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Hard facing for steep reinforced soil slopes: A case history from the UK

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SYNOPSIS : The use of modular concrete blocks (MCB) as facing to geogrid reinforced soil retaining walls have already gained wide success in North America and Canada. Their use in Europe in general and the UK in particular is also gaining wide popularity. This paper extends the use of MCBs to facing of over-steep geogrid reinforced slopes as opposed to walls. A brief review of the design methodologies is presented and a case study is described in the South of England where MCBs were successfully used as facing to over-steep reinforced slope cuttings with an overall slope angle of 70 degrees.

1.0 INTRODUCTION

Over-steep geogrid reinforced slopes are usually associated with vegetation and the facing of the slope is wrapped around by the geogrids or sometimes the facing is temporarily supported by a steel mesh allowing vegetation to grow through the mesh apertures. Hard facing as opposed to soft facing refers to large precast concrete panels or the smaller modular concrete blocks (MCB). The United Kingdom saw last year a noticeable increase in the use of geogrid reinforced modular concrete block wall systems (GRMCBWS). The system uses modular concrete blocks (MCB) as facing to geogrid reinforced soil walls. The blocks are laid dry (i.e. without mortar) and the geogrid reinforcements are placed between the block courses and connected by means of insert keys or pins or by only the frictional interface between the courses. The footings for the GRMCBWSs can be constructed from granular compacted materials or from cast in place concrete. The walls are usually constructed with stepped facing resulting in a batter ranging between 5 to 20 degrees. Furthermore, portions of the height may be tiered thus producing an overall shape equivalent to a steep slope as opposed to a vertical wall, and therefore analysis can be carried out using steep-slope procedures. To avoid confusion between over-steep slopes and walls, this paper will attempt to distinguish between the two terminologies.

Analysis theories and design procedures were initially based on large precast concrete panel systems and did not address fully the performance of MCB systems, but recently new documents were published describing the design methodologies. In the USA the National Concrete Masonary Association have recently adopted new design methods as described by Bathurst and Simac (1994). Other organisations such as the Federal Highway Administration and the American Association of State Highway and Transportation Officials have also introduced guidelines for the analysis and design of GRMCBWSs. In the UK the latest publication is the BS8006 which covers many aspects of the reinforced-soil practice including concepts, materials, vertical walls, steep slopes and soil-reinforced embankments. Another important publication is the Document HA68/94 published by the Department of Transport. This document is an Advise Note giving guidance on design methods for the strengthening of highway slopes. It has been recently accepted in the U.K. that slopes steeper than 70° are to be considered as structures and therefore will require Technical Certification from the Engineer. and that slopes shallower than 70° require only Geotechnical approval.
Therefore we will define as steep slopes those soil reinforced structures with an inclination up to 70°, while we will define "walls" the structures with an inclination of more than 70°. This paper will briefly

review recent design methods and present a case study in the South of England where MCBs were used successfully as facing to geogrid reinforced over-steep slopes with an overall slope angle of 70°.

2.0 MODULAR CONCRETE BLOCKS

Modular concrete blocks (MCB) are manufactured from concrete and produced in different sizes, texture and colours, therefore they provide a varied choice to the engineer.
The blocks sometime have some kind of keys or inserts which provide a mechanical interlock with the layer above. MCBs provide flexibility with respect to layout of curves, and corners. They can tolerate larger differential settlements than conventional structures. Another advantage of GRMCBWSs is the simplicity of installation because the blocks are easily transportable. It is estimated that 30 to 40 sqm of wall can be erected by four persons over an eight hour working day. As for cost comparison, it is estimated that walls exceeding 1.0m in height typically offer a 25 to 35 % cost saving over conventional cast in place concrete retaining walls.

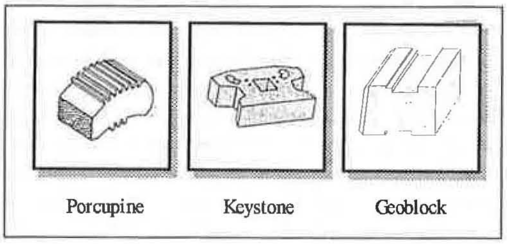

Figure 1. Examples of MCB units used in the U.K.

In the UK three MCBs are available: Porcupine, Keystone, and Geoblock, the latter giving a high efficiency of connection between the geogrids and the blocks (Fig. 1). Typically all the blocks are 250mm to 450mm in depth, 250mm to 500mm in width and 150mm to 200mm in height. The mass of each block varies typically from 25kg to 48kg. GRMCBWSs are usually constructed with a stepped face that results in a facing batter that ranges from 5 to 20 degrees.

3.0 DESIGN METHODOLOGIES ... A BRIEF REVIEW.

When codes of practices or guidelines are not available to the engineer then uncertainties and probably conservative designs become inevitable. This phenomena has been experienced whenever a new system or technology emerges, and there are always pioneers in establishing design and analyses theories. In the case of geosynthetics this has emerged from manufactures and academics simultaneously. But this stage has ended in the case of geosynthetics where during the last few years we have seen the emergence of important documents and codes in many countries. In France a new standard NF G 38064 is due to be published this year (1996) to standardise design methods for steep slopes and walls, and in Germany a working group is currently preparing design guidelines for reinforced soils which is hoped to be approved by the Federal government and the Highways Authorities.
Therefore the publication of recent design documents have unveiled several uncertainties to the practising engineers which were understood previously by only few specialists in the field.
All the cited references use the so called "tie back wedge method" design procedures for geogrid reinforced soil structures whereby two limit states shall be complied with:

a) Ultimate limit state - in which relevant potential collapse mechanisms are identified and considered together with limit state factors.
b) Serviceability limit state - in which relevant working conditions are identified and the structure checked to ensure that it will retain the characteristics necessary for it to fulfil its function throughout its life without the need for abnormal maintenance.

This limit state design philosophy for reinforced soil walls involves increasing the soil weight and live loading by the appropriate partial load factors and reducing the soil properties and reinforcement strength by appropriate partial material factors. Details of the "tie back wedge" method is described in BS8006.

In the document HA64/98, the limit equilibrium approach is also adopted for designing reinforcement of steep slopes. It also incorporates partial factors and the design is based on a two-part wedge mechanism which is preferred because it provides a simple method for obtaining safe and economical solutions.

4.0 SEVENOAKS SCHOOL TUNNEL APPROACH CUTTINGS, A CASE STUDY.

The construction of a tunnel under the main A225 Tonbridge Road, Sevenoaks, Kent required steep cuttings for the approaches. The invert of the tunnel was approximately 8m below natural ground level. Several options to retain the backslope were considered by the client (Sevenoaks School) and the main Contractor (Johnston Civil Engineering) such as soil nailing, sheet piling and conventional reinforced concrete retaining walls.. Economy and ease of construction in this complicated site lead the contractor to opt for the GRMCBWS system.

Two walls were designed and built at each end of the tunnel with a total length of 120m, and heights varying from 6.3m to 1.0m. The geometry of the walls were chosen in a manner to give a pleasant aesthetic view and for adequate stability.

The walls were built in two portions, the first having a height of 3.0m and the second wall was variable in height and stepped back by 1.0m so that the angle as measured from the toe at the base to the crest of the top course was 70° as shown in Figure 2. The batter above the top was made 45° then laid with grass turf and the 1.0m area between the two walls was planted with shrubs.

As the slope was 70 ° the design was carried out using the limit equilibrium analysis method based on the two-part wedge mechanism for the internal stability. Site investigation reports revealed an effective angle of internal friction for the reinforced fill and foundation soil as 30 ° and 35 ° respectively. The ground water was found at an elevation corresponding to the invert of the tunnel and it was suspected that it would fluctuate during the year thus causing flooding of the tunnel, therefore a pore water pressure ratio r_u of 0.1 was adopted in the design and as an extra precaution horizontal drains were installed at the base of the walls as shown in Figure 2. A surcharge load of 5kPa was adopted in the design. The design value for the reinforcement strength was derived from the unfactored long term characteristic strength, Tc for ex-works product using a set of partial factors as follows:

-FS_1=1.05 for the possible reduction in strength compared with the characteristic value;

-FS_2=1.1 for the loss of strength due to site damage;

-FS_3=1.5 for the earth pressures;

-FS_4=1.1 for inaccurate assessment of the loading.

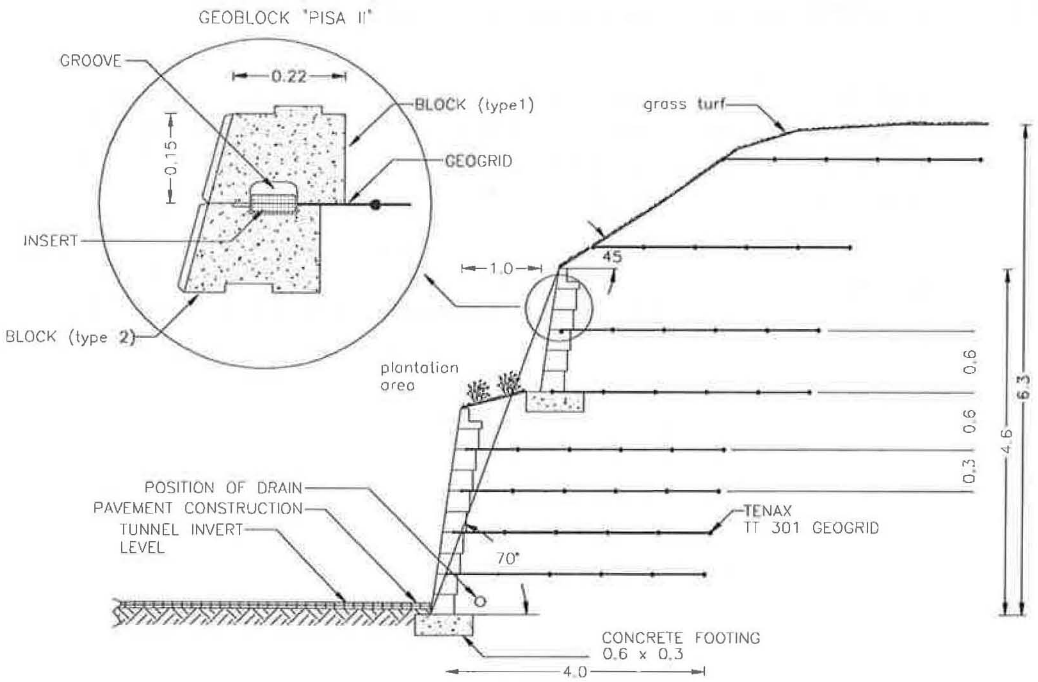

Figure 2. Geogrid-reinforced modular concrete block wall, Sevenoaks School, Kent.

Therefore the long term design strength for the TENAX TT 301 SAMP geogrids was calculated as follows:

$$Td = \frac{Tc}{FS_1 \times FS_2 \times FS_3 \times FS_4} =$$

$$= \frac{23.5}{(1.05 \times 1.1 \times 1.5 \times 1.1)} = 12.3 \quad kN/m \qquad (1)$$

Overall stability analysis was carried out using Bishop's modified Method to calculate the factor of safety for circular slip surfaces as shown in Figure 3. As the structure was defined as on the border between a steep slope and a wall, it was decided to perform other stability checks including sliding, overturning, tilting and bearing capacity calculations. These checks are usually carried out for walls and are seldom necessary in case of steep slopes. A summary of the factor of safeties achieved are shown in Table 1.

Table 1. Summary of the factors of safeties achieved.

Analysis	Factor of safety.
Overall stability analysis.	1.39
Check against sliding.	2.11
Check against overturning.	4.06
Check against tilting and bearing capacity failure.	2.0

5.0 CONSTRUCTION SEQUENCE FOR THE GRMVBWS.

The blocks used in the project were of the "GEOBLOCK" type (see Fig. 1), and the construction sequence was as follows:

1. The foundation was prepared and the footings were cast using mass concrete.
2. The first course of the blocks were placed along the desired building line using standard rib units of Type 1 (see Fig 2).
3. The second course was built using the insert blocks of the Type 2 (Fig. 2) where the first layer of Tenax TT301 SAMP geogrid was required.
4. The inserts were placed in the groove in the top of the block with the narrow end of the finger pointing towards the face of the wall as shown in Figure 4.
5. Tenax TT301 SAMP geogrids were cut to the required lengths and placed over the inserts so that every aperture in the grid was located over a finger of the inserts as shown in Figure 4. The next row of blocks were placed over the insert and geogrid to hold the grid in place. The geogrid was then pulled from the back of the wall so that the transverse rib of the grid was pulled back across the end of the fingers of the inserts.

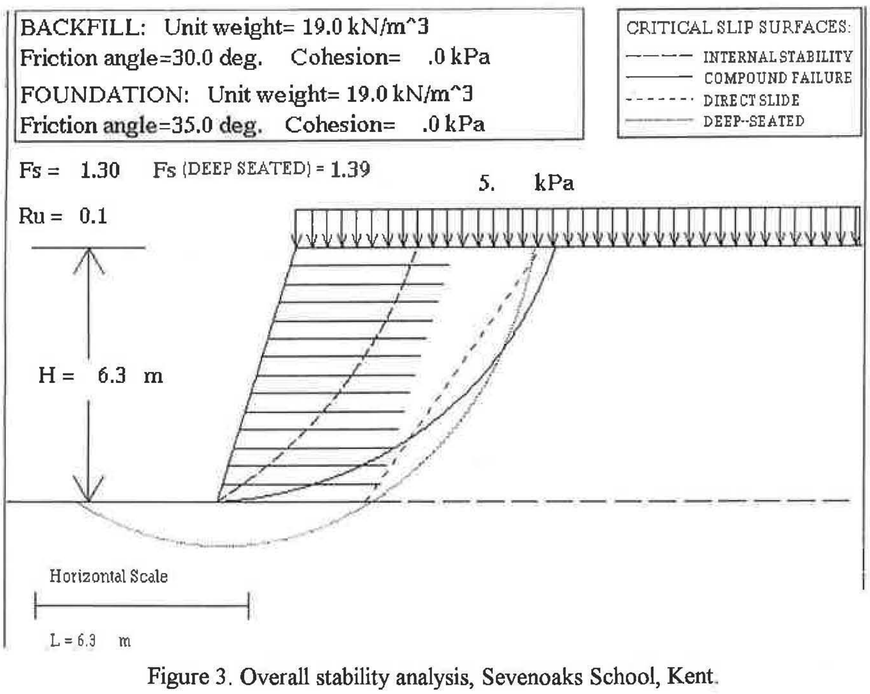

Figure 3. Overall stability analysis, Sevenoaks School, Kent.

6. As dug silty sand materials were used for the geogrid reinforced fill, the compaction was carried out in 150mm layers using a plate compactor in areas within 1.0m from the face of the wall and a vibrating roller with a mass per metre width of 1300 kg for the remainder of the length of the reinforcement.

7. When the fill was placed and compacted up to the level of the next geogrid, the geogrid was then

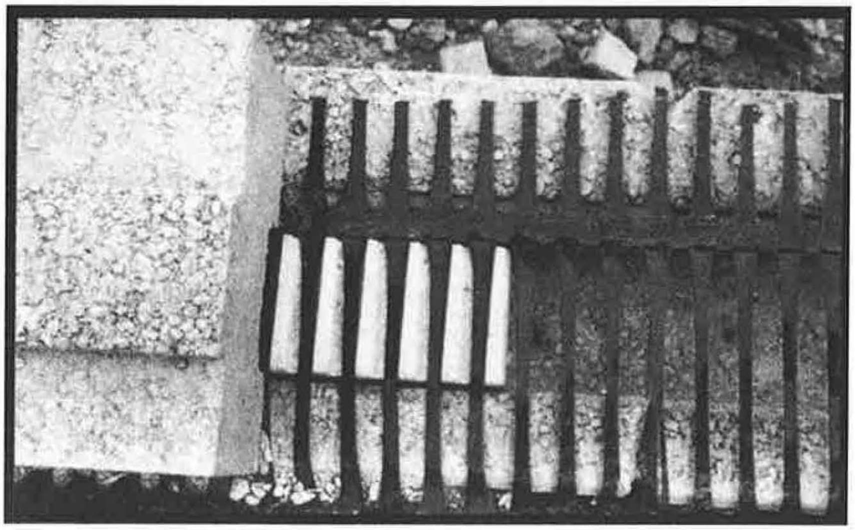

Figure 4. Geogrid placed in position on the blocks.

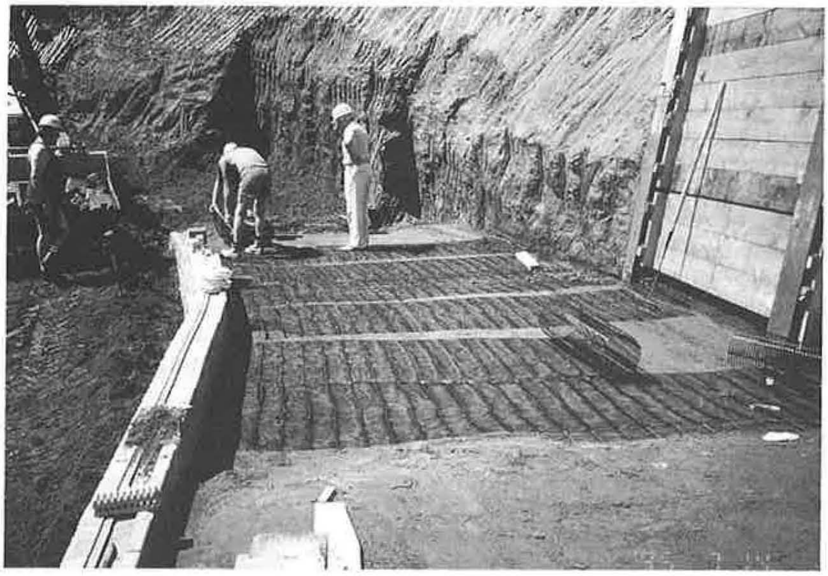

Figure 5. Construction of GRMCBWS in progress at Sevenoaks School.

Figure 6. Job completed, and grass turf being laid in position.

laid down on the top of the fill and the construction continued as in steps 2 to 6.
In Figure 5 construction is shown in progress and Figure 6 shows the placement of grass turf over the back slopes. The projects was completed successfully in January 1996 and handed over to the client.

6.0 SUMMARY AND CONCLUSIONS.

The following conclusions are drawn from this paper:

1. The use of precast modular concrete blocks (MCB) as facing to geogrid reinforced soil walls and over-steep slopes have gained wide acceptance in Europe.
2. The use of MCBs is explained and its advantages presented.
3. The GRMCBWSs can offer a 25 to 35 % cost saving over conventional cast in place concrete retaining walls.
4. In case of over steep-slopes with angles less than 70 ° the design can be carried out using the two-part wedge mechanism together with the appropriate partial factors of safety.
5. In the case of walls the "tie back wedge method" is preferred whereby the ultimate limit state and the serviceability limit shall be complied with.
6. A case is presented in the UK where MCBs were successfully used for facing steep geogrid reinforced cuttings.

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