DEEP DRAINING TRENCHES MADE BY MEAN OF SECANT PILES TO STABILISE LANDSLIDES

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ABSTRACT: The stabilization of a slope in a saturated cohesive soil mass can be achieved by means to the execution of a drainage intervention with the aim of generating a reduction of interstitial pressures along the sliding surface with a consequential increase in the shear resistance along the sliding surface.
This design solution is the most effective when the instability conditions are caused by high values of interstitial pressures. This occurs especially for the mechanisms of shallow instabilities, which are strongly affected by seasonal variations in interstitial pressures depending on the development of the atmospheric precipitations.
In these cases, the degree of safety varies over time and the movements are generally reactivated during the autumn seasons, when the interstitial pressures reach the maximum levels. In these cases, the drainage system reduces interstitial pressures and the amplitude of seasonal oscillations by limiting the maximum values that can be achieved. "Drainage trenches" are certainly among the most effective drainage interventions. They are generally used to stabilize superficial landslides of a translational nature, very common in steep slopes in cohesive soils. Even large landslides with deep sliding surfaces can still be effectively tackled through drainage by mean of deep trenches. This paper presents the use of a deep drainage system used for stabilizing an unstable slope on the A2 motorway in southern Italy. This drainage system consists of a net of deep trenches executed by mean of a series of secant piles made of permeable concrete.

Keywords: **drainage trenches, interstitial pressures, secant piles, permeable concrete**

METHODOLOGY PROPOSAL

Ground water is probably the most important single contributor to landslide initiation. Not surprisingly, therefore, of all possible solutions to be considered for the correction of existing or potential landslides, proper drainage is undoubtedly the single most important. Drainage is effective because it increases the stability of the soil and reduces the weight of the sliding mass. The design of the system capable of increasing the shear strength in the sliding area must lead to the definition of the location, distance and depth of the trenches. It must start from the identification of the collapse mechanism, of the location of the sliding surface and of the interstitial pressure regime existing in the slope. In the dimensioning of the intervention it must be considered that the effectiveness of the same is not necessarily associated with the decrease in the level of the groundwater, nor to de-saturation processes of the unstable slope. The increase in safety is achieved when the new flow conditions can generate a reduction in interstitial pressures. The effectiveness of the intervention is therefore not linked to the quantity of water removed, but to the variation of the interstitial pressure regime that the system is able to generate. The drainage trenches generally have a rectangular cross-section, of a width of 0.5 ÷ 1m and a maximum depth of 5 ÷ 6m if excavated with an excavator. For the realization of deeper trenches the techniques of secant piles or diaphragms with rectangular panels are used. Generally the deep trenches are made according to the following phases (Figure 1, 2):

PHASE A1 - execution of the circular excavation, with the equipment used for bored piles;

PHASE A2 - insertion in the hole of a "hunched tube";

PHASE A3 - positioning in the tube of a TNT geotextile casing and of the minimum support reinforcement;

PHASE A4 - filling the geotextile casing with draining material up to the drainage head height;

PHASE B1 - bending of the edges of the geotextile to close the casing;

PHASE B2 - creation of a cap with clay;

STEP B3 - backfill with vegetable topsoil;

PHASE B4 - execution of the excavation for the housing of the second "hunched tube";

PHASE B5 - insertion of the second "hunched tube".

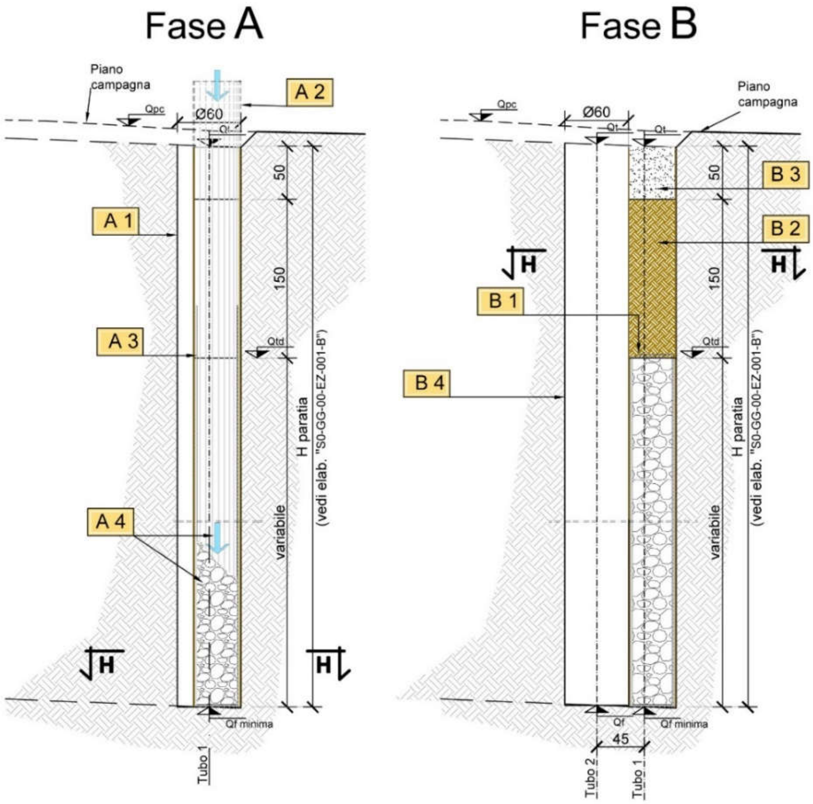

Figure 1. Construction phases of the drainage trenches of secant piles - classic method - longitudinal sections

After having completed all the operations as indicated in phases A and B, the third hole is executed; the “hunched tube” slipped off from the first hole is then inserted into it. The most critical aspect is certainly the insertion and subsequent extraction of the "hunched tube". This phase involves considerable delays in the execution of drainage secant piles and the risk of discontinuity in the draining system due to possible localized landslides of the hole. This aspect frequently constitutes a reason that discourages the use of this drainage system.

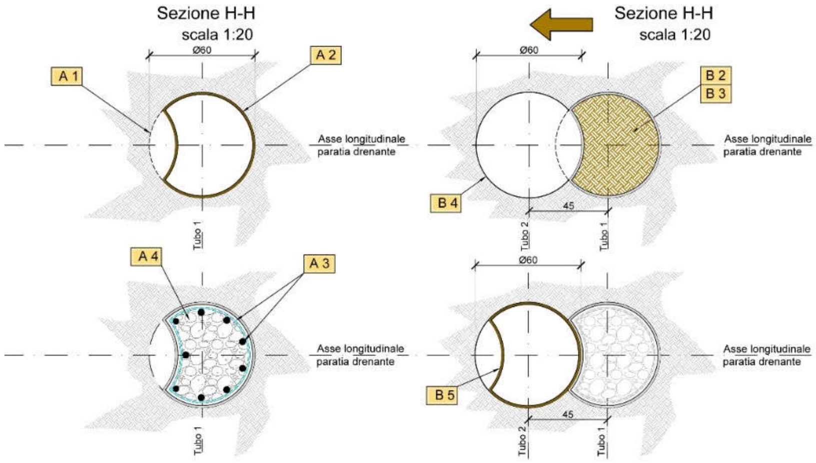

Figure 2. Construction phases of the drainage trenches of secant piles - classic method – cross- sections

To overcome this "critical issue" the writers have developed a system of trenches that involves the use of permeable concrete for filling the piles. The mix design of permeable concrete is suitably sized to achieve the required design performance in terms of permeability and strength. This system allows the creation of trenches at great depths with significantly better timing and quality than those of the "hunched-tube" system described above.

APPLICATION OF THE METHOD TO A REAL CASE

The stabilization interventions carried out in an unstable area near the northern entrance of the Serra Rotonda tunnel are illustrated below. The Serra Rotonda tunnel is part of the modernization work on the A2 Autostrada del Mediterraneo. The interventions consist in the execution of a deep drainage system of a landslide body realized with the methodology mentioned above.

Geological and Geo-mechanical Framework

The unstable area is characterized by the formation of the Galestri Flysch, belonging to the Lagonegro II tectonic unit. It is composed by alternations of siliceous foliated shales with colours ranging from greenish grey to dark grey, marl, calcareous marl, silicified grey and yellowish calcescists and grey, locally brecciate calcilutites. In the more superficial portions, the substrate has suffered intense phenomena of alteration and softening, caused by alternating imbibition and drying cycles and by the attack of atmospheric agents. The analysis of the instability phenomena has highlighted the presence of a groundwater table, even if locally discontinuous, inside the low permeability soils of the Flysch of Galestri and of the calcareous lenses intercalated to them, characterized by relatively greater permeability. The groundwater level is found at a depth within the range 0.5 ÷ 3m (areas with groundwater level emerging on ground surface were found).

The back analysis carried out starting from the results of the monitoring and the available surveys allowed us to hypothesize the sliding surface of the unstable mass (Figure 3).

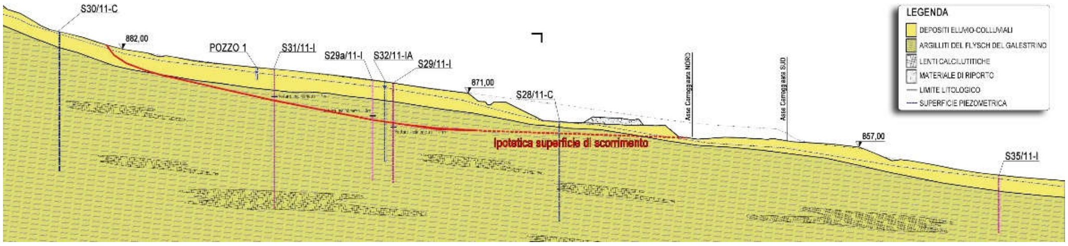

Figure 3. Back analysis section model (with definition of more probable sliding surface)

Description of the interventions

In order to increase the shear strength along the sliding surface, a deep drainage intervention and a surface water regimentation were carried out. These were done through the execution of a combined system of rows of draining secant piles and superficial drainage channels (Figures 4, 5).

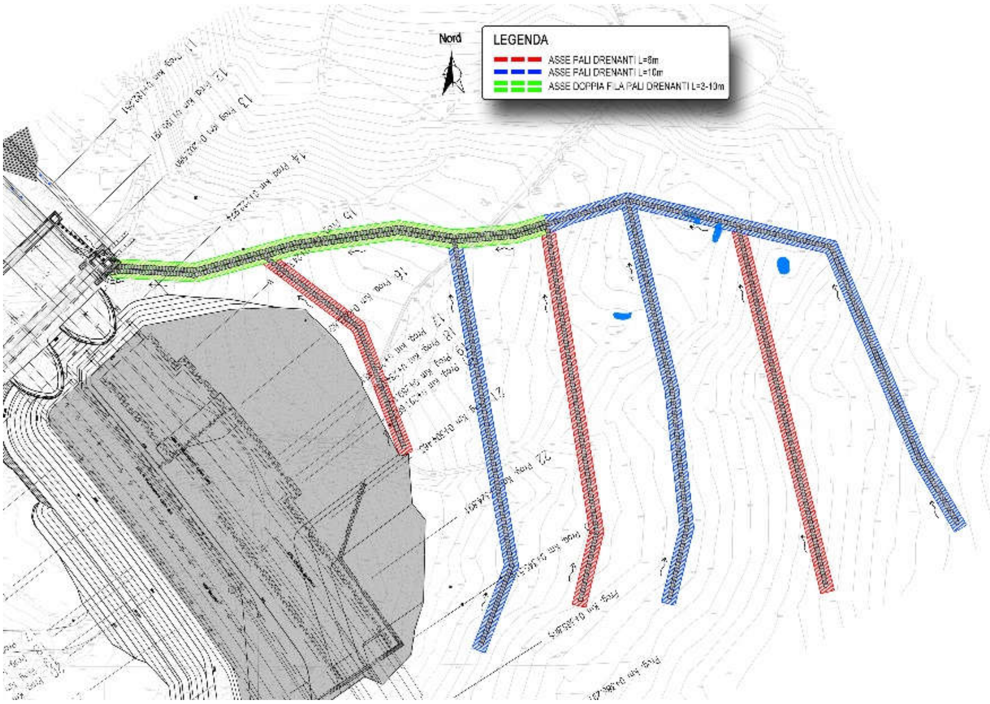

Figure 4. Planimetric diagram of the deep drainage network

The draining piles have a diameter of 1.20 meters and a length of 6-10 meters. The spacing between the rows of the draining piles is on average equal to about 26m. A doubling of the number of drainage piles is realized in the final stretch of the drainage network that ends in a collection drain (Figure 5).

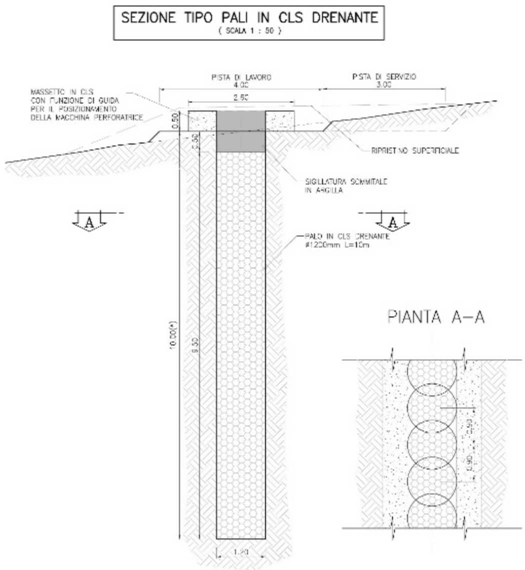

Figure 5. Typical section of the secant drainage piles in cellular concrete

Hydraulic calculation for the definition of interventions

The dimensioning of the deep drainage system was conducted by means of a FEM analysis with the calculation code Plaxis 2D® assuming plan filtration state. This hypothesis is of course valid for this drainage system considering its development in the longitudinal direction with respect to the dimensions of the analyzed cross section. Figure 6 shows the geometry of the calculation mesh. The discretized domain has a width of 100m and a depth of 50m (ground level at 50m of the model).

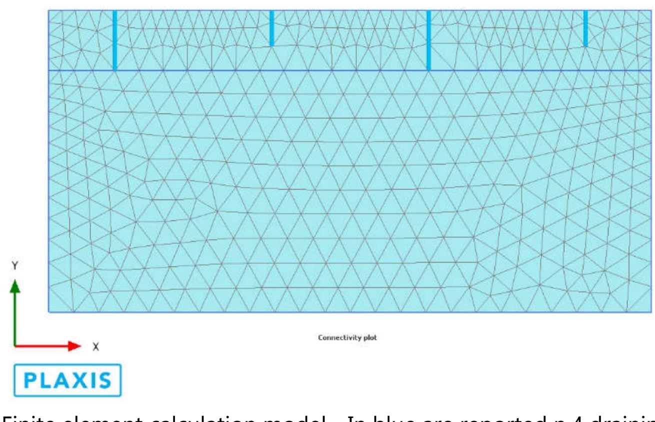

Figure 6. Finite element calculation model - In blue are reported n.4 draining trenches

Calculation phases:

- phase 0 – Initialization: at this stage the pore pressures of the model are initialized with reference to the groundwater level coincident with that of surface ground level;
- phase 1 and following ones – Drainage: the "drain" elements are activated to simulate the presence of the rows of draining piles; a filtration analysis is carried out under transient conditions with reference to filtration times of 1, 2, 4, 6, 12 months.

In the development of the draining system design, numerous sensitivity analyzes were carried out, varying the permeability characteristics of the mass, the depth and the spacing of the trenches, the depth of the groundwater. In this way it was possible to identify the optimal solution from a technical and economic point of view. In particular, the value of the permeability coefficient "k", in both vertical and horizontal directions, was defined with reference to the results of some pumping tests carried out on site. The numerical analyzes were conducted in parametric form, considering a value of the permeability coefficient variable around the values identified in the tests (1x10-7m / s and 5x10-8m / s).

The analysis allowed to determine:

- tendency in the groundwater level;
- flow rates drained by draining trenches.

The analyzes show a minimum of about 4,5m lowering; therefore, the average lowering (decisive parameter for stability) is greater (Figure 7).

As expected, lower values of the permeability coefficient correspond to longer system start-up times.

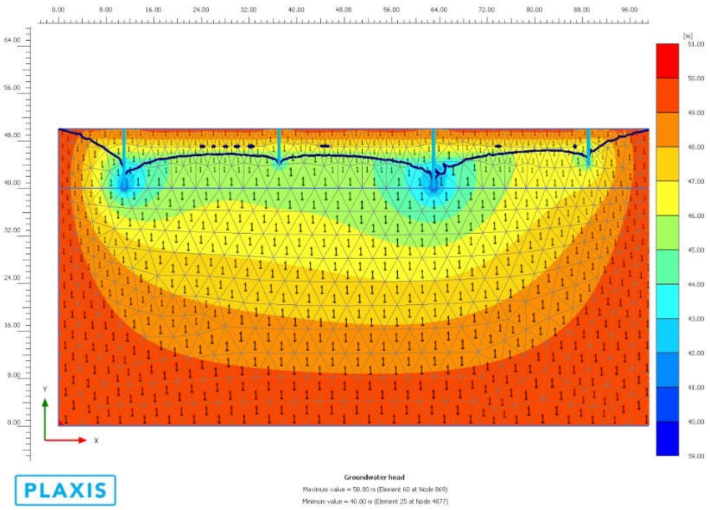

Figure 7. Trend of the flow rates drained by the trenches as a function of the permeability coefficient k = 1x10-7m / s at 6 months from the intervention

Regarding the value of the drained flows values vary between 10 and 20l / day / m in a row of drainage piles (depending on the permeability coefficient considered); this value is consistent with the removal capacity.

Construction Phase

Unstable area is characterized by an average slope of about 8 °. It is between the quotas of 893 and 858 m s.l.m. The landslide body has an extension of about 35.000sqm, a width of about 130m and has affected the entire slope for a length of about 260m.The set of first observations allowed us to recognize that the slope is characterized by poor safety margins, being in an active landslide condition and in the phase of expansion (Figure 8).

Figure 8. Cracks appearing on the right side of the detachment area

The interventions executed to stabilize the landslide body consist of a deep drainage system made with a network of rows of drainage piles Φ 1200mm with variable length of 6 ÷ 10 meters (for a total development of about 760m) and a double row of piles with variable length of 3 ÷ 10 meters (for a total development of about 150m). A total amount of around 7850 linear meters of 1200mm diameter perforations were made, using about 8850 cubic meters of draining permeable concrete as filling material (Figure 8).

Figure 9. Double row of drainage piles with permeable concrete (level change section)

Figure 10. Construction of the secant draining pile (Phase B)

Particular attention was paid to the study of the mix design of permeable concrete and, in particular, to the definition of the Particle Size Distribution and the amount of cement useful for assure the criterion of permeability and self-stability of the mixture (Figure 9). During the qualification phase of the alveolar concrete mix, each sample was subjected to permeability tests (UNI EN 12390-8) and to compression tests (UNI EN 12390-3). The results of these tests were in line with the project expectations both about permeability (value higher than 10-3 m / s) and for minimum compression resistance. The works for the construction of the drainage piles and for the regimentation of surface water started in February 2012 and ended in August of the same year.

Effectiveness / Monitoring

During the work the effectiveness of the intervention was observed directly, at a macroscopic level, in terms of the draining effect of the mass involved in the intervention itself. The intervention produced an evident slowing down of the deformations taking place immediately after its completion. In photo 11 the water drained at the valley end of the trenches is visible.

The effectiveness of the drainage system was also confirmed by the analysis of the data provided by the monitoring system, consisting in the execution of piezometric and inclinometric measurements. The data collected after the execution of the work were compared with those collected in the months preceding the intervention (ante operam).In particular, if compared with the deductions made from the observations made before the intervention in drainage piles, the extent of the deformation phenomena observed was reduced since the period immediately following the realization of the intervention itself, passing from deformations with speed also of the order of cm / day at deformations with deformation speed of the order of mm / month, to then reach complete stabilization in the following months. Even the piezometric readings provided positive indications, highlighting a maximum decrease in the piezometric altitude of about 1.5m already in the first 30 days after the installation of the instrument.

Figure 11. Run-off of drained water in the final section of the draining trench

CONCLUSION

For stabilizing an unstable slope on the A2 motorway, in southern Italy, an innovative deep drainage system was used. This drainage system consists of a net of deep trenches executed by mean of a series of secant piles made of permeable concrete.

This system allowed the creation of trenches at great depths with better timing and quality than those of the classical "hunched-tube" system. It allowed to overcome the critical aspects involved in the classical construction methods of deep drainage trenches that can cause delays in the execution and the risk of discontinuity in the draining system.

The system was able to attain the required design performance in terms of permeability and strength.

During the work the effectiveness of the intervention was observed directly, at a macroscopic level, in terms of the draining effect and of an evident slowing down of the deformations taking place immediately after its completion. It was also confirmed by the analysis of the data provided by the monitoring system.

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