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SYNOPSIS The widening of National Road no. 66 at the Bussang Pass in southern Alsace is the first "major" job on a national road using the Pneusol technique, a combination of old tyres and soils : 600 m of walls 2 to 7 m high ; 55,000 passenger-car tyres and 2,000 truck tyres (a total of 500 tonnes !). Precious knowledge is gleaned from the diverse conditions of use.

INTRODUCTION

In spite of the enchanting setting, crossing the Vosges via the Bussang Pass, through the valleys of the Thur and the Moselle, had for a few years ceased to be a pleasure. The steady growth in traffic, in particular truck traffic, in the last decade, had made this two-lane national highway a nightmare for motorists.

In 1987, work to widen the pass to three lanes was undertaken. Towards the top of the pass. this work provided an opportunity for large-scale use of the Pneusol technique. previously limited to experimental sections or small operations in the field of retaining walls (Long 1984) (Gaiottino, Long 1987).

DIFFICULT GEOTECHNICAL CONDITIONS

In the upper part of the Bussang Pass, the characteristics of the soil in places posed difficult problems of stability.

The road, with a composite profile, is located on the North side of the primary massif of the Grand Ballon, represented by shales and volcanic rocks. The wooded natural slope is steep (35 to 38°) in spite of the presence of clayey surface scree and a highly weathered and cracked rocky substratum.

The part cut-part fill profile of the new route was positioned with allowance for the following two constraints:

• on the uphill side, the difficulty of making cuts of large height that would be stable in the long term in a highly fragmented and friable massif. In addition, very high slopes would have had a large impact on the environment in a particularly sensitive touristic sector.

• on the downhill side, the difficulty of founding walls on coarse but clayey screes that were not very compact (characterized by maximum pressures of the order of 3.10 E-5Pa). Given the slopes involved (up to 45° downhill of the road) and the many cracks that can be seen in the edges of the pavements, the current road embankments can be regarded as at the limit of stability.

The composite profile chosen - limited cuts on the uphill side, lightened reinforced embankments on the downhill side - made it possible from the outset to plan to reuse all materials excavated on the uphill side in the reinforced embankments.

CHOICE OF SOLUTION

General

The Pneusol-reinforced embankment technique developed by the L.C.P.C. had first been used in 1984 in the THANN Subdivision, on a small section of mountain road, Departemental Road 27, after a first experimental structure had been tested in 1982 (Long 1984).
Other jobs had been done in France from 1984 to 1987 in many areas of Civil Engineering (Bailly et al 1988).

The Bussang Pass, in 1987, was the first large, major site on the national network to use this material.
Following the experimental applications, 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 in height from 2 to 7 m were built. Some of them even used a lightened structure.

The new material PNEUSOL has a number of advantages over common processes; in effect, in addition to reinforcing the soil in the transverse direction~ it makes it possible:

• to reinforce the structure longitudinally. This advantage is particularly valuable in the case of foundations on a heterogeneous soil: the presence of blocks of rock, of crevices, of zones that are not very compact;

• to be rather undemanding in the choice of fill materials. Generally, all excavated materials can be re-used, provided that they can be driven on, which was the case of a large share of the materials in place (0/250-mm scree).

• to lighten the embankment at reasonable cost if the bearing capacity of the foundation soil is inadequate, through the use of "lightweight PNEUSOL" made with truck tyres (Long, Valeux 1989), (Long 1990).

• to match the relief easily

• to use prefabricated facings of any shape or else to make very steep slopes (2 vertical per 1 horizontal), easy to plant, faced with the tyres themselves. In this last case the walls are particularly economical. This is the Pneusol facing.

Definition of Pneusol

Pneusol is made with old tyres that can not be retreaded; they may be whole, partially cut up (one sidewall removed), or completely cut apart (into two sidewalls and one tread).
Mechanical tests have shown that the mean tensile strength of the treads and sidewalls is 56 kN with a standard deviation of 24 kN and 25 kN with a standard deviation of 10 kN, respectively.

Furthermore, full-scale tensile tests of tyre parts embedded in the embankment were conducted to determine the best assembly and type of tie to obtain good soiltyre adherence. We chose an orthogonal assembly with treads on edge, tied together by strips of woven geotextiles.

In a Pneusol mass, as in any reinforced soil mass, it is necessary to provide a facing to prevent the grains of soil from flowing out between two reinforcements.

Two types of facing were used:

- a facing made of concrete slabs
- a facing made of Pneusol

BUILDING OF THE STRUCTURES

The reinforced embankment

The reinforcement of the embankment consists of passenger-car tyres of which both sidewalls have been cut away. These tyres must be sorted to eliminate any that are too badly damaged or have too little tensile strength (tensile tests on batches). A tyre cutting machine was developed. The contractor chose cutting in the shop over cutting on site (the mean output was between 700 and 900 tyres a day). 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. Filling with excavated materials (diameter less than 250 mm) is done from the edge of the old pavement using a special excavator with a long arm (fig. 1).

Very special attention must be given to the characteristics of the fill materials. While their quality may be less than perfect, the water content of the materials must be monitored very closely to avoid compaction problems.

In this respect, wall no. 3 of the Bussang Pass (the first wall built, in a rainy period, without special precautions) may be regarded as a problem wall. The kneading of the tyre + fill mixture made it impossible to achieve optimum compaction, and substantial internal settlement occurred after commissioning. The grading and compaction specifications, identical to those for Reinforced Earth (Long 1985), were not observed. This point was of course regularly checked by the Strasbourg Laboratory. At the end of 1988 the structure had stabilized.

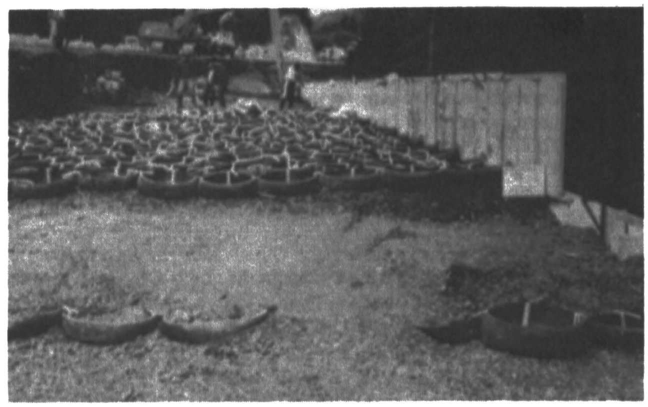


Fig. 1 : Establishing Pneusol

On the strength of this experience, the construction of the five other walls was modified and checked more closely: protection of the fill by tarpaulins, the addition of materials less sensitive to water in rainy weather, with the site materials re-used in dry weather.

Finally, we should note that the research results published by very many workers have shown that the rubber of tyres provides very good long-term performance, even in seawater.

However, the metallic fasteners or geotextile strips used might be made oversize, especially since the quantities are so very small.

"Lightweight" Pneusol

Some walls required lightening of the fill. The technique is substantially the same, except that:

- uncut truck tyres are used;

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

- each layer of tyres is covered with a nonwoven geotextile. The voids so created lighten the embankment, and the linked tyres contribute to its reinforcement (even though this is not their purpose here) (fig. 2).

The density of such a material is of the order of 8 to 10 kN/m3 and depends, of course. on the thickness of the intermediate layer of fill.

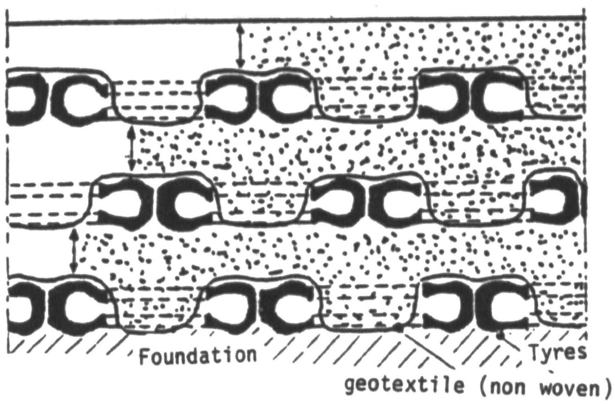


Fig. 2 : Cross-section of "lightweight Pneusol"

Old tyres constitute a diverse and varied population in terms of brand, size, degree of ageing and wear, shapes of holes and tears, internal reinforcement of treads and beads, etc.

For all these reasons, loading tests on two stacks of tyres (without soil) will not yield the same force-strain curves. It is here that the fill acts, performing a very important function, that of attenuating the dispersions resulting from the differences in structure and shape among the tyres. This fill gives Pneusol a modulus sufficient to withstand the vertical and horizontal forces without vibrations that might harm the pavement structures.

The first structure using this quality of "lightness" was built on the CannesMandelieu motorway in the South of France in 1985 and has given complete satisfaction (Long 1990); the pavement is built on a 50-cm capping layer. The last was built on a landslip (Bricourt et al. 1992).

The "lightweight Pneusol" structure of the Bussang Pass, like the walls, has a concrete facing.

The concrete facing (fig. 3)

This facing is made of self-stabilizing concrete slabs measuring 1.10 x 2.40 m. The facing is attached to the layers of truck or passenger-car tyres by special fasteners. The batter at installation is the desired final batter plus an excess batter that depends on the material used and on the compaction. The contractor must take special care with this point. For reasons of appearance, five walls had concrete facing. It should be noted that the slabs are placed with a negative batter (the facing being inclined to the embankment) of the order of 5 %.

The reinforcements are placed flat on the compacted fill quite taut so that there is no clearance between elements or with the facing. The reinforcements are filled in such a way that they are not subjected to large displacements because of their thickness and light weight. Levelling is done in strips substantially parallel to the facing, starting from the facing and working strip by strip to the back of the mass (Long 1985).

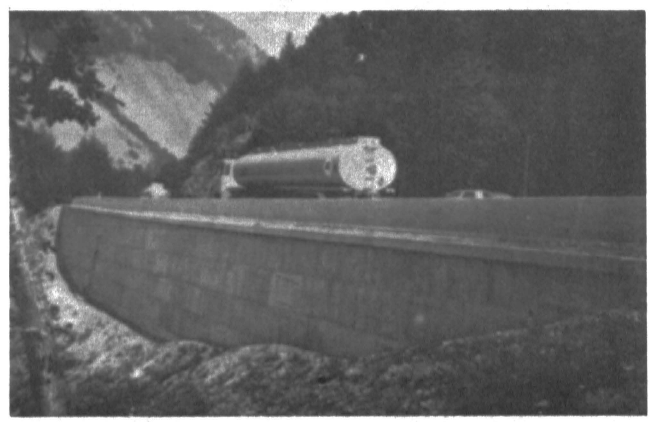


Fig. 3 : Pneusol wall Bussang (Haut-Rhin) (concrete facing)

The Pneusol facing

Only one wall (no. 2) was made with a Pneusol facing. The end tyres of the layers. with only one sidewall cut away (forming troughs to hold topsoil and rainwater), are apparent on the outside of the very steep embankment. They should quickly be hidden by vegetation. In any case, they can not be seen at all from the road, and only barely from the nearby hillsides. This type of facing was not difficult to place (fig. 4) and was very economical.

It should be noted that acoustic tests performed according to standards showed that this type of

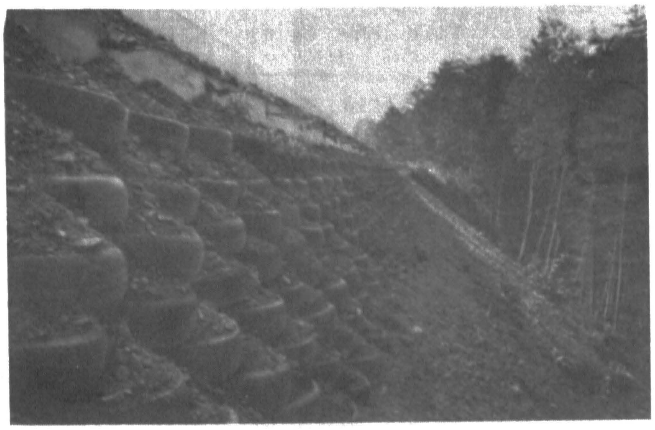
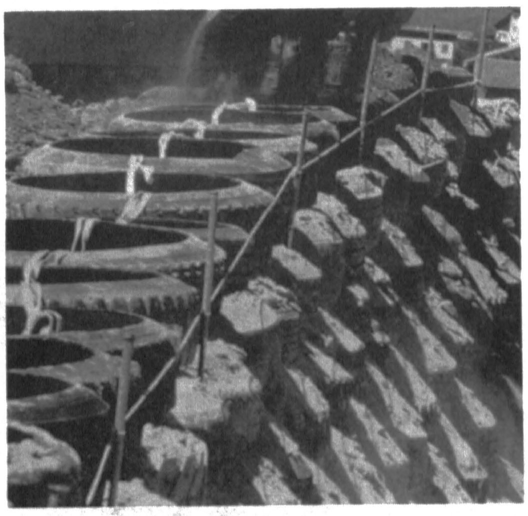


Fig. 4 : Pneusol wall at Bussang (Haut-Rhin) (Pneusol facing)



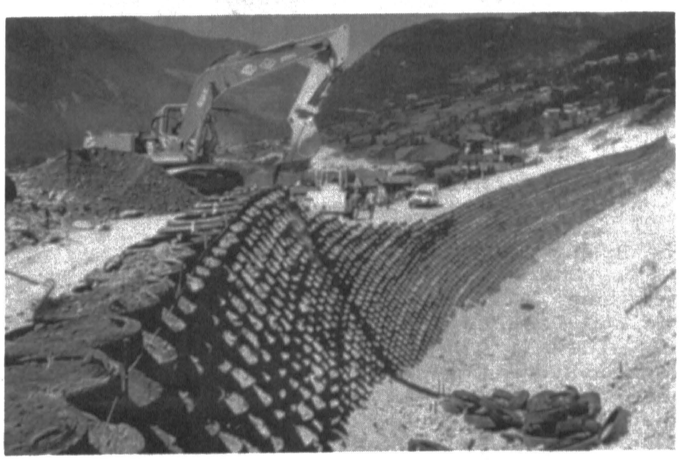


Fig. 5 : Energy absorption at Aigueblanche (Pneusol facings - Reinforcements with geotextiles) (Savoie)

facing has a very good noise absorption coefficient. It is also used In earthworks to protect against falling rock, in conjunction with geotextile reinforcements (fig. 5).

Pneusol saves a historic monument

During the clearing of the right of way, copper mines and a foundry dating from the 18th century were discovered and immediately classified as an archeological site by the Ministry ot Culture. Luck had it that the whole site lay outside the right of way of the new pavement.

Fig. 6 : Reduce active earth pressure at Bussang (Haut-Rhin) (behind a wall)

However, a retaining wall near the old foundry, of 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 out.side. The historic wall was accordingly lined, inside, with pressure-reducing Pneusol. (Laréal. Long 1992) (fig. 6).

OTHERS APPLICATIONS

Today more than 200 structures have been built in France and in many foreign countries for exemple in Germany, in Switzerland, in Algeria, in Roumania, in Jordania,... and in Rwanda ! covering a wide range of civil engineering applications.

We mention a few of these applications :

* Arching to counteract the Marston Effect

Construction experts are familar with the fact that when a rigid concrete pipe is buried under a large depth of fill, there is a large stress concentration at the crown, equivalent sometimes to as much as twice the depth. This results from differential settlement between the underground structure and the surrounding fill. The use of Pneusol, which is light, in conjunction with a rigid pipe enables the latter to behave as a "flexible pipe" because of the arching the results from the difference in modulus between the Pneusol and the fill.

The Monistrol work in the Haute Loire, built in 1985 which is 137 m long, as a span of 5.10, and buried under 13 m of fill is the first application of this type (fig. 7).

Fig. 7 : Creation of arching at Monistrol-sur-Loire (Haute-Loire)

Measurements results have confirmed the designer' thingking. Since then, more than 60 others structures using this technique have been built in France and twelve in Algeria.

* Energy absorption

The idea of Pneusol as an "energy absorber" springs from a commonplace observation of daily life. One often sees tyres place 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. Tyres are also hung singly or grouped on a wooden plank along dock walls to soften impacts by ships.

Fig. 8 : Energy absorption at La Grave

The first test results showed that the energy restitution coefficient of Pneusol is very low, about 0,10 (this is the ratio of the rebound height H of a falling weight to the height Ho from which it was dropped). This means that Pneusol restores very little impact energy and a very large absorbing power.

This material has been used on the avalanche protector at La Grave - the Pneusol is 1 m thick (fig. 8).

CONCLUSIONS

In all, 55,000 passenger-car tyres and 2,000 truck tyres having a combined weight of 500 tonnes and 1,612 m^2 of facing (693 concrete slabs) were used for thc widening of this national road.

Generally, while the PNEUSOL process in many cases has advantages over conventional processes, it does not eliminate the need for the usual checks of road earthworks ; rather the contrary, since it is much easier to violate the usual standards - just because the process is so good.
The six walls built in this stage have a total length of 600 metres. They have been instrumented and are being monitored regularly. Their behaviour so far is very good. even in zones filled with very wet materials. A more complete assessment will be given later.

One of the main benefits of the Pneusol technique is the re-use of wastes that are regarded as hard to recycle and are available in large quantities.

But we must point out that the contractor encountered difficulties in procuring tyres, and this was a surprise. The available stocks were often very small with respect to site needs. They were scattered, entailing non-negligible transport costs. Finally, they had been created without any special precautions, a fact that made costly sorting and handling necessary.

If Pneusol is to become an industrial rather than a small-scale technique, this crucial point must be dealt with.

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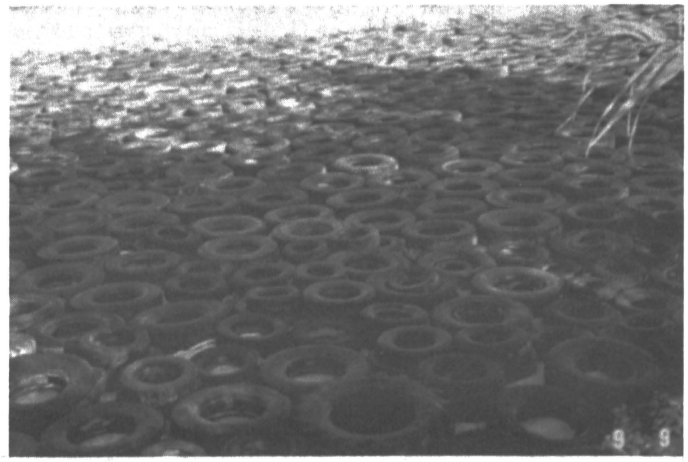
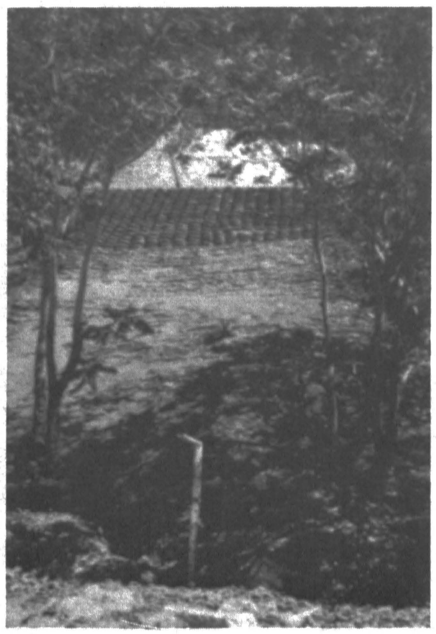
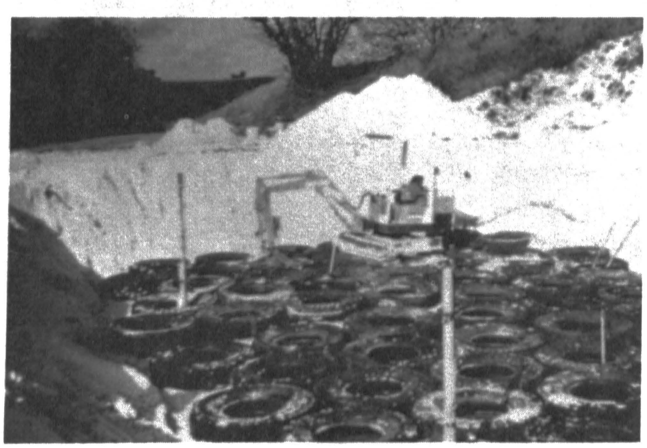


Pneusol and Geotextiles again differential settlement Cannes Mandelieu (Alpes Maritimes)



Safety device of slopes at Beaulieu-sur-Mer (Alpes Maritimes)

Military applications



Bearing capacity tests