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Utilization of used tyres in civil engineering – The Pneusol 'Tyresoil'

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ABSTRACT : About five hundreds structures have been built with Pneusol-"Tyresoil" (a combination of tyres that cannot be retreated and any type of soil, natural, artificial or wastes!), for many civil engineering applications. This paper presents some principal utilizations of this material.

1 INTRODUCTION

Old tyres constitute a waste that has excellent mechanical properties and is available in quantity in all parts of our countries.

While old tyres do not contribute directly to pollution (unless they are burned in the open air), they affect our environment in the long term because they are not biodegradable. If numerous valorizing processes had been invented (retreads, incineration, farm use, rubber powder, ...) an important quantity of tyres remains nevertheless unused. So as to use a part of those wastes, the Pneusol material was invented by the Laboratoire Central des Ponts et Chaussées.

Pneusol-Tyresoil, a combination of natural, artificial soils or wastes and tyres that cannot be retreated ; they may be whole, partially cut up (one sidewall removed), or completely cut apart (into two sidewalls and one tread) (Long 1980, 1985, 1987).

Today more than 500 structures have been built in France, 12 in Algeria, in the United States of America, in Norway, in England, in Germany, Roumania and even in....Rwanda! covering a wide range of civil engineering applications mainly in order to reinforce earth structures, at a lower cost than conventional technologies.

Our paper deals with the description of some important structures using Pneusol and its different areas of use.

2 AREAS OF USE

One of the qualities of Pneusol is its flexibility, which enables it to withstand large differential settlements. The use of tyres arranged in tiers also gives a better distribution of forces in the reinforced soil mass and on the foundations.

This essential quality makes Pneusol Tyresoil a very good civil engineering material, which has the following advantages :

* standardization and speed of execution ;
* construction intages and in sections ;
* possibility of using a mediocre fill ;
* improvement of the environment through the consumption of an abundant and cumbersone waste.

3 RETAINING STRUCTURES AND PNEUSOL "LIGHT".

The reinforcement of the embankment consists of passenger-car tyres of which both side walls have been cut away. The tyres, tied together by rot-proof straps, are assembled into layers, which are then placed in tiers (0.35 and 0.50 m.apart) on the compacted embankment.

An experimental wall 5 m high and 10 m long, built at Nancy in 1982, has demonstrated how easy it is to place multi-layer Pneusol structures.

The *Bussang Pass*, in 1987, was the first large, major site on the national network to use this material. This site was used for the development, in a real-life situation, of the "technologies" of various potential applications of Pneusol : six hundred meters of Pneusol walls ranging height from 2 to 7 m were built.(Photo n°1)

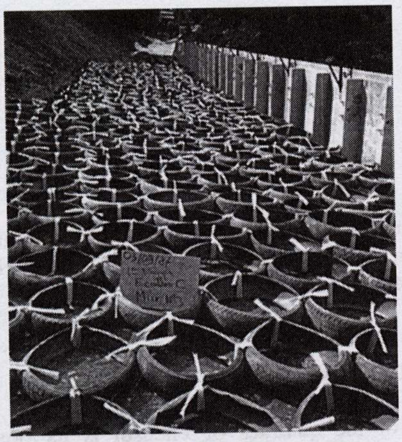
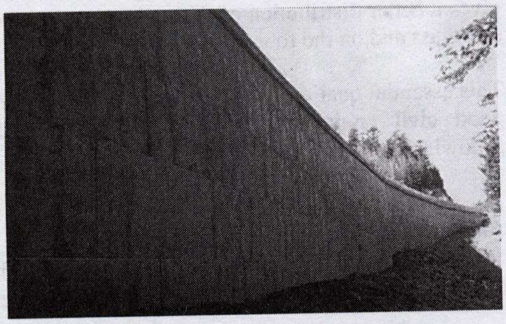


Photo n°1: Establishing Pneusol with different layers



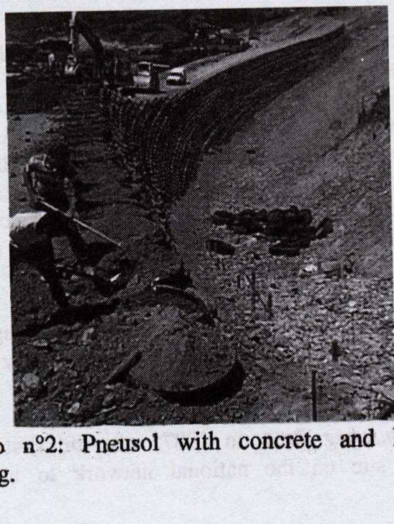


Photo n°2: Pneusol with concrete and Pneusol facing.

Some of them even used a lightened structure (Pneusol "light") (Long, Valeux 1989). This technique is substantially the same, except that :

* uncut truck tyres are used ;

* they are joined together, if necessary, by metallic parts attached to the sidewalls (for speed of placement) or by ties;

* each layer of tyres is covered with a non-woven geotextile. The voids thus created lighten the embankment, and the linked tyres contribute to its reinforcement. The density of such a material is of the order of 8 to 10 kN/m^3 and depends of course on the thichness of the intermediate layer of fill and also on the volumic weight of the fill itself. For example a Pneusol with clinker (another waste) has only 5 or 6 kN/m^3. Presently many slopes sliding repairs have been made with Pneusol "light" of different kinds.of fills (gravel, clinker, pozzolana,..). Pneusol "light" is extremely cost-competitive.(Bailly and al. 1988, Bricout and al.1992)

In all, 55,000 passenger-car tyres and 2,000 trucks tyres having a combined weight of 500 tons and 1,612 of facing (693 concrete slabs) were used for the widening of the Bussang national road.(Photo n°2)

Repair of the Boulsios landslip in Lozere (1990)

The Boulsios embankment, just outside Millau on the Béziers-Neussargues rail line (southern France), is built on an unstable slope of the right bank of the Tarn. As an indication, the mean settlements of the line have been of the order of 0.50 to 1 cm per month since 1968!. This embankment has therefore often been built back up to raise the line and so compensate for the general slippage of the unstable slope.(Photo n°3)

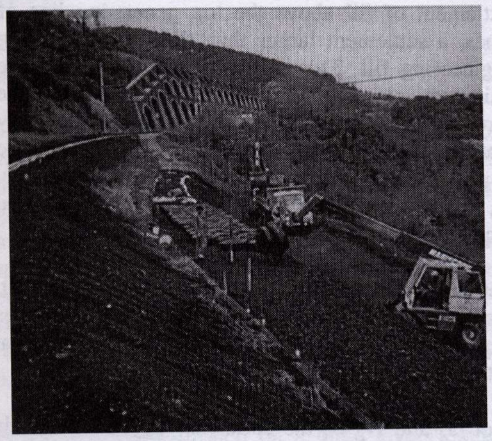
The SNCF (French National Railways) wished to raise the rails 0.50 m and shift them slightly - about 0.50 m - in the downslope direction to make room for two footpaths along the sides to allow its crews to move about safely.

This solution required adding approximately 7 m^3 of fill per linear meter of line, increasing the loading by about 140 kPa - hardly the thing to promote general stability. The "Mecasol" geotechnical engineering firm had approved only half of this additional loading.

The solution finally chosen to raise the embankment was the following:

- in the part supporting the rail traffic, i.e. under the line itself, with the usual load diffusion angle, ballast is used ;
- elsewhere, the slope of the embankment is stiffened and made lighter by the use of Pneusol with pozzolan; this already has a relatively low density (10kN/m^3), making it possible to produce a lightweight Pneusol having a density of only 5 kN/m^3 (Long 1993).

The work as a whole resulted in a small, even negligible, increase in the surcharge on this unstable slope. This solution is very interesting because the Pneusol can be made very much lighter.



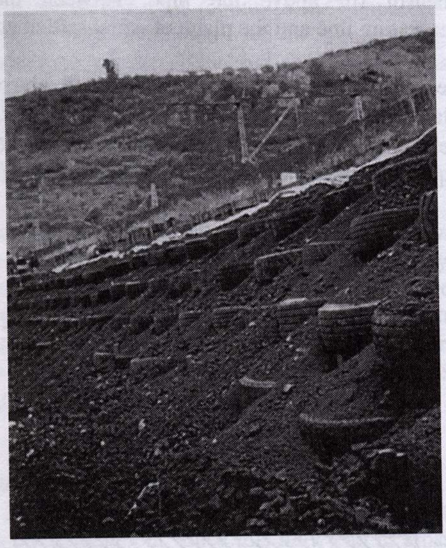


Photo n°3 : Cutaway view of the Boulsios embankment.

4 REDUCING ACTIVE EARTH PRESSURE

First of these structures built in 1986 is a cantilever retaining wall fifty four meters long and five meters high founded on two rows of piles. Before filling behind the wall, the contractor became aware that the shell of the wall was too thin (Long 1990).

"Heavy" Pneusol was used to relieve the active earth pressure and also to eliminate tensile forces on the piles. It was made of treads arranged in layers and tied together by polyester straps. Since the fill inside the treads exerts no active earth pressure and that between two layers is highly confined, the Pneusol mass, provided that the spacing between layers is small, behaves like gravity wall made up of thousands of tiny gabions stacked one to another.

But the structure most used is that of the Fonderie Wall. One hour before work to widen a heavily travelled road was begun, this 18th-Century wall was classified as an historic monument, so it could not be demolished. Luck had it that the whole site lay outside of the right of way of the new pavement. However, a retaining wall near the old foundry, of a very doubtful stability, was right at the base of the embankment of the new road. Being classified, it could not of course, be reinforced from the outside. It is made up of more or less closely spaced blocks.

The historic wall was accordingly lined, inside, with pressure-reducing Pneusol. The Pneusol placed behind the wall consists of layers of truck tyres. Equipped with soil sensors, it gives very good results. (Laréal and Long 1987)

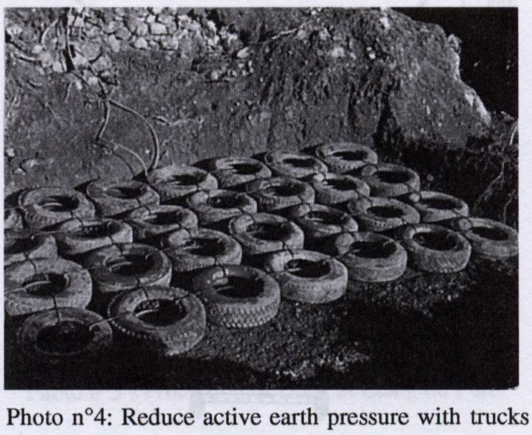


Photo n°4: Reduce active earth pressure with trucks tyres

5 CREATION OF ARCHING

All builders know how to reduce overloading rigid concrete pipes under a large depth : they incorporate a flexible material with a lower modulus than the one of the fill.

So the French authorities have conducted some experiments to relieve the stress concentration on underground culverts and quantify the arching created by the use of Pneusol. (Long 1990)

The Monistrol work in Haute-Loire, built in 1985 which is 137 m long, as a span of 5.10, and buried under 13 m is the first application of this type. The work consists of an ogival vault 22 cm thick supported by two sills resting on micropiles. Runners at regular intervals provide transverse stiffening.

To avoid overloading the work, in particular its foundation, pressure relief using the Pneusol technique was chosen because of the consistency of its geotechnical characteristics. A thichness of about 2.2 m of Pneusol, made using six layers of truck tyres, was placed above the work, over a zone wider than the work itself. To test the efficacy of the process, seven pressure sensors were placed in each of two profiles.(Fig.n°1)

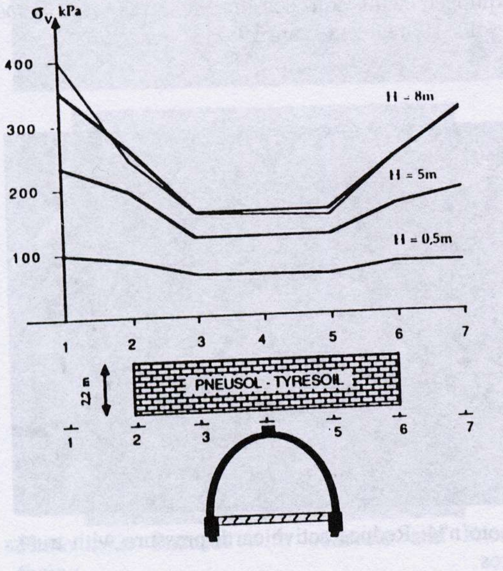


Figure 1 : Culvert of Monistrol-sur-Loire

The pressure curves show that the desired effect appears immediately with the first placement of fill above the Pneusol. The ratio of the mean vertical pressure on the work to the vertical earth pressure is about 0.8 here, whereas the theoretical value for conventional fill is 1.6.

The calculation of this thickness of "soft" Pneusol to create the arching effect has, strangely, never been approached by any researcher (to our knowledge).

In a first stage, we opted for simplicity in the calculations, to encourage widespread use of Pneusol by civil engineering contractors.

To avoid the Marston effect, it suffices to cause a settlement of fill above the top generating line of pipes, a settlement larger than that of surrounding engineering fill. This is the principle of "pressure relieving placement", which is to stage the earthworks and the modulus of the fill in such a way that the plane of equal settlement is located as close as possible to the top generating line of the structure. In this way, the weight of earth will not not be increased.

Let E_1 and H_1 be the modulus and height, respectively, of the engineered fill on the sides between the foundation level and the plane of equal settlement.

Let E_2 and H_2 be the corresponding values for the Pneusol fill above the pipe, between the top generating line and the plane of equal settlement.

Let σ_v be the uniform stress exerted above this plane. Assuming that the pipe is very rigid (not deformable), then by the definition of the plane of equal settlement, one has approximately (Fig.n°2):

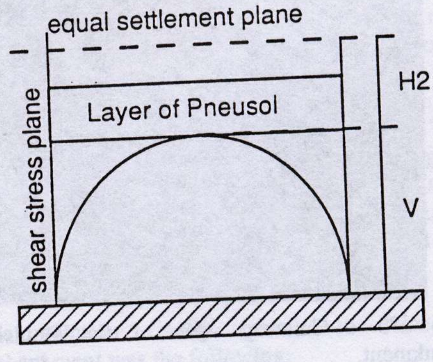


Figure 2 : Thickness calculation

$$(H_1/E_1) = (H_2/E_2)$$

If the sag of the structure is V :

$$H_2 = V\,(E_2/(E_1 - E_2))$$

The numerical modeling for analysing the elastic and elasto-plastic behaviour was carried out thanks to a general-purpose finite element software (CESAR-LCPC). The numerical results are obtained in fair agreement with the experimental observations.

Since then, more than 200 other structures using this technique were built in France, twelve in Algeria, in Spain.

6 ENERGY ABSORPTION

The idea of Pneusol as an "energy absorption" springs from a common place observation of daily life. One often sees tyres stored casually against garage walls. And tyres are used at tricky corners on motor racing circuits to slow the occasional car that spins off the track. The test results showed that the energy restitution coefficient of Pneusol is very low, about 0,10 (this is the ratio of rebound height H of a falling weight to height H_o from which it was dropped).

A real test ist performed on a three layers'Pneusol built on a concrete roof (about 25 m^2)supported by twelve poles equipped with strain gages. Experimental results show that the Pneusol has a very good absorption power.

7 OTHERS APPLICATIONS

Pneusol is a combination of two components, tyres and soils. So it is possible to built any structure you wants depending on the destination of your structure. For example, a Pneusol "light" is a good material for the subgrade of a road in cold countries again frost because it has many voids (Québec). (Long 1990, 1993).

It is sometimes difficult to ensure the stability of structures built in water, because the soil must be held in place without disturbing the flow of water along the embakment, since this may lead to erosion of the banks.

We present here the investigations and works of reinforcement of a dike built between 1852 and 1859, using Pneusol to protect the banks.

The dike is 950 m long and reaches a maximum height of 11 m. It has always been the site of leaks, the extent of which increases with the height of water.

Its upstream slope has a gradient of 1 in 2.7 and covered with a layer of dry stones, of which the portion out of the water has been repointed.

Its dowstream slope, which is steeper 1 in 1.67, is covered with brambles, bushes and many trees. At the low point of the site, the dike has a masonry drainage aqueduct, the downstream head of which shows signs of fracturing, overturning and extensive seepage.

This dike was instrumented with three piezometers tubes and a clinometer at the south head of the drainage aqueduct. In addition, cores were taken and penetrometer, shear and permeability tests were carried out.

It was found that in the tallest cross-section of the dike, at the aqueduct, body of the dike consists of a very loose ground that is waterlogged and shows local signs of internal erosion. There is also water pressure on the wing walls of the downstream head of the aqueduct and extensive fracturing.

Because of the wooded character of the downstream slope and the width of the dike, it was decided to improve the overall watertightness of the dike by waterproofing the upstream slope.

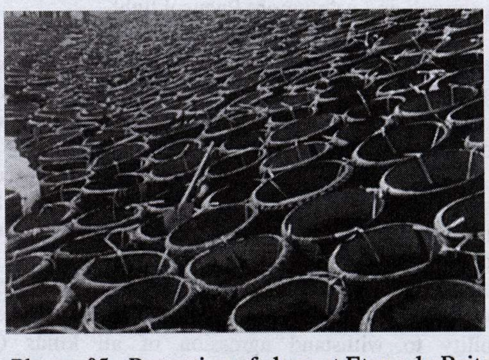


Photo n°5 : Protection of slope at Etang du Puits

The approach chosen included the following stages :

* application of a coasting of mortar to the dry stone surfacing;

* placement of a GSUV PVC geomembrane 1.5 mm thick, protected on both sides by MT 300 woven and needle-bonded polypropylene felt to provide both drainage and protection against punching;

* vertical waterproofing of the foot of the dike, to a height of 2 to 2.5 m, by continuous cement grout wall;

* mechanical protection of the geomembrane by Pneusol-Tyresoil including, at the top, a tier of tyres tied together after removal of the upper sidewall; this system is then covered with a layer of levelled sand; at the top over a length of 3.5 m, there is a second tier of tyres holding 80/160-mm loose stones to protect the slope from impacts by motorboats.(Photo n°5)

8 CONCLUSIONS

This papier touches on pratically all facets of the use of Pneusol-Tyresoil as a civil engineering material.

Basing upon ten years of experience (the first real stucture was built in 1984) some significant findings may be pointed out :

*Tensile tests of tyre parts and soil-tyre adherence have yielded good results.

*The construction Pneusol "light" cost found at different sites is quite attractive and compares favourably to polystyrene foam or expanded clay. In some cases (in particular for embankments on unstable slopes), it is possible to compensate for the difference in mean density by doing additional earthwork and using more Pneusol light.

* Globally, the Pneusol embankment behaves as an embankment that is reinforced and therefore has cohesion. This cohesion enables it to withstand much larger differential settlements than conventional embankments.

*The presence of the tyres and the voids they create gives the Pneusol embankment good anti-vibration, anti-frost and perhaps anti-sismic properties.

* Finally, among the things we are sure of, we may mention the long life of the tyres, their ability to withstand agression of all kinds (in particular chemical), the simplicity of the process, its univerticality - the basic materials are available practically on the spot in all countries, and, of course, its ecological character - wastes are not only eliminated but also made useful in process.

The promising research results, the good behaviour of different structures built (500), ease of use and excellent long-term performance make Pneusol-Tyresoil a good civil engineering material.

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