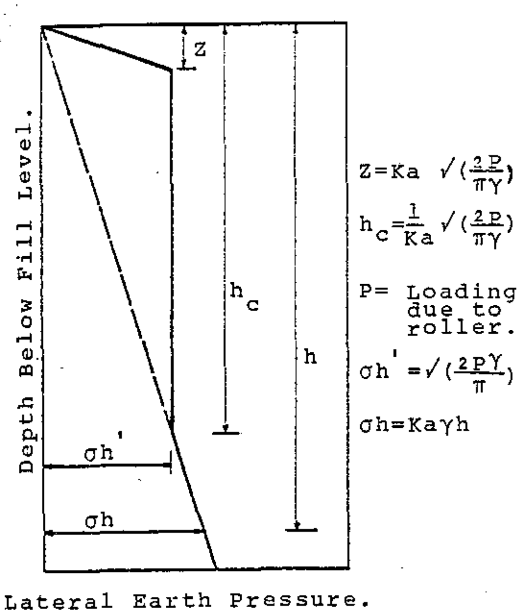

Fig. 1. Compaction Pressures, (Ingold (1979a)).

The action of the reinforcing members during compaction will be to resist the tensile strain in the fill. Tensile stresses will develop in the reinforcment proportional to the residual lateral pressure acting normal to the face of the wall. The intensity of the lateral pressure generated by compaction can be derived from the expression developed by Ingold (1979a), Fig.1.

Influence of the Reinforcement on Compaction

Although reinforced earth is normally assumed to be two dimensional for the purposes of design it has been shown that it behaves in a three dimensional manner dependent upon the intensity and distribution of the reinforcement, Smith (1977). This point is further demonstrated by comparing the distribution of tensile stresses in the reinforcement of two near identical full size structures constructed using the same technique, materials and fill. The only difference being the width and spacing of the reinforcement, Fig. 2, Mallinder (1978). The results show that where little reinforcement is provided in terms of a restricted cross section area, (used to encourage high reinforcement stresses), the zone of peak tension is close to the face and high lateral pressures are evident against the facing. Mallinder describes the reinforcement in this situation as acting in a way similar to that of anchors. Interestingly, where the reinforcement is not connected to the facing the zone of peak tension moves away from the face and the tension in the strip near the face will be minimal as will be expected, Fig. 2. In the other experimental wall containing a more conventional distribution of reinforcement the intensity of stress on the facing/reinforcement connection is very low in accordance with the intentions of this form of construction, Jones (1978).

An explanation for the difference in lateral pressures acting on the face in Fig. 2 is that in the case of the wall with a normal distribution of reinforcement the reinforcement is sufficiently distributed to influence the complete mass of fill. Thus, as the reinforcement is designed to provide internal stability against gravitational forces so it is also capable of restricting the influence of the compaction plant. The presence of reinforcement raises the threshold for the lateral pressure which can be generated in the fill as is demonstrated by Iwasaki and Wakanabe (1978) who have used reinforcing nets specifically to increase the stiffness of railway embankments.

Terzaghi has shown that the stiffer the fill the smaller is the movement required to reduce the lateral earth pressure at the face to a minimum. In a well compacted fill this movement is in the order of 0.0005 H (H = height of wall). In a conventional retaining wall such a movement is tacitly

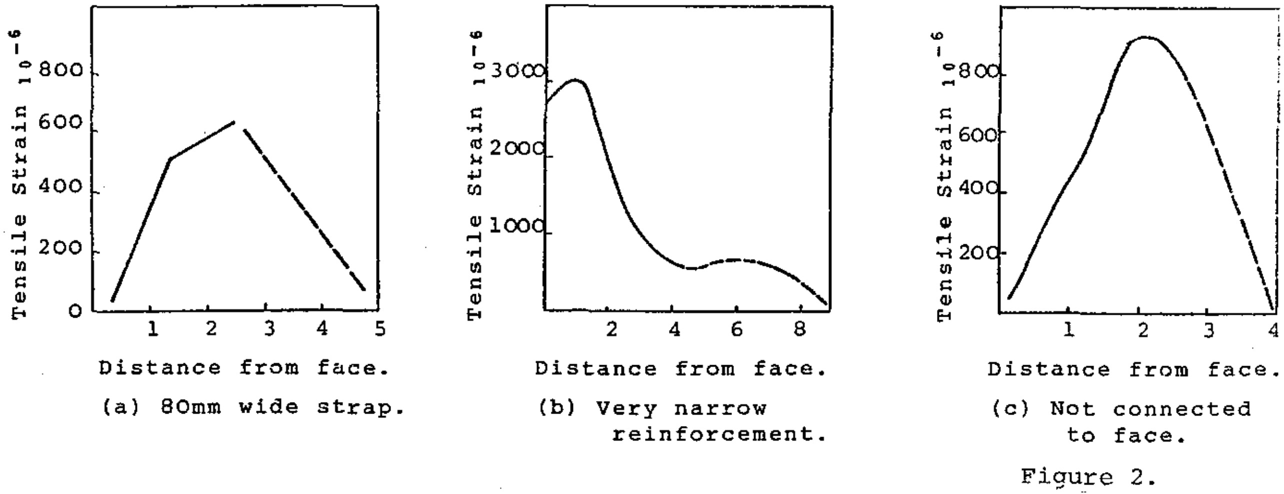

Fig. 2. *Strain Distribution Along Reinforcement Under Various Conditions. (Mallinder, (1978)).*

assumed to take place by most designers when designing for the Ka condition. Lateral movement of the facing of reinforced earth structures after construction is usually impossible due to the fixity of the connection between the reinforcement and the facing. Consequently the connection of the facing to the reinforcement has to be designed to cater for the maximum tensile stresses, Memorandum BE 3/78. Indeed, in the upper part of the structure, Fig. 1, it can be argued that the Ko conditions should be employed in the design, a point that has been recognised in the past. The result is that the design of the reinforcement against tensile failure is determined by the strength of the reinforcing strip at the connection of the facing where the presence of bolt holes in the reinforcement produces stress raisers.

If the facing could move laterally a small distance after construction then the lateral pressures acting on the face would be reduced to the Ka (Coulomb) condition and the design criteria for the reinforcement end connections would be reduced. This is confirmed by Naylor (1978) in an analysis using a facility for "slip strip" of reinforcement in which a degree of slackness at the connection was simulated. The differences found by Naylor between the rigid and the slack connection is shown in Fig. 3. In addition slackness at the connection causes the zone of peak tension to move further from the face which is in agreement with the tension distribution shown in the unconnected reinforcement by Mallinder.

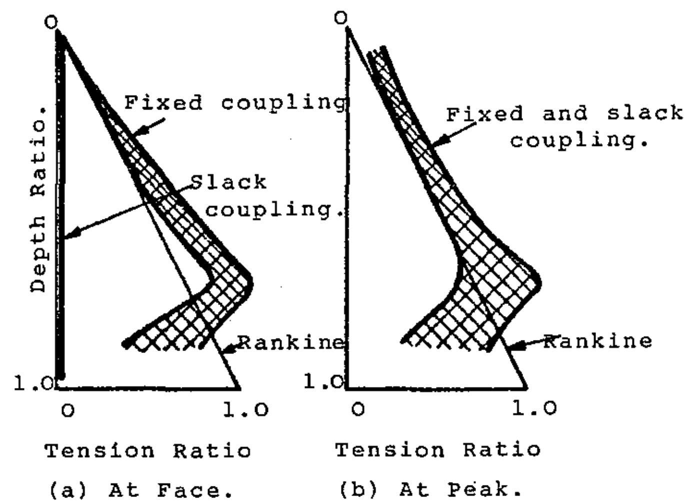

Fig. 3. *Effect of Slackness in Reinforcement/Face Coupling. (Naylor 1978).*

Collapsible Coupling Earth Structure.

A method whereby slackness in the reinforcement/facing coupling can be achieved is shown in Fig. 4(a), 4(b) in which the following construction sequence is used:-

(i) Erect and prop the facing unit.
(ii) Place layer of fill and compact.
(iii) Place and couple the first row of reinforcing strips (the coupling used incorporates a collapsible element capable of allowing a small finite movement).
(iv) Repeat (ii) and (iii) as necessary.
(v) Remove prop.

Theoretically this principle can be used with any size of facing element. However cost exercises show that the use of substantial members up to 6 to 7m tall provide the most economical solution. A member formed from double 'T' pre-tensioned floor or bridge deck units 1200m wide, standing on edge, is particularly attractive, since this product is readily available in quantity, requires no development and provides a most satisfying appearance. There is abundant scope for their application on bridge abutments and small/medium size walls.

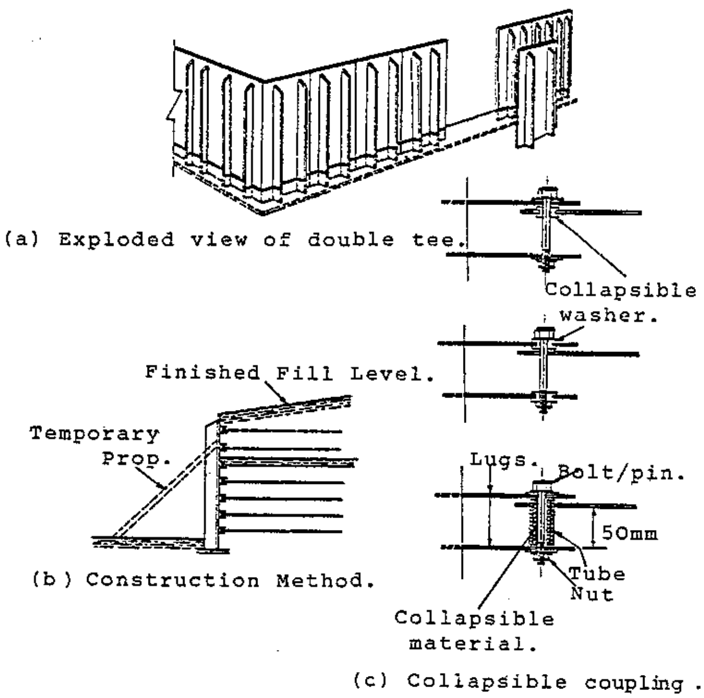

Fig. 4. Collapsible Coupling Earth Structure.

To gain optimum benefit from the system, good uniform compaction of the reinforced fill is required. This can be achieved without distorting the face by the props providing support to counter the lateral earth pressure generated during compaction. When the props are removed the facing is free to move forward to the limit of the collapsible element of the coupling detail. The collapsing element of the coupling can be achieved in a number of ways, Fig. 4(c). An associated benefit dervied from the ability to compact the reinforced fill to a uniform density is a reduction in the risk of corrosion of the reinforcement in the high risk area adjacent to the facing units, King (1978).

Finally, the double'T' units need to be linked together to prevent them from spreading in the plane of the wall. One method of achieving this is to construct whalers across the back of the units attached to the connecting lugs in such a manner that they act like Tsagareli's platforms, Bolton et al (1978). Arguably the residual lateral pressure acting against the facing at any level would then be reduced to Ka (Coulomb) γh_v, where h_v is the vertical spacing between reinforcing layers and γ is the fill density.

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