REVIEW AND DESIGN APPROACH OF A RETAINING STRUCTURE BUILT AGAINST AND CONNECTED TO A NAILED EMBANKMENT.

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ABSTRACT: Various attempts have been made to connect a facing, which retains a new embankment, to the nails heads located in a nailed slope. But until now no simple method was enough successful to meet this need. To answer this problem, a recent technology, called PRO'LINK® has been developed: at each construction stage a continuous geosynthetic strap links successively a new facing to the nail heads of the slope. The space between the slope and the vertical or sub-vertical facing is backfilled with a technical soil or with cobbles when a gabion aspect is foreseen. The facing itself is made of prefabricated elements in cast concrete or steel mesh.
This paper presents the different parts of this composite wall. The application of this technique is mainly correlated to nailing works. On the one hand, the tensile strength in the strap is calculated to design this element: the tensile strength must compensate the lateral earth pressure. On the other hand, the nailed embankment stability is computed with a geotechnical software. This article underlines the different steps of the design aspect of this non homogeneous wall. The implementation of calculation stages ensure the long term stability of the structure. The design of each component is carried out to ensure a great safety.

1 INTRODUCTION

Link nails heads to a new facing is an attractive idea, but until now it hadn't found an interesting practical answer. The patented process brings from now on a smart solution. The objective of this article is to understand how this technique works and draw attention to applications of this new solution.

First of all, the process will be briefly described. Then, the applications of this technique will be presented. Finally, the structure dimensioning method will be pointed out.

2 DESCRIPTION

This first part presents the new process in order to understand the soil-structure stresses that exist in this retaining structure and then the principal calculation stages.

Generally, the structure consists of a front part and of a nailed back part (cf. Figure 1).

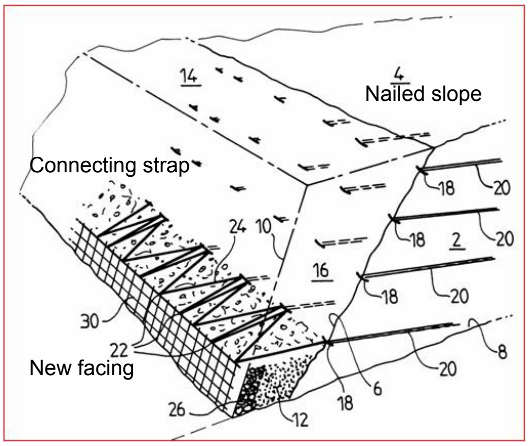

Figure 1: Cross section of the structure

2.1 *The front part*

The front part includes the embankment and the facing which is fixed to the nails by flexible straps.

2.1.1 *The flexible strap*

The technique makes it possible to link the nails heads, which are solid but not precisely located in x, y, z to manufactured facing units. This facing presents connection points at well defined positions.

Thanks to a flexible and continuous strap, the anchoring points are linked successively to facing connecting points (cf. Figure 2). Indeed, the strap, which is a flat cable, is adjustable.

So an embankment, which is built against an existing wall, is raised.

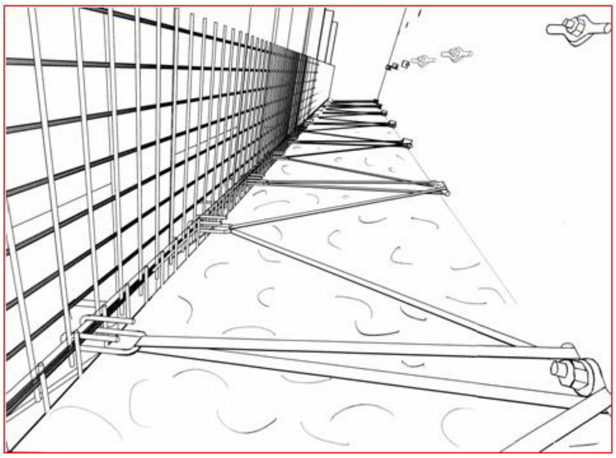

Figure 2: A view of a current layer during construction

On the anchoring side, nails heads are equipped with a device; so it's possible to fix the strap.

On the facing side, only a simple hook is needed to fix the strap. There's no need to thread the strap from all its length through any fixing points of the system.

2.1.2 *Facings*

This new structure fits all types of facing: mineral aspect when stones are installed behind a steel mesh (resistant and durable), concrete aspect, flower box aspect, etc.

According to the facing stiffness, a “silo” effect can develop.

The stone embankment is well adapted to the sites where mineral predominates. That’s the case in mountain. An alternative consists in using an adapted geotextile at the back of the steel mesh and a backfill which makes it possible vegetation to develop (cf. Figure 3). With this new process, the facing is integrated in a rural landscape.

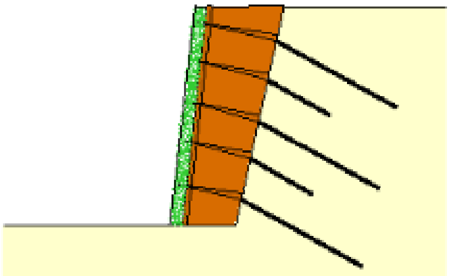

Figure 3: Vegetal facing

Facings in concrete panels, facings which use open units in order to put in there flower boxes (cf. Figure 4), or an installation of terraces are feasible. The strap fixings will fit in the manufactured elements the adequate positions.

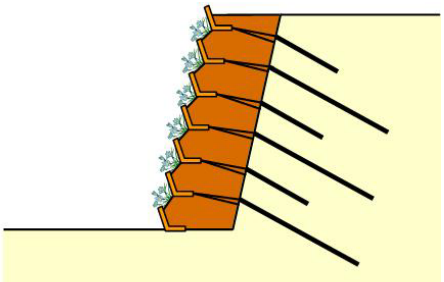

Figure 4: Flower boxes

2.2 *The nailed back part*

In the back part, we can distinguish two types of nails :

- the short nails ensure the anchoring of the flexible strap ;
- the long nails are not only used to fix the flexible strap, but also they play an important part in the stability of the structure.

3 APPLICATIONS

There are many applications of this structure. They are divided in three families : nailed slopes covering, roads and motorways widening, wall rehabilitation.

3.1 *Nailed slopes covering*

Nailed slopes covering gives an attractive aesthetics to the wall and creates a widened crest (cf. Figure 5). With this new process, embankments with vegetal facing (flower boxes or stiffened slopes) built against a wall, can be created.

3.2 *Roads and motorways widening*

This solution is very efficient for roads and motorways widening. This technique is well adapted when the width at the base is limited or in the mountainous area when the access is difficult (stiff slope, no excavation possibility, maintenance of existing circulation) (cf. Figure 5).

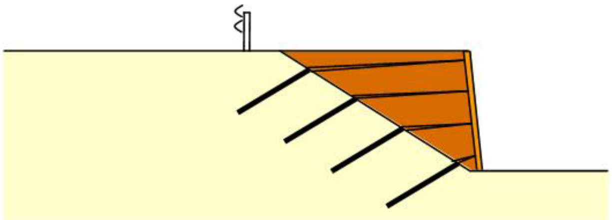

Figure 5: Widening

3.3 *Wall rehabilitation*

This technique can also be used for the wall rehabilitation with restitution or even widening of the platform (cf. Figure 6). This process can be chosen for old dry stone walls which collapse or cliffs which are deteriorated.

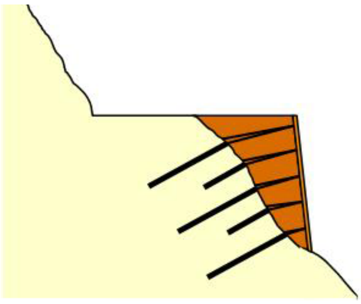

Figure 6: Rehabilitation

4 CALCULATION METHOD

This part describes the different stages necessary to compute the different components of the structure. The slope stability is determined by an Ultimate State Analysis. The stability is evaluated along circular failure surfaces.

4.1 *Strengths in the process*

The straps work in traction. This traction is caused by the soil friction on the nail (in the resistant zone) and the earth pressure on the facing wall. The resistant zone is located behind the failure surface.

Continuity between the strap and the nail is ensured thanks to the anchoring points, on the anchoring side. The force T_i on the nail heads is also an internal force (cf. Figure 7).

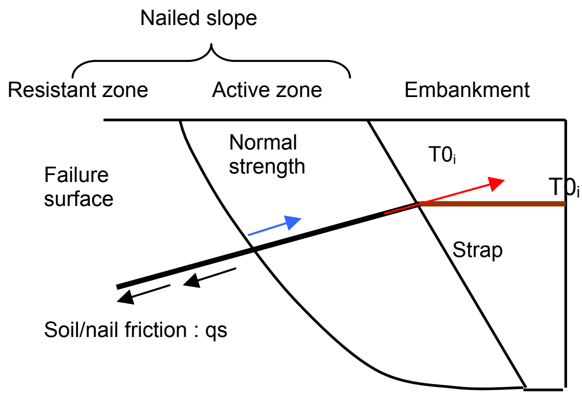

Figure 7: Forces at the failure surface

The study is divided into two parts:

- Calculation of the tensile force T0i ;
- Study of the potential failure surfaces in the nailed back part.

4.2 *Hypothesis*

For modeling and computing, it will be considered that the nails work only in traction. That's why, when the calculation of failure of the non homogeneous reinforcement is run, two criterias are retained for the stress analysis in the nails:

- The tensile resistance of the nail ;
- The friction between the soil and the nail.

Many simulations have shown that the friction is the limiting factor.

4.3 *First step : Calculation of the tensile strength*

Firstly, the front part is dealt with. The aim of this calculation is to adjust the mechanical and dimensional characteristics of the strap to each project. The idea is the following: the tensile strength must compensate the lateral earth pressure and the superimposed load (cf. Figure 8).

The calculation method is based on a local equilibrium.

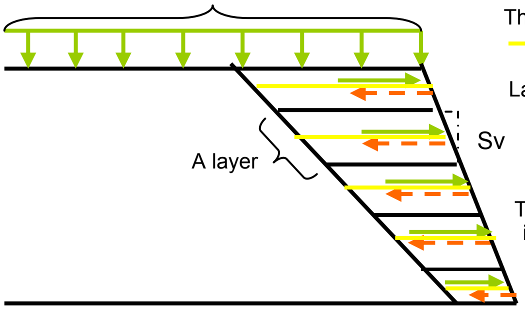

Figure 8: Embankment divided into layers

The different notations are :

- $T0_i$, force in the strap, at each layer ;
- q, superimposed strength ;
- Sv, vertical spacing ;
- Sh, horizontal spacing ;
- H, height between the crest of the embankment and the strap ;
- γ, unit weight ;
- Ka, coefficient of earth pressure ;

$$T0_i = Ka.(\gamma.H.Sv.Sh + q.Sv.Sh) \quad (1)$$

with Ka, according to the formula of Coulomb:

$$Ka = \frac{\sin^2(\eta - \varphi)}{\sin^2\eta.\sin(\eta+\delta).\left[1+\sqrt{\frac{\sin(\varphi+\delta).\sin(\varphi-\beta)}{\sin(\eta+\delta).\sin(\eta-\beta)}}\right]^2} \quad (2)$$

The various notations pertaining to formula (2) are noted on the figure 9.

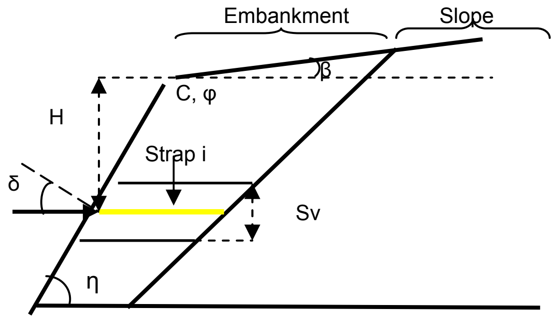

Figure 9: Notations used for the calculation of the earth pressure coefficient

Note: Notice that if a local and accidental rupture of the strap happens, the strap can't slip because of the friction between the soil and the strap. The next meter, the strap is anchored again. Friction is then useful to hold the loose end of the strap.

4.4 *Second step : potential failure surfaces in the nailed back part*

4.4.1 *General principle of the stability analysis*

The idea is the following: return to the usual configuration of the nailed walls.

The back part stability is handled by the geotechnical software TALREN. The potential failure surfaces are located in the nailed part, because the selected soil and the dimensioning of strap exclude a rupture in the front part.

Program determines the stability of the structure at limit equilibrium using classical moment equilibrium (Bishop's method). The analysis method consists in comparing the shear stresses, generated by the loads, to the mobilized shear resistance. Each parameter is factored by a weighting factor (for loads) or by a partial safety factor (for resisting forces).

The static equilibrium is given by :

$$\Gamma_{s3}.\tau \le \tau_{max} \quad (3)$$

with

- Γ_{S3} = coefficient inherent to the uncertainty of the analysis method ;
- τ, mobilized shear resistance ;
- τ_{max}, shear stress.

4.4.2 *Example of a calculation technique in the case of non homogeneous reinforced soil*

A computing process is run :

The friction being the principal limiting factor, the nails length behind the failure surface plays the main role. In the following figure, for the nails, which are intercepted by the failure surface, this length ist noted LU.(cf. Figure 10).

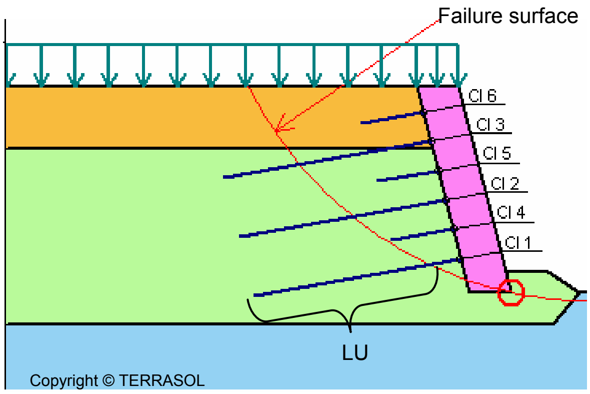

Figure 10: Length of nail behind the failure surface

If the minimum safety factor is greater than 1, it means that the total available shear resistance along the slip surface is greater than the mobilized shear stress. The slope stability is ensured.

Note:

If the safety factor is greater than 1.1, an another computing process is run. The optimal length of the nails is searched. In this second calculation process, smaller nails are chosen. For a safety factor between 1 and 1.1, the nails dimensioning is regarded as suitable.

If the safety factor is smaller than 1, an another test is carried out with longer nails or with another nails spacing to reach a safety factor equal or grater than 1.

5 CONCLUSION

As developed above, these different steps of the design process conduct to yield the optimum reinforcement layout to ensure satisfactory stability. First of all, the mechanical and dimensional characteristics of the straps are chosen to enable the stability of the front part. Then, the length and the spacing of the nails are determined with a calculation of failure.

Moreover, this earth retaining technique design makes it possible:

- A small width at the base of the structure ;
- no excavation is necessary.

Properties and characteristics of this new process show that this earth retaining technique construction is an innovating idea making it possible to realize substantial savings.

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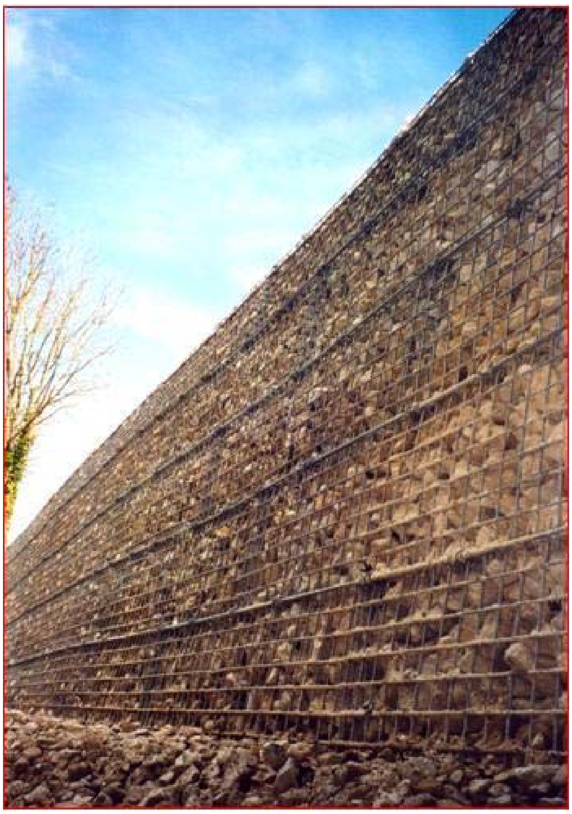

Figure 11: Slope reinforcement on the secondary road 514 in the "Moulin de la maison Fort" in Bitry – Nièvre- France