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Technical Note

Field measurements of anchored flexible systems for slope stabilisation: Evidence of passive behaviour

E. Blanco-Fernandez [a,*], D. Castro-Fresno [a,1], J.J. Del Coz Díaz [b,2], J. Díaz [c,3]

[a] Area of Construction Engineering, ETSICCP, University of Cantabria, Avenida de los Castros s/n. C.P. 39005 Santander, Spain
[b] Area of Construction Engineering, EPSIG, University of Oviedo, Edificio Oeste N° 7 Dpcho.7.1.02, Campus de Gijón, 33204 Gijón, Spain
[c] Department of Architecture and Civil Engineering (AEC), Technische Hochschule Mittelhessen - University of Applied Sciences, Wiesenstrasse 14, D-35390 Giessen, Germany

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ABSTRACT

Flexible systems anchored to the ground constitute a technique for slope surface stabilisation. They are formed by membranes (cable nets, wire mesh, ring net), reinforcement cables and bolts tightly anchored to the ground forming regular patterns. Most manufacturers and independent researchers assume active behaviour of these systems when they propose their design models, which means that the system avoids occurrence of instability. To consider active behaviour, two conditions have to be fulfilled: the membrane has to be initially prestressed and the slope must present a convex shape. Neither of these two conditions has been verified so far, therefore, there are no guarantees that current design methods are adequate. Review of the technical brochures of manufacturers shows that applied prestress force on membranes and reinforcement cables is nonexistent or very low.

In this paper, three field systems in north Spain with cable nets anchored to the ground have been instrumented. Net cables, reinforcement cables and bolt heads have been instrumented by using sensors based on electrical extensometry. Tensile forces on cables and compression forces on bolt heads have been monitored for more than a year from the beginning of installation. Initial tensile forces in net and reinforcement cables induced an average value of 0.7% and 2.1%, respectively, of the ultimate strength of each component. In relation to bolts, average compression force on bolt heads was 5.3% of their ultimate strength.

These measurements demonstrate that prestress force on flexible systems is very low, and nearly negligible. Therefore, flexible systems anchored to the ground cannot be considered as active, but passive, which means that most current design methods are not adequate.

1. Introduction

Flexible systems anchored to the ground constitute a technique for slope surface stabilisation. These systems are formed by membranes, made of cable nets, wire meshes or ring nets, bolts anchored to the ground and reinforcement cables forming regular patterns. This technique has spread extensively due to its low visual impact and its minimal influence on traffic during installation.

Flexible systems may be classified as either low or high resistance systems. A low resistance system is generally formed by a triple torsion wire mesh manufactured with standard steel (ultimate strength ≤ 400 MPa) and anchored to the ground at a few points through bolts, allowing material to slide due to a loose contact between membrane and slope surface. The main application of this system is to work as a curtain, preventing small rock pieces from getting to the road after detachment by steering them along the slope surface till the ditch. As for high resistant flexible systems, these are formed by a cable net, single torsion wire mesh or ring net presenting a relatively more closed and rigid contact with the slope surface, and manufactured with medium to high-resistance steel (ultimate strength ≈ 600–1700 MPa). The main application of these systems is to avoid soil sliding or rock detachment in slopes by exerting a normal pressure to the ground, p, which prevents occurrence of instability by increasing internal shear resistance in the sliding plane. This pressure p is apparently due to a prestress force applied to the membrane and reinforcement cables during installation, which finally induces the stabilisation effect. Manufacturers and some researchers refer to this behaviour as *'active'* (see Figure 1).

Low-resistance flexible systems were first used in the 50s (Peckover and Kerr, 1976; Geobrugg North America L., n.d), while high-resistance ones appeared in the 80s (Justo et al., 2009). As a rough estimation, around 1,000,000 m^2 of high-resistance flexible systems could be placed yearly throughout the world nowadays. Although the use of flexible high-resistance systems has generalised throughout the world, only one

* Corresponding author. Tel.: +34 942201565; fax: +34 942201703.
E-mail addresses: elena.blanco@unican.es (E. Blanco-Fernandez), daniel.castro@unican.es (D. Castro-Fresno), juanjo@constru.uniovi.es (J.J. Del Coz Díaz), joaquin.diaz@bau.th-mittelhessen.de (J. Díaz).
[1] Tel.: +34 942202053; fax: +34 942201703.
[2] Tel.: +34 985182042; fax: +34 985182433.
[3] Tel.: +49 641 3091830; fax: +49 641 3091839.

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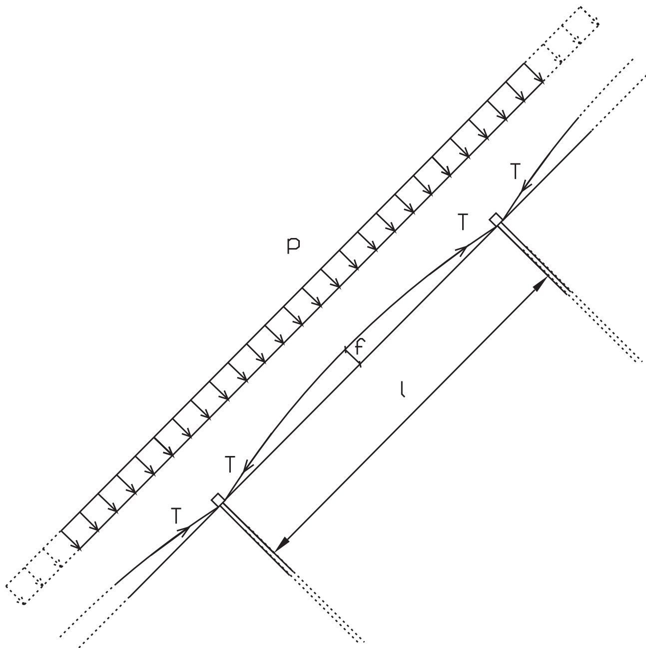

Fig. 1. Active behaviour of flexible systems. Theoretical scheme.

official technical document has been found to guide the design and calculation of these systems (Phear et al., 2005). Moreover, there are few scientific references tackling the topic of design methodology except for those of the manufacturers of cable nets and high-resistance wire meshes themselves, and two PhD theses by independent researchers from the University of Cantabria (Castro Fresno, 2000; Da Costa García, 2004).

Only two field monitoring studies have been found in the bibliography, one in the USA (Muhunthan et al., 2005; Shu et al., 2005) and another in Italy (Bertolo et al., 2009). In none of these studies was initial prestress force on the membrane measured, so there are no references on the prestress force applied in the membrane systems themselves.

In the USA, vertical slings on top of the slope were fitted with strain gauges. The research was promoted by the Washington State Transportation Centre. The aim was to try to find some correlation between data recorded (voltage output in strain gauges) and snow events, rainfalls, and temperature. Gauges were placed on slings some years after installation, so there are no records of initial pretension of the flexible system. The membrane itself and bolt heads were not instrumented.

The second study was carried out in Italy by the University of Turin and the manufacturer Maccaferri. An in situ test device to apply a point load was installed in field with a cable net anchored into a rock slope. The test device consists of a jack embedded in the rock matrix that was able to exert a point load on the midpoint of a panel. Forces on reinforcement cables, bolt heads and displacements at the midpoint panel of the wire mesh were measured, for different loads applied. However, forces on net cables were not measured. The initial tensile force on reinforcement cables was 3 kN approximately.

Most manufacturers and independent researchers assume active behaviour of these systems when they propose their models. Most models found in the bibliography are analytical, except for two attempts at performing a numerical simulation (Da Costa García, 2004; Luis Fonseca, 2010) but without realistic solutions. In most existing models limit equilibrium analysis is considered with a particular failure mechanism, either wedge shaped or infinite slope. A uniform pressure p normal to the ground is calculated so that it increases the normal effective stress on the slope surface and therefore the shear resistance between potential sliding surfaces. However, the hypothesis of active behaviour has not been demonstrated by any company, designer or independent researcher. Two main conditions must necessarily be satisfied by a flexible system in order to be considered as active:

- The membrane has to be initially prestressed with a known tensile force T, which depends on stabilisation pressure p and slope curvature.
- The membrane (and therefore slope surface) should present a convex shape, either catenary, circumference or parabola.

Field visits and review of photographic databases show that there is no real control on prestress force applied to membranes. In addition, the slope generally has a flat surface geometry or is even concave, buy rarely convex.

The main problems found regarding all the information collected at the initial stage are:

- The prestress force on membranes (cable net, wire mesh or ring net) has not been measured on site.
- Most existing models assume active behaviour of high-resistance flexible systems, while this main assumption has not been demonstrated so far.
- If high-resistance flexible systems are not active, most existing design methods are incorrect, leading to human risk in some cases or to unnecessary costs in others.

Therefore, the main hypothesis of this research work is:

- High-resistance flexible systems must be considered as passive systems, rather than active ones. Hence, the system only retains the unstable mass after the sliding has already occurred.

Accordingly, the objective of this article is:

- To measure the real forces on flexible systems in different field locations.
- To revise installation procedures from different manufacturers in order to extrapolate conclusions from those field systems instrumented.

2. Description of the systems

In this section, a complete review has been done of the majority of flexible systems existing on the market. Seven different companies which sell their products all over the world have been included (Iberotalud, Geobrugg, Macaferri, Tubosider, Saggam, Avaroc, Inchalam).

All of them present common elements, such as a non-continuous membrane, reinforcement cables and bolts. The main differences among some systems are the type of membrane, the connection between rolls or panels, and the pattern formed by reinforcement cables and bolt arrangements (square, rectangular, rhomboidal, only rows, etc.). In order to simplify the description of the installation procedure, three main types have been defined and briefly described according to the bibliography reviewed, which are: cable nets, wire meshes and ring nets.

2.1. Cable nets

This type is fabricated by most manufacturers. It includes the following elements:

- Wire mesh: triple torsion fabricated with low resistant steel. Its function is to reduce the net grid spacing to prevent detachment of small fragments of soil or rock. It is not considered to provide any additional resistance to the overall stability. It is the first element installed.
- Cable nets: manufactured with braided 8 to 10 mm galvanised steel cable that forms a weave of grids from 200 to 300 mm. The cables are fixed at the intersection points of the net weave by staples. Cable nets are usually provided by manufacturers in square or rectangular panels of different dimensions, with sides varying from 2 to 6 m.