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Structures reinforced with geosynthetics – some illustrated causes of failure

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ABSTRACT: This paper is intended to demonstrate that even if the best structural designs incorporating geogrid reinforcement are issued for construction, cost-cutting clients and incompetent or uncaring installers can bring the engineer's efforts to ruin. It also serves as a warning that those engineers who allow their clients to dictate design-by-cost principles to them do so at their own peril. A number of grid-reinforced structures have failed in Southern Africa and, embarrassingly, having been rebuilt, some of them have failed again. Why? Is there a principle identifiable cause of failure that is common to these problem structures? These failures have occurred despite the substantial public-domain literature base on the design of structures reinforced with geosynthetics. Publications include the UK Code of Practice for reinforced soils (BS8006 1995) which has been adopted by South African National Standards (SANS) as SANS 207, as well as the South African Concrete Manufacturers Association *Design of Reinforced Concrete Retaining Block (CRB) Walls* (2000), and a number of commercial software design packages as well as a huge base of conference proceedings). The paper illustrates what the author believes to be the most common causes of failure – and examples of these are presented in the hopes that design engineers and installers will acknowledge the common problem areas and move to eliminate them on their projects.

1 INTRODUCTION

Although the known use of reinforcement in soil structures dates back thousands of years to the construction of ziggurats in ancient Sumeria (Davies, 2001) geosynthetic reinforced soil structures were progressively introduced into modem civil engineering practice during the 1970s (Greenway *et al*. 1990). In common with their international counterparts, South African engineers incorporate geosynthetics when designing structures with various end-uses, where earth and geosynthetic reinforcement associated with some form of facing element are the major components of the structure. Geosynthetic products used in these designs include woven and nonwoven geotextiles, and woven, knitted, and extruded geogrids, usually fabricated of High Density Polyethylene (HDPE), Polypropylene (PP), Polyester (PET), and Aramid (PPA).

Structures incorporating these elements include soil walls (with or without facing elements), gabion structures, bioreactors for effluent treatment works, bridge abutments, loading areas, paved roads, and railway applications. They are often used as alternatives to conventional reinforced concrete solutions and when used with imagination, such arrangements can realise significant cost savings over standard RC designs. However, a number of these walls have failed and the question is why? Three main problem areas that contribute to such malfunctions have been isolated.

2 PROBLEM AREAS

2.1 *The client who will not pay for appropriate engineering*

The fall of the system of the once-common client/consultant relationship where a standardised scale of fees applied for work done may have resulted in cheaper design costs for some clients, with consulting firms competing with one another on a fees or a design-and-construct basis. However "*There is hardly anything in the world that a man can not make a little worse and sell a little cheaper. And people who consider price alone are this man's lawful prey*." (John Ruskin 1819-1900). This is a maxim that really holds as good for engineering as it does for pots and pans (or geosynthetics).

It is becoming fairly common practise in South Africa for some client organisations to instruct consulting engineers that they will pay for a design, but balk at paying the engineers rates for competent supervision of the construction of the works. Schemes aimed at driving project design costs down have become common and given that a consulting practice needs commissions to survive, the temptation to acquiesce becomes too strong for some engineers and they find themselves forced to submit designs where insufficient thought has been allocated to project specifications.

Picture 1 shows an extreme example of this, where a geosynthetic reinforced CRB wall is being overtopped by rainwater because of nonexistent surface water control. This wall fail ed further to the left of the location shown here and is the subject of discussion later in this paper.

Picture 1. No surface water control . . .

The poor quality of construction supervision staff employed by many installers today, added to cost-cutting stipulations from the client, means the engineer who accepts a commission on this basis is being exposed to an unfairly high level of professional risk. It is the author's belief that pressure of this kind is a prime cause of inadequate project specifications, and risky practises being allowed to occur unchecked on site.

2.2 *The inadequate specification*

What may have been considered acceptable in the past can no longer be considered safe practise. In the past, the author has come across specifications where the engineer, in specifying the nature of the soil to be used as backfill, limited his description of this fill to the words "coarse backfill". That seems to be a reasonable statement, and in the normal course of events, one might expect that the installer (with whom the consulting engineer had a good working relationship and many successful retaining wall projects prior to the events that follow) would understand what was required.

Unfortunately the installer had made use of an outside, contracted project supervisor, and Picture 2 shows what this supervisor considered to be suitable "coarse" material as backfill to be used in constructing an eight metre high retaining wall. This project was one of those where the client did not want to pay for project supervision by the design engineer, so he never saw this abuse during construction.

Common sense dictates that material such as that shown in Picture 2 would be highly likely to damage the geosynthetic reinforcement when compaction was taking place, but it is a sad fact that an engineer should not rely on "common sense" always being shown on site.

Picture 2. "Coarse material" . . .

This was not an isolated incident. Picture 3 on page 3 is from a different site, in a different country, but with a major South African installer doing the work.

Picture 3. Gross negligence . . .

The man with his back to the camera in the picture below is the contract manager, a qualified civil engineer.

He is watching a woven multifilament geotextile reinforcement being placed over a coarse rocky substrate, (not even in the same plane as the top surface of the lift of the facing elements), and then covered with an extremely harsh fill, which was compacted to 95% mod AASHTO.

Once again, the project specification for the backfill material for the walls did not specify a maximum and minimum particle size. The project manager was allowing construction plant such as that seen in the background to ride over the geotextile that in turn was laid over a harsh rocky surface. When the author examined the fabric, it was riddled with holes, soaked in hydraulic fluid leaking from the plant shown in the background, and its reinforcing ability was completely compromised.

When this was pointed out to the contract manager, At time of construction and subsequently, the he seemed unconcerned. writing this paper, no bonded or extruded geogrids

This was not an isolated incident on this site. There were more walls of this type elsewhere on the project and many of the same problems were noted there. It was not surprising to find that the constructed walls were out of plumb, in some cases quite alarmingly.

The problem of don't-give-a-damn installers in southern Africa seems to be rather common and it is a dangerous trend.

Picture 4 (different installer) shows yet another example of the same problem, on yet another site.

Picture 4. More "Coarse material" . . .

Not only is the backfill most unsuitable, but here too the reinforcement is not even installed in the same plane as the top of the lift of facing elements. This is the worst case the author has seen and it seems inconceivable that an installer could show such a careless approach. Once again, the specifier had trusted to common sense, and the backfill material was merely specified as "coarse".

In the projects shown in Pictures 2, 3 and 4, hard extruded or bonded geogrids would have been far more appropriate than the woven multifilament geotextile specified (good as it may be), had the designer known what would happen on site.

At time of construction and subsequently, the writing this paper, no bonded or extruded geogrids are currently manufactured in South Africa and the weakness of the South African Rand vs. major international currencies means that these products are expensive to import compared to the locally manufactured grid and textile products. Hence, they are little used.

However, there is more to consider than initial cost. Many uninformed installers have tended to use grid cost per kN of tensile strength as their main comparison yardstick, and have discounted or been ignorant of elongation and creep characteristics.

This makes locally produced woven polypropylene (PP) tape geotextiles seem very attractive when compared to the cost of a proper geogrid of the same tensile strength.

The CRB retaining wall market in South Africa is extremely competitive; and many installers who have not taken the time to study geosynthetic products properly, frequently make use of woven PP tape fabrics.

What they fail to take into account is that by the time the partial factors of safety recommended by BS8006 for polymer creep and thin product survivability have been applied to woven PP tape geotextiles, as little as 4% of the ultimate tensile strength of these products may be used in the design (BS8006). Consequently, when properly analysed, these fabrics are not as cost-effective as they may first seem, and it is probable that many walls reinforced with them are going to fail in time, when creep effects come into play.

2.3 *The inadequate installer*

A major cause of many of the failures the author has assessed. Even where comprehensive project specifications have been issued, a careless, ignorant, or even dishonest installer can ruin the whole design. Very often, when a reinforced soil wall has failed, the installer will move heaven and hell to show that he/she is innocent, and that poor design is the root cause of the failure. This is where comprehensive photographic records of the project become indispensable, or a *your-word against mine* scenario can develop. Common construction faults that are frequently observed are:

- *Untensioned reinforcing elements*

The designer should specify in the contract documentation, at tender stage, that the reinforcing elements should be laid in tension as far as is practically possible.

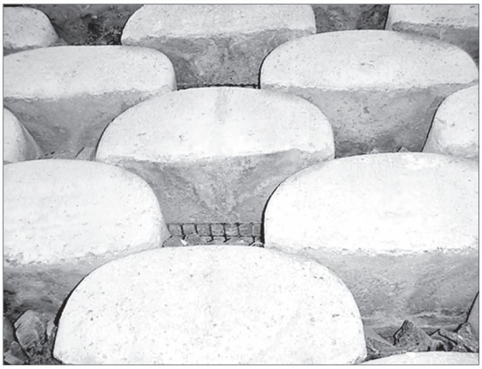
It would seem obvious that the reinforcing component of a reinforced soil wall cannot be laid as seen in Picture 5 on the following page, and be expected to work as intended, yet fabric or grids which have been laid slack or full of wrinkles are a common sight on many projects. The result can be walls with facings that bulge outwards even before they are complete, and which fail in due course.

Figure 5. Untensioned reinforcing elements.

• *Reinforcing elements not properly clamped between facing elements*

This has proved to be a common problem in South Africa. Many successful concrete retaining block (CRB) wall designs rely on the reinforcing elements being clamped between the facing elements to tie the reinforced soil and the facing elements into a structure where the three elements interact and support one another.

We have often come across instances where the reinforcement/block tie-in length has been inadequate as shown in Picture 6, or in some instances, reinforcement does not connect with the blocks at all.



Picture 6. Reinforcing not properly clamped in CRB.

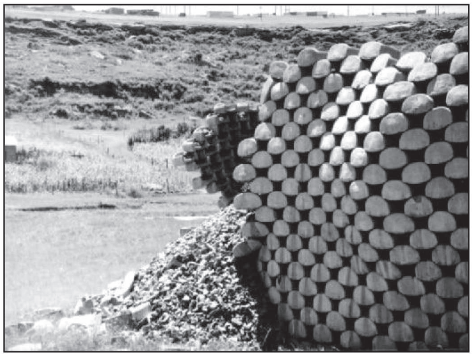
The result can be catastrophic. This is particularly true in the case of trickling filters for water purification works, where the temperature inside the structure can be higher than the ambient temperature when the structure was built, due to the heat generated by the biological action within the stone media.

The expansion of the heated media can result in extra pressure on the CRB face, and if the reinforcing is not properly clamped in position, the blocks can pull free and the structure then collapses (see pictures 7 & 8 – all the same structure).

The author recommends that the reinforcing elements should be designed and clearly specified to protrude a small distance beyond the face of the retaining blocks during construction, so that it can be seen to be in place on inspection and then properly clamped in position.

When the structure has been completed, the protruding reinforcing can then be neatly trimmed up against the face of the CRBs. The result of not insisting on this can be seen in Pictures 7 & 8.

Picture 7. Unreinforced CRBs bulging.



Picture 8. Failure.

This suggestion has been resisted by some contractors, reasoning that such a procedure is "unnecessarily fiddly" . . .

• *Multiple combinations of construction errors*

Frequently, it requires a combination of factors to coincide before civil engineering failures occur.

A geosynthetic – reinforced eight metres high CRB faced retaining wall was constructed near Johannesburg in late 1999/early 2000.

During construction, heavy rains fell. No surface water removal provisions had been made. The wall was inundated and the block facing failed in a number of locations. The failed areas were repaired. However, in December 2000, again after heavy rains, a portion of the wall that had previously been repaired collapsed again. Engineers appointed by both the designer and the installer who built the wall investigated the failures (Parrock and Oosthuizen 2001).

Observations that came out of this investigation included:

- Reinforcement installed at level of top of block 3, but only clamped between blocks 4 and 5 (see Pictures 9 & 10 and note how the reinforced soil is still intact – just the blocks have fallen off). Errors of this type were noted in several other locations on this site.
- The reinforcement sheets were not installed horizontally as specified. The sheet ends were clamped between the blocks at a level much higher than the sheet elevation, clearly shown in Picture 10. This resulted in a vertical reinforcing discontinuity against the wall, so that no tieback forces could be mobilised. The wall, with little or no horizontal resistance, experienced large outward movement under the action of imposed soil and water pressures.
- Once the top of this base wall had moved out, the retaining facing and the reinforced soil mass moved slightly out and downward, creating a void/tension crack at the top of the wall (see Picture 12 on page 6). Water not only entered this crack, causing further outward movement, but also entered the wall area between the blocks and the reinforced soil mass.

Picture 9. Failure – note skewed fabric tie into block joint.

Picture 10. Failure – note minimal fabric tie into block

As the blocks were in many cases not restrained by the reinforcing, they progressively fell from the face. This situation was exacerbated by block-on-block interlock, thus causing progressively larger areas to fail.

The stormwater referred to is a contentious issue. As early as June 1999, the designer of the geosynthetic-reinforced structures discussed here had warned the site developer that surface water control was needed – particularly in the areas shown in Pictures 11 and 12.

Picture 11. Inundation – no stormwater control . . .

Provision for designing such control was not included in the wall designer's brief and he had no control over site conditions not immediately connected with the structures he was commissioned to design. The measures requested were not attended to, and the result is seen is Picture 1 on page 2 of this paper, Picture 11 above, and Picture 12 on page 6.

While these conditions are not the fault of the wall installer, they triggered the collapses that followed.

A number of other factors contributed to the failures, including:

- Reinforcement stopping short and thus not properly clamped between blocks.
- Specified reinforcement layers absent in some locations.
- Poorly compacted backfill containing large rocks and cobbles, resulting in a very porous fill (see Picture 2). The net result of everything that has been shown here is a most unsatisfactory situation for every party involved in this project – The owner of the property, the designer of the walls, the installer who built them, the tenant who hires the site, and the supplier of the geosynthetic reinforcing products.

Picture 12. Failure – tension crack – note angle of poles

3 CONCLUSIONS

Geosynthetic-reinforced CRB walls as well as walls with other facings are popular around the world, and are successfully built in large numbers – including in South Africa, where despite the examples shown here, the vast majority of these structures do not give any problem at all.

There is a substantial database of case histories and design methodology and there is no reason why CRB and structures with other facings should not continue to be a suitable alternative to more expensive forms of construction.

In particular, the advent of warp-knitted grid technology has seen the appearance of a range of high quality, comparatively low-cost geogrids made of polyester appearing on the world market. The addition of these versatile products to the engineer's design toolkit will greatly enhance flexibility and innovative design in future years.

One has but to look at the performance of geosynthetic-reinforced structures that survived the devastating 1995 Japanese Kobe earthquake, to appreciate that these structures offer more than just cost saving benefits – their comparative flexibility means that they can also be the correct initial choice of design over "conventional" reinforced concrete designs, even where such designs are intended to be "earthquake-resistant"

The author has demonstrated some of the common construction-related causes of failure, the most prevalent of which are: poor construction technique and lack of adherence to design specifications, compounded by lack of proper construction monitoring and construction quality assurance (CQA) programmes.

These inadequacies are frequently caused by client bodies being reluctant to pay for the costs of competent supervisors. They have only themselves to blame when failure occurs.

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