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Sea walls (designed as reinforced soil walls) with vertical concrete facings combined with fully synthetic reinforcements and connections

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ABSTRACT: In order to offer a coherent earth reinforcement system suitable for the most highly chemically aggressive fills (as for sea walls) a fully synthetic system (reinforcements and connections to panels) combined with vertical facing panels has been developed. This paper describes the development of a new fully synthetic method of fastening main reinforcements to panels and then several practical applications. This system is based on the use of fully synthetic main reinforcing strips.The innovation consists of the new generic methods of fastening the reinforcements to panels made with : Synthetic continuous loop which is half embedded inside the concrete facing panel and half protruding in the form of two external handles. Synthetic toggle in Pultruded Glass Fibre around which the main reinforcing strip is folded and anchored. To date a total area of facing of more than 110,000 m² has been successfully built. The main advantages of this system are the use of locally available fill and the efficiency of vertical concrete facings.

1 INTRODUCTION

The FREYSSINET/TERRE ARMEE INTERNATIONALE Group needs to offer two complementary and similar families of strip-reinforced flexible retaining walls with vertical facing panels. Thus a totally synthetic system has been developed which forms the subject of this publication.

2 SPECIFICATIONS

The new generic method of fastening the reinforcements to panels had to be developed to meet the following specifications:

2.1 *Mechanical characteristics*

The tensile strength of the assembly had to be 65 kN for the attachments corresponding to 30 and 50 kN grade reinforcement and 130 kN for the other grades.
It was agreed that this new attachment must be compatible with the stock of existing moulds to which only minor modifications should be needed.

2.2 *Physical and chemical characteristics*

The new fastening method of reinforcements to panels had to tolerate the same soil characteristics as the existing main strip synthetic reinforcement, that is:
- ground having a pH level outside the 5/9 range
- risks of stray currents, high chloride ion or high sulfate content (due to the use of de-icing salts, for example)

It would then be suitable for use as sea walls and for use where reinforcements will not cause electromagnetic interference (airports,…).

3 PREFERRED SOLUTION

After an extensive review of potential solutions, it appeared that a generic method using synthetic loops anchored partly in the concrete and equipped with two external hoops and a synthetic pin located inside these two hoops would be the best solution to fulfill the specifications (figure 1)

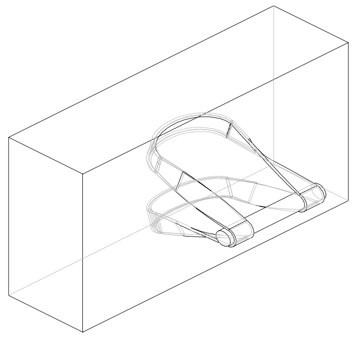

Figure 1. An overall view of synthetic connection

3.1 *Synthetic loops*

3.1.1 *Overall design*

The synthetic loops are manufactured from reinforcement strips that are made of identical to the main reinforcement, although not as wide (33 or 44 mm instead of the normal 90 mm).
The concept involves forming continuous loops from the strips that are wrapped and fully bonded several times around themselves using a successfully developed technology.

These strips are made of polyester fibers grouped into 10 separate bundles; the assembly is protected by a common polyethylene sheath.
From a geometric point of view, the idea consists in making the straight, flat “mother loops" (as described above). They are then deformed to obtain a "gondola" shape in order to fit the two "interior" hoops, that form the anchor in the concrete, and the two external hoops that provide bearing areas for the pins.

3.1.2 *Strength Characteristics*

The strips used are of the following type:

Table 1 - Loop characteristics

Individual "grid-web strips	33mm/15kN	44 mm/25kN
Strip width	33 mm	44 mm/25kN
Breaking load guaranteed on a single strip	15kN	25kN
Theoretical breaking load of a straight mother loop (4strips)	15kNx4=60kN	25kNx4=100kN

3.1.3 *Identification*

Two loop models were developed:
Loops "50 kN/500-600" for main reinforcement grades 30 and 50 kN (where 500 represents their length measured flat in mm and 600 represents the coverage length in mm).
Loops "100 kN/600-900" for main reinforcement of grades 75 and 100 kN.

3.2 *Synthetic pins*

3.2.1 *Overall design*

The pin functions as a short beam resting on two simple bearing surfaces that are formed by the loops protruding from the concrete.

3.2.2 *Investigations to be conducted*

Although pultruded glass fibre component technology is being increasingly used in the field of civil engineering, two specific lines of research are still very important:
Knowledge of the rupture mode specific type of load/stress.
Physico-chemical behaviour in the specified chemical environments.

3.2.3 *Initial choices*

In light of these parameters, the initial decision was made to use "vinyl-ester" resin-based pultruded glass fiber pins.

4 TESTS CONDUCTED

Complete tests were conducted on:

- The isolated loops, either straight or gondola shaped, concerning their intrinsic mechanical resistance as well as the appreciation of possible fiber/sheath slippage risks, and their possible measurement.
- The pins alone, in order to determine their premature breaking criterion as well as their resistance over time.
- The complete assembly consisting of a loop/pin attachment anchored in the concrete.

4.1 *Tests conducted on loops*

4.1.1 *Prior testing*

Prior testing has been conducted concerning the alkaline hydrolysis resistance of the main reinforcements used.

4.1.2 *Resistance testing on “mother” loops*

Resistance tests on the straight mother loops were conducted. These tests allowed us to fine tune the number of strands necessary as well as the amount of overlap necessary.

4.1.3 *Sheath/fiber slippage tests*

Slippage tests were also conducted in order to highlight the possible existence of this phenomenon and to measure its speed in order to predict its significance for the expected service life of the particular project.
These measurements showed that significant slippage occurred during loading, then extremely slow slippage which would amount to only 4mm over a period of 70 years.

4.2 *Pin tests*

4.2.1 *Mechanical strength tests*

The mechanical strength tests showed that the critical design characteristic is the interlamilinar shear strength (ILSS).
All of the measurements conducted showed an interlaminar shear strength of 60 Mpa (60 N/mm2).

4.2.2 *Accelerated ageing tests*

In the last few years synthetic pins are being more widely used however their long-term behaviour is still not totally quantified.
In order to validate the ageing coefficient used, accelerated ageing tests are being conducted in order to fine tune the coefficient used which is currently extremely conservative.

4.2.3 *Dimensioning retained*

A reduction/safety coefficient of 3 was applied to the ILS to determine the diameter of the pins for long term service. This gave the following diameters:

- Reinforcements, grade 30 kN: 30 mm
- Reinforcements, grade 50 kN: 36.8 mm

4.3 *Testing of the loop + pin assembly anchored in the concrete*

Pull Out Tests of the loop/pin assemblies anchored in the concrete were conducted, simulating as close as possible the in service loading on the panels.

5 FABRICATION

5.1 *Loop fabrication*

Two loops are fabricated from double width strips side by side in one operation and then are separated from the double width into single loops during cooling. The overlap weld is carried out hot with strict control of the polyethylene softening temperature.

5.2 *Pin fabrication*

The pins are fabricated by continuous pultrusion. They are cut into 200 mm bars and the ends are dipped in the same resin to seal them thereby increasing their resistance to alkaline hydrolysis.

The cost of the pins depends directly on their diameter and the quantity manufactured during one manufacturing run. For this reason the following most economical combination was chosen between the numbers of different size pins and the main Soil Reinforcement grade.

Table 2 - Toggles combination

Renforcement grade	30	50	75	100
Proposed diameter	1x30 mm	1x36,8 mm	2x30 mm	2x36,8 mm

6 ACTUAL APPLICATIONS

Several project applications have been successfully completed:

6.1 *Sea walls application*

A seaside quay wall in Ireland, subjected to the effects of large tidal fall. The use of reinforcements and metallic attachments for this structure was not permitted. (figures 2, 3, 4 and 5)

Figure 2. A PARAWEB V strip connected to the synthetic connection

Figure 3. Loops in place before casting

Figure 4. Loops after concrete casting

Figure 5. A global view of DUN LAOGHAIRE quay wall

-Longitudinal canal sea walls, in the UNITED ARAB EMIRATES (figure 6)

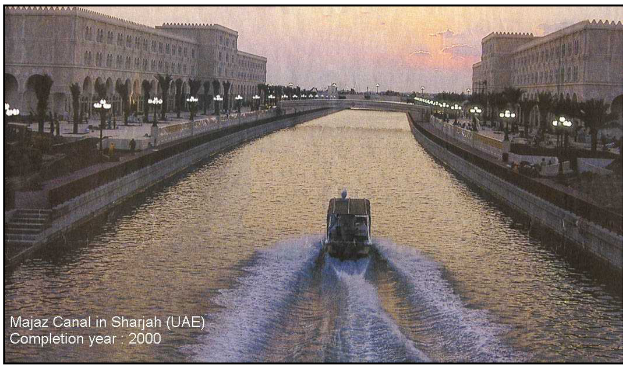

Figure 6. A night view of AL MAJAS CANAL once completed

For this particular application 350 mm thick un -reinforced concrete panels have been used.; great adaptability of this method of fastening has been demonstrated for this particular application (Figures 7 & 8).

Figure 7. MAJAS canal during construction

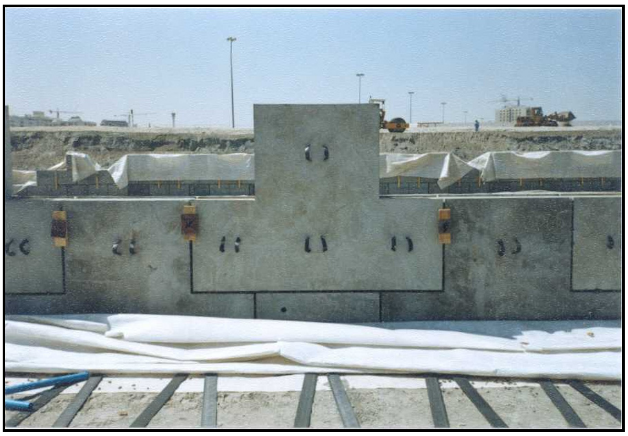

Figure 8. Rear view of panels with attachments

6.2 *Applications using sand fill with high salt content.*

More than 100,000 m2 of facing representing 10 different projects have been successfully built.

- Spandrel Walls are being built across a Wadi in the Northern Emirates of the UAE. The bridge stands in Sea water during very high tides (figure 9).

Figure 9. A view during construction

7 DISCUSSION

Except for more precise accelerated ageing tests which are under way, the development of this entirely synthetic method of fastening may be considered as complete. It is considered to be "universal" in that it does not require significant mould modification and functions with panels of varying thickness, regardless of the layout of reinforcement bars.
This method has formed the subject of a patent application that is currently under examination.
This connection works also with totally unreinforced panels; its strength depends directly on the handle spacing inside concrete: the larger the distance is, the stronger will be the connection.
The ultimate strength of the various components of this connection ie main reinforcing strips, loops, pins, concrete are similar. Therefore whatever the factor of safety applied to main reinforcing strips, the same value can be applied to the connecting loops meaning that this system always remains balanced from a load/cost perspective.
This connection is easily dismantled during wall erection thereby allowing any panel misalignment to be corrected immediately.

8 CONCLUSION

The projects so far completed have confirmed that the choices of material and components for this new method of fastening main reinforcements to panels are valid and that this technology is very satisfactory for the construction of such structures in extreme physico-chemical conditions.
This innovation extends the scope of use of concrete faced Reinforced Earth walls to soil/fill types that were previously considered not suitable. It is clear that more and more fills that would not historically been considered as suitable for this type of construction will be chosen due to cost and environmental reasons.

9 REFERENCES

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