WHAT CONNECTION TO FACING FOR POLYESTER STRIPS IN MECHANICALLY STABILISED EARTH WALLS ?

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ABSTRACT: This paper first presents the current state of Freyssinet – Terre Armée development for a synthetic connection between polyester-based reinforcing strips and concrete precast panels. It mainly deals with the assessment of durability of the connection. Further to this system currently used in structures around the world, we also disclose another innovative solution. This system only comprises structural elements which work in their natural way, e.g. tension for strips and compression/friction for the fill. Although the global functioning of the system makes no doubt, it may be further optimised, which is quite challenging and will involve a whole set of checkings, including classical local equilibrium approaches, numerical simulation and true-scale test-walls.

1 INTRODUCTION

It has been now more than 25 years since the first mechanically stabilised earth (MSE) walls were built using polyester strips under a sheath of polyethylene as reinforcements. Over these years, this type of structure has shown increasing success, especially in countries where the chemical contents of the backfills available are not compatible with thin metallic reinforcements, because of their aggressiveness (particularly high chloride contents which may be found in the Middle East for example).

This kind of reinforcement is generally associated with a segmental concrete facing, made of precast panels. The reinforcement is then connected to the facing panels during construction. There are several types of connection. Initially the connections were made of metallic elements, either galvanised or covered by a thermo-plastic layer. In order to better comply with the chemical aggressiveness of the soils, fully synthetic connections were designed.

The fully synthetic connection currently used by the Freyssinet – Terre Armée group along with synthetic geostraps is composed by a polyester loop embedded in concrete and a glass-fibre toggle (cf. Orsat & Freitag (2001) and Orsat & Hall (2002)).

2 SYNTHETIC CONNECTION

2.1 *Description*

The current solution considered to connect the polyester geostraps to the concrete facing consists of a loop and a composite toggle (illustrated in *Figure 1*).

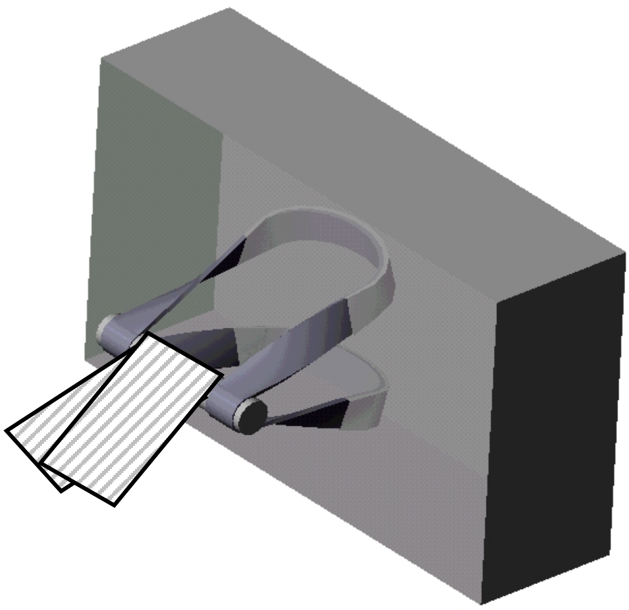

Figure 1 - Fully synthetic connection (patent pending*)*

2.1.1 *Loop*

The loop is made of the same material as the reinforcement, i.e. high-tenacity polyester yarns protected by a sheath of low-density polyethylene. In the precasting factory, the loop is twisted so that it forms a shape similar to a gondola. The gondola is embedded in the concrete panel, so that finally two ends of the loop are left outside concrete.

As it is made of the same material as the reinforcement, the long term behaviour is well known today, as mostly controlled by three phenomena : installation damage, creep rupture and hydrolysis. Higher temperatures inside the facing concrete can be taken into account in the design (especially of concern regarding hydrolysis).

Hydrolysis of polyester is known be accelerated in environment with higher pH levels. Thus the contact between the polyester fibres and the concrete has to be avoided. The impervious polyethylene sheath plays a major role in protecting the fibres.

2.1.2 *Synthetic toggle*

This is certainly the most sensitive element in the connection. We are currently using a toggle synthetic made of continuous glass-fibre (E-glass 70%) and a vinyl-ester resin. This type of resin is known to have a very good performance in terms of durability, compared to other types of resin (e.g. polyester resin).

This type of composite material has been primarily developed to substitute for steel as rebars in reinforced concrete. The European research programme Eurocrete launched in 1990 showed the superiority of vinyl-ester resin, for durability in concrete but also gave some clues about the mechanisms of degradation of the material.

In our case, the main mode of failure of the toggle is longitudinal shear. As the material is obtained by pultrusion, the fibres are all orientated in the longitudinal direction. The longitudinal shear is transmitted inside the material through the resin and the interfaces between resin and fibres. This interface is the mechanical weak point of the material. The shear which develops inside the toggle when it is bent leads to rupture of the toggle when it becomes higher than the “interlaminar shear strength” (ILSS). Water is the main cause of degradation of this interface, by hydrolysis. It first has to penetrate the resin matrix by microporosity. This degradation process is slow and, in order to be better assessed, needs to simulated in accelerated-ageing.

Dejke, V., 2001, shows clearly the superiority of E-glass and vinyl-ester resin regarding ILSS retention, compared to AR-glass and vinyl-ester. He also shows E-glass and polyester resin lead rapidly a complete loss of ILSS with the action of water.

A series of accelerated-ageing tests, partially financed by Terre Armée, were carried out in ERA Ltd (UK) under the direction of Prof. John Greenwood. These tests started in late 2001 and lasted 21 months for the longer ones. They consisted in bathing toggles and thin strips of the same material in water at a constant temperature (40°C, 60°C and 80°C). Pure water was used, as it is known to be more aggressive for this kind of composite material than salted water. After a certain time in water at a given temperature, samples were taken out of the baths and weighed. The residual strength of a certain number of them was tested, the other ones were put back in the baths.

Several factors make the interpretation of the results difficult. First of all, the variability of the initial resistance of the toggles leads to two consequences :

- comparing the resistance of degraded toggles with the initial value is difficult ;
- the characteristic value used for final design (i.e. 95% lower confidence limit) is quite low compared to the mean value, since the standard deviation is large.

Another factor is that for the lower temperatures (40°C and 60°C), the rate of degradation for the 30 mm toggles was not measurable, or too scattered, to allow any conclusion. Only the 30 mm toggles which stayed at 80°C for up to 21 months led to consistent and exploitable results. Those results, once associated with a conservative law for temperature dependence, can be used for designing the toggles based on the design service life and loading.

Globally, this approach leads to a very conservative design because of the following points :

- most of our structures using this technology are in mostly dry conditions, which is much less aggressive for the toggle than permanently submerged ;
- the few permanently submerged structures are in sea-water which is less aggressive than fresh water because the salts tend to slow down the degradation process.

The experience with such products is not wide yet, which leads to be over-conservative. We hope that in the future new research on this kind of products will give more accuracy in the understanding of the degradation process in saturated and unsaturated backfills, which would certainly allow to increase the working loads and thus decrease the size of the toggles.

2.2 *Conclusion*

This system, which has been already used in several structures, essentially in the Middle East but also in Ireland and in the Netherlands, has proved to work well. However the durability issue has led us to have a conservative attitude regarding the degradation rates, especially for the toggle. We are thus led to think about other solutions, where only well-known products are used in their natural way of working. This is not totally the case with the synthetic connection, as the pultruded profiles are excellent products for use in tension, but less optimised for bending and shear.

Figure 2 – IJmuiden, Netherlands – 2003

Figure 3 - IJmuiden, Netherlands – 2003

3 WHAT NOT REMOVING THE POSITIVE CONNECTION ?

The Reinforced Earth company has always and rightly claimed that the facing has not a major structural role in the stability of a MSE wall. But now imagine that we disconnect the reinforcements from the facing : the retaining wall will partially fall down ! This is confirmed by measurements on test walls and numerical models which show that the tension at the facing is generally comprised between 50% and 100% of the maximum tension along the reinforcement.

However, if we disconnect the reinforcement from the facing, we may anchor the facing inside the reinforced soil mass to restore its stability. So the use of short elements embedded in the concrete facing panels at the precasting factory and anchoring the panels by friction in the reinforced soil mass is an answer. The anchoring elements and the main reinforcements can be designed and optimised separately.

3.1 *System description*

A patent is pending which describes an MSE wall system with a facing, main reinforcements for the stability of the embankment which are not connected to the facing and secondary elements which anchor the facing in the reinforced soil, so that efforts between the main and secondary elements are transmitted through the backfill. A possible application is illustrated in Figure 4.

Of particular interest is the application of this principle with polyester strips. The main reinforcement is placed by layers as usual in a zigzag pattern. They are not durably connected to the facing, or even not connected at all. At the same level or preferably at intermediate levels are placed the short strips which are embedded in the facing panels.

We finally get a system where the strips work in tension and the backfill in compression and shear. All the elements are used in their natural way of working.

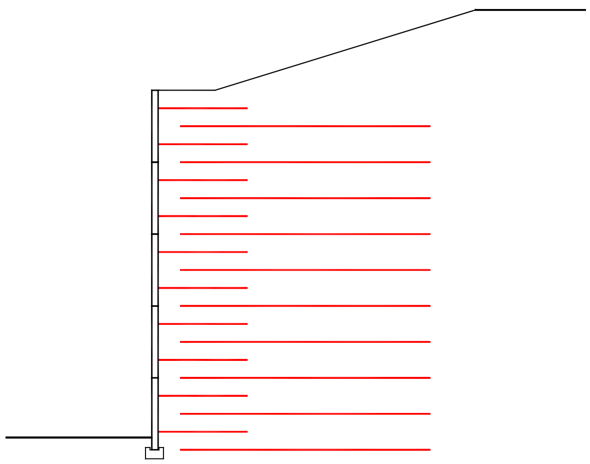

Figure 4 - New system

3.2 *Design related to possible modes of failure*

3.2.1 *“Classical“ modes of failure*

These modes of failure are the ones which are already checked in the standard design method for MSE walls reinforced by flexible strips, i.e. the local equilibrium method. This method is described in several national design standards, as the French norm NF-P94-220 and seq. (1994) and the British standard BS8006:1995.

External stability (as for classical retaining walls) :

- Sliding
- Overturning
- Bearing capacity of the foundation soil

Internal stability at each main reinforcement level :

- Ultimate tensile strength (long term)
- Adherence capacity

3.2.2 *Additional modes of failure*

In addition to the classical modes of failure listed above, some other modes of failure regarding internal stability are to be taken into account.

Main reinforcements :

- Adherence in the “active zone”

Secondary short elements :

- Ultimate tensile strength
- Adherence

Vulova, C. and Leshchinsky, D., 2002, studied the effects of layers in between layers of long reinforcements on the behaviour of block walls. The configuration they studied is not the same as the one we are interested in, as in their case all the reinforcement layers are connected to the block facing by friction between two layers of blocks. They showed a decrease in the tensile load of the main reinforcements and an increase in the stability of the structure compared to the situation where the secondary reinforcements are not in place. This conclusion is certainly still valid in our case.

3.2.3 *Numerical simulation*

We carried out numerical simulation with the geotechnical finite difference program FLAC (Fast Lagrangian analysis of Continuum).

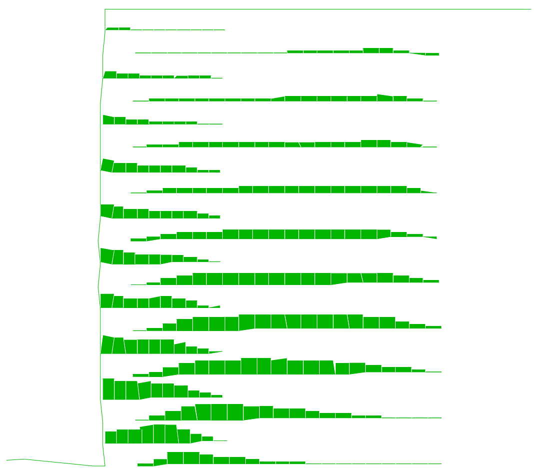

Figure 5 - Tension along the reinforcements - FLAC

3.3 *Advantages*

This configuration presents a series of advantages.

3.3.1 *Durability*

The systems makes only use of polyester strips protected by polyethylene. This product has been subject to many long term tests which give quite a good knowledge of the degradation process (mostly hydrolysis) and the creep behaviour. Thus it is possible to predict the long-term minimum tensile strength up to the requested design life without much error.

3.3.2 *Flexibility – Ductility*

Lack of compaction during construction or heterogeneity of the foundation soils are leading sometimes to differential settlements between the facing elements and the reinforcements. One part of this effect is compensated with the use of flexible compressive pads between superimposed panels. This is sometimes not sufficient when not enough care was taken regarding compaction. In this case, the system presented here gives additional flexibility, as the differential settlement will be partly compensated by some relative sliding between the main reinforcements and the short connecting elements, without leading to any increase in tensile efforts inside the reinforcements

Another field which may be of interest is the seismic capacity. MSE walls, especially when using flexible or segmental facings, have proved during the last three decades to be highly resistant to seismic solicitations. The key point to explain this fact is the high flexibility of such a structure. It can follow the imposed movements without concentrating in one particular location the resulting efforts. Our new concept is from that point of view even more flexible. Thus we believe that its performance regarding earthquakes can be even better than for conventional MSE walls.

3.3.3 *Optimisation*

All the existing systems for MSE walls use a discrete range of reinforcement. This is the case for strip reinforcements connected to facing panels, as their number is function of the number of connections in the panels, which is an integer number for a certain width of wall (generally equivalent to the width of two consecutive panels). It is also the case for geogrids and geotextiles, as the range of strengths available is limited. Sometimes the vertical spacing between the reinforcement layers varies along the height of the walls, but this is not very practical, especially when precast concrete facing panels are used.

Thus, when we compare the actual quantity of reinforcement to the necessary quantity to be in accordance with the design method (both for tensile capacity and for adherence) , there is always an offset. It is common to have between 15 and 20 % of excessive quantity of reinforcement.

The laying of the flexible reinforcing strips in a zigzag configuration without influence from the geometry of facing elements makes it possible to refine the density of reinforcement by adjusting the distance between “zigs” and “zags”.

3.4 *Next steps*

This innovative solution is quite challenging. There are quite many things which still need to be checked. Among those things, here are some of the major ones :

- Numerical approach : better understand the functioning of the structure, i.e. essentially better address the way the efforts are transmitted from the short elements to the main reinforcements.
- Test walls : such an innovative system makes the construction of instrumented test-walls essential. These test walls would have two functions : first to measure displacements and efforts, in order to confirm the numerical and theoretical approaches ; second to set up a good installation method.
- Elaboration of a new design method. This one would probably be based on the classical local equilibrium method, taking into account the measurements which would be done on the test walls. This would stick to the spirit which led to the elaboration of the method for standard MSE walls in the past.
- Confirm our intuition concerning the additional ductility when submitted to earthquakes or other accidental dynamic impact.

4 CONCLUSION

We have currently a system which is fully synthetic and provides a good performance regarding durability. However it makes use of a material (pultruded glass-fibre) which long term is not accurately known at the moment. This leads to some over-conservatism in its design., and consequently decreases its competitiveness.

To overcome this situation, we are developing an innovative system which makes use off the friction of the backfill to connect the facing panels to the main reinforcement, with the aid of smaller secondary elements which work essentially in friction/tension.

This system is quite challenging both from the engineering and commercial points of view, as it represents a new step in the use of soil-reinforcement interaction. Numerical analysis and full-scale test walls will help us to give confidence in the system to the scientific community and to our clients.

5 REFERENCE

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