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SLOPE STABILISATION USING HIGH-TENSILE STAINLESS-STEEL WIRE MESH

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Abstract

Slope stabilisation systems with meshes made of high-tensile steel wire have been in use for 20 years and have proven to be reliable systems on loose rock and soil slopes. The optimization of the nailing pattern thanks to the high load bearing capacity of the system permits a reduction of the overall costs and represents an economical solution as well as an ecological solution. The expected service life with regards to corrosion depends, in addition to the corrosion protection used, on the environmental conditions and the corresponding chemical wear. The definition of aggressive corrosive environments for slope stabilisation projects are for example: coastlines by the sea, aggressive ground (low pH-value, sulphur content) and roads with de-icing (salt). If the micro-climatic conditions on site are known, systems made of stainless steel can be installed to counteract the aggressiveness and keep up a long service life. Stainless steel is a steel alloy, with a minimum of 10.5% chromium and less than 1.2% carbon content. The chromium produces a thin layer of oxide on the surface of the steel known as the ‘passive layer’. This prevents any further corrosion of the surface.
In this contribution the pilot project for stainless steel-based slope stabilisation is presented, which has been installed 14 years ago in an aggressive environment, along the coastline in the UK. It was installed in 2007, with a stainless high-tensile steel wire mesh. Not only does the slope stabilisation mesh have to be made out of stainless steel, the additional components have to present the same protection to avoid the phenomenon of bi-metallic corrosion. Therefore, the nails, spike plates and press claws were as well made of stainless steel. After fourteen years, the slope is still undisturbed and the material in good conditions although exposed constantly to the sea breeze.

Keywords: slope stabilisation, stainless steel, high-tensile steel, natural hazards protection

1 Slope stabilisation using high-tensile steel mesh

1.1 What is a flexible high tensile steel mesh?

The so-called Tecco System is an engineered slope protection and stabilisation system which is used to stabilise steep slopes of unconsolidated soils and/or rocky material. It also prevents stones and blocks in disintegrated, loose or weathered rock faces from breaking out. Together with soil nails or rock bolts the mesh is fastened to the slope and pretensioned. The Tecco System consists of high-tensile steel wire mesh and associated with suitably adapted spike plates, clips for joining the mesh panels with full force transmission as well as boundary wire ropes and wire rope clips. The tensile strength of the mesh lies around 1’770 N/mm^2. This system has been validated by full-scale testing and is in use since 2000 (see Fig. 1).

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The nail grid can be optimized due to the high load bearing of the system. This reduces overall costs and thus represents an economical solution compared to conventional systems such as shotcrete and wire mesh with lower tensile strength. With the dimensioning concept RUVOLUM, the computational evidence can be provided. The level of safety and reliability are therefore significantly higher compared to constructive measures. The sustainability and cost-effectiveness of appropriate security systems can be determined taking into account the expected useful life.

Figure 1 1:1 large field test to verify the RUVOLUM concept (left) and installed slope stabilisation project (right)

1.2 Dimensioning concept

The design is based on the RUVOLUM concept for superficial instabilities. This online design tool is used to optimise the system by finding the most cost-effective combination of nail diameter, nail spacing and the mesh type.
The basis for the design is the support resistance of the individual components, which were determined in realistic, repeatable tests. The design concept RUVOLUM is described in detail by Rüegger [1] [2] and can be viewed and used under www.geobrugg.com. The design concept includes the investigation of near-surface, parallel instabilities as well as the investigation of local instabilities between the individual nails (see Figure 2).

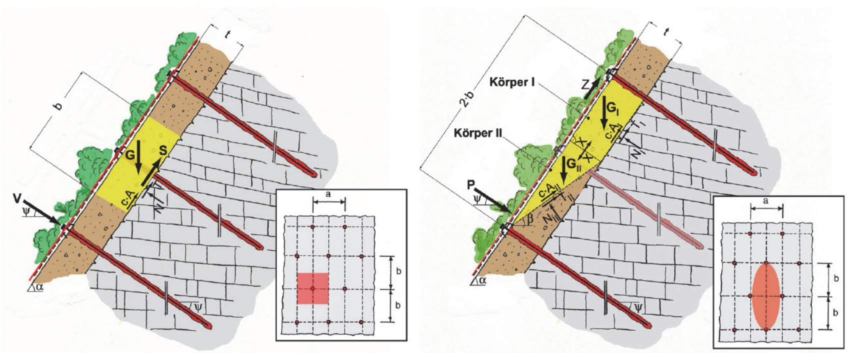

Figure 2 Near-surface, parallel instabilities (left). Local instabilities between the individual nails (right).

1.3 Long term experience of slope stabilisation using high tensile stainless-steel mesh

In this contribution two projects are described which lead to the development of a new material application by means of using high-tensile stainless steel to protect slopes in aggressive environments in terms of environmental corrosion. After material development, the first installation on site began in 2007, since then 14 years have passed and conclusion on its effectiveness can be drawn.

2 Environmental corrosivity and its effect on flexible steel protection measures against natural hazards

2.1 Corrosion protection on flexible slope stabilisation meshes

The design life of galvanized steel mesh products could be improved substantially since the introduction of zinc-aluminium coating in the 1980's. This kind of corrosion protection provides up to 3 – 4 times more durability compared to pure zinc coated wire products. In general, the corrosion protection of the Tecco System must be in accordance with the project-specific requirements. Geobrugg high-tensile wires come in Zinc-Aluminium galvanising as standard providing three times better corrosion protection than zinc galvanised wires. The corrosivity of the environment is described in classes, acc. to ISO 9223:2012-05, ranging from C1 to CX, where simply said C1 is unproblematic to a ZnAl coating, whereas this same coating would disappear in a matter of years in a CX environment.
However, with large quantities of the UK rail network near the coast, corresponding to C4 or C5 environments. Geobrugg undertook a research and development project in the early 2000s, developing stainless steel for the Tecco System, which had to still fulfil the definition of high-tensile steel. This was achieved around 2007.

2.2 Expected Useful Life of ZnAl coating

The expected service life in relation to corrosion depends on the environmental conditions and the corresponding chemical wear in addition to the corrosion protection used. DIN EN ISO 12944-2 [4] divides environmental conditions into 6 coronary conditions for the atmosphere and assigns these removal rates. Corresponding experiences were presented in 2013 at the FSR Continuing Education Seminar, on the basis of the valid standards and specialist literature [5]. The average values in a long-term assessment of ZnAl coating on high-tensile steel stabilisation projects obtained show a strong variation [6] and are plotted as diamonds in Figure 3 and extrapolated on the basis of the specialist literature [7] [8]. The sampling consisted in taken a sample of wire and analyse the remaining coating thickness after a certain amount of years, in the case of figure 3, between 20 and 25 years. This means that even within individual measures, different removal rates can be assumed, depending on the situation. In extreme cases, different categories of corrosivity may occur in an installation. On this basis, an expected useful life of greater than 50 years for a single sample and a larger 70 years for all other samples is estimated for the values determined (see Figure 3).

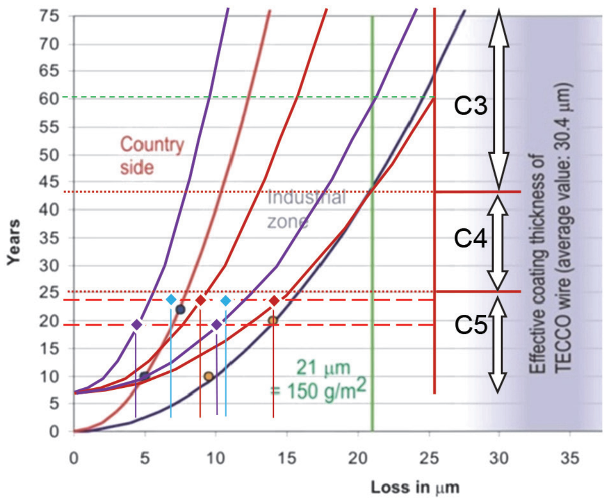

Figure 3 Graphic representation of the expected useful life for Tecco meshes in years (y-axis), based on the literature (circles) [7] and the sampling done in [6], represented by the coloured diamonds. The estimates refer to Nünninghoff, 2003 [7]. The green line represents the minimum thickness of ZnAl on a high-tensile steel wire, whereas the purple zone represents the average thickness of coating on the Tecco wires. On this basis, the removal process was extrapolated. The associated corrosivity categories are shown on the right.

2.3 The development of a high-tensile stainless-steel mesh

The pilot project, which will be highlighted in the next section, set out a "design working life" of 120 years for all new structures, therefore only marine grade stainless steel turned out to be the only suitable meshing solution. Therefore, Tecco G65/3 Stainless is a high tensile steel mesh with a 3mm wire diameter and a tensile strength of 1650 N/mm2, constructed from 1.4462 [3] marine grade stainless steel and has a tensile strength ≥ 140 kN/m. The Tecco Stainless is a fully compliant system with stainless steel spike plates, connection clips, boundary ropes and wire rope clips all made in the stainless-steel quality. Tecco Stainless steel is integrated in the online design tool RUVOLUM separately, due it slightly lower tensile strength and can be designed accordingly.

3 Over 10 years of experience in the field with high tensile stainless-steel mesh – the pilot project and a follow-up project

As previously mentioned, a pilot project between Network Rail and Geobrugg was set out to develop a high-tensile steel mesh in stainless steel quality, that withstands the aggressive environment of the seacoast with highly salty and humid air. Two sites of the pilot project will be discussed briefly. A third project undertaken a few years later is equally discussed to highlight the fact that coastal corrosive areas are as dangerous when being salty and dry instead of humid. Indeed, the salt itself is attacking the galvanized steel, but also humidity in general is a damaging factor, but the dryness has also to be considered, since the salt will then not be washed down regularly from the mesh.

3.1 The Cambrian Rock Cutting Campaign of Network Rail

This campaign is a multi-year pilot project for with a number of eight sites along two railway lines in West Wales, UK. Site investigations and historic rockfalls have indicated the requirement of protection measures. Five of eight sites are close to the sea and exposed to salt spray water, corresponding to a corrosion category at the high end of C3 [4, 9]. To achieve a 120-year design life a high quality of rockfall netting was necessary to withstand the high environmental corrosivity. In total 15,800 m² of Tecco Stainless and 2893 rock bolts were installed over 6 projects and 3 years.

3.1.1 Parton

The site comprises a 35m high slope above the eastern side of the railway line on the Cumbrian Coastline. The line is single tracked and a vehicle track runs parallel to the railway line, situated between the toe of the slope and the rail. The northern half of the site comprises a 35° slope with the cut being formed in rock for approx. the lower 3m. The remainder of the site consists of a sub-vertical rock slope of approx. 4m height with a sub-horizontal bench at its crest below a 35° soil slope of approx. 30m height. Rock fall netting was installed in 2002 to mitigate the risk of falling rock debris from the lower rock slope. Netting was also anchored on the soil slope for approx. 8 to 12 m above the top of rock slope as a temporary containment measure [10]. There was evidence that standard galvanized products do not stand the test of time and the rockfall netting had to be replaced. This was done in 2007 and it has proved to be successful: thanks to the corrosion-resistant system, the embankment right next to the railway line on the coast is still in perfect condition after 14 years in aggressive sea air (see Figure 4). The findings of this project were decisive for the development of Tecco Stainless and its expansion to several more projects worldwide.

Figure 4 Stabilised soil slope above the rails, with high-tensile stainless-steel mesh. The proximity to the see is evident as well as the exposure to constant salt spray.

3.1.2 Aberdovey

The site of Aberdovey belongs as well to the Cumbrian Rock Cutting Campaign, where the slopes around and above the tunnel portal were protected with stainless high tensile steel mesh, since it is equally exposed to the sea (see Figure 5).

Figure 5 The exposure of the rail and the slope at Aberdovey tunnel approach (left) and stainless-steel mesh installation at tunnel portal (right).

The success of this pilot project led to a new consideration of looking at the whole-life costing approach of a geotechnical meshing project. It can be shown that the increased material costs of Tecco Stainless are only a small percentage of the total package costs compared with that of a standard galvanised or plastic-coated mesh product, which needs regular maintenance and timely replacement.

3.2 La Gomera, Canary Islands, Spain

La Gomera is an island of the Canaries, on whose coasts numerous unstable embankments are in frequented locations. This was also the case in the popular hiking region "Pescante de Agulo", where a practically vertical rock face had to be secured in the immediate vicinity of the shore. For the Spanish Coastal Protection Authority, it was clear that only a corrosion-resistant solution is possible.
Among other protection solutions, a surface of 5000m^2 was stabilized with this stainless-steel mesh. In order to ensure that the entire system can withstand permanently the saline and dry air, the connection clips between mesh panels, the spike plates and the wire rope clops were used in stainless steel quality [11].

Figure 6 Installation of stainless steel on a rocky outcrop on La Gomera in 2015

4 Conclusion

Several installations over the last decade in Italy, Gibraltar, United States of America, Costa Rica and more show the usefulness of the stainless high-tensile steel development. An estimate of the expected useful life for slope stabilisation protection systems is difficult and depends on many factors. In most cases, these can have a very large variation and the estimates become correspondingly inaccurate. For many applications a useful life can be assumed of greater than 50 years to greater than 70 years. Depending on the location, chosen corrosion protection and corrosivity category, a shorter service life has to be expected. If this is known, e.g. stainless-steel systems, with a significantly longer service life, should be provided. In comparison, a zinc coating on diagonal meshes, according to Krauter (1996), have rather a useful life of 20 - 25 years [12].

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