THE EFFECT OF GEOSYNTHETIC SOIL REINFORCEMENT DESIGN STANDARDS ON COSTS FOR EARTH-RETAINING STRUCTURES: A QUALITATIVE APPROACH

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ABSTRACT

The use of soil reinforcement in civil engineering applications is not new and in fact, this technology has existed for over 2000 years in the form of natural fibres used as soil inclusions in the Great Wall of China. Today, modern technology and science have developed soil reinforcement solutions that are consistent and mass reproducible. High tenacity polymers, with high molecular weight usually in the form of polyester or high density polyethylene are the most common materials used to achieve superior creep performance vital in earth-retaining structures. Design standards in Australia and around the world are available to provide design guidelines in the specification and design of earth-retaining structures using geosynthetics. These include AS4678:2002 and BS8006:2010 as the official design codes. However, Government road authorities have published their own design guidelines such as the NSW Roads & Maritime Services R57 document and the Qld Main Roads MRS11.06 document to name a few. Different applications and loading conditions require different polymer types to get the maximum design benefits such as creep performance from polyester (PET) and high density polyethylene (HDPE), and installation damage resistance from polypropylene (PP) and HDPE. However, other installation and commercial factors may influence the preferred polymer type. This relates to issues such as; the ease of handling, cutting and unrolling of the product and of course even if it satisfies the design criteria, the cost of the product will ultimately determine if the solution is feasible. For permanent earth-retaining structures, the two most common polymers used for soil reinforcement are polyester and HDPE. This paper will review two design codes adopted in Australia and how they impact on the feasibility (cost) of constructing a reinforced soil structure using geogrids.

1 INTRODUCTION

With so many different products and solutions out in the market place, it is not surprising that consulting engineers get it wrong or sometimes get confused when specifying geosynthetics in civil engineering applicatons, especially for earth-retaining structures. Engineers, young and old will sometimes resort to conventional solutions using conventional building materials such as concrete and steel. These materials have been proven for many centuries, and as a result, have the confidence from consulting engineers. It is only through education and re-education that the industry may move forward in embracing new technologies in material sciences, where geosynthetics for example may solve complex geotechnical and structural problems. For that reason, design standards for geosynthetic reinforced earth-retaining structures are available for practicing engineers. However, depending on the client requirements or the design firm's policy, a specific design standard may need to be adopted. This paper is to address some of the design issues relating to reinforced (geosynthetic) segmental block wall design standards and its affect on the overall cost of designing and building that structure.

The design of reinforced soil walls is essentially the same as for reinforced soil slopes, however, the facing of the structure must also be designed and checked. By definition, a wall is defined as being greater than 70 degrees from the horizontal. This limit has been defined in the scope of AS4678. The facing of geosynthetic reinforced soil walls may vary depending on architectural and aesthetic requirements. Typical facings include:

- Gabions,
- Masonry segmental block units,
- Wrap-around geosynthetic facing (with a non-structural facade),
- Precast concrete panels, and

- Angled preformed steel facing (near 70deg limit) with revegetated face.

2 DESIGN STANDARDS

This paper will focus on two design standards used in Australia for geosynthetic soil reinforcement used in earth-retaining structures, highlighting its cost implications based on different standards adopted. The two design standards that will be compared will be the New South Wales Roads & Maritime Services R57 and the Australian Standard AS4678-2002 described in more detail later in this paper.

With segmental block walls, the maximum allowable vertical spacing for the soil reinforcement is usually 600mm, or three block height spacings, however, under R57 the geogrid-block unit connection capacity is predetermined and reduced based on long-term connection reduction factors. Under R57, this approach will usually govern the spacing of the geogrid and significantly limit the ultimate capacity of the geogrid. This is to prevent bulging of the block units and a geogrid-block unit connection failure in theory. The spacing of the geosynthetic soil reinforcement (e.g. geogrid) is determined conventionally by either the Coherent Gravity Method or the Tie-back Wedge Method (AS4678-2002). Both the strength and serviceability limit states should be checked when considering the face-geogrid connection design. A method statement for testing the geogrid-segmental block facing connection capacity is outlined in the *Design Manual for Segmental Retaining Walls* (Simac et al. 1993).

3 DESIGN COMPARISONS

In this paper, the comparison will focus on AS4678 and R57. The adoption of different design standards will lead to different requirements for the reinforced soil wall components. This includes:

i) the concrete block facing unit
ii) the geogrid spacing and grade
iii) the type of select reinforced fill required or allowed for construction
iv) the design philosophy
v) the construction procedure

The above items are the main contributing factors that will ultimately lead to the variability of the cost of the structure. Although both standards are used commercially, the flexibility in the design standard is apparent in AS4678. Good practice information is documented in the Australian Standard, but the engineer and wall contractor has more control over the design and construction of the reinforced soil wall structure. In addition, R57 have pre-approved systems and in essence, a new reinforced soil wall system would not be permissible unless it was reviewed and approved by the road authority, even if it satisfied AS4678.

3.1 Concrete block facing unit

Refer to R57, Cl. 5.8 for the minimum strength requirements and refer to AS4678 Cl. 5.3, AS3700 (Masonry structures) and AS4456 (Masonry units and segmental pavers and flags) for minimum strength requirements for masonry modular units. Typically, the standard compressive strength is >10MPa for commercial walls as opposed to 25MPa for R57.

3.2 Geogrid strength grade and spacing

Refer to R57 Annexure R57/E for pre-approved systems. The predetermined connection strength values takes into account the strength reduction factors due to creep, installation damage, environmental effects and data extrapolation uncertainty and applies it to the tested peak connection strength of the block-geogrid retaining wall system. It is also strain limited to meet the serviceability criteria.

3.3 Select reinforced fill type and quality

Refer to R57 Cl. 5.3. Typically, free-draining granular material is suitable with a maximum particle size of 75mm. The soil pH should be between 3 to 10 for geosynthetic soil reinforcement. However, much of the time, the ability to use in-situ backfill material creates obvious cost savings. AS4678 provides some guidelines on what select reinforced fill (c.f. AS4678 Appendix D) should be used, however, this is not mandatory. Provided the characteristic soil properties (e.g. internal friction angle) are known for that particular site, those values may be adopted for design. In addition, larger aggregate size may be used provided the installation damage factor is adjusted accordingly.

3.4 Design philosophy

R57 incorporates a mandatory limit states design procedure that is to be followed based on BS 8006-1995 (Code of practice for strengthened/reinforced soils and other fills) with modifications in line with AS 5100.3-2004 (Bridge design – Foundations and soil supporting structures). AS 4678 is a limit states design approach, but does not prescribe to specific methods of analysis. Informative guidelines are provided with regards to best engineering practice, but they are not mandatory and sound engineering judgment may be exercised.

3.5 Construction procedure

Refer to R58 (Construction of Reinforced Soil Walls) Annexure R58/L. Although not strictly related to design, the R57 standard also requires the reinforced soil structure to comply with R58 construction procedures. For example, an Inspection and Test Plan testing frequency for the soils to be used is mandatory and hold points for quality assurance.

4 COST AND SAFETY IMPLICATIONS

The consequences of changing design standards has a significant effect on the cost of building the structure. For example, the wall structural components will need to be increased in quantity, quality and strength to satisfy the R57 standard.

As described in Section 3, the following reinforced soil wall cost components have implications as a direct result of the design specifications required for compliance.

i) The concrete block face in R57 requires a higher compressive strength block unit
ii) The geogrid strength grade is required to be higher and spacing closer together in R57
iii) The select backfill required must be imported and a higher quality as described in R57 Cl. 5.3
iv) The construction procedures required for compliance, for instance the testing frequency in R58/L and increased labour and plant costs due to extra installation time

The resulting cost implication is approximately $200 per square metre of wall face area (for a typical 800sqm face wall project). There is no doubt that the wall design is safer and more conservative, but this does not mean that the AS4678 design standard is incorrect or unsafe. This exercise of comparing design standards used in Australia for the design of a reinforced soil wall illustrates how the same structure under the same loading conditions, could be built with a significant cost difference. However, it does not consider that the fact that the asset is owned by the public sector and not by the private sector. Consequences of failure for a retaining wall on a public road could be considered more significant compared to a retaining structure failure in a backyard. However, with good engineering design, judgement and good construction practices the AS4678 Standard is perfectly fit for purpose and as long as it is designed within its scope.

5 WHAT PROPERTIES ARE MOST IMPORTANT FOR SOIL REINFORCEMENT

When considering geosynthetic soil reinforcement, the questions designers need to consider will determine the polymer required. Although the type of polymer selected will affect cost, the fundamental issues need to be satisfied. They include:

- What sustained period of time does the design loads act on the soil reinforcement and how long is its design life? The soil reinforcement technical datasheet should provide a creep factor for specific design lives.
- What limiting strains are required initially (i.e. instantaneous strain) and over its design life (i.e. creep strain)? A master stress-strain curve should be available from the manufacturer as well as a creep-strain curve over time.

- What soil pH environment will the soil reinforcement be subjected to over its design life? The recommended soil pH range should be stated on the datasheet.
- What type of backfill material will be used on the soil reinforcement in construction? Typical installation damage partial reduction factors should be provided by the manufacturer. For critical project-specific designs, field tests may also be required to determine non-standard backfill and compaction equipment effects.

The type of polymer selected will depend on the application and the benefit-cost ratio of the solution. As a rule of thumb, for long-term sustained loading situations where creep performance is critical, polyester (PET) and HDPE materials will be the most suitable. For road sub-base reinforcement applications, where short-term dynamic loads are present, stiff and robust polypropylene (PP) materials are most appropriate. However, other installation and commercial factors may influence the preferred polymer type. This relates to issues such as; the ease of handling, cutting and unrolling of the product and of course even if it satisfies the design criteria, the cost of the product will ultimately determine if the solution is feasible.

6 GUIDELINES FOR SELECTING & DESIGNING WITH GEOSYNTHETIC SOIL REINFORCEMENT

Current design standards mostly used for reinforced soil structures include:

- the Australian Standard AS 4678-2002,
- the British Standard BS 8006-1:2010,
- the NSW Roads and Maritime Services R57 design document,
- the American Standards, including the US Department of Transportation - Federal Highway Administration FHWA-NHI-00-043 (Elias et al 2001) and the National Concrete Masonry Association Design Manual (Simac et al., 1993).

7 CONCLUSIONS

It is obvious that design standards are very important in assuring that the general public are provided with safe, functional and cost-effective infrastructure. It is also important that developed countries lead the way in providing on-going research and development into the behaviour and design practices of such important and common infrastructure such as reinforced soil retaining structures. With greater awareness and continuing education in the engineering community, these structures should be designed with confidence and although different standards may be more conservative than others, the basic minimum standards should be exceeded in any case with sound engineering judgment and good geotechnical information. In this particular example, an additional cost difference of $200 per square metre of wall face area was indicated for the same structure designed and built under R57 as compared with AS4678. In any case, consulting engineers should seek and be aware of new technologies and design methodologies when conventional solutions are expensive and impractical.

8 ACKNOWLEDGEMENTS

Many thanks to United Crib Block Constructions Pty Ltd for their assistance on the costs involved in building reinforced soil wall structures.

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