

## GEOGRIDS IN WALLS AND SLOPES

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### INTRODUCTION

In this paper we will look at the history of the design process for geogrid reinforcement of walls and slopes, developed over the last 25 years. We will discuss some of the inherent confusions and problems designers experience in applying these design methods. The interaction between geogrid reinforcement and the soil in walls and steep slopes will be reviewed, to help researchers move the design process into new areas.

The limit state design processes in use today treat the soil and the geogrids separately. Developments in the design process are necessary to ensure that all parts of the systems are compatible. These developments should be expected to maintain the economic position of geogrid structures, without reducing the volume of geogrid used in this sector of the market.

### HISTORY OF GEOGRID DESIGN

Geosynthetic reinforced soil walls and slopes have been used since the mid 1970's. Design methods developed during the 1980's have remained largely unchanged for the last 20 years. In the UK, BS8006 was published in 1995 following ten years of discussion in committee. It was followed by other design codes in Germany, France, the USA and Hong Kong. All the current codes are based on either equilibrium or current limit state design methods, with partial factors applied to the fills, reinforcement and external loadings.

Internal stability analysis of reinforced soil structures is performed, to quantify the required strength, vertical spacing and length of the geogrid reinforcement. The codes describe methods of analysis using either the coherent gravity or the tied-back wedge methods of analysis. These methods have been extensively proven by full scale instrumented tests. Various researchers have also worked with finite element analysis methods, but none have yet been developed for use as routine methods of analysis.

The methods developed by Henri Vidal in the 1960s have been developed into the codes used globally for analysis of internal stability, with Rankine earth pressure theories used to determine the external forces on the reinforced block.

#### Standards

##### *BS8006- Section 6 Walls*

The design methods for walls set out in BS8006 Section 6, allow designers to use either the tied-back wedge method or the coherent gravity method for analysis of internal stability. Reinforced soil walls are defined as "structures with a rigid face steeper than 70° to the horizontal". The facings used for walls can be formed using any one of a number of systems. A variety of these facings are shown in Figs. 1 to 5.



**Figure 1.** Vertical concrete facing with geogrid tails



**Figure 2.** Full-height precast concrete facing



**Figure 3.** King post and plank-faced reinforced soil wall



**Figure 4.** Geogrid-reinforced modular block-faced wall



**Figure 5.** Modular block facing showing connection

Figure 1 shows a wall being formed using hexagonal precast concrete facing panels, with geogrid tails joined to the main reinforcement using a bodkin joint.

Figure 2 shows a full height precast facing panel, with geogrid tails ready to be connected to the main reinforcement as fill is placed. The facing supports will be removed when the fill reaches about mid height, after which the fill alone will be able to support the facing.

Figure 3 shows the abutment and wing wall for a temporary bridge, intended to support a haul road for large dump trucks. The geogrid reinforcement is fixed to the planks, which are supported laterally by vertical H-piles.

Figures 4 and 5 show modular precast facing systems reinforced with geogrid. The system shown in Figure 4 includes pins between the blocks, over which locks the geogrid between the blocks. The system shown in Figure 5 includes a comb locking bar to ensure a positive connection.

*BS8006 –Section 7 Slopes*

Confusion can develop, as a reinforced slope is defined in BS 8006, as being inclined at any angle between 40° and 90°, the vertical. For slopes with a face inclined between 70° and the vertical, the designer can choose to use the design methods in BS8006 Section 6 Walls and Abutments, or the methods in Section 7 Reinforced Slopes.

If the design is for a structure or slope required to comply with HA68/94 (HA DMRB), then slopes steeper than 70° are subject to approvals and checks in the same way as all other highway structures.

Slopes may be formed with the main geogrid wrapped around the fill, to support the fill and any topsoil placed at the face, allowing for the establishment of vegetation. Alternatively a slope may have a semi rigid facing e.g. galvanised steel mesh. There have been a number of reinforced soil steep slopes where vegetation has failed to establish. To prevent this, the face should be detailed to ensure that some moisture is retained; vegetation should be selected to suit the aspect of the slope face.

Typical examples of reinforced slopes are shown in Figs. 6 to 10.



**Figure 6.** Geogrid-reinforced slopes, mesh-faced at 78° to horizontal



**Figure 7.** Steep slope with geogrid wrap-around facing



**Figure 8.** Steep slope with geogrid wrap-around facing- fire damage was easily repaired



**Figure 9.** Geogrid-reinforced slope, mesh-faced at 78° to horizontal

#### *Other National Codes*

In North America, current limit equilibrium-based design methods are used to assess internal stability of geosynthetic-reinforced soil walls. These are based on the American Association of State Highway and Transportation Officials (AASHTO) Simplified Method. A deficiency of this method is that it does not consider the influence of the facing type on reinforcement loads, Bathurst *et al* (2005). Sankey and Segrestin (2001) point out that current seismic design codes do not fully take account of the inherent flexibility of reinforced earth structures. At present, available codes for seismic design of reinforced soil wall systems, FHWA (1996), AASHTO (1998) and

NCMA (1998), follow a pseudo-static approach to determine the total lateral forces imposed by the earth behind the wall. In addition, the assumed distribution of dynamic earth pressure behind the wall is based on limited studies of metallic reinforced soil walls, Segrestin and Bastick (1988). The results of current studies, Bathurst and Hatami (1998) indicate significant shortcomings in current design approaches.



**Figure 10.** Geogrid-reinforced, very lightweight fill with steel mesh-face

In Europe, the two methods generally used for design are the lateral earth pressure and the displacement methods. External stability checks assume the failure surface lies completely outside the reinforced soil mass. Internal stability checks have to cover all possible failures for which the assumed sliding surface intersects the reinforcement. An adequate factor of safety against rupture and pullout of the reinforcing elements has to be proven (Mannsbart and Wenner, 1995).

In Germany, for example, DIN Standard 1054 (DIN 1054) looks at external and internal stability using the residual angle of friction of the reinforced soil. External stability, based on Coulomb's equation, enables the design to be specific to the actual slope angle of the back face of the reinforced soil block, rather than requiring all slopes between 70° and 90° to be designed as if they were vertical, Jenner (1995). For Coulomb's equation to remain applicable, the slope angle of the back face must not fall below 70°.

Several countries including the USA and Hong Kong need to consider seismicity as an important factor in design. The response to ground motion in seismically-active areas is complex - safety, serviceability and an economical design approach must be considered carefully.

#### *Steep Slopes*

How is a steep slope defined? In BS 8006 and other normal UK practice, a steep slope is defined as being between 45° and 70° to the horizontal. There is no logical reason, based on the design theory, for the limit to be 70°. BS8006 allows the design approach set out in Section 7 to be applied to slopes up to the vertical. Jewell (1984) produces a set of design curves based on log spiral failure surfaces, which can be applied to slopes with face inclinations between 45° and the vertical. Rankilor (2006) suggests in his proposed new design method, that there is a marked change in behaviour in slopes steeper than 80° to the horizontal

### **PROBLEMS WITH EXISTING DESIGN METHODS**

Existing design methods are based on analysis where the fills and the reinforcement are factored and considered as separate parts of the calculation. Questions which need to be addressed include the following:

- Have we measured strength correctly? Rankilor (2006) suggests that in situ tests would provide a better understanding of the mechanisms involved. Otherwise scale effects need to be considered.
- The standard ENISO 10319 Tensile Test is intended as a quality assurance Index test, but is the value appropriate for design? Do we over-factor the geogrid strength to allow for ignorance?
- BS8006 includes Partial Factors for serviceability assessment - but these are rarely used, as calculations for displacements are not formally set out in the standard. Could the Finite Element Method help?
- The equations in Section 7 of BS8006 include a moment correction factor  $\chi$  - it seems that some programmers / designers may have missed this feature from software and subsequent analysis.
- When the failure surface cuts some of the reinforcing layers, a decision needs to be made - either the principles set out in BS8006 Section 6 or 7 are used, or the normal earthworks principles from BS6031 or EN 1997-1 are used.
- Is it valid to assume that the reinforcing force is horizontal at the intersection with the shear plane? Do we need to be able to consider inclination of the force tangential to the shear plane?

## CONCLUSIONS

The use of reinforced soil walls and slopes has developed such that, using existing design methods, we have economic and generally robust systems which offer significant advantages over alternative retaining walls and slope strengthening systems. If current design methods are to be reviewed, the economics need to be carefully considered. While reducing the geogrid element of the system may offer some savings on overall cost, as the geogrid is not the largest cost, reducing the amount of geogrid may not be attractive to manufacturers as sales volumes may not increase to balance the reduced quantity in each wall or slope.

Finally, continuity of research funding is a problem – much research has been started and never completely finished.

## RECOMMENDATIONS FOR FUTURE RESEARCH

Having reviewed the current UK design methods, and in the knowledge that a revised version of BS8006 is due for publication in 2010, the following areas of research into the design of walls and slopes could be targeted.

- Full integration with EN1997-1.
- Use of displacement methods of analysis, finite element or finite displacement, as routine.
- Can the stresses in the reinforcement be calculated to simulate the construction process and the strains as they are developed (Rankilor 2006).

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