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Performance of Geotextiles in Stabilization of Clay Slopes in Italy

Comportement des géotextiles dans la stabilization de pentes argileuses en Italie

The use of geotextiles in drainage and landslide correction works has been increasing in Italy since the last ten years. A concise description of constructive schemes and of site arrangement for draining trenches is preliminarly reported. Then, the drainage system designed for correcting a landslide in clayey soils, adopting a polyester non woven fabric, is described. The effectiveness was controlled after 30 months: the geotextile, the surrounding soil and the draining gravelly and sandy material were sampled and tested in the laboratory; results of permeability and tear tests, both on contaminated and on "virgin" fabric, are reported. The functioning of the soil/fabric double layer as a filter and the satisfactory maintenance of geotextile properties were assessed.

L'emploi des géotextiles dans le drainage et dans la stabilisation des éboulements a crû en Italie depuis une dizaine d'années. Pour les tranchées drainantes, on rapporte préliminairement une concise description des schèmes de construction aussi que du leur arrangement en campagne. De suite, on décrit un drainage construit pour la stabilisation d'un éboulement en argiles, avec l'emploi d'un géotextile non-tissé en fibre polyester. Le comportement de l'ouvrage a été contrôlé 30 mois après: le géotextile, le sol environnant et la sable et gravier du drainage ont été échantillonés et soumis à essais en laboratoire; on rapporte les résultats des essais de perméabilité et de déchirure sur des échantillons de géotextile, soit vieux, soit nouveaux. Le fonctionnement de la double couche sol/géotextile tel que un filtre et la conservation satisfaisante des proprietés du géotextile ont été confirmés.

1 INTRODUCTION

The use of geotextiles in drainage works, specifically for the stabilization of landslides or unstable slopes, has been increasing in Italy since the last ten years. At present, geotextiles are currently employed as a protection against contamination ond occlusion of the water-bearing material, in partial substitution of traditional graded filters, made of purposely selected natural soils: the main advantages are safety and economy, thanks to a shorter time that is necessary for their setting in place.

In this paper, a summary of the evolution of drainage technology and a brief description of constructive schemes and modalities for draining trenches and of their arrangement for slope stabilization are preliminarly reported. Successively, a case history concerning the correction of a landslide crossed by an important oil pipeline in Northern Italy is told: an exploration pit was excavated after 30 months since the construction of a draining trench; the surrounding natural soil, the contaminated geotextile and the water-bearing material were closely examined, sampled and tested in the laboratory. The functioning of the self-established double layer "geotextile / adjacent soil" as a filter and the satisfactory maintenance of the main geotextile properties were assessed.

2 DRAINAGE TECHNOLOGY IN ITALY

The following considerations are restricted to drainage trenches; other deep draining structures, such as galleries, pits, vertical drains or sub-horizontal pipes, are out of the scope of this paper.

2.1 Evolution of Drainage Technology

The progress achieved in design and construction of drainage trenches in Italy is synthesized in fig. 1. The oldest drains (since 19th Century to 2nd World War) consisted of shallow trenches, filled with coarse gravel and cobbles, without sand (fig. 1 a); the use of such drains, also provided with a bottom collector pipe (fig. 1 b), but designed without following any filter design criterium, continued to about 1950 ÷ 1955.

In order to avoid a too rapid clogging and loss of efficiency, the well known criteria for selection of filter material (1) were introduced; graded filters in natural soils (clean sand with gravel in the main part of the drain, fine uniform gravel around the collector pipe) began to be adopted; besides, the filetr material was protected against surface water by backfilling the upper part of trenches with clay (fig. 1 c).

In many cases, such drains are provided with a concave concrete slab at the bottom (fig. 1 d), stepped for high slope of the sliding surface (2).

During the last ten years, these traditional drains have become more and more expensive, owing to the increasing costs of natural filter materials; on the contrary, the use of geotextiles in substitution of natural sand removes the uncertainties related to grain size composition of the sand itself and reduces the construction times. Therefore, modern trenches with geotextiles (fig. 1 e) result technically more effective and economically advantageous, in comparison with traditional trenches with graded filters in natural soils.

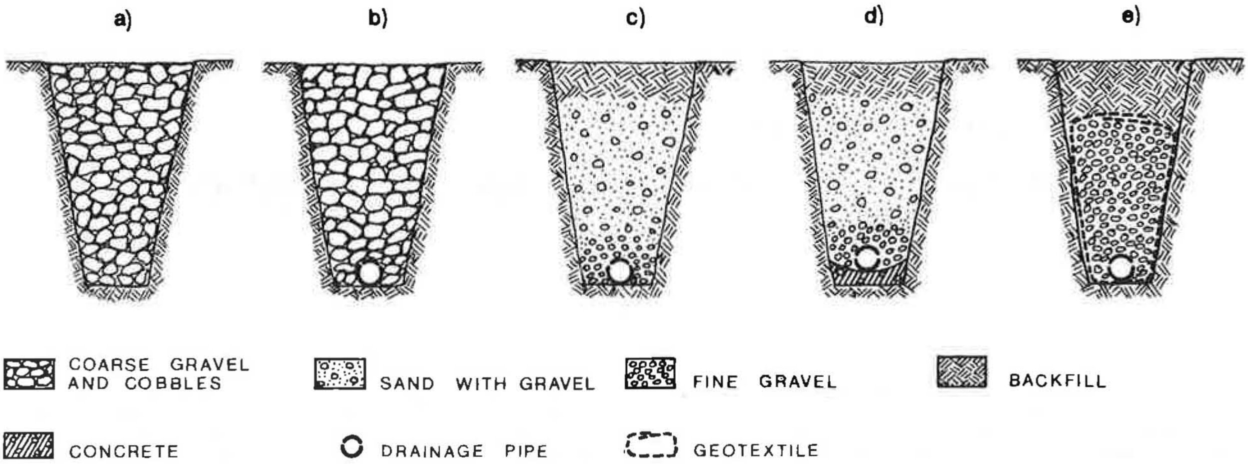

Fig. 1 Evolution of drainage trenches in Italy (transversal sections): a) - b) obsolete drains; c) - d) drains with graded filter in natural soil; e) modern drain with geotextile.

2.2 Current Drainage Technology

According to the typical transversal section (fig. 1 e), draining trenches generally include the following basic components:

- coarse granular soil, as hydraulically pervious material, in the main part of the trench;
- geotextile sheet, as filter around the draining body;
- collector pipe at the base of the trench;
- surface backfill with impervious soil (clay), in order to prevent the trench against surface water and against agricultural works (minimum thickness = 1 m).

As for variability of basic components:

- many kinds of non-woven fabrics, with a preference for polyester fibers, are employed (alternatively, needle-felt or spun-bonded), the mass per unit area varying from 300 to 500 g/m^2;
- the grain size composition of draining materials ranges from coarse gravel to coarse and medium sand;
- reinforced concrete, steel or PVC, perforated pipes are employed to collect the drained water (diameter varying from 200 to 300 mm).

Several criteria for geotextile selection can be found in the literature (3), depending on the opening size of the geotextile itself (O_{90} or O_{98}) and on some grain size characteristics of the adjacent soil (diameters d_{85} or d_{50}, coefficient of uniformity $U = d_{60}/d_{10}$). Nevertheless, natural soils are generally so disuniform and heterogeneous, that such criteria can be applied only with rough approximations.

Longitudinal dimension, depth and planimetrical arrangement of drainage trenches depend on geometrical and hydrogeological characteristics of the landslide to be stabilized. Lengths up to 100 m and depths of about 6÷8 m can be attained; as a general rule, these draining structures are disposed parallel to the direction of maximum slope, so that they cannot be damaged by subsequent slope movements.

3 A CASE HISTORY

In order to control the performance of geotextiles in landslide correction, a slope movement near the small town of S. Cristoforo (Alessandria District - Northern Italy) was selected.

The hillside was crossed by a pre-existing oil pipeline (from Genoa to the River Po Basin - diameter d = 800 mm), whose economical importance justified detailed investigations and landslide corrective works.

3.1 Description of the Landslide

The investigated area lies on the northern side of a hill, constituted by overconsolidated, fissured, marine clays (Lower Pliocene).

The geometrical parameters of the sliding mass are:

- angle of slope to horizontal $\beta = 8°$ (mean value);
- maximum length L = 200 m;
- maximum breadth B = 230 m;
- maximum thickness D = 9 m (as resulting by borings and by the subsequent excavation of drainage trenches).

The following representative lithological sequence was recognized:

a) 0 ÷ 5 m: reddish brown clayey silt, with traces of sand and elements of gravel (colluvial soil);

b) 5 ÷ 8 m: light brown silt with clay and traces of sand (in-situ weathered zone of the marine formation);

c) > 8 m: grey-blue silt with clay (unweathered marine formation).

In general, the deepest slip surface passed along the contact between soils (b) and (c), but locally entered in the grey unweathered soil (involved in the sliding mass by a softening process).

This landslide can be classified as a periodical mass movement, whose stability is governed by the residual angle of shearing strength ϕ'_r (11 ÷ 13°) and by the height of water level above the slip surface.

The piezometric level, measured during the last movement of the slide (spring 1979), was only 2 ÷ 3 m deep in the main part of the area; besides, some ponds of water could be observed in the upper part of the landslide. Therefore, it was outstanding that the slope stability could be increased by appropriate drainage works.

3.2 Drainage System

As the pipeline trend was close to the axis of the sliding area, the following draining system was proposed:

a) a central draining trench, near and parallel to the pipeline itself, 200 m long;

b) two lateral drains, each about 50 m long (not considered in this paper).

For the former and most important drain, the use of geotextiles was proposed, in order to reduce the construction times and the consequent risks for the pipeline. The (uncommon) transversal section of this drain is represented in fig. 2.

In order to avoid clogging of the geotextile, and bearing in mind that soils to be drained were constituted in prevalence by silt and clay fractions, a fabric characterized by low values of the "filtration diameter" (4) was selected: its commercial name is "Terbond TF" and it is produced in Italy by ANIC-Fibre.

According to well established classification criteria (5), Terbond TF 500 can be described as follows: nonwoven felt; mechanically matted; polyester fibers (density ρ_f = 1380 kg/m^3); mass per unit area μ = 500 g/m^2; thickness T_g equal to 4.0 and 1.9 mm, respectively under 2 and 200 kPa.

As for concerns hydraulic properties, the coefficient of permeability (both normal and planar) is of the order of 10^{-3} m/s.

The filtration diameter was determined on the basis of tests formerly suggested by Fayoux (4), slightly modified by ANIC-Fibre Laboratories (6). The results are reported in fig. 3: the filtration diameter, defined as the dimension corresponding to d_{98} for the soil passed through the tested geotextile, resulted about 60 µm.

For the draining body, the most appropriate material (fine to medium gravel) was available only in small amount and a compromise between technical and economical exigencies became necessary. Uniform gravel (d = 10 ÷ 30 mm) was put in place only around the collector pipe; the main part of the trench was filled in with alluvial, clean sand with gravel (fig. 2): this natural material was economically available from the bed of River Lemme, close to the sliding hillside.

The grain size characteristics of the natural soils and of the draining materials are reported in fig. 4. The coefficient of permeability of the alluvial sand, determined by falling head permeameter, resulted ranging from

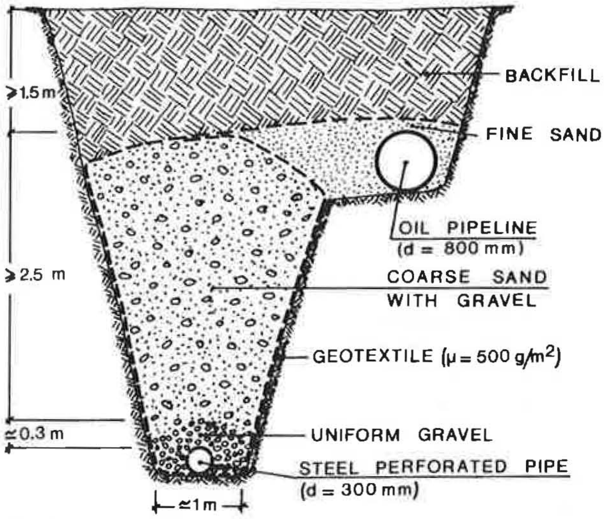

Fig. 2 Transversal section of the drainage trench.

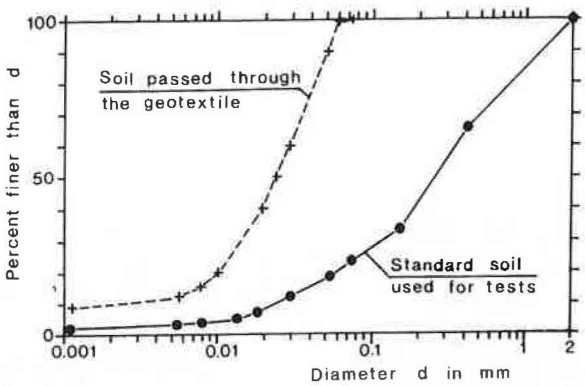

Fig. 3 Results of the test for determining the filtration diameter of the geotextile.

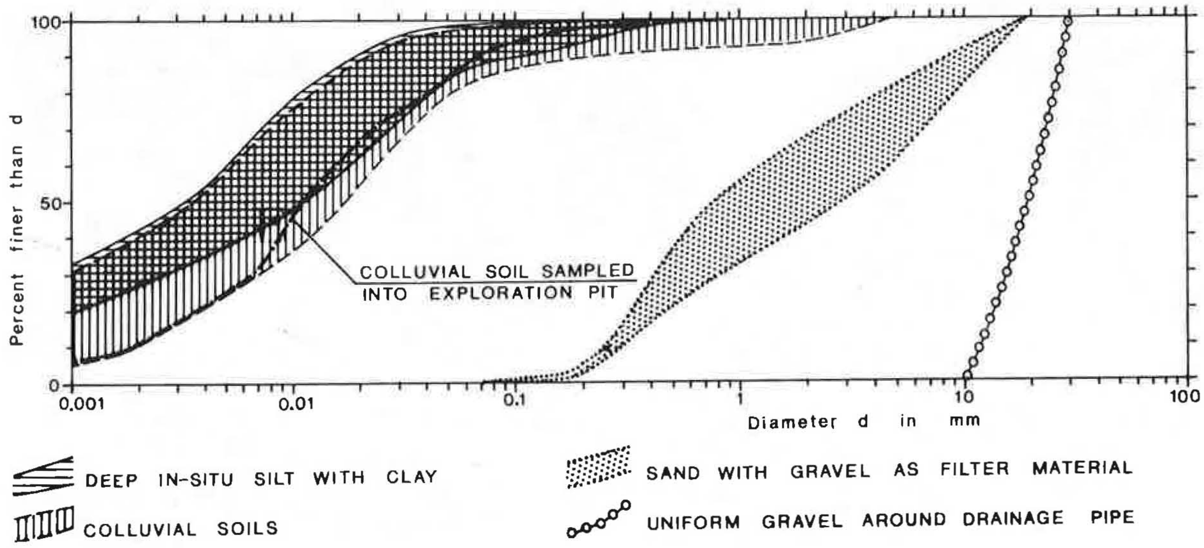

Fig. 4 Grain size characteristics of the natural soils and of the draining materials.

1 to 2 . 10^{-3} m/s; for the uniform gravel, k can be computed according to Allen Hazen's formula.

The construction was completed within July, 1979, according to the following procedure:

a) general excavation until the pipeline base level, in order to allow small movements and detensioning of the structure;

b) partial excavation until the bottom level of the drain (each portion no longer than 10 m, to reduce risks for the pipeline);

c) filling in the excavated portion and excavation of the next one (see photo - fig. 5);

d) covering the pipeline with protective fine sand and general backfilling.

3.3 In-situ Control

The effectiveness of the draining system on the slope stability was ascertained during the years 1979÷1981, when the hillside underwent long rainy periods, without any movement. However, a control pit was excavated in February, 1982, in order to control the conditions of the geotextile and of the adjacent soil after about 30 months since construction.

The exploration pit, situated in the lower part of the landslide, was excavated (initially by backhoe, then by hand operator), to a depth of about 3.5 m; the upper backfill, the geotextile, the underlying draining material and the lateral original colluvial soil were put in evidence (see photo - fig. 6).

The water table was not achieved within the explored depth (3.5 m); this fact finds his explanation partly in a satisfactory performance of the drainage system as a whole, partly in the scarceness of precipitations during last winter 1981/82. However, is was clear that the trench had really acted as a drain; a thin layer (about 1 mm thick), formed by silt-sand particles vould be observed on the external surface of geotextile; many pores of the fabric itself appeared blocked and clogged; besides, a blackish layer, about 20 mm thick, could be seen on the drainage sand (originally grey), at the sand/fabric interface.

The polyester fabric was found apparently unaltered and not attacked by roots or by animals.

3.4 Laboratory Tests

The external colluvial soil, the geotextile and the internal sand were sampled for laboratory tests.

Fig. 5 View of the drainage trench along the pipeline during construction.

Fig. 6 Excavating the exploration pit.

The colluvial soil, sampled on the trench side opposite to pipeline, was constituted essentially by silt fraction (about 80 %), with minor amounts of clay and sand. The grain size curve of this sample is reported in fig. 4, in comparison to the envelope of all the granulometrical curves that had been previously determined for colluvial soils; in particular, the percentage of soil retained to 0.074 mm sieve was 8.6 %.

A block of the same colluvial soil was taken at the contact with fabric. A small amount of soil was scraped by a knife from the contact surface and a sieve analysis carried out: the percentage of soil retained to 0.074 mm sieve resulted 10.2, gaving a proof of relative enrichment in coarser particles in proximity of the upstream geotextile surface.

As for regards sand with gravel forming the draining body, laboratory tests took into consideration the apparent differences between the blackish outer layer and the inner grey mass. On the basis of qualitative analysis by immersion for 24 hours in 3 % solution of NaOH, the black layer resulted to contain a remarkable amount of organic substances (likely of vegetal origin). Owing to natural variability of alluvial material, and in order to distinguish eventual differences due to the presence of geotextile, granulometrical analyses were performed only on fractions passing to 2 mm sieve. Under such limitation, sieve analyses gave the following results:

- black layer: 7.1 % passing to 0.074 mm sieve;
- grey sand: 3.2 % passing to 0.074 mm sieve.

The relative enrichment in finer particles in proximity of the downstream geotextile surface resulted evident.

Finally, laboratory tests were carried out on fabric samples, contaminated after 30 months since their burying, and, for comparison, on "virgin" geotextile samples.

The coefficient of permeability was measured both normally (k_n), both in the plane of geotextile (k_p), under normal pressures ranging from 50 up to 218 kPa. The results are summarized in fig. 7: the measured values are conform to the values declared by the Productor and the decrease of k_n (or k_p) due to contamination appears very limited.

The fabric resistance was controlled by trapezoid tear test (ASTM D2263). The breaking force F_T was measured respectively on virgin and on aged samples, both longitudinally (L) and transversally (T). The measured values are summarized in table 1.

Table 1. Results of trapezoid tear tests (ASTM D2263).

Breaking force	virgin fabric	aged fabric
$F_{T(L)}$	850 N	700 N
$F_{T(T)}$	600 N	470 N

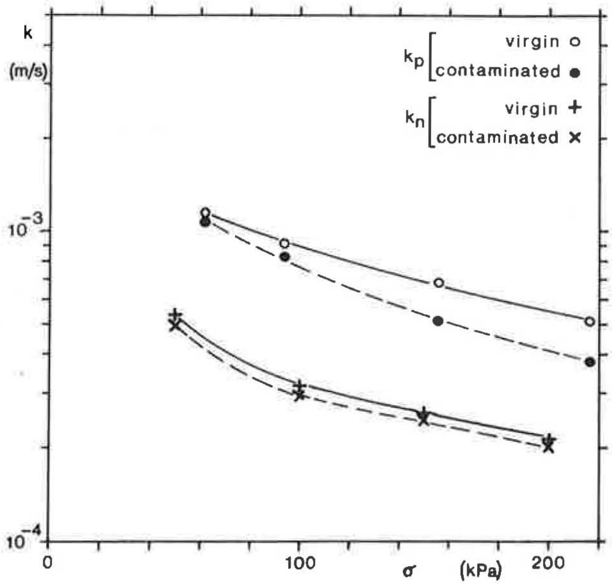

Fig. 7 Coefficient of permeability k versus normal pressure σ, for "virgin" and contaminated samples (k_p planar, k_n normal to geotextile).

The diminution with reference to initial values can be partly ascribed to variability of production; however, such a loss of resistance (about 20 %) is tolerable for practical purposes and is in agreement with results published for other polyester geotextiles (7).

4 COMMENTS AND CONCLUSIONS

From direct inspection of soil/fabric interface and from grain size analyses on sampled soils, the self-establishing of a thin layer (less than 3 mm), impoverished of fine particles, adjacent to the upstream face of geotextile, was proved. Along the downstream face of geotextile, the draining sand was found enriched in fine particles: the thickness of this partially clogged layer was found to be about 20 mm. This investigation strengthened that the so-modified assembly "soil/geotextile/sand" can act as a graded filter, and after a short time can reduce and stop any further piping of fine particles.

Accordingly, from the case history previously described it was also clear that the particular polyester fibre non-woven geotextile named Terbond TF 500 had supported more than 2 years of burying, with tolerable losses of the hydraulic and mechanical properties.

For future investigations, the following two topics can be proposed:

- soil/fabric shear angle and its eventual evolution with time;
- influence of soil water chemism on hydraulic and mechanical behaviour of the assembly soil/fabric/drain.

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