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# Reinforced soil formed using synthetic polymeric anchors

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ABSTRACT: The construction of reinforced soil structures using anchors as reinforcing elements has been pioneered in Japan, the United Kingdom and the United States. The technique, which is frequently referred to as Anchored Earth, provides technical benefits over conventional reinforced soil systems based upon the use of strip reinforcement. Current earth anchors used in reinforced soil are formed from steel or polymer ties supporting concrete deadman anchors. The steel anchors can be costly to manufacture and are susceptible to corrosion, whilst the concrete anchors are heavy and require special facing units.
A new anchor formed entirely from synthetic polymeric material has been developed which can be used with all existing reinforced soil facing systems. The paper describes the new anchor, provides details of design analysis and identifies the technical benefits and economic advantages offered by the new technique.

## 1 INTRODUCTION

To date, most reinforced soil walls have been built using steel strip reinforcement which relies upon friction to develop adhesion with the soil fill. An improvement with respect to the adhesion characteristics of strips is provided by grids which offer resistance to pull-out failure by the use of transverse members providing interlock with the soil. Similarly fabrics provide better adherance characteristics than strips due to the greatly increased surface area provided. A direct improvement in pull-out resistance of soil reinforcement can be achieved by forming the reinforcement as an anchor. Anchored earth systems have been developed from a combination of the techniques used in reinforced soil and soil anchoring. A range of different anchored soil systems exist, including those illustrated in Figure 1, which shows methods originating from different parts of the world. The Japanese system exploits the local passive resistance generated by small rectangular plates, Fukuoka (1980), Figure 1(a). The first anchor developed in the United Kingdom for vertical walls was formed from a steel reinforcing bar shaped into a triangle, Murray and Irwin (1981), Figure 1(b). The Austrian method uses polymeric strips formed into loops connecting concrete wall blocks and semi-circular anchors formed from mass concrete, Brandl and Dalmatiner (1986), Figure 1(c). In addition the anchored earth concept can be adapted for slopes by using waste automobile tyres. In this method polymer strips are used to connect the anchors formed from used tyres from which one side wall had been removed, Dalton (1982), Figure 1(d). In the United

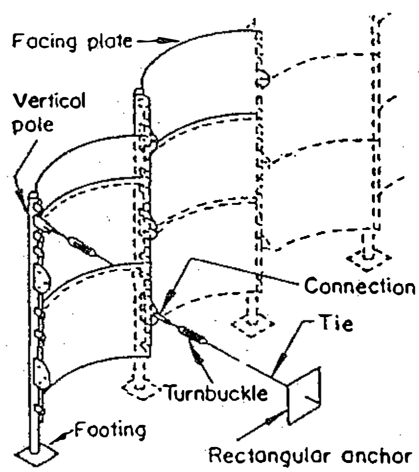



Fig.1(a) Use of rectangular plate anchors (Japanese system)

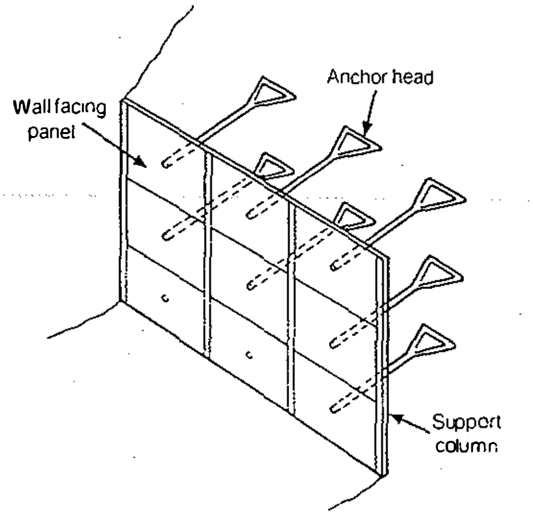



Fig.1(b) Use of triangular steel anchors (UK, TRRL system)

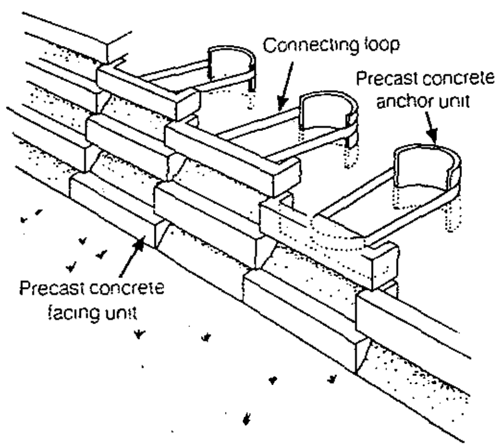



Fig.1(c) Use of concrete blocks, polymer strips and anchors (Austrian system)

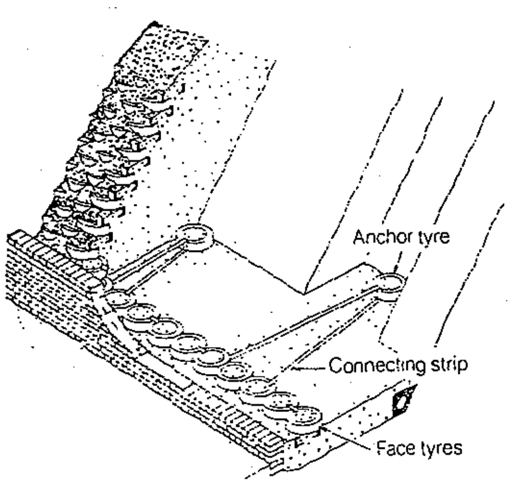



Fig. 1(d) Use of waste tyres and geotextiles (UK)

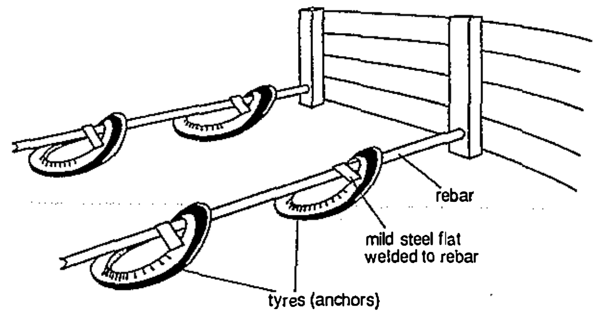



Fig.1(e) Use of waste tyres and steel bars (Caltrans USA)

States the California Highway Authority, Caltrans, has developed a system of Tie Anchored Timber Walls (TAT) which are used for low cost walls. These use timber facings and metal ties connected to the side walls of tyres to form multiple anchors, Jones (1991), Figure 1(e). Anchored soil walls can be shown to have several advantages over conventional reinforced soil structures employing strip reinforcements. Unlike strip reinforcement, whose carrying capacity relies on friction with the surrounding fill, an anchored soil system derives its resistance to pull-out mainly from the bearing resistance in front of the anchor element. A major benefit of using anchored soil is that it is possible to relax the criteria associated with the selection of fill materials, and to use marginal fill materials without concern for loss of stability or serviceability. Structures built using anchor reinforcement can withstand earthquakes and unlike structures reinforced with plane strip reinforcement are not susceptible to failure as a result of vibrating loads, Al-Ashou (1981).

The tension member connecting the anchor to the facing does not need to be wide and thin but can be circular or square. This can have practical advantages in that a circular member provides the most efficient section in respect of durability, whilst any protective coating is reduced to approximately a fifth because of the reduction in surface area, with no loss of effectiveness. This can represent a significant saving as the volume of sacrificial material provided in some reinforcing members is greater than the volume required to provide resistance in tension.

Just as anchor systems provide benefits with respect to strip reinforcement so the use of polymeric reinforcements can provide advantages over conventional metallic reinforcements. A number of polymeric reinforcing materials are more durable than steel and permit the use of fill materials not possible with the metallic reinforcements. As an example pulverised fuel ash (PFA) can be used with polymeric material but is excluded from use with steel reinforcement, BS8006 (1991). Another advantage is that being lightweight, polymeric reinforcement can provide logistical advantages associated with easy handling and reduced transport costs.

## 2 POLYMER ANCHORS

To date anchor systems have been formed from steel or from polymers used in conjunction with steel or concrete. Recent research in the United Kingdom aimed at optimising the benefits of the use of polymeric reinforcements and the concept of an anchor, has produced a new anchoring system (PEAN) based upon the use of polymeric materials alone. The system is formed from polymeric tubing used as an anchor, which is connected to the facing unit by polymeric ties or strips, Figure 2.

To illustrate the effectiveness of the system large scale pull-out tests have been undertaken with and without the transverse tube anchor. In the conventional, non anchor, method proprietary polymeric reinforcing straps, Paraweb, grade 100 were used. Paraweb is formed as a tape made from polyester fibres encased in a polyethylene sheath, Lawson (1991). In the anchor method, a 20 mm diameter high density polyethylene pipe was used to form a single transverse anchor held in place by the same proprietary reinforcing straps. Tests were performed using Leighton Buzzard sand grade 14/25 as soil fill in which the anchors were subjected to vertical pressures of 20, 40 and 60 kN/m$^2$. A range of tests were carried out on similar sized anchors each having different axial stiffnesses.

Typical results of the tests are presented in the form of a plot of pull-out force against displacement of the ties at the front of the pull-out box, Figures 3 and 4, together with a plot of the anchor forces against displacement of the middle of the hollow pipe anchor, Figure 5.

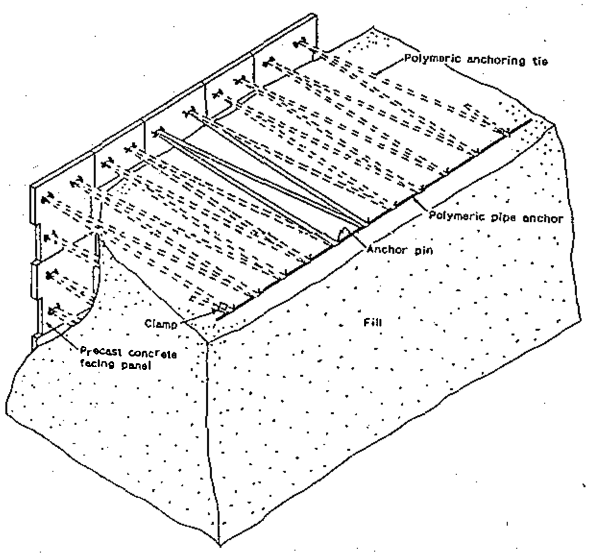



Fig.2 Polymeric earth anchor system adopted for use with the Webson system

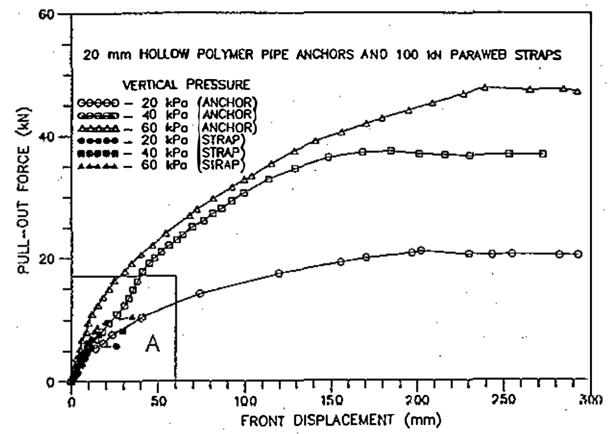



Fig.3 Comparison of pull-out force for tests with and without anchor

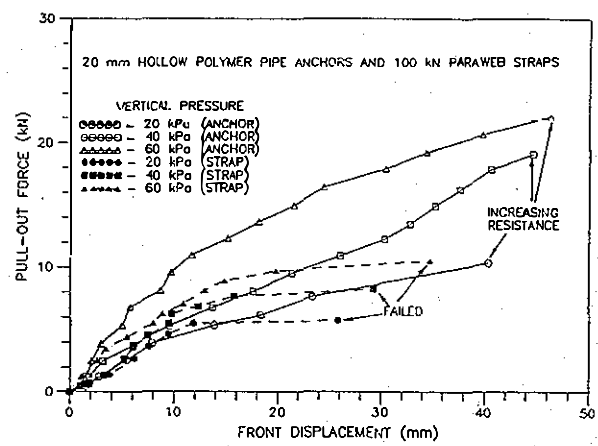



Fig.4 Comparison of pull-out force for tests with and without anchor (view A - enlarged

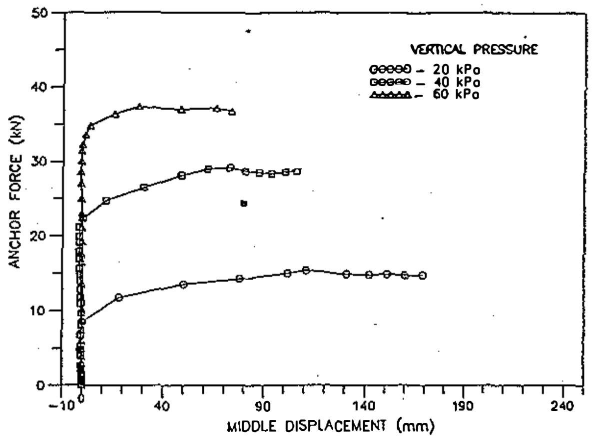



Fig.5 Force-displacement relationship for 20 mm diameter hollow polymer pipe anchors

Table 1. Test results of Paraweb reinforcing straps

| Test no. | $\sigma_v$ (kPa) | Strap Force at failure (kN) | Front displacement at failure (mm) |
|---|---|---|---|
| STR-1N | 20 | 2.87 | 25.82 |
| STR-2N | 40 | 4.11 | 29.32 |
| STR-3N | 60 | 5.26 | 34.76 |

Table 2. Pull-out test results of 20 mm diameter polymer pipe anchors

| Test no. | $\sigma_v$ (kPa) | Anchor force at failure (kN) | Displacement at failure (mm) | |
|---|---|---|---|---|
| | | | Middle of anchor | Front |
| AN-1 | 20 | 15.38 | 110.86 | 196.48 |
| AN-2 | 40 | 29.12 | 72.46 | 184.60 |
| AN-3 | 60 | 37.27 | 27.66 | 238.89 |
| PR-1 | 20 | 12.70 | 23.37 | 112.48 |
| PR-2 | 40 | 19.76 | 19.48 | 136.75 |
| PR-3 | 60 | 30.92 | 15.89 | 171.68 |
| PS-1 | 20 | 11.96 | 126.72 | 161.64 |
| PS-2 | 40 | 19.41 | 90.77 | 130.48 |
| PS-3 | 60 | 25.31 | 69.29 | 140.19 |

Notations:

AN - Hollow pipe (lowest stiffness)
PR - Reinforced with a steel rod and cement mortar
PS - Reinforced with a solid steel bar (highest stiffness)

A summary of the test results is given in Table 1 for the reinforcing straps and in Table 2 for the 20 mm anchors.
It is apparent that the use of a single transverse anchor has increased the pull-out capacity of an established reinforcing system by 4-5 times.
Table 2 shows that the most flexible anchor produces a higher pull-out resistance than the stiffer anchors. In addition, the anchor pull-out resistance increases with increased vertical pressure. Details of the soil/reinforcement mechanism developed by the flexible polymeric tube anchors are described by Hassan (1992).

## 3 DESIGN USING POLYMER ANCHORS

The polymeric earth anchor system (PEAN) has two major components; the anchoring tie and the small diameter polymer tube forming the anchor, Figure 2. The system can be used with any form of facing and design of the system is based on the established tie back hypothesis as defined in BS8006 (1991).
Two stability requirements concerning internal and external stability need to be satisfied. External stability is considered in the conventional manner. Internal stability considers rupture failure of the anchoring tie and the pull-out failure of the entire system. The general equation for the total pull-out resistance of the PEAN system, $F_T$, is given by, BS8006 (1991);

$$F_T = F_{rt} + F_{ba} \qquad (1)$$

where $F_{rt}$ = frictional resistance of the anchoring tie
= $2\ B\ \mu\ \sigma_v\ L_{ft}$ for a polymeric strip acting as the tie
$B$ = total width of anchoring tie per metre length of wall
$\mu$ = coefficient of friction between the fill and anchoring tie
$\sigma_v$ = vertical stress at level considered
$L_{ft}$ = length of part of the ith layer of anchoring tie beyond the potential failure plane

$F_{ba}$ = bearing resistance of the transverse anchor

It can be shown that a conservative value for ($F_{ba}$) can be determined from, Hassan (1992); $F_{ba} = D_s\ \sigma_v\ N_q$
where $D_s$ = diameter of the transverse bar anchor
$\sigma_v$ = vertical stress at anchor position
$N_q$ = bearing capacity factor for a punching failure mechanism

Hence, the total pull-out resistance, $F_T$, per metre length of wall is given by;

$$F_T = 2\ B\ \mu\ \sigma_v\ L_{ft} + D_s\ \sigma_v\ N_q \qquad (2)$$

Allowable pull-out load, FA, may be taken as;

$$F_A = F_T/FS \qquad (3)$$

where FS = factor of safety against pull-out
= 1.5-3.0

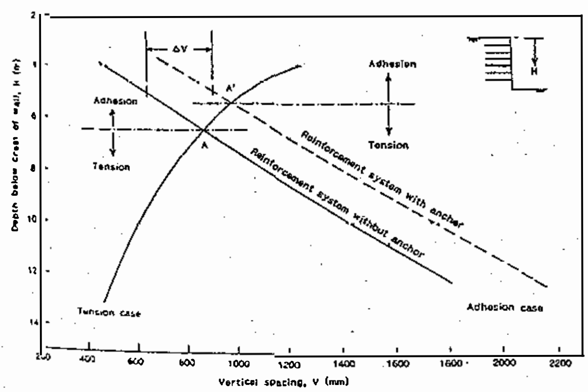
The maximum tensile force in each anchoring tie, $T_{max}$ must not exceed its ultimate characteristic strength, divided by a factor of safety against rupture,

$$T_{max} < T_u / F_{su} \qquad (4)$$

where $T_u$ = ultimate characteristic strength of the anchoring tie

$F_{su}$ = factor of safety against rupture.

The economic benefits of the new anchor can be illustrated in a comparative design study of a typical reinforced soil structure, Figure 6. Figure 6 shows that, at the top of a reinforced soil wall, adhesion is the dominant design criteria (adhesion curve); at lower levels the rupture strength of the reinforcement (tension curve) controls the quantity of reinforcement required. The transfer from the adhesion criteria to the tension criteria occurs when the two curves intersect, marked A in Figure 6.
The addition of the polymeric tube anchor to the system has the effect of widening the required spacing of the reinforcement on the adhesion curve. The transfer of the design criteria from the adhesion condition to the tensile condition occurs *higher* in the wall and at a *wider spacing* (A') leading to a more efficient design. As an example, at a depth of 5 m from the top of the wall the use of a single transverse anchor of 20 mm diameter provides an increase in vertical spacing of $\Delta_V$, equivalent to a 40 per cent reduction in the required reinforcement This is achieved without reducing the effective stability of the design in any manner.




NB: Graph is based on the following design assumptions:
1. Surcharge loading = 37.5 units H.B.
2. Fill properties:
   $\gamma$ = 19 kN/m³
   c' = 0
   $\phi'$ = 37°
3. Reinforcement system:
   Length of reinforcement, L = 0.7H
   Length of anchor, $L_s$ = 667 mm
   Diameter of anchor, $D_s$ = 20 mm
   Average horizontal spacing of reinforcing strap, S = 333 mm
4. Factor of safety against rupture and pull-out = 3

Fig.6 Beneficial effect of a transverse anchor (PEAN)

## 4 CONCLUSIONS

The polymeric earth anchor system, (PEAN), described in this paper optimises the usage of the soil reinforcing materials by utilising the available passive resistance of the fill as well as using the frictional resistance developed by the reinforcing straps. The system has a simple configuration, is durable and economic and can be designed using the tie back method of analysis. It may be used with any form of conventional reinforced soil facing units and can be used directly with existing earth retention systems, such as the Websol system for permanent structures, Kempton et al (1985).
The use of a single polymeric anchor formed from a 20 mm tube provides direct financial savings in design in every reinforced soil wall where adhesion of the reinforcement is the limiting design criteria, as is the case at the top of most reinforced soil walls.

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