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Soil reinforcement applications: Promising directions for the future

J.P.Gourc
IRIGM, University Joseph Fourier, Grenoble, France

ABSTRACT : Retaining structures with the association of soil and geosynthetics now can be considered as conventional earthworks. But new applications of this technique of reinforcement, related to the versatility of geosynthetics, are coming to light. Some of them are presented here, reinforcement of waste and poor geomaterials, reinforcement by geocells structures, reinforced soil raft. The development of these concepts, already experimented in the field needs an accompaning research to quantify and to adapt the efficiency of the reinforcement to the problem.

1 INTRODUCTION

The application of geosynthetics in reinforcement is not exclusively the use of horizontal sheets associated to soil body in embankments and retaining structures. Recent experimental and research works open promising directions for the future of soil reinforcement. Some examples are presented below. It is reasonable to think these applications will be able to bring a new development of the market of geosynthetics.

2 REINFORCEMENT OF WASTE AND POOR GEOMATERIALS

2.1 *Landfills and waste*

To find new sites for storage of waste is more and more difficult. Consequently the landfills become bigger and bigger. Vertical expansions of waste disposals imply new concept of dumping. It is now frequent to notice sliding of slopes in landfills because these embankments are steeper and steeper, and furthermore the geotechnical properties of waste are not well known. Geotechnical survey of waste is up to date.

Reinforcement is a new solution to stabilise dump : the first application was the use of reinforcement of soils for dikes surrounding the dump (figure 1) but reinforcement of waste itself can be proposed.

Here is the cross section figure 2 (Artières et al, 1994) where the domestic waste is reinforced by successive sheets of geosynthetics, in this case dual function geosynthetics, woven structure for reinforcement and non-woven structure for drainage of leachate. Of course, the functions of the geotextile have to be considered as temporary because durability

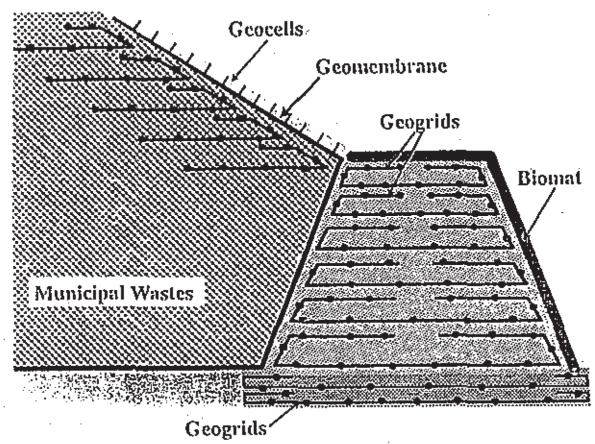

Figure 1 : Reinforcement of dikes and waste in a landfill

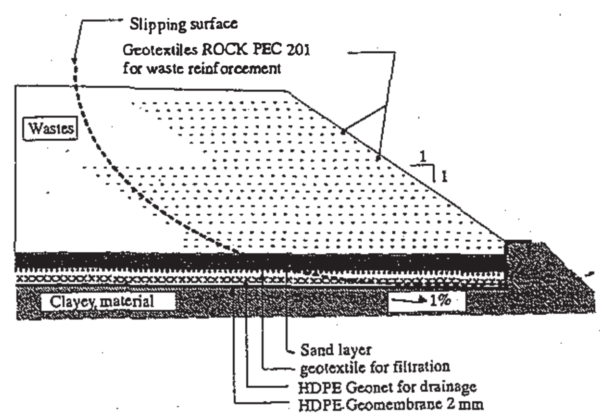

Figure 2 : Cross section of a landfill with reinforcement of waste

of polymers in these conditions are problematical. Domestic waste is generally an alkaline material (pH > 9). But it is worth noting that, for domestic waste, a significative improvement of mechanical properties is observed with elapsed time, correlated to a chemical + physical evolution of the material which is not properly consolidation observed for soils.

2.2 *Reinforcement of slags of incineration*

New requirements of the French Ministry of Environment involve from the year 2002 a treatment of all the solid waste before disposal, for instance incineration. But from four tonnes of waste, it remains 1 tonne of bottom ash. In the present time these slags resulting from incineration are dumped in landfills. According to present european regulations (January 1992), these slags can be used for public works, depending of the heavy metals content. The quality of ash is of course correlated to the type of domestic waste : the increasing use of sorting process after collection is very efficient to improve the environmental safety of slags.

However the use of slags of incineration is only acceptable after several months of "maturation". During this period, chemical-physical evolution of the material is observed, with an exothermic reaction.

In the present time, this geomaterial is free of charge for the contractor, because its use is stimulated by the environmental authorities.

The mechanical properties of the ash are quite good, the average value of the friction angle ϕ is higher than 30° and the cohesion higher than 5 kPa. Several applications were carried out in the region of Grenoble, where the backfill in ash was associated to reinforcement by geogrids or geotextiles. The main application was the remediation of roads in landslide areas. In this case, it is efficient to lighten the backfill by the way of layers of old tires, not entirely filled with ash or even separated of the ash layers by geotextiles. Here is the cross section (figure 3) of a slag backfill reinforced by geogrids in polyethylene (Bossoney et al, 1995) and on the figure 4 a photo of a backfill combining ash, old tires and woven geotextile in polypropylene.

These embankments were monitored but no significative increase of the temperature was observed.

Old tires constitute an huge problem for the environment, the fire risk of this kind of storage is important. We mention an example of application related by Prof. Wu from Denver University : old tires are cut up, and the small pieces can be used as a light granular geomaterial. To protect a landslide in Colorado, a backfill in cut tires reinforced by geogrids was built (figure 5).

Finally, the spreading of the reinforcement of these specific materials is founded on a better knowledge of the specific mechanical behaviour of these materials and of their interfaces with additive geosynthetics.

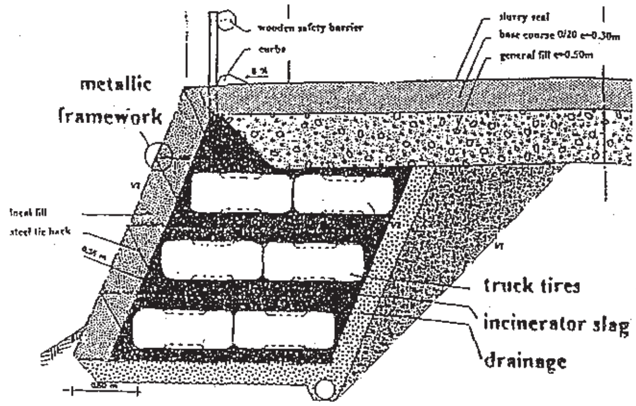

Figure 3 : Cross section of a reinforced backfill in ash of incineration

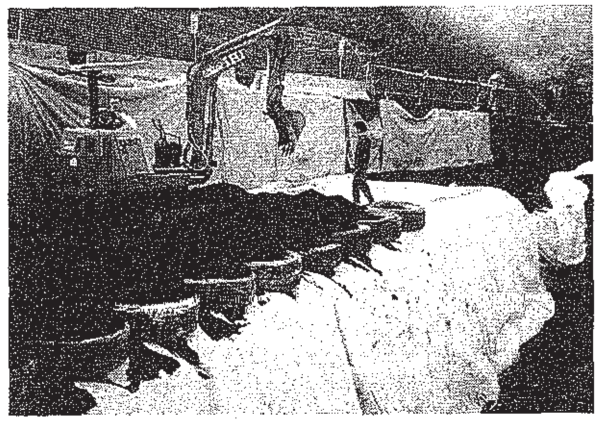

Figure 4 : Backfill combining ash, old tires and geotextile

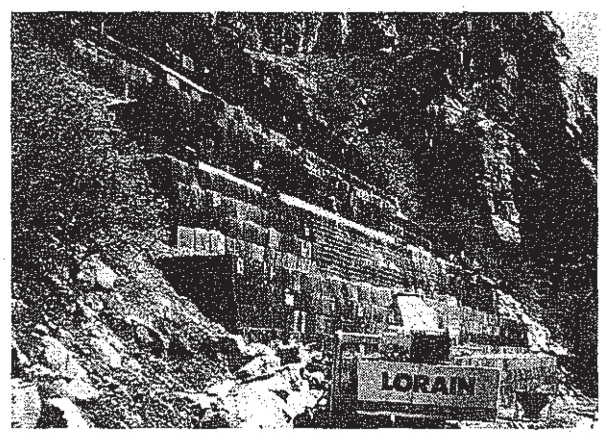

Figure 5 : Light backfill in pieces of tire with geogrid reinforcement (Wu)

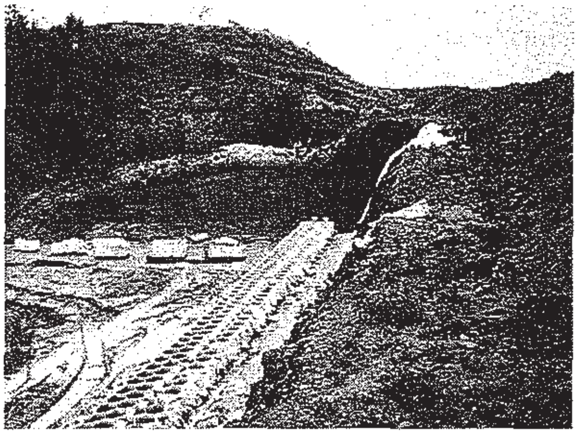

Figure 6 : Retaining structure in clay reinforced by geocell for a landfill

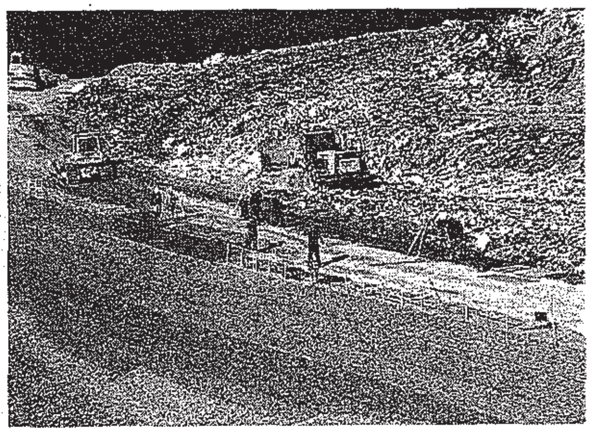

Figure 7 : Clay barrier reinforced by metallic gabions

3 REINFORCEMENT BY GEOCELLS STRUCTURES

Since several years, geocells, initially used for erosion control of slopes to improve vegetalisation of the facing, are experimented for retaining structures.

The layers of geocells are lied horizontally and filled with compacted soil. One interest of this technique is the confinement of poor mechanical or cohesive soils. In the past, mattress of geogrids were proposed to create a rigid raft for embankments on weak soil. An example of experimental retaining structure with geocells is presented at the conference Kyushu IS 96 (Gourvés et al, 1996) : the wall is 5.4 m high with a width corresponding to two or three cells and is anchored by means of longer sheets of geocells. The experience of reinforcement of a very wet soil demonstrated the capability of this type of reinforcement to support large strains.

Another recent application (figure 6) was the construction of a vertical dike in clay for a landfill with reinforcement by Geocells. In this case, the function of this structure is only to act as a retaining wall, but a new relevant application could be the use of this technique to produce vertical clay barriers for landfills.

In many countries, the environmental regulations require a five meters wide clay barrier for waste disposal, and to build a such artificial barrier on steep slopes is very difficult. Geocells could be one of the only ways to success to obtain economically very steep or even vertical mineral barriers. It would be however necessary to specify for geocells impermeable sheets of geosynthetics.

Here it is an example of an alternative technique for vertical clay barriers (figure 7), in Germany, reported by L. Wechter : the body of the barrier is in clay reinforced by a metallic grid and the double facing is in gabions used as protection and filter-drain.

However, the development of geocells technique needs a better knowledge of the mechanical behaviour of this three dimensional reinforcement. Interesting results on pull-out tests and simple shear tests in a large box performed for different directions of the geocells layers were published (Gourvés et al, 1996).

4 REINFORCED SOIL RAFT

4.1 *Foundation upon a heterogeneous soil (figure 3)*

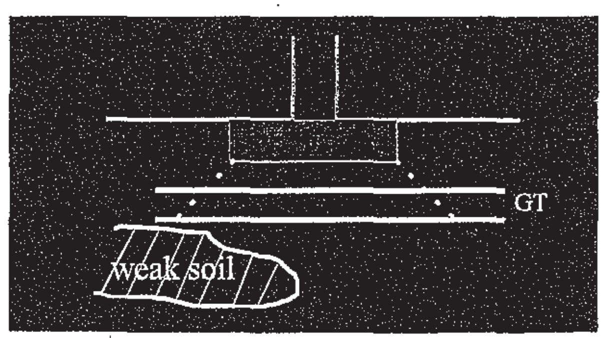

Figure 8 : Reinforced soil raft

The basic concept is to realise a mattress of soil below the foundation, rigid enough to be able to spread the localised overburden, so that differential settlements will be restricted.

It is typically an important application of reinforcement of soil. But surprisingly, reinforced soil raft is not a widespread technique, when the cases of potential use are numerous. In the literature, a lot of researches on this topic are displayed, numerical approaches or small scale models, but almost all the studies are focalised exclusively on the bearing capacity problem. And, still today, to evaluate the settlements in a serviceability state is a difficult process on account of the lack in the interaction soil-reinforcement knowledge.

The results obtained by different researchers are

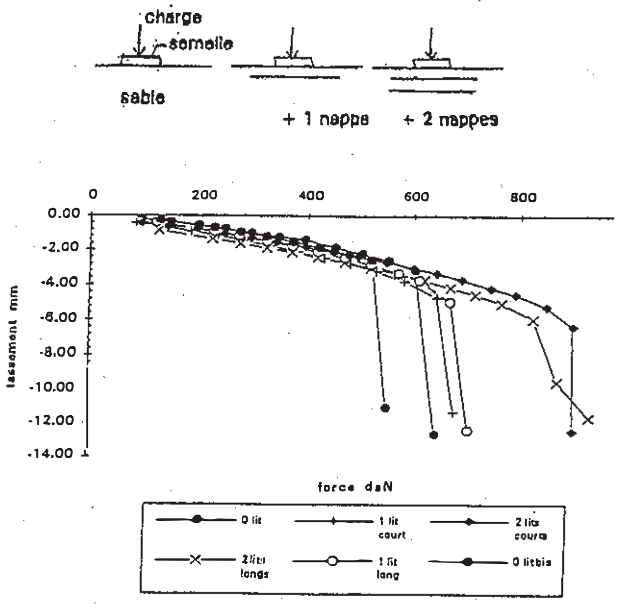

Figure 9 : Punching test in centrifuge (Dubreucq)

also often controversial. We exhibit here some recent diagrams obtained by Dubreucq by means of centrifugal tests in Lcpc Nantes on sand reinforced by geotextile. The sheets of geotextiles (figure 9) are short (the width of the foundation) or long (three times the width of the foundation).

Clearly there is no influence of the length of the reinforcement. Only the central part of the geotextile is efficient along all the test.

We believe important to encourage research (and large scale experimentation) on this topic likely to open a lot of applications.

4.2 *Foundations upon sinkholes (figure 10)*

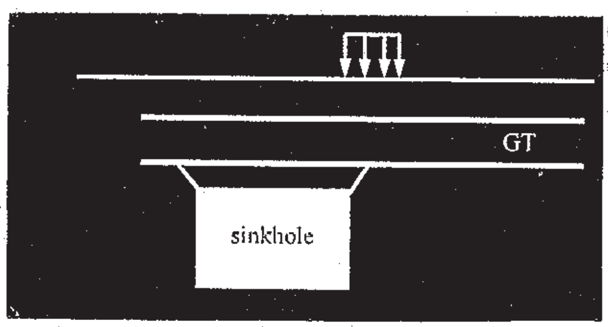

Figure 10 : Foundation on sinkhole

The development of sinkhole can result of many reasons (Kempton et al, 1996), mining work, gypsus cavities, ...

The challenge is generally, not to prevent any settlement, but only to avoid a catastrophic subsidence above the holes which weren not localised. As in the former case of heterogeneous soil foundation, the proposal is to include a reinforced

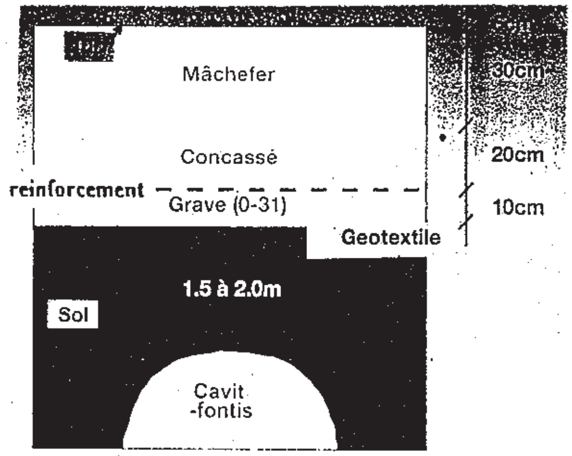

Figure 11 : St Etienne Stadium : reinforcement to prevent sinkhole

layer providing bending strength to support the load above the void.

For the design of this reinforced structure, the first idea was to propose a mechanism where the geosynthetic acts as a membrane (with exclusively tensile strength). It is analytically proven that the membrane effect needs large deformations to be effective. This being so, catastrophic subsidence is avoided, but the structure is not yet in situation to fulfil its function (for instance regular traffic for a road).

Different researches are in progress to evaluate a combined behaviour of soil and geosynthetic, with a more sophisticated approach than the membrane effect. In France, a large programme is initiated by Irigm, with Lcpc and the french companies for railways and highways with different requirements in the two different applications (very small differential settlements allowable for railways).

Tests of subsidence in large pits will be carry out to calibrate the numerical approach.

It is really a large market. For example, more than 300 km of the new track for the Tgv train are concerned.

To demonstrate the versatility of this technique, finally we present a particular application : for the world cup of football in 1998 in France, the stadium of St Etienne was remediated. Mining galleries are localized beneath the lawn, being the cause of local settlements. A reinforcement by geogrid of the subgrade was carried out (figure 11).

The technique of reinforced soil raft has still other applications like the reinforcement of caps of landfills subjected to local differential settlements. But the challenge here is different, it is to keep the water-tightness of the cap liner, to avoid tensile breaking of the geomembrane or bending cracks of the clay mineral barrier.

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