Nearly Vertical Retaining Walls Reinforced By High-Stiffness Geosynthetic.

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1. INTRODUCTION

Geosynthetic-reinforced, concrete block retaining walls have traditionally been constructed at face slopes of approximately 70º. This face angle, allowed some movement during the service life of the structure, such that on strain of the reinforcement, neither the appearance nor the serviceability characteristics of the structure were compromised.

However this face angle utilised much-needed space, especially for high walls. The pressure for vertical walls developed, especially when used as bridge abutments. However, for these structures to withstand the internal and external applied loads, the requirements of the BS 8006-based RSA code SANS 207 (2006), must be met. This code specifies not only the design methods to be used for these types of structures but places limits on the in-service creep characteristics of the reinforcing geosynthetic.

High-stiffness, low-creep geosynthetics, coupled with the use of SANS 207 and simple-to-use finite element models, have revolutionised not only the way walls are designed but also the long-term performance of these unique structures.

This note examines the use of finite element models in the design of these near-vertical walls and compares deflection and force predictions with actual observed performance. Case studies of two, near-vertical, geosynthetic-reinforced structures, are presented.

2. PAST PRACTICE

In the initial stages of geosynthetic-reinforced, concrete block retaining walls, it was very common to specify and use woven polypropylene geotextiles for use as tensile reinforcement.

3. CREEP TESTING

Figure 1 below depicts the results of creep testing on just such a slit film woven tape polypropylene geotextile. From this graph it can be seen that if the geotextile had been designed (as was common practice up until a few years ago) to a safety factor of 2.5 or 40% of the ultimate strength, a service life of only some 400 hours would have resulted. It is thus not surprising that many walls fell down after only a few weeks of service when the structure was first exposed to rainfall and the seepage forces which this rainfall produces within the reinforced soil. A factor of safety (FOS) of at least 5, would have been necessary to ensure strain levels stayed below 10% for up 10 000 hours of field installation. This latter figure only however represents just over one year of service life. This may be sufficient for temporary structures, but is definitely insufficient for most other structures, which would require design lives greatly in excess of this value.

4. FIELD PERFORMANCE

Also of note is the fact that at 10 000 hours under a load of 20% of ultimate, the geotextile would have experienced axial strains of approximately 10%. Consider for one moment a wall of say 5m height. Typically the length of geosynthetic used for reinforcement would have been specified at say 0.7 x the height. This 3.5m length would not all have been strained to 10% under service conditions. However even if a representative affected length of only 1m were assigned, 10% strain represents an outward movement of some 100mm.

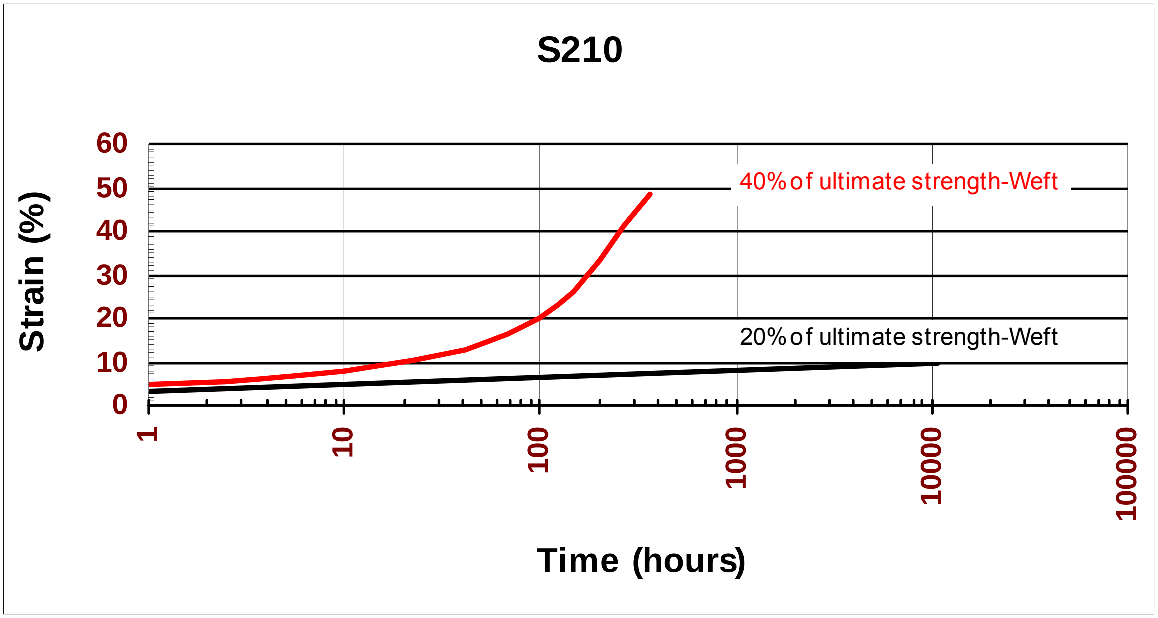


Figure 1: Creep testing of slit film, woven, polypropylene tape.

If the wall was designed, (as is common) at a face angle of 70°, then an outward movement of some 100mm over a height of 5m would represent an angular rotation of only some 1°. This in all likelihood would be unnoticeable to most people and the wall would have been adjudged to have performed adequately.

However if the wall were constructed vertically and 100mm of outward movement were to occur, the naked eye would have registered this negatively and generated the perception that the wall was leaning over and maybe even the perception that it was on the point of falling over. Thus special attention to detail is necessary when designing and constructing near-vertical geosynthetic reinforced retaining walls; both from an aesthetic and an analytical point of view.

5. SANS 207

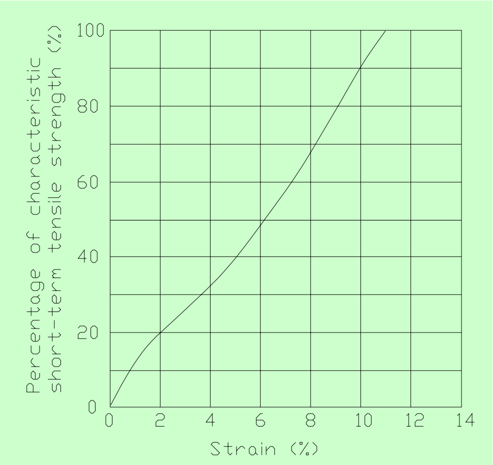
SANS 207 defines reinforced slopes as any structure with a face angle < 70° while walls are defined as those steeper than 70°. In addition in order to restrict movement, **post-construction internal strains are limited to 0.5% in bridge abutments, 1% in retaining walls and 5% in reinforced slopes.** For these stringent criteria to be met, it is usual that bridge abutments use steel as the reinforcing element, flexible retaining walls use high-strength, high-stiffness geosynthetics, while reinforced slopes may generally be much less critical as regards the type of reinforcement used.

6. NEW GENERATION MATERIALS

The above limitation has necessitated that for retaining walls, a new mindset be developed. In the early days of geosynthetic reinforced soils, materials which had traditionally been used for drainage or separation purposes, were utilised as reinforcing elements. This has now progressed to the situation where high-stiffness, low-creep geosynthetics are used as reinforcement.

Consider the material as depicted in Figure 2. If the ultimate strength of this geo-material were taken as 35kN/m and for a strain at break of some 11%, then the reinforcement stiffness may be calculated at 35/0.11 ≈ 320kN/m. Compare this to the weft direction of the material as depicted in Figure 4. Here the ultimate tensile strength is also approximately 35kN/m while the strain at break is about 14%. In this case the reinforcement stiffness may be calculated at 35/0.14 = 250kN/m. This is not significantly different from the value for the geogrid material.

However the difference arises when the creep characteristics are compared. From Figure 1, at 40% of the ultimate strength, the material ruptured after some 400 hours, while if Figure 3 is consulted it can be seen that at 40% of ultimate strength, the geogrid safely generates a service life of 1 000 000 hours. This essentially is the difference between the old generation geotextiles and the new generation geosynthetics.



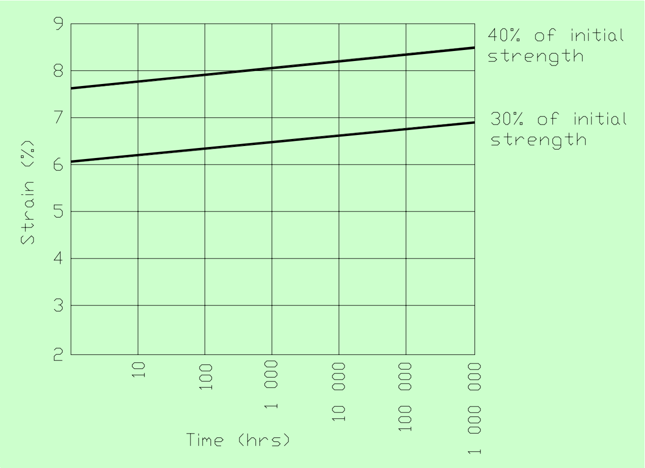


Figure 2: Load strain characteristics.

Figure 3: Creep strain characteristics.

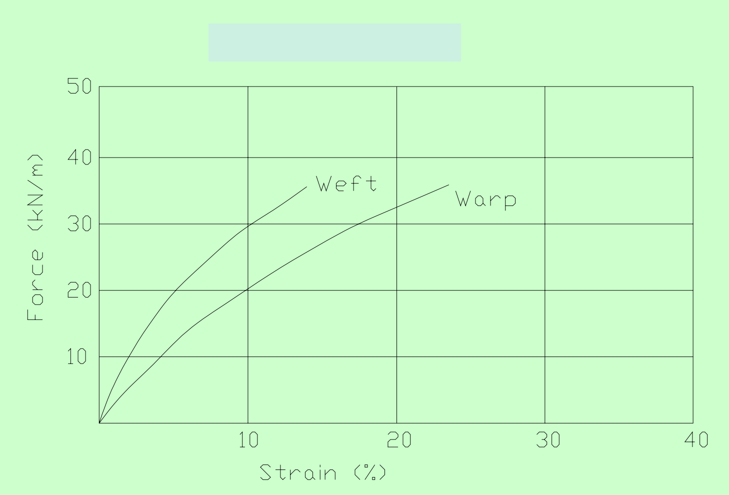


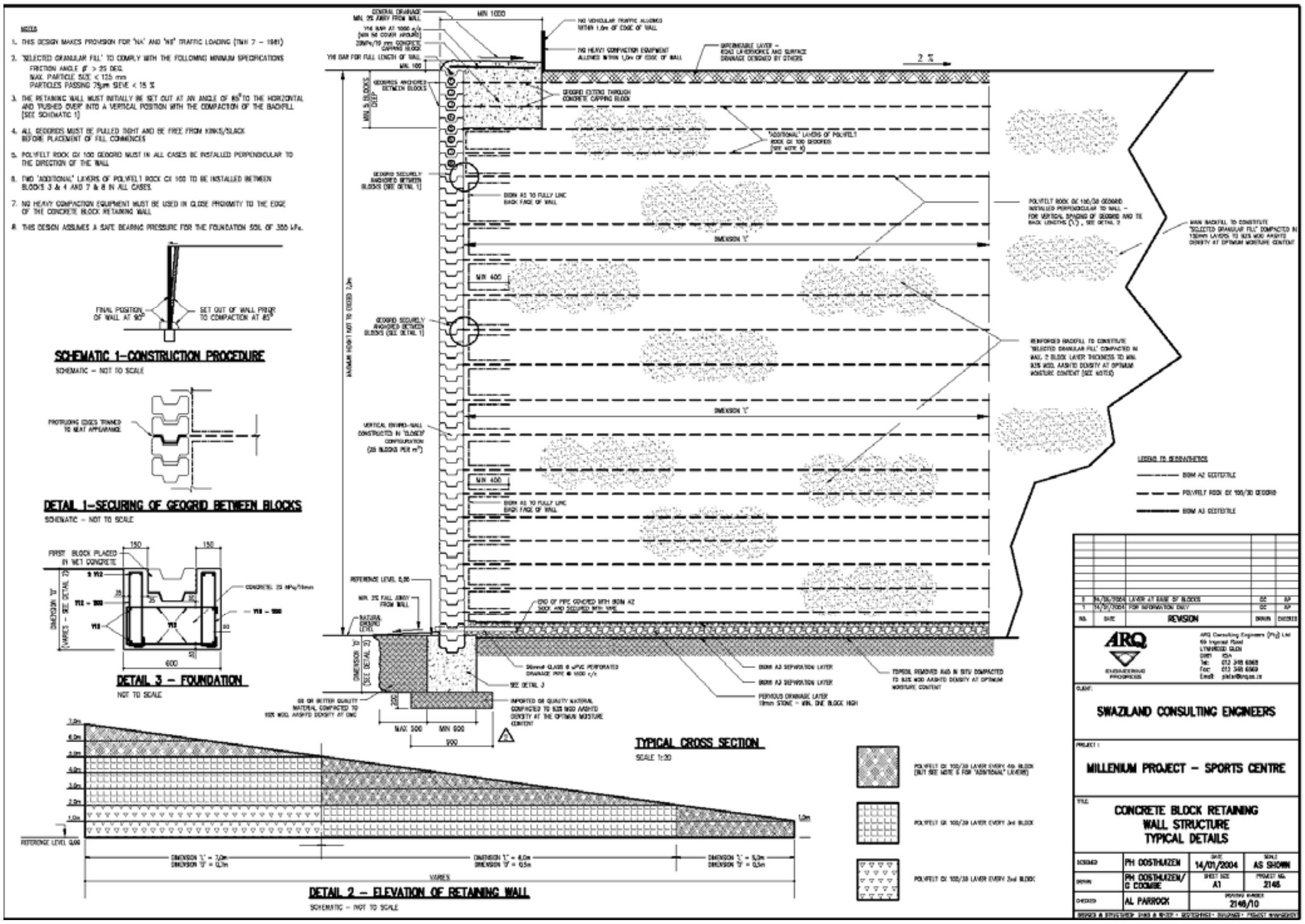
Figure 4: Load strain characteristics for “old generation” geotextiles.

7. POSSIBILITIES

These “new generation” geosynthetic reinforcing materials are eminently suitable for retaining walls which are specified as vertical or near-vertical and which were generally the preserve of those constructed using either metallic reinforcement or those built traditionally in reinforced concrete.

Various designs according to SANS 207 for vertical or near-vertical walls have been conducted, while the first examples using these new-generation geo-materials have now been in operation for nearly 5 years.

Figure 5 details such a typical design.



NOTES

1. THIS DESIGN MAKES PROVISION FOR 'NA' AND 'NB' TRAFFIC LOADING (TMH 7 – 1981)
2. 'SELECTED GRANULAR FILL' TO COMPLY WITH THE FOLLOWING MINIMUM SPECIFICATIONS
   FRICTION ANGLE Ø > 35 DEG
   MAX. PARTICLE SIZE < 125 mm
   PARTICLES PASSING 75μm SIEVE < 15 %
3. THE RETAINING WALL MUST INITIALLY BE SET OUT AT AN ANGLE OF 85° TO THE HORIZONTAL AND 'PUSHED OVER' INTO A VERTICAL POSITION WITH THE COMPACTION OF THE BACKFILL (SEE SCHEMATIC 1)
4. ALL GEOGRIDS MUST BE PULLED TIGHT AND BE FREE FROM KINKS/SLACK BEFORE PLACEMENT OF FILL COMMENCES
5. POLYFELT ROCK GX 100 GEOGRID MUST IN ALL CASES BE INSTALLED PERPENDICULAR TO THE DIRECTION OF THE WALL
6. TWO 'ADDITIONAL' LAYERS OF POLYFELT ROCK GX 100 TO BE INSTALLED BETWEEN BLOCKS 3 & 4 AND 7 & 8 IN ALL CASES.
7. NO HEAVY COMPACTION EQUIPMENT MUST BE USED IN CLOSE PROXIMITY TO THE EDGE OF THE CONCRETE BLOCK RETAINING WALL
8. THIS DESIGN ASSUMES A SAFE BEARING PRESSURE FOR THE FOUNDATION SOIL OF 350 kPa.

Figure 5: Design details.

8. FINITE ELEMENT ANALYSIS

To obtain a deeper understanding of the mechanisms at play within near-vertical, geosynthetic-reinforced, concrete-block-faced, retaining walls, a finite element analysis using the Phase II software of RocScience was undertaken. The wall was specified at a face angle of 85° and representative material properties for a G6 type backfill were used in the analysis. The top of the wall was subjected to traffic loads simulated using a 25kPa overall surcharge and two 40kN/m line loads acting simultaneously. 3.5m wide geosynthetics were installed at 600mm centres vertically, while the facing was assigned a low stiffness value to simulate a concrete block retaining wall.

For illustrative purposes; in the first analysis, a very low strength, "old generation" non-woven, needle-punched geotextile was used as reinforcement while for the second a "new generation" 35kN/m geosynthetic was utilised. The results are depicted graphically in Figures 6-11 with pertinent comment.

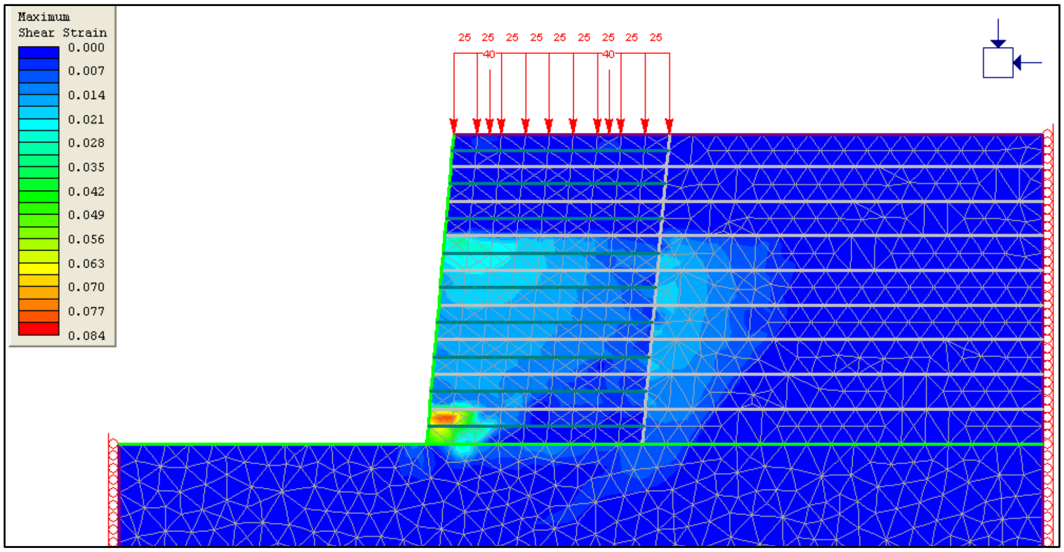


Figure 6: Low strength (Reinforcement stiffness = 20kN/m) model showing high shear strain areas.

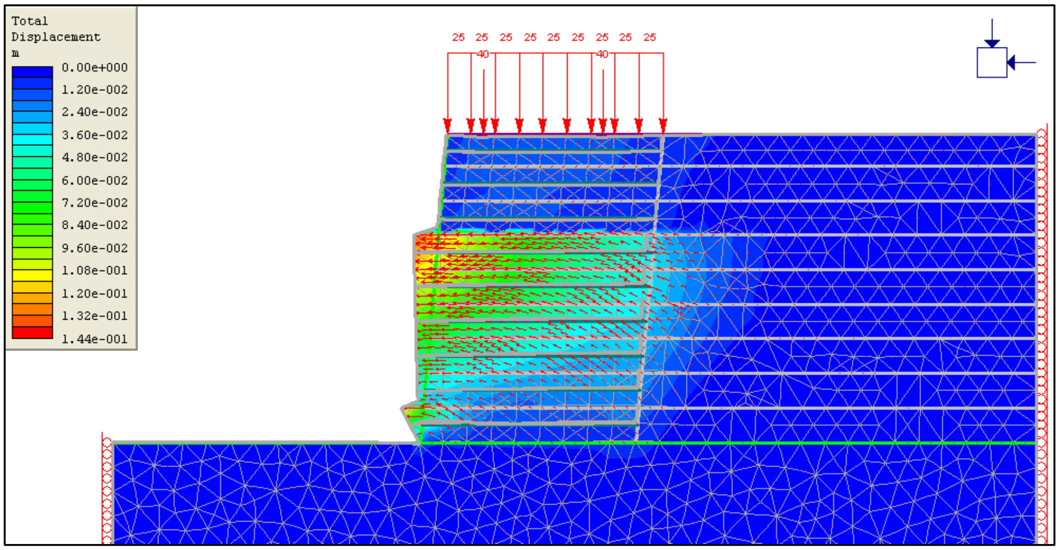


Figure 7: Low strength geotextile – predicted displacements.

In the above figure the predicted shear strains at mid height are in the order of 2.1% while those at the base are approaching 8%. At these elevated levels most soil-structure systems would have failed.

In this figure failure manifested in the form of excessive displacement (≈100 to 140mm) at mid height and at the base, is predicted.

Figure 8 and 9 below represent the settlement at various stages of construction using a “new-generation” geosynthetic. The maximum displacement is now limited to some 35mm

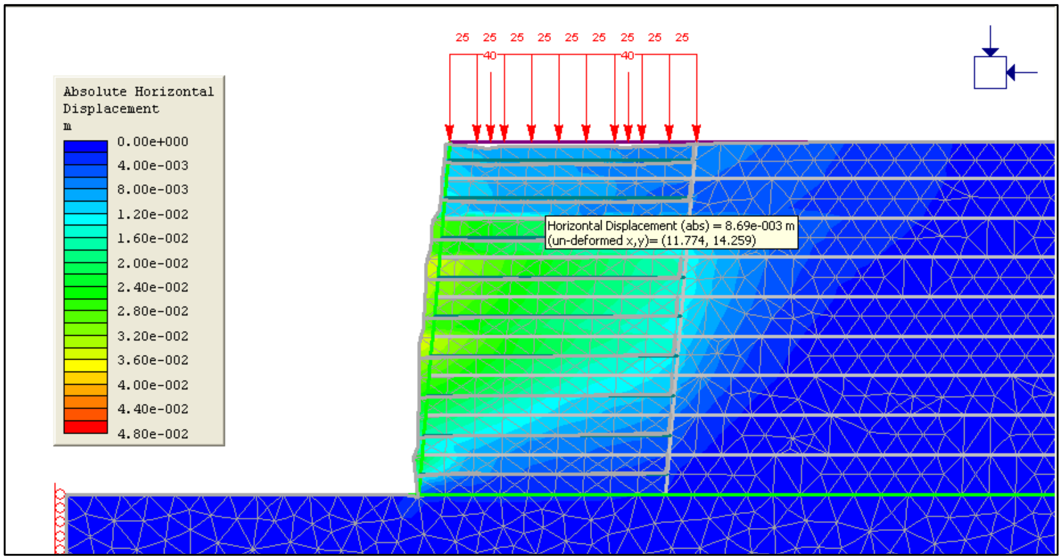
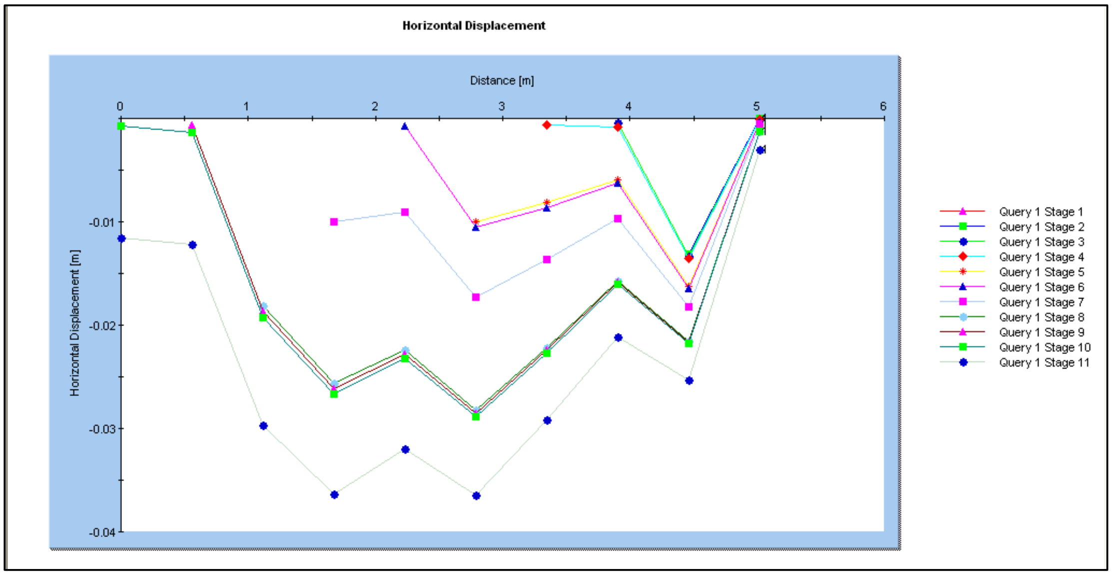


Figure 8: Horizontal movements

Figure 9: Wall face displacements at various stages of construction.



From the graphics in Figures 8 and 9, it is noticeable that much of the movement occurs during construction and will in all likelihood be “built out”. Thus whereas Figure 9 depicts a maximum deflection of 35mm, the displacement due to the applied live loads is only some 10mm.

Figures 10 depicts in the red areas the tensions which are generated within the geosynthetic under the condition at end-of-construction while Figure 11 shows how this changes when the top of the slope is subjected to a uniformly distributed load of 25kPa plus two line loads of 40kN/m. Of significance is the tension in the upper geosynthetics near the areas where the load is applied.

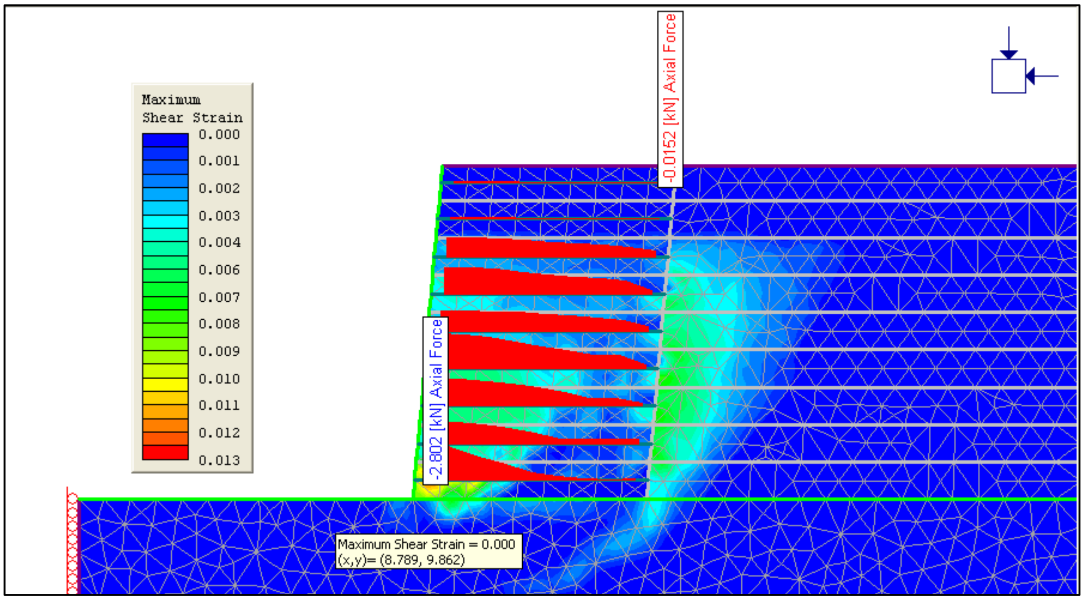
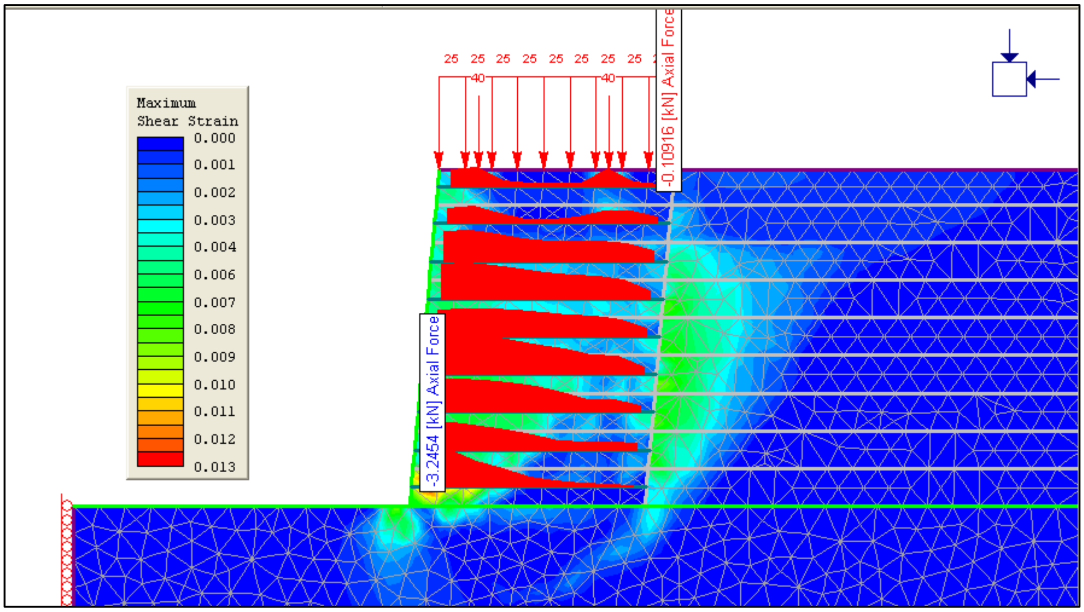


Figure 10: Tension in the geosynthetic layers at end-of-construction.

Figure 11: Tension in geosynthetic layers under the action of loading.



SOIL STRUCTURE INTERACTION

Examination of Figure 6 and 7 indicates that for the low-stiffness geosynthetic used, the predicted movement of the wall was in the order of 140mm while the graphic output illustrates that the length over which this movement took place was roughly half the total. The approximate strain in the geosynthetic would be 140/ 1750 = 8%.

These types of non-woven, needle punched geosynthetics typically exhibited ultimate tensile strengths of some 15kN but at strains as high as 55%.

The tension in this geosynthetic at 8% strain may thus be calculated as 8/55 x 15 = 2.2kN. This is a very low value and indicates that these types of materials were of little assistance in generating a reinforced soil.

Now consider the new generation materials. These are typically constructed of high density polyester which exhibits a strain-at-break of some 11%.

Here the analysis as depicted in Figures 8 and 9 indicates that movements would be limited to a total of some 35mm when 35kN materials are used. Using the same reasoning as given above, the strain in the geosynthetic may be calculated as 35/1 750 = 2%. The tension in the geosynthetic may be calculated as 2/11 x 35 = 6.4kN

The finite element analyses however indicate that the predicted tensions in the geosynthetics usually span the range of 3-4kN. This appears to be at odds with the values predicted by SANS 207 (2006) but the answer probably lies in the fact that the soil-structure interaction effects of the geosynthetic and the backfill material generates a situation where the end result is better than the sum of the two contributing inputs.

This is not as far-fetched as it appears as at the optimal operating condition a) the strain is sufficiently small to generate very high stiffnesses in the soil structure mass b) the friction angle is at its peak value and c) the geosynthetic is very lightly tensioned.

The aim of any design is thus to ensure that:

- The strains in both the backfill soil and the geosynthetic under serviceability conditions are sufficiently low so as to cause very small movements,

- These very small movements in turn ensure that the soil is at its stiffest,

- The soil and the geosynthetic must act together such that each is equally stressed.

The formulations contained in SANS 207 (2006) contain an envelope to the above and thus represent an overall conservative estimate. The finite element method enables a much finer analysis of the actual situation, which occurs in practice, to be undertaken.

SOME EXAMPLES

Figures 12 to 14 show examples of projects completed using a finite element analysis and the construction techniques as detailed in Figure 5. The first was for a temporary access bridge for construction traffic across a major arterial as detailed in Figure 12. The requirements of SANS 207 (2006) indicate that the geosynthetic reinforced walls used as abutments for the bridge required that the long-term creep-strains in these elements did not exceed 0.5%. This necessitated that they be designed for low tension to satisfy the 2 year design life of this structure.

Measurements of movement on the structure were made for some time in its early life and indicated that very few positions exceeded an outward value of 20mm.

Figure 12: Abutment structure for a temporary bridge

As a quality assurance check, all geosynthetics were brought to the face of the wall to ensure that the as-designed spacing requirements were satisfied. After inspection the excess material was cut back and burnt off with a blow torch. The smouldering material was quenched with water to ensure that the burn-back did not extend into the block. Figure 13 details this.

Figure 13: Trimmed and burnt back geosynthetic

Figure 14 depicts a wall in Swaziland. This forms the outside face of a retained slope which contains an athletics track

Figure 14: Wall in Swaziland at athletics track.

Inspection of the wall and track a year after completion indicates that little, if any movement of this wall has occurred.

9. DISCUSSION

The above models were generated generally using the material parameters as indicated in Appendix 1. It is believed that they represent indicative values of materials which would be specified for these types of walls.

Some may question the wisdom of specifying the wall at 85°. This in practice has been found to be very beneficial as a certain amount of movement takes place during compaction (usually 1-2°) while creep of the geosynthetic during the design life of the structure is then accommodated in the remaining 2-3°, without the wall ever being in a position of leaning over at angles in excess of 90°.

The tensions predicted by the finite element analyses, in the geosynthetics used as reinforcement, are very much lower than those calculated using the SANS 207 code. It is believed, as it should, that the code represents conservative design practice and thus allocates higher forces to these critical elements of the system.

However when, as required by ISO 9000, an approximate hand calculation is conducted to verify the above, the FE analysis is found to be substantially correct.

10. CONCLUSION

The ease of constructing near-vertical retaining walls utilising concrete blocks as a facing and high stiffness geosynthetics as reinforcement, combined with the relative cost-efficiency of these systems, makes them eminently suitable as retaining systems.

SANS 207 places an onus not only on the Engineer to design these walls to internationally recognised standards. It is also a requirement that the supplier of the components of the system demonstrate that the desired design life of the structure will be attained when using these components

It is the aim of the industry that safe and cost-effective retaining structures, free from defects during serviceability (excessive movement) and limit state (collapse) conditions, are the norm and hopefully the era of “many collapsed or excessively bulging walls” is a distant memory.

REFERENCE

SANS 207. 2006. The design and construction of reinforced soils and fills. South African National Standard. Published by Standards of South Africa . Edition 1. 245 pp.

11. APPENDIX 1

Material properties Material: foundation soil Initial loading: field stress & body force Unit weight: 18kN/m^3 Elastic type: isotropic Young's modulus: 45 000kPa Poisson's ratio: 0.3 Failure criterion: Mohr-Coulomb Tensile strength: 3kPa Peak friction angle: 28degrees Peak cohesion: 5kPa Material type: Plastic Dilation Angle: 0 degrees Residual Friction Angle: 28degrees Residual Cohesion: 5kPa Piezo to use: None Ru value: 0	Material: reinforced backfill Initial element loading: body force only Unit weight: 19kN/m3 Elastic type: isotropic Young's modulus: 80 000kPa Poisson's ratio: 0.3 Failure criterion: Mohr-Coulomb Tensile strength: 5kPa Peak friction angle: 35degrees Peak cohesion: 15kPa Material type: Plastic Dilation Angle: 0degrees Residual Friction Angle: 35degrees Residual Cohesion: 15kPa Piezo to use: None Ru value: 0
Material: main backfill Initial element loading: body force only Unit weight: 19kN/m^3 Elastic type: isotropic Young's modulus: 45 000kPa Poisson's ratio: 0.3 Failure criterion: Mohr-Coulomb Tensile strength: 3kPa Peak friction angle: 28degrees Peak cohesion: 5kPa Material type: Plastic Dilation Angle: 0degrees Residual Friction Angle: 28degrees Residual Cohesion: 5kPa Piezo to use: None Ru value: 0	**Liner Properties** Liner: Polyfelt Rock 35/35 Liner Type: Geogrid Elastic properties: Reinforcement stiffness: 320kN/m Strength parameters: Peak tensile strength 19kN/m Residual tensile strength 0kN/m 12.
Liner Properties Liner: Bidim Liner Type: Geotextile Elastic properties: Reinforcement stiffness: 20kN/m Strength parameters: Peak tensile strength 6kN/m Residual tensile strength 0kN/m	Liner: Envirowall blocks Liner Type: Beam Formulation: Timoshenko Geometry: Thickness: 0.3m Elastic properties: Young's modulus: 400 000kPa Poisson's ratio: 0.25 Unit Weight of liner included in analysis Unit Weight: 12kN/m^3
Joint Properties Joint: Joint 1 Normal stiffness: 100 000kPa/m Shear stiffness: 10 000kPa/m Initial joint deformation: not allowed Pressure from Groundwater: Not Included Additional Pressure Inside Joint: Not Included	**Structural Interface Properties** Structural Interface: Structural 1 Joint (positive side): Joint 1 Liner: Rockgrid GX 35/35 Joint (negative side): Joint 1 13.

Mohr-Coulomb slip criteria Tensile strength: 0kPa (tension positive) Cohesion: 3kPa Friction angle: 45degrees	

14.