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Reinforced soil systems in embankments – Construction practices

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ABSTRACT: Extensive experience has shown that reinforced soil techniques are very effective in the construction of embankments over soft foundations. The paper uses case studies to examine the construction details of three separate systems which use the range of 'Tensar' polymer grids as reinforcement. Reinforced soil is also used in the repair of slip failures in embankments and cuttings. Case studies are again used to discuss construction methods and comparative costs.

1 NEW EMBANKMENTS

The problem of constructing embankments on soft foundations is common in many parts of the world. A number of solutions are available including piling, excavation of the soft layers and slow, staged construction.

Over the past ten years or so, reinforced soil techniques have been used very effectively to reduce the cost and time for construction of such embankments.

The reinforcement materials considered in this paper are the range of 'Tensar' polymer geogrids. The grids are manufactured by punching a regular array of holes in a sheet of polymer which is then heated and stretched at carefully controlled temperature and strain rates. The stretching process aligns the long chain molecules of the polymer thus increasing substantially the tensile strength and tensile modulus and correspondingly reducing the potential for creep. Stretching in one direction produces uniaxial grids which have enhanced properties in the direction of stretch. A second process of stretching in the transverse direction produces biaxial grids which have similar properties in each direction (Fig. 1).

Most embankment designs utilise uniaxial grids since this is a two dimensional problem with forces acting at right angles to the centre-line. However, when reinforcement stresses are low, the lightweight biaxial grids can often provide a cost-effective solution.

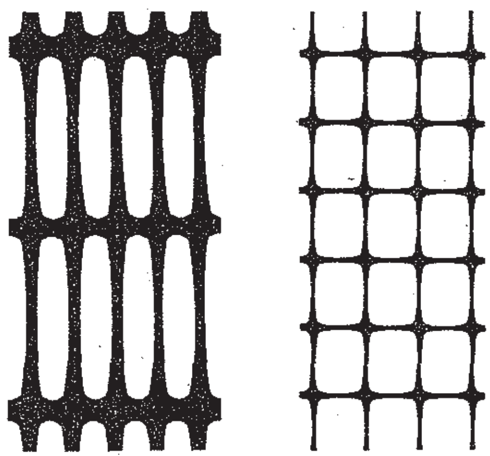

Figure 1. Uniaxial and Biaxial grids

1.1 Horizontal layers

The simplest application of reinforced soil techniques is to use the reinforcement to intercept potential failure surfaces passing through the embankment and into the soft foundation.

Such a system was adopted on the A12, Chelmsford By-Pass in Essex, England.

The road embankment is 8.5m high constructed of London Clay and has side slopes of 2.5:1. The foundation consists of weathered London Clay the upper 2.5m of which contains polished, pre-sheared surfaces aligned approximately parallel with the ground surface. The design parameters for this relatively weak surface layer are:- $c' = 1.5$ kN/m², $Ø' = 14°$ $r_u = 0.5$

The critical mechanism was a translational failure within the upper clay aligned with the direction of the weak shear planes. To avoid the cost of removing the weak layer a reinforced soil solution was adopted.

Unlike other grid-type products, 'Tensar' grids have integral, full strength junctions between the ribs and cross bars. They are therefore extremely efficient in transferring stresses from the soil into the reinforcement by abutment against the cross bars. For this reason the coefficient of interaction with the soil is very high and anchorage lengths are correspondingly short. It is quite possible therefore to place the reinforcement in the zone where it is required without the need to have layers continuous across the full embankment width. Since stress transfer is through abutment and not surface friction, the grids can be used with many different soil types including clays. The polymers used in their manufacture are very inert forms of high density polyethylene and polypropylene, the grids may be used in very acid or alkaline materials such as Fly Ash or other waste materials.

On the Chelmsford By-Pass four layers of 'Tensar' SR2 grid were used as shown in Figure 2.

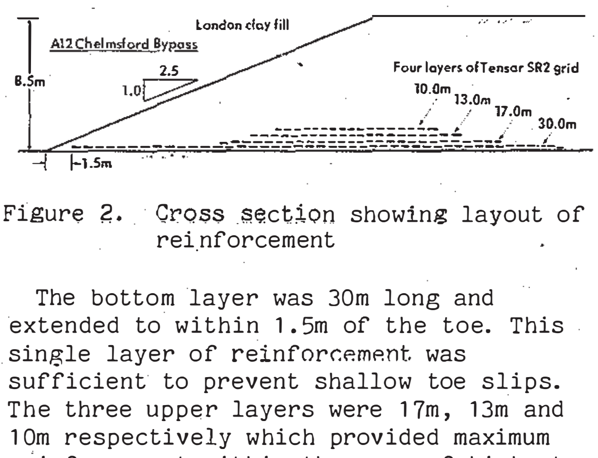

Figure 2. Cross section showing layout of reinforcement

The bottom layer was 30m long and extended to within 1.5m of the toe. This single layer of reinforcement was sufficient to prevent shallow toe slips. The three upper layers were 17m, 13m and 10m respectively which provided maximum reinforcement within the zone of highest stresses.

After preparation of the formation the bottom 30m length of grid was laid in position at right angles to the centre-line. 'Tensar' SR2 grids are uniaxial products manufactured at 1m wide. Since the embankment is long and is built up evenly no forces are induced parallel to the centre-line and there is no need to overlap adjacent rolls. The grids were therefore laid side by side to form a continuous strip 1.5m to 31.5m from the toe. Embankment fill was then spread and compacted on top using standard construction equipment and standard techniques, the compaction specification being exactly the same for reinforced and unreinforced areas. When the embankment level was raised by 250mm the second layer of reinforcement was placed as before. At 500mm and 750mm the third and fourth layers were placed. Figure 3 shows the second layer of grid ready to receive the next layer of fill.

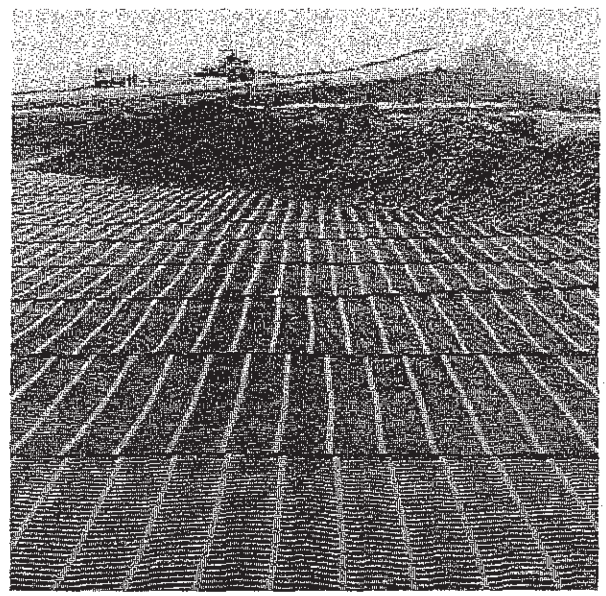

Figure 3. Placing fill on reinforcement grids

By using grid reinforcement the designer was able to minimise costs by placing the reinforcement only in areas where the calculated factor of safety was insufficient. The techniques for construction were very simple and required no alteration to the standard earthworks specification for fill placement or compaction.

1.2 Reinforcement mattress

In areas of deep soft deposits there are two main problems, short term stability and differential settlement. Such was the case on the A47, Great Yarmouth Western By-Pass in Norfolk, England. Details of the design have previously been reported by Williams and Sanders (1985). Essentially the embankment rises to a height of 8m and is founded on very soft organic alluvial deposits 22m deep.

The design solution adopted was to encapsulate the basal drainage blanket with the biaxial grid 'Tensar' SS2. In this way the toes of the embankment were prevented from moving outwards by the two layers of reinforcement, preserving the integrity of the high shear strength granular drainage blanket. Instrumentation was monitored during fill placement to avoid excess pore pressures and over-stressing the grid.

'Tensar' SS2 has quality control tensile strengths of 31.5 kN/m across the 4m width of the roll and 17 kN/m along the 50m length. For maximum economy the higher strength was required at right angles to the centre-line. That meant that the rolls had to be laid parallel to the centre-line but that the high tensile strength should be continuous across the full base width.

To provide this full strength joint between adjacent rolls a high density polyethylene braid was used to stitch the rolls together. Several configurations of stitching were tested and two were found to provide the required strength. In practice one was easier to form on site and was therefore adopted.

The construction procedure involved rolling out the grids parallel to the centre-line and overlapping adjacent rolls by one aperture (approximately 40mm). The high density polyethylene braid was then interwoven through every aperture of the two geogrids using a crescent shaped needle.

While it appears to be a labour intensive operation it is in fact fast and efficient. Output rates of 50 linear metres of joint per man hour were easily achieved and the cost of the joint is only equivalent to the cost of approximately 200mm of overlap. In all, 250,000m² of grid were used on the project with all edges stitched as described.

A team of two men collecting and unrolling the 4m wide grid and forming 80 linear metres of joint per hour is equivalent to an all-in laying and fixing rate of 160m² per man hour for the fully stitched mattress.

On one particularly soft area a tracked excavator had sunk into the soft clay. However, when the first layer of reinforcement and the first layer of drainage material had been laid all traffic was able to cross the area without damage. This is an indication of the effectiveness of the grid in interlocking with the fill particles and spreading load. Limitation of differential settlement is achieved by the stiff composite action of the reinforcement mattress and on the Great Yarmouth By-Pass the embankment, which was constructed in 1983, is performing extremely well. In contrast, an adjacent section which used only a geotextile as a separation membrane is suffering from significant differential settlement.

1.3 Geocell mattress

The third reinforced soil system is one which can only be constructed using 'Tensar' polymer grids:- the Geocell mattress.

The Geocell is particularly useful where an embankment is to be constructed on a relatively thin layer of soft soil (less than 12m in depth). A method of analysis and design has been developed based on plasticity theories and is reported elsewhere (Jenner Bassett and Bush, 1988).

It is also used on deep layers of soft material where the stresses within the mattress would be higher than could be carried by the system using biaxial grids as described above. Once again the main purpose is to increase short term stability and to regulate long term differential settlement.

The Geocell mattress is a honeycomb structure formed by constructing a series of interlocking cells using the 1m wide uniaxial grids in a vertical orientation. The mattress is therefore 1m thick and is connected to a biaxial grid base. When filled with a granular material it forms a very rigid base to the embankment.

Site erection begins by unrolling a biaxial grid onto the soft foundation parallel to the centre-line of the embankment with 300mm overlap between adjacent rolls. The overlap is used rather than stitching to increase speed of installation and to balance erection and filling times. A uniaxial grid is then laid transversely across the embankment and one edge stitched to the base. A second grid is laid abutting the first and again one edge is stitched. This procedure continues, advancing out over the soft area. When a number of transverse grids have been stitched in place they are rotated about the stitched edge into a vertical position and temporarily tensioned (Fig. 4).

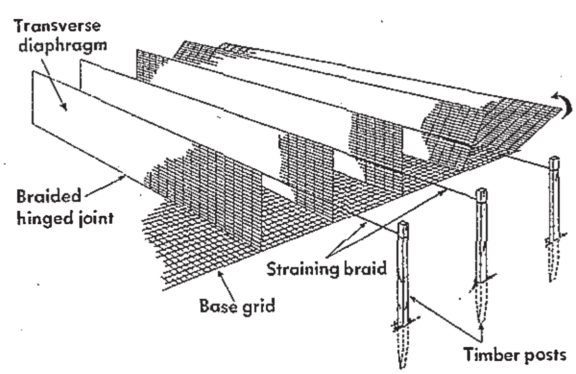

Figure 4. Construction of geocell mattress

The cell structure is formed by unrolling a roll of uniaxial grid between two transverse diaphragms and connecting it to the diaphragm using a hooked steel bar (Figs. 5 and 6)

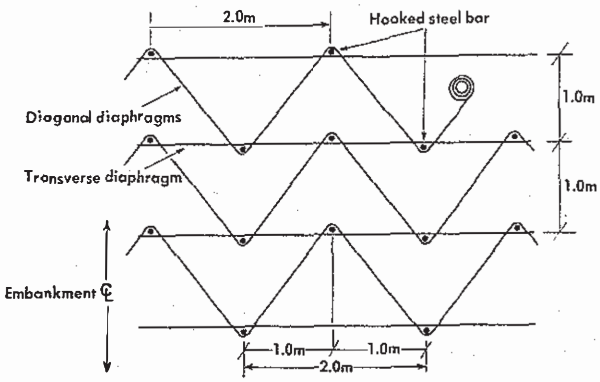

Figure 5. Geocell mattress - plan view

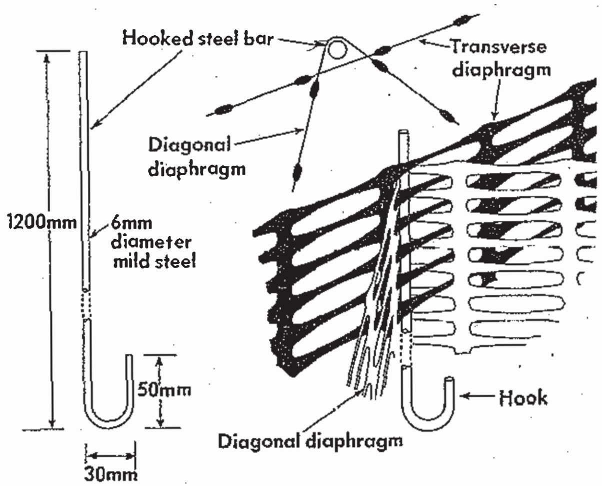

Figure 6. Connection detail

During the winter of 1985/86 a Geocell mattress was used to carry a 4.5m high embankment over very soft foundation soils at Auchenhowie, near Glasgow, Scotland. The foundation comprised:

1. Peaty topsoil - 0.4m thick
2. Loose, brown, organic, clayey silt and peat - 1.5m thick
3. Very soft brown, laminated silty clay - 2.5m thick
4. Weathered, friable, grey mudstone

Design was based on a soft layer depth of 4m having an average undrained shear strength of 15 kN/m².

Use of the Geocell mattress increased the factor of safety against foundation failure from 0.9 to 1.5.

Four alternative methods of construction were examined:

a. Partial excavation of the soft material and replacing by displacement of the remainder with rock fill. Lack of control over costs and performance made this option unacceptable.
b. Installation of drainage followed by staged construction. The need for rapid construction of the embankment to provide access to other sections of the contract ruled out this option.
c. Complete excavation of the soft layer and replacement with rock fill. Estimated cost - £152,000. In addition, this option would have caused a substantial increase in heavy site traffic on adjacent minor roads in this predominantly residential area.
d. Construction of a high strength geogrid mattress to provide a stiff base to the embankment eliminating stability problems and providing an effective drainage layer. Estimated cost - £104,000 (saving 31%).

The Geocell mattress option was therefore adopted.

Construction of the mattress at Auchenhowie involved working out over an old lake bed.

The construction team comprised three men laying, stitching and tensioning the grids plus an hydraulic excavator and driver to fill the Geocell with imported granular fill.

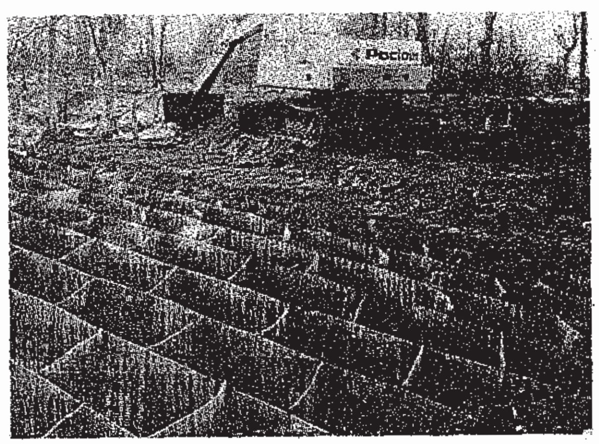

Figure 7. Filling geocell mattress

As can be seen from Figure 7 the excavator sits on previously filled sections of the mattress. Stone delivery wagons also travel on the mattress and dump adjacent to the excavator - thus no mechanical plant needs to run on the very soft foundation, the Geocell providing a stiff, 1m thick construction platform.

The filling procedure is to fill two rows of cells to half height before filling the first to full height. This system is continued, always ensuring that no cell is filled to full height before adjacent cells are at least half filled. In this way, potential distortion of the cell structure is avoided.

It is impractical to compact the fill in the cells therefore 150mm of overfilling is normally specified to cater for the slight compaction settlements which will be induced by construction traffic. It also protects the top edges of the diaphragms.

In this fairly typical project, erection and filling rates for the mattress averaged 350m² per day for the 3 men plus the excavator team.

Construction of the embankment to its full height of 4.5m was completed in about 7 days following completion of the mattress.

Settlement pins were installed within the embankment on top of the mattress. Approximately 90mm of initial settlement was recorded at the end of the embankment construction with no significant differential settlement noted either longitudinally or transversely.

Major advantages of this system are that construction can take place rapidly over very soft foundations without the normal problems of access for mechanical plant and that construction can continue in all weather conditions.

2 REPAIR OF SLIP FAILURES

A study carried out in England by TRRL showed that of five systems used to repair a slip in a 7m high road embankment, the reinforced soil technique using 'Tensar' geogrids was the cheapest (Johnson, 1985).

The five methods and associated costs for a 20m length are shown in Table 1.

Table 1. Repair options

Reinstatement techniques	Time taken (days)	Total cost (£)
Gabion wall	18	8360
Granular replacement	5	5020
Anchored tyre wall	8	4760
Lime stabilisation	7	4730
Geogrid reinforcement	6	3430

Only the lime stabilisation and geogrid reinforcement solutions re-used the soft clay. All other systems involved excavation and disposal off site along with importation of substitute granular fill.

Of the five systems investigated the reinforced soil repair using 'Tensar' geogrids was one of the fastest solutions and substantially less expensive than all of the others.

The A406 forms the North Circular Road close to the centre of London, England. Several years after its construction in 1968, slip failures began to occur in a cutting near Waterworks Corner where the A406 runs through Epping Forest. The 500m long cutting is up to 8m in depth through London clay and was constructed with side slopes of 1:2. Although the cutting was stable for the first 7 years after construction, slips began to occur with increasing regularity causing damage to fence lines and spillage onto the carriageway.

Several remedial measures were considered, including granular replacement and toe retention with crib walling or sheet piling combined with flatter slopes. These options were prohibitively expensive. Lime stabilisation was ruled out mainly due to doubts on the viability of achieving uniform mixing on site and uncertainty about long term performance.

A reinforced soil solution was selected on the basis of cost, ease of construction and confidence in the design, which involved reinstatement of the failed London clay, reinforced with horizontal layers of 'Tensar' geogrids. Drainage was also provided.

To achieve the specified factor of safety, horizontal layers of 'Tensar' SR2 grids were installed at 1.5m vertical spacing. To prevent sloughing at the surface, short horizontal layers of the lightweight biaxial grid 'Tensar' SS1 were installed at 0.5m vertically between the primary reinforcement layers (Fig. 8).

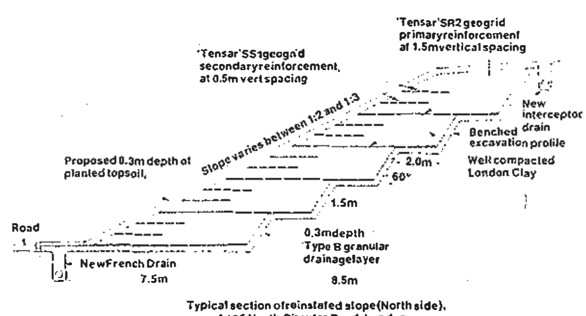

Figure 8. A406 – cross section showing reinforcement layout

Work was begun in September 1985 using a standard earthworks team of one Cat 215 tracked excavator, one Volvo four wheel drive dumptruck and one Cat 951 dozer with a four-in-one bucket and towed vibrating roller. Manual operations were carried out by two labourers.

Use of the reinforced soil system reduced traffic management measures to a minimum since there was a minimal removal of spoil and no importation of granular fill which would have involved large numbers of trucks reversing on to and off the carriageway.

Main earthworks began with the excavation and removal from site of a 35m long strip of slipped soil. Excavation extended beyond the failure plane with benched steps cut into the undisturbed clay. The general sequence then adopted was to reinstate the first strip using fill excavated from an adjacent second strip, to minimise double handling. The second strip was then reinstated using fill excavated from a third strip and so on.

Fill was tipped from the Volvo, placed using the Cat 951, and compacted to a maximum layer depth of 200mm using the vibrating roller towed by the Cat 951. The 2m widths of 'Tensar' SS1 secondary reinforcement were obtained by cutting the standard 4m wide rolls in half with a disc cutter.

'Tensar' SR2 rolls were cut to the required lengths and laid perpendicular to the slope face. Adjacent rolls were butt jointed (Fig. 9). The slope face was over filled and trimmed in the conventional manner.

Along part of the slope where additional land was available the gradient reduced to 1:3.

Figure 9. Laying reinforcement grids

Approximate quantities involved in the 500m long repair were:

Excavation	23,000m^3
Refilling	12,800m^3
Gravel drainage layer	5,400m^3
'Tensar' SR2 primary reinforcement	17,000m^2
'Tensar' SS1 secondary reinforcement	8,000m^2

In spring 1986 approximately 5000 cubic metres of topsoil were placed on the reconstructed slope for subsequent planting.

In the South East of England the more traditional repair involving removal of the slipped material and replacement with granular fill typically costs around £25/m^3. The reinforced soil technique using 'Tensar' geogrids has been shown to cost between £7 and £12/m^3 i.e. savings of between 50% and 70% (1985 prices).

3 CONCLUSIONS

The application of reinforced soil techniques using polymer geogrid reinforcement has in all cases shown substantial cost savings over more traditional construction systems.

The 'Tensar' Geocell mattress is a unique structure which allows rapid construction of embankments on soft foundations and avoids costly and time consuming excavation and replacement of the foundation soils. In a number of cases the system has been shown to produce substantial cost savings by reducing land-take due to the elimination of berms required for unreinforced constructions.

In all of the other systems discussed, the incorporation of 'Tensar' geogrids required no specialist equipment or techniques and required no amendment to standard earthworks specificaitons.

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