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Evaluation of the resistant capacity of cable nets using the finite element method and experimental validation

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ABSTRACT

This work evaluates the resistant capacity of cable nets for the stabilization of slopes. Two tests have been carried out, one with a concentrated load and the other with distributed load, in order to simulate the in situ working conditions of these systems. Tensile, sliding and shear tests were also carried out on the joint elements of the net cables. The results of the tests were used to simulate different geometrical configurations using the finite element method (FEM) by means of the ANSYS program. This approach permits the extrapolation from tested cable nets to untested simulated cable nets, maintaining a basic configuration of constant parameters. The lab tests provide information about the strain and maximum resistance, but they do not establish a relationship between the values of stresses of each net element. These data have been obtained through the computational simulation by FEM generating a new methodology for the design of these systems. At this time, there is no testing standard, but Northern Spain manufacturers are certifying products with these tests. The testing and simulation provide useful results for the design of slope stabilization systems comprised of anchored cable nets.

1. Introduction

Slope instabilities are a common problem in civil construction. They occur especially in the construction of roads and have high recurrence when the slopes of the affected zone are steeply inclined and are subject to climatic factors, which can lead to accelerated soil and rock erosion (Shu et al., 2005).

Slope instabilities are common in Northern Spain. Public authorities and companies are seeking suitable solutions to reduce the frequent landslides that affect normal road traffic.

With this aim, the Construction Technology Research Group (GITECO) at the University of Cantabria undertook a research project named 'Development of the cable net for a slope protection system'. To develop the project, we have counted on the experience of private companies, who have installed certified cable nets for the last ten years. With this aim, GITECO started to test cable nets in October 2003 in the Structures Laboratory of the University of Cantabria (Spain), for 283 mm grids. These tests produced useful information about the methodology for carrying out the future tests on cable net meshes (Castro, 2000). The experience acquired helped establish the right configuration of the tests regarding the position, shape and size of a distributed load, and to generate a methodology to extrapolate the laboratory data (Del Coz Díaz et al., 2007).

1.1. The system

In a slope with discrete and/or continuous instabilities along the hillside, one way to stabilize the situation is to cover the erodible or landslide-prone areas with shotcrete or a continuous concrete wall. In the case of shotcrete, the water pressure and widespread instability can rapidly lead to system failure. In the second case, a wall applies greater resistance and there is more detailed knowledge of the calculation parameters. This solution, however, has high cost and aesthetic disadvantages.

As an alternative, an anchored cable net is easy and quick to install, is homogeneous and has known material behaviour, is potentially more aesthetic, is easy to repair and has long life expectancy (Hobst and Zajic, 1983; Castro, 2000; López, 2007).

An anchored cable net is a pattern-anchored but flexible system used for the stabilization of slopes. It consists of cable nets panels joined by a perimetric cable. The panels support loads developed from detached blocks and transmit this load to the perimetric cables. In the corner of each panel is an anchor that takes the load from perimetric cables and transmits it into the deep and stable portion of the slope. The cable nets increase the resistant parameters of a theoretical sliding plane by applying pressure on the surface, stabilizing the slope, and increasing the safety coefficient (Da Costa and Sagaseta, 2000). The pattern-anchoring extends through the unstable ground and secures the system behind a known or theoretical failure surface, similar to soil nailing systems (Fig. 1).

The woven net is made up of steel cables joined together with anti-slip clamps. To choose the appropriate net, it is necessary to know the

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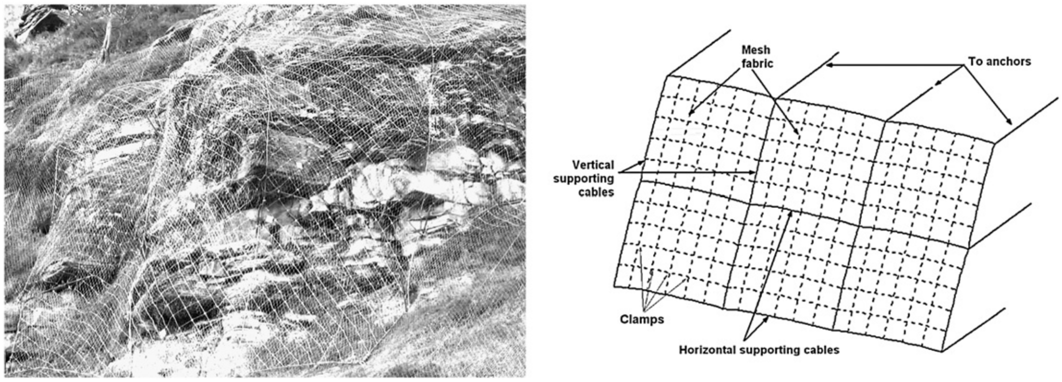

Fig. 1. Schematic and photograph of the cable net.

pressure it will be exposed to during its useful life. This pressure is calculated with the classical methods of global stability, methods of extreme equilibrium, finite element methods, etc. Once this pressure is determined, the cable net is chosen. As an initial hypothesis, it is assumed that in situ a mesh bears, at most, the maximum strength determined by laboratory testing. This is important because the values generally supplied by the manufactures correspond to the yield strength determined from the laboratory testing, so that a safety factor has not been taken into account. The overall safety depends on two factors: the safety factor used in the calculation of the slope pressure and the safety factor used in the calculation of the cable net.

It is important to establish this system. It should be used when it is necessary to apply a stabilization pressure over an unstable slope to avoid a soil or rock movement downhill, unlike the other systems commonly used, where the meshes are not anchored to the slope, just on top, letting the debris fall into ditch. In this case, it is not necessary to apply pressure, only lead the rock because the unstable part of the slope is only superficial.

1.2. Design of the net

In order to use a particular product, a cable net manufactured with a new designed clamp, its tensile and puncture resistance has to be certified and its behaviour known. There are methodologies to calculate the maximum resistance (Hobst and Zajic, 1983; Castro, 2000), but none is efficient and accurate enough since they are sensitive to geometrical changes. In this paper, a new clamp is evaluated to determine its behaviour.

The new cable net was studied and certified by means of five design points:

- Simulation of the net as a system subject to concentrated and uniform loads.
- Tests of the net with specified and uniform loads.
- Tests of the cable clamps.
- Installation of the system and inspection of the construction works.
- In situ instrumentation of the system.

All but the last task were completed during this phase of the research.

2. Laboratory tests

2.1. Tests of the nets

A square steel frame of dimensions 2 m by 2 m was designed to carry out the tests. Cable nets were fastened to its perimeter. Four concentrated load tests and four uniform load tests were carried for the research.

The concentrated load test consists of a perpendicular load applied in the middle of the mesh. The load is applied by means of the distribution plate. Failure of the net occurs when one or more of its elements fail: cables, clamps or the connector's used to join the ends of the cable used to weave the net. This load represents the concentrated stresses that the net experiences once anchored to an irregular slope surface or from the load of a rock of small diameter.

The procedure of the test is to anchor the cable net to the test frame so that the external points stay fixed. The concentrated load is applied through a hydraulic jack that applies the loads to the net by means of a circular plate of 600 mm diameter. Simultaneously, the net strain is measured at the axis of the applied load (Fig. 2 left). The results of the test include the maximum load supported by the sample and its displacement at the centre of the unit mesh.

For the distributed load test (Fig. 2 right), the minimum force is sought that causes the failure of a cable net when a perpendicular load is uniformly applied to the mesh. This test simulates the forces induced by a loosened mass of soil or rock against the secured cable net.

Fig. 2. Laboratory concentrated load test (left) and uniform load test (right).