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'Lightweight Pneusol', the stability of slopes and recovering the residual value of industrial byproducts

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ABSTRACT: Several hundreds of structures have been built with Pneusol (a combination of tyres that cannot be retreaded and any type of soil), for many civil engineering applications. This paper presents an original combination, a Pneusol made with a lightweight fill (pozzolan, clinker, etc.) to achieve an even lighter weight and allow repairs of hillside landslips and construction on unstable slopes.

INTRODUCTION

The use of lightweight materials opens up interesting solutions to the problem of crossing ground having a low bearing capacity. Whether the weakness comes from the nature of the soil (silt, peat, clay, etc.) or from the instability of slopes (slides, etc.), a foundation down to hard, stable layers is very expensive, while an ordinary conventional embankment will suffer strains and differential settlements that are intolerable for users and for the structure itself. In many cases, the ideal solution is a lightweight embankment that avoids adding a load incompatible with the stability of the subgrade or nearby structures and substantially reduces settlements at an acceptable extra cost.

The difficulty lies in finding a light and economical material. This last criterion led us to consider the use in the form of Pneusol (Long 1984, 1985, 1987) of worn tyres that cannot be retreaded. The notion of light weight applied to the materials is relative, because we consider it necessary, when comparing various materials, to take into account not only their own densities, but also the densities of all reinforcing materials and structures necessary (slab, thicker capping layer, over-engineering of the pavement). The direct cost of using the lightweight material must also be considered with allowance for this possible extra cost.

Generally speaking, there are two sorts of Pneusol:

- a Pneusol made with whole truck tyres, which is a "lightweight Pneusol" having a density between 8 kN and 12 kN/m3; the fill material does not enter the inner tube space but serves primarily to level the set of tyres, which vary in size and condition. In this case, the Pneusol has half the density of the basic fill. In some cases, one could also use, for example, pozzolan, fly ash, clinker (5 kN/m3), etc., provided that they are compatible and react well in water, to avoid pollution problems (this calls for strict compliance with the recommendations of the Ministry of the Environment);

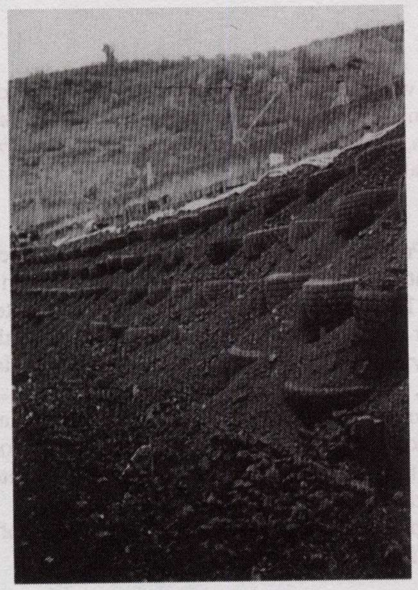
- a "heavy" Pneusol, made of parts of tyres (treads with sidewalls removed, placed on edge); this forms a set of gabions, small or large according to the size of the tyres, in other words according to what is locally available; there is also another possible type made with sidewalls joined to form sheets, which functions much like structures made of reinforced soil.

We have already described the use of "heavy" Pneusol for landslips (Audeoud et al. 1986, Long et al. 1989) and of "lightweight" Pneusol on compressible soils (Bailly et al. 1988) and for the repair of the Dommiers landslip, the results of which were presented at the Christchurch conference (Bricout et al 1992).

The present paper describes a few cases of its use on unstable slopes and for the repair of slope failures, possibly in combination with lightweight materials such as pozzolan or clinker.

1 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.



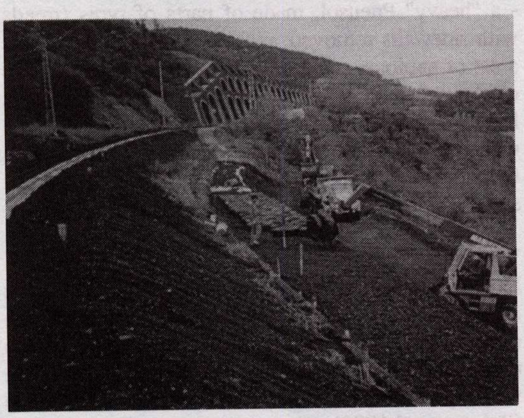


Figure 1: Cutaway view of the Boulsios embankment

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 m3 of fill per linear metre 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/m3), making it possible to produce a lightweight Pneusol having a density of only 5 kN/m3.

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. Five years later, the structure and the slope are performing properly (Fig. 1).

2 RECOVERING THE RESIDUAL VALUE OF INDUSTRIAL BYPRODUCTS

2.1 *General*

Generally speaking, the density of a lightweight Pneusol is half that of the basic material. In addition to pozzolan, Pneusol can be made with clinker or fly ash.

These byproducts of household waste incineration plants, fuel-burning power stations, and blast furnaces are already used in various road construction processes. Their sources, concentrated in zones of heavy industry and near large cities, represent several tens of millions of tonnes a year. Used as fill (with a density of approximately 10 to 14 kN/m3), they are generally placed 30 cm above the maximum high water level, between two protecting masks. These materials are economical up to a distance of 50 to 100 km from where they are produced.

Currently, there are several Pneusol structures, near Grenoble and Strasbourg, that use clinker as basic material to achieve lighter weight on unstable slopes. It is however necessary to check its compatibility and heavy-metals content. Recommendations issued by the Ministry of the Environment precisely and strictly specify the various tests that must be performed.

2.2 *Use of clinker*

We describe below two structures designed by P. Plotto's engineering firm, "Ingenierie des Mouvements de Sols", in Grenoble.

The widening of departmental road RD 520 required raising the road by about 1.50 m. The embankment, to be built on the crest of an old rubble wall, would have added a surcharge load that was too large - incompatible with the stability of the old structure.

The first operation consisted of readjusting the crest of the wall, then rearranging the stones of the facing. This was followed by the placement of precast reinforced-concrete elements tied together by a concrete sill. Whole truck tyres were then placed in an orthorhombic pattern, with an offset of a half diameter between layers. The fill used was a clinker placed using a pneumatic tamper. All of this was covered with a non-woven geotextile and topped by a capping layer of about 0.50 m of good quality granular materials (Fig. 2).

Figure 2: Arrangement of truck tyres

This structure is a perfect illustration of the combination of a thrust-reducing Pneusol behind the wall made of precast elements and a lightweight Pneusol made with clinker so as not to overload the old wall!

Since this structure was built, the "Ingenierie des Mouvements de Sols" engineering firm has designed and built several others, including one for Departmental Road RD 8b, with a height of Pneusol of the order of 6 m with respect to the level of the pavement, to allow re-opening it to traffic following the failure of the old road (Fig. 3).

Figure 3: View of slippage of RD 8b

3 PROTECTION OF SLOPES AT BEAULIEU-SUR-MER (1988)

This last example illustrates the flexibility of use of this material and its many possibilities in the area of the stability of slopes.

3.1 *Description of the incident*

On 8 December 1988, a slippage affected about fifteen metres of the rail embankment at the entrance of the Saint-Laurent tunnel on the Nice-Vintimille line (France-Italy). This was a surface slippage of the ungraded fill material, affecting a thickness of the order of one metre to 1.50 metres.

The failure was caused by the fact that in the course of renewal of the track, some old ballast had been deposited at the top of the slope, and in addition rather heavy earth-moving machines were parked on the edge of the track. To top it all off, torrential rains had been falling on the region since the day before the slippage.

The distance between where the track crossed and the end of the failure was relatively large (approximately 5 m), and there was no immediate danger to rail traffic. However, because of a few visible cracks on the edges of the slope, and the potential risk of heavy rains, protection in the form of a plastic film was placed on the upper third of the slope to avoid slips.

3.2 *Choice of a solution*

Various inspections of the site showed that while there was almost no risk in the very short term, there was a medium-term risk and a reinforcing structure would have to be built rapidly.

The first approaches to the problem, designed jointly by the SNCF and a local contractor, called for strengthening the foot (gabions or retaining wall) and reshaping the slope.

However, the inaccessibility of the site (no access road, very difficult pedestrian access for transport of materials) led to these solutions being dropped - delivery by sea (barges) or by helicopter was judged too risky and too expensive by both the SNCF and the contractor.

The final solution adopted is a cellular type wall. A call for tender was issued to construction contractors, who were also allowed some technical options in the execution (Peller wall, Reboul type lightweight caissons, Loffel wall, etc.), with supply by train only, site work by manual means, and re-use of the existing fill (a high-quality ungraded material).

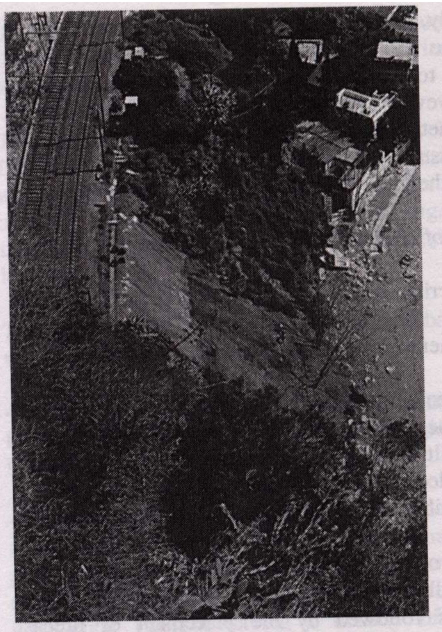
Four contractors replied to the call for tender, submitting 8 variants. The most economical solution was always Pneusol.

It was agreed that:

- the bottom two thirds of the slope could be treated using treads, placed on edge, filled, and compacted;

- approximately the top third, which had a steeper slope because of the slippage, with a bench at the base that could be used for support, would be strengthened by a cellular wall of Pneusol: two horizontal rows of tyres, tied together and filled to form rows separated by a layer of 10 to 15 cm of compacted fill.

It was further decided to strengthen the whole by anchors (iron pins) two metres long and 25 mm in diameter.



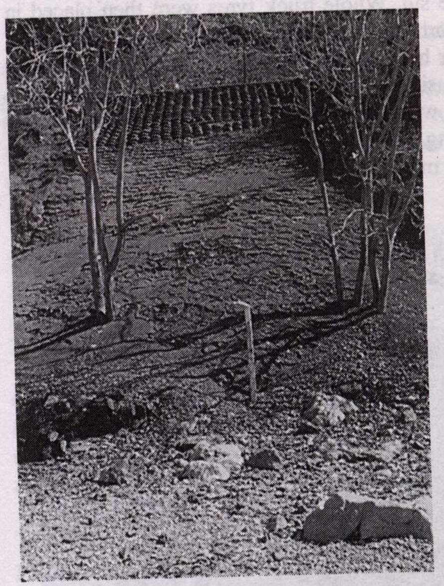
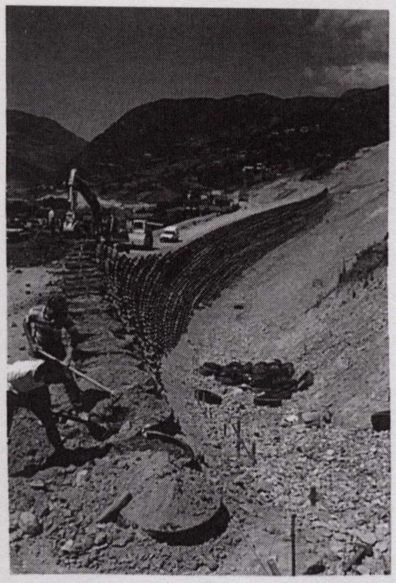
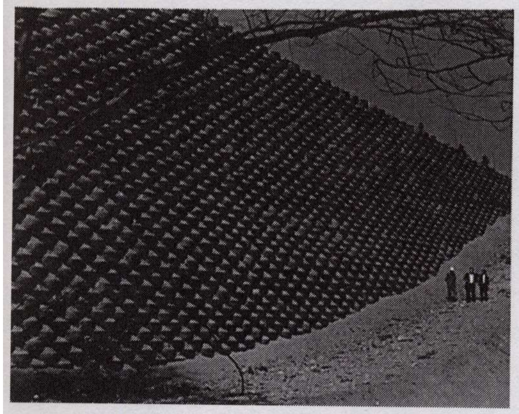


Figure 4: Protection of slopes at Beaulieu-sur-Mer

2,250 tyres attached by polyester straps were used. Fifty anchors were driven (Fig. 4). The work went smoothly and took 15 days, spread over a one-month period because of inclement weather. It cost approximately 200,000 F, which should be compared to the least expensive conventional solution, at 900,000F.





CONCLUSIONS

More than two hundred and fifty known structures have been built in France, twelve in Algeria, Switzerland, Germany, Romania, Jordan, the United States, Rwanda!, etc., in various civil engineering applications (retaining structures, stiffening of slopes, energy absorbers against rockfalls, vibrations, noise, creation of the arching effect above rigid underground pipes, etc.) (Long 1993).

The use of lightweight Pneusol, in particular for repairs of embankment slippages, gives very good results, both technically and economically.

It is also possible to vary the "density" parameter to match it to each particular situation, notably by using different materials (natural or artificial) or even wastes (clinker or fly ash). With these last materials, the recommendations of the Ministry of the Environment must be strictly observed.

Furthermore, when the saving of weight is insufficient, one can consider a larger earthwork to increase the volume of Pneusol placed, because the earthwork is much less expensive when the equipment is already on site.

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