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Review of design methods for geosynthetic reinforced soil walls – an Australian perspective

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ABSTRACT: The design of reinforced soil walls, in particularly segmental retaining walls have been documented comprehensively in Australia and around the world. International design standards have been developed, with segmental block manufacturers incorporating these different standards in their design software. In practice, most design methodologies are conservative and it has been documented through full-scale field studies that actual applied forces are lower than calculated theoretical forces in reinforced soil walls. Nevertheless, it is generally good practice to design conservatively, especially when soil parameters have not been tested and only based on soil descriptions and assumptions. Since different standards apply in different countries and for different government authorities within a country, inexperienced practicing engineers face a confusing task when designing reinforced soil walls for their clients. With increasing research and development occurring for designs of reinforced soil walls using geogrids, and better sharing of current knowledge and new design techniques on an international scale, it would be ideal to see design standards adopted around the world reflect the new developments, having a universal approach to designing reinforced soil walls using geogrids. But like other design codes such as those for steel and concrete structures, standards will vary from country to country, however, the basic design concept should be consistent no matter where you go around the world. The review of existing standards should also be carried out on a periodic basis to incorporate the latest proven theories and methodologies. The most important issue to engineers is safety or structural integrity, but designers also have a duty to provide their clients with the most cost-effective solution available on the market while meeting serviceability, architectural and construction requirements. Therefore, building a safe and economical structure should be the goal for every design engineer. This paper will review the current state of knowledge for designing segmental retaining walls using geogrids in Australia and detail how practitioners in Australia adopt a limit states or working stress approach to designing segmental retaining walls using geogrids. The focus will be on the reduction factors for geosynthetic geogrids and connection strength values for geogrids in segmental retaining walls using the Australian design standard for earth-retaining structures, AS4678-2002. Other international design standards will also be briefly investigated and compared on specific issues. A discussion on the direction of future design methodologies will be explored, with emphasis on the importance of geogrid connection strength values and the use of relevant partial or reduction factors for determining long-term connection strength capacities.

1 INTRODUCTION

The use of soil reinforcement, in particularly geosynthetics in retaining structures have been around for over 30 years in modern times and has gained popularity in recent years. As a result numerous design standards have been created to assist designers with reinforced soil structures using geosynthetics, namely for segmental concrete block walls and other facing systems. However, unlike other engineered structures, for example steel and concrete structures, the standards for geosynthetic reinforced soil structures vary significantly within the local engineering industry and perhaps internationally as well. Although our modern steel and concrete standards may have been modified from working stress designs to ultimate limit states designs, the fundamental concepts and design methodology remain relatively the same. This may be attributed to the advances in steel and concrete research, and the better awareness of these common building materials in the engineering industry. On the other hand, although some advances and awareness have been made on the geotechnical engineering front, mainstream engineers are still comfortable with designing geosynthetic reinforced soil retaining structures using the working stress approach. This may lead to confusion when determining the minimum factor of safety in internal, external and global stability checks.

In Australia, Standards Australia has developed a Code that covers reinforced soil structures using steel & geosynthetics. The standard, AS4678-2002: Earth-retaining structures is based on limit-states design and is similar to the British Standard BS8006. It is interesting to note that the main principles of the standard are similar, and this will be discussed briefly later in the paper. The focus of this paper will be largely on the design of reinforced soil retaining structures using geosynthetic soil reinforcement under static loading. A contrast in some other standards will also be briefly reviewed, namely American design standards, and finally, some suggestions on how the field of geosynthetics can progress to form better and more universal design methodologies for practitioners in Australia and Internationally on reinforced soil structures.

1.1 *Background*

Soil reinforced walls using geosynthetics have been around for over 30 years, with the first of these structures being built in France in 1970 (Leflaive 1988; Puig et al. 1977; Allen et al. 2002). Research into the design of reinforced soil walls have progressed over the years, and as more research and information regarding geosynthetic soil reinforcement have emerged, this has further improved design procedures. It is also known that methodologies and theories to determine the applied forces in the geosynthetic soil reinforcement elements have relatively remained the same over the years, and that these theories over-estimate actual design loads. The resultant design is a conservative retaining structure that is still commercially viable and more economical compared to conventional reinforced concrete or mass gravity retaining walls within certain heights. Only recently has Australia published a standard for design of earth-retaining structures. This standard is titled AS4678–2002: Earth-retaining structures. This standard adopts an ultimate limit-states approach similar to the British Standard BS8006. In the United States, a number of government authorities and associations have published design standards for segmental retaining walls. For instance, the National Concrete Masonry Association have published design manuals (Simac et al. 1993) for segmental retaining wall structures under static and dynamic load environments. In addition, the American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA) have released numerous public documents for assisting engineers in the design and analysis of Mechanically Stabilized Earth (MSE) structures.

2 THE AUSTRALIAN DESIGN STANDARD

The Australian design standard used for earth retaining structures, including geosynthetic reinforced soil walls is titled AS4678–2002: Earth retaining structures. The determination of the long term design strength of the soil reinforcement has been controversial amongst designers and manufacturers, but the determination of the long term connection strength between the geogrid and the block facing has been even more controversial.

2.1 *Design philosophy*

Most structural design engineers in Australia adopt the ultimate limit states approach for strength and stability; where the design resistance effect (R*) shall be greater than or equal to the design action effect (S*) for the most critical loads and combinations, i.e.

$$R^* \geq S^*$$

where R* and S* are appropriately factored. That is, $R^*/S^* \geq 1.0$.

However, adding to the problem geotechnical engineers must also check the global stability of reinforced soil structures, in addition to its internal and external stability. The dilemma posed to geotechnical engineers is do they adopt a working limit stress approach and use a factor of safety of 1.3 say or use load factors and partial factors on the soil parameters and follow an ultimate limit states design? Since no strict guidelines are in place for global stability checks, different designers may yield more conservative designs than others and hence will affect the overall project costs.

2.2 *Long term design strength (LTDS), T*d*

The LTDS of a geosynthetic tensile element or soil reinforcement (e.g. a geogrid) may be calculated as follows using the AS4678 design approach:

$$T^*d =$$

$$Tu\cdot(\Phi up)\cdot(\Phi rc\cdot\Phi ue)\cdot(\Phi ri)\cdot(\Phi rt\cdot\Phi rs\cdot\Phi rst\cdot\Phi ud)\cdot(\Phi n)$$

where Φ values are specific reduction partial factors. It is clear from this equation that a number of factors will govern the LTDS of a geosynthetic soil reinforcement. The main contributing reduction factor for a geosynthetic soil reinforcement is the creep reduction factor, Φrc. This value depends on the type of polymer used and is typically polyester (PET) or high density polyethylene (HDPE) and these values are normally obtained from the manufacturers. Typical Φrc values suggested by AS4678 in the absence of appropriate test results are as follows: (for 100 years service life)

PET: 0.50

HDPE: 0.30

Another significant reduction factor is creep-time extrapolation, Φue. Interpretation of the standard may vary between designers, but it is assumed that extrapolating data from real time or accelerated tests (e.g. Stepped Isothermal Method or SIM tests) should result in additional reduction factors for the uncertainty from the projected trend line depending on the number of log cycles of time. SIM tests have been used in conjunction with short-duration, conventional real time creep tests to verify results. These SIM tests have demonstrated that they are more practical and have been proven to be reliable especially for polyester geogrids (Greenwood et al. 2004). As a result, reasonably accurate creep-rupture trend lines have been obtained through accelerated tests that do not require any or only minor extrapolation of test results. This may lead to a Φue value of 1.0.

2.3 *Connection strength*

The design connection strength, T*cd, shall be determined using the following equation in accordance with AS4678:

$$T^*cd = Tc \cdot \Phi ucon . \Phi n$$

where Tc is the peak connection strength determined by tests; $\Phi ucon$ is the uncertainty factor for connection strength (given as 0.75 to determine the design peak connection strength); and Φn is the structure classification factor (typically equals to 1.0). Conventionally, $\Phi ucon$ is conservatively given a value of 0.66 (or a safety factor of 1.5). The design connection strength should be the lesser of the design peak connection strength and the tested serviceability connection strength governed by the allowable displacement of the soil reinforcement from the facing.

The concept of design connection strength and the calculation of the connection loads at the geogrid-segmental block interface have been well documented, but standards vary between government authorities and the engineering industry within Australia and internationally. For example, the determination of the design connection strength under AS4678 assumes that the long term and short term connection strengths are equal throughout the wall's design service life. In BS8006, no exact procedure has been outlined for calculating the design connection strength between the geosynthetic soil reinforcement and the block unit. However, the determination of the design connection load has been suggested by using the "tie-back wedge method" or the "coherent gravity method" for various facing systems. The AASHTO/FHWA design guideline report (Elias & Christopher 2001) recommends a "long term" design connection strength approach based on long term pullout connection tests. In essence, the extrapolated allowable long term connection strength, Tac, is calculated as follows:

$$Tac = (Tult \times CRcr)/(RFd \times 1.5)$$

where Tult is the ultimate wide-width tensile strength of the geosynthetic soil reinforcement;

$$CRcr = Tcrc/Tlot$$

where Tcrc is the extrapolated creep-reduced connection strength at 75 years based on actual test values; Tlot is the ultimate wide-width tensile strength of the geosynthetic soil reinforcement lot used in the connection tests; RFd is the reduction factor for long term environmental aging at the connection. Tac also has a built-in factor of safety of 1.5. The determination of the allowable connection strength capacity is a subject of heavy debate and sometimes even confusion amongst engineers. For example, do you need to include an additional reduction factor for extrapolation? Can you use the creep reduction factor for the soil reinforcement when determining the creep-reduced connection strength? In addition, the design problem is also complicated by the degree of uncertainty in calculating the actual tensile forces at the soil reinforcement-block unit interface. Current design methodologies are considered to be very conservative (Allen, T.M., Bathurst, R.J. 2003).

2.4 *Soil parameters*

The determination of the soil parameters is critical when calculating the applied forces in the soil reinforcement elements. These parameters include the apparent cohesion, c, and the internal friction angle, ϕ. Regardless of what design model you adopt for analysis, these soil parameters will have a significant influence on the magnitude of the applied forces and hence the factor of safety against a potential failure mode. AS4678 suggests using "partial design factors" for the cohesion and the internal friction angle values for the reinforced soil, foundation and other backfill materials. This essentially means the characteristic values of c and ϕ determined by a combination of laboratory and field testing, local site knowledge and engineering judgement will be further reduced for design. That is, the design cohesion value, c*, is given by the following equation:

$$c^* = \Phi uc . c$$

However, it is common practice to ignore any apparent cohesion strength in the soils except for the foundation materials in the long term. This assumption simplifies calculations and as a result will provide a more conservative design. The design internal friction angle, ϕ^*, is given by the following equation:

$$\tan \phi^* = \Phi uphi \cdot (\tan \phi)$$

where $\Phi uphi$ is the partial design factor for ϕ (ranging in value from 0.95 to 0.75 depending on the soil or fill conditions). Although this approach seems consistent with the limit-states design methodology, this design approach is actually inconsistent with other international design standards adopting ultimate limit-states and working stress methodologies. For example, the BS8006 (UK) standard applies a partial factor of 1.0 to the characteristic internal friction angle value of the soil for ultimate limit-states calculations. Furthermore, the NCMA & AASHTO/FHWA (USA) design methods also use the soil shear strength parameters based on the characteristic peak strength values and are not reduced by any reduction factors. Hence, the characteristic soil parameters should be used to calculate the active earth-pressure coefficient, Ka. In essence, the designer should be confident in the soil parameters used in design such that it will represent the most probable soil conditions on-site.

3 DISCUSSION

The behaviour of geosynthetic reinforced soil walls have been researched and documented well in recent years. However, the need to provide more consistent design methods internationally and between authorities within a country need to be considered. If the objectives for a practicing engineer is to design a safe, economical and practical structure, then there should be no reason why the design methods should be any different around the world in developed countries. Of course, seismic loading will always need to be considered for a given geographical location, but under static loading conditions, the fundamental principles should be the same. Review of the concept of long term connection strength is paramount as the design of high segmental retaining walls will likely be governed by the long term connection strength. Do we need to change current design methodologies in Australia? Is the current design standard too conservative? In any case, the Australian design standard should be in line with international standards and be reviewed periodically to reflect the current state of knowledge in designing reinforced soil walls. Collaboration between local authorities, industry representatives and Standards Australia may occur already, but international developments should be reviewed regularly as it is usually the more industrialized countries that have the resources and expertise to research new and existing ideas. As a result, fundamental design principles may need to be reviewed and even changed if safety has been compromised, or design constraints relaxed because it is considered too conservative.

4 CONCLUSIONS

The development of a limit-states design standard for earth retaining structures, namely AS4678-2002 which includes the design of geosynthetic reinforced soil walls is the first step towards educating the engineering industry in Australia on how to design safe and economical retaining walls using geosynthetic soil reinforcement. However, it is apparent that although the Australian design standard is similar in many ways to other international and local authority design standards, there are some fundamental differences as well. These differences include how we determine: i) the LTDS of the geosynthetic soil reinforcement; ii) the LTDS of the connection capacity; and iii) the calculation of Ka and the soil's shear strength design parameters c^* and ϕ^*. Current design methodologies in Australia do seem adequate and conservative. However, in today's modern age of technology where engineers and academics around the world can collaborate easily together, we should all work as one towards developing a universal design standard for geosynthetic reinforced soil walls. Our common goal should be to produce a safe and economical structure for people to use for many years to come.

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