Fast, safe, and fully mechanized installation of high-tensile chain-link mesh for underground support

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Synopsis

The ever-increasing depth of mineral extraction presents a challenging environment for hard-rock underground mines. High *in situ* stresses and associated seismicity with potential rockburst hazards are the major decisive factors contributing to the choice of a ground support regime.

Conventional ground support systems, designed primarily for static loads, are not always capable of providing safe working conditions for underground personnel in seismically active mines. Systems specifically developed to resist dynamic loading and allowing for larger deformations are therefore preferred alternatives.

High-tensile chain-link mesh has a proven record of successful use in open cut operations in various rockfall barrier installations due to its high energy absorption capacity. It has also been used in underground operations in various parts of the world. Its application in South African underground mining, however, is limited due to the high labour intensity.

This paper describes a method of mechanized installation of a chain-link mesh as evaluation at Gold Fields' South Deep Gold Mine situated some 45 km south-west of Johannesburg.

A purpose-built mechanized roll mesh handler, developed in Australia, was used in this trial. The handler is compatible with all standard multi-boom underground drill rigs and is operated utilizing the hydraulic circuit normally used for the feed arrangement.

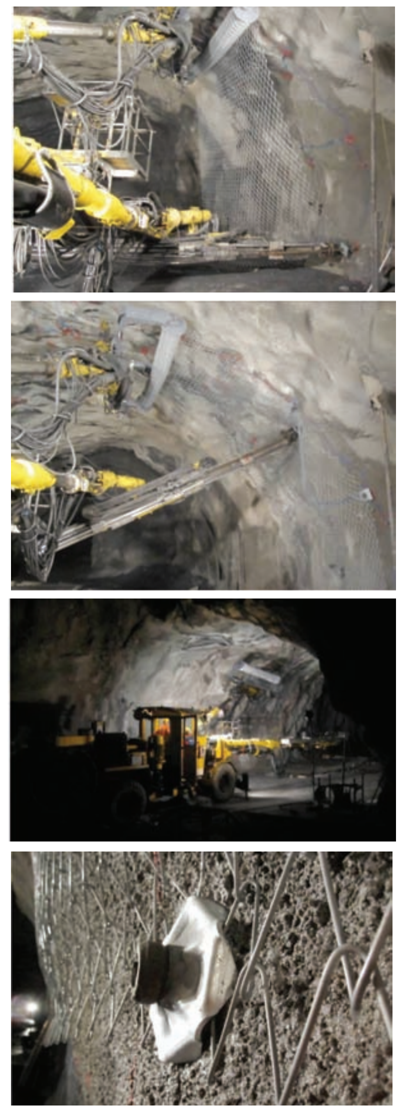
A number of key performance indicators have been specified as success criteria by Gold Fields:

- A 30% faster installation compared to the conventional methodology
- The mesh should sustain any blast damage when applied to the blasting face
- No unravelling of the mesh when cut
- No failure of mesh under normal conditions
- Reliability of the MESHA® installation handler (availability >90%)
- Compatibility of the MESHA® installation handler with AC 282 boomers.

Although the energy-absorbing mesh combined with yielding rockbolts is a ground support system of choice for rockburst-prone conditions, the operational upsides recognized during the trial imply that this product can also be competitively used in less demanding ground conditions where weld mesh or shotcrete are customarily used as a primary surface support.

Keywords

underground support, rockburst, mesh handler, high-tensile chain-link mesh.



Installation of the high-tensile chain-link mesh with handler on a twin-boom jumbo

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This paper was first presented at the, MineSafe Conference, 15–18 August 2011, Emperors Palace, Hotel Casino Convention Resort, Johannesburg.

Introduction

Increasing stresses and associated seismicity with the risk of rockbursts is a serious challenge for deep hard-rock underground mines. Conventional ground support systems are not effective in rockburst conditions and thus have to be replaced by systems specifically designed for dynamic loading and large deformations. One of the ground support products used in rockbursting conditions is high-tensile chain-link mesh.

High-tensile steel wire mesh showed good performance in rockfall and rockburst testing. Due to its strength and flexibility, the mesh was able to absorb the kinetic energy thereby slowing down the impacting rock masses.

The high strength of the mesh is required to transfer the rockburst loads to the anchors and to avoid puncturing of the mesh by the rock fragments. Although its ability to withstand large rock mass deformations has been proven, its use in mines is limited due to the high labour intensity.

To use chain-link mesh as a standard product for ground support in mechanized mines, a safe and automated installation method had to be developed. The aim is to provide mine operators with an efficient and effective way to install rolled high-tensile chain-link mesh. Furthermore, it was considered desirable that the mesh handler should be capable of being retrofitted on all commonly used underground drilling equipment, thus obviating the purchase of new machines.

To test the practical aspects of such installation, a trial was organized at the Gold Fields South Deep, twin shaft. A purpose-built mechanized roll mesh handler developed in Australia was used in this trial.

High-tensile chain-link mesh for ground support

High-tensile wire mesh offers a surface support for most ground conditions. The mesh is made of high-tensile steel wire with a diameter of 4 or 3 mm and a tensile strength of 1 770 N/mm^2. The mesh is diamond shaped, and along the edges the wires are bent over and double twisted such that this connection is as strong as the mesh, which is also proofed by independent test institutes. Both meshes are produced in rolls which reduce the storage space and can be manufactured in widths of up to 3.5 m and in tailor-made lengths corresponding to the tunnel surface.

Due to the use of high-tensile wire, the mesh is very light in relation with its strength (TECCO®: G80/4 2.6 kg/m^2, DELTAX®: G80/3 1.45 kg/m^2). For corrosion protection, the wires are coated with a special aluminum-zinc coating which has a higher corrosion resistance than standard galvanizing. Comparison tests with conventional galvanized wires yield at least a three to four times longer lifespan.

The MESHA® installation handler offers a fast and safe method of application of both the TECCO® and DELTAX® meshes and can be retrofitted to any multi-boom underground jumbo.

The mesh geometry was designed to have a very high breaking load as well as low deformation characteristics to avoid unacceptable deformation rates and unravelling of the rock after a rockburst impact. The resistance properties of the mesh were determined in a series of laboratory tests by Torres[1] at the University of Cantabria in Santander, Spain. The properties of the meshes G80/4 and G80/3 are summarized in Table I.

A specially designed spike plate has been developed by GEOBRUGG to transfer loads from the mesh through the spike plate to the anchoring system (Figure 2). The plates are made out of 5 mm thick galvanized steel and with a shape which best fits to the mesh. The spike plate grabs the mesh in six positions plus the rock bolt in the centre. Due to its three-dimensional shape it is very stiff and does not bend.

Testing and modelling of high-tensile chain-link mesh

In order to determine the mechanical properties of the mesh, TECCO® was extensively tested for static and dynamic loading conditions, and DELTAX® was tested for static loading, at the Western Australian School of Mines (WASM).

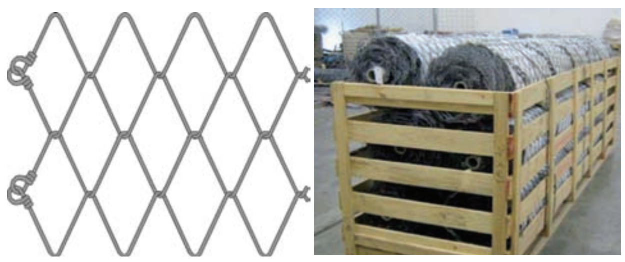


Figure 1—Geometry of the high-tensile steel wire mesh and the delivery of the mesh in rolls

Table I

Properties of the high-tensile mesh G80/4 and G80/3

Material	Tecco G80/4	Deltax G80/3
Mesh width	80 mm	80 mm
Diagonal	102 x 177 mm	103 x 180 mm
Wire diameter	4 mm	3 mm
Wire strength	1770 MPa	1770 MPa
Breaking load of single wire	22 kN	12.5 kN
Tensile strength	190 kN/m	110 kN/m
Weight	2.6 kg/m^2	1.45 kg/m^2

Figure 2—Specially designed spike plates for the underground system

For the dimensioning of the support system consisting of mesh and bolts, a finite element numerical model was developed, calibrated, and verified by the Swiss Federal Research Institute (WSL).

Static testing

The static response of high-tensile chain-link mesh was determined by test work in the WASM laboratory in Kalgoorlie. Figure 3 shows the response of three samples of the high-tensile TECCO® G80/4 mesh where a 1.3 x 1.3 m panel was loaded with a 300 x 300 mm steel plate. The test setup is described by Morton *et al.*[2] The high-tensile mesh was able to bear a load of up to 100 to 110 kN before it failed at the edge of the loading plate.

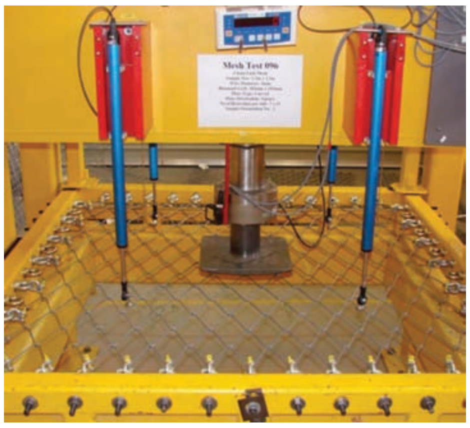
Weld mesh, in comparison, failed at approximately 40 kN, and mild steel chain-link failed at less than 20 kN using the same test setup. For the heavy mild steel chain-link mesh (5 mm diameter, mesh width 100 mm, tensile strength 460 N/mm²), failure occurred at 30 to 40 kN due to bending over of wires at the mesh ends (according to the test report by Villaes-cusa[3]). After closing the ends with wire rope clips (see Figure 4), rupture occurred at 60 to 70 kN. All mesh types require some initial displacement to be activated and loaded.

The high-tensile mesh G80/3 was able to bear a load of up to 50 kN before it failed at the edge of the loading plate (Figure 5).

It was also found that the high-tensile chain-link mesh can sustain an increase in load even after a wire has failed. It also does not unravel once a wire has failed.

In earlier tests, the high-tensile mesh was tested in a way similar to an application underground with four bolts and plates. It was established in that test that rupture generally starts at the crossing points, but does not shear at the edge of the plates due to the higher steel quality of the mesh compared to the mild steel plates. Based on experiece with mild steel chain-link mesh, there was always the concern that if one of the chain-link mesh strands is broken, the mesh will unravel and open. It has been proven that this is not the case for high-tensile chain link mesh in the above-mentioned test, where the mesh was loaded with one of the wires cut.

The test results, capacity, and deformation of the high-tensile chain-link mesh have been shown to be unaffected by the broken wire (Roth *et al.*[4]), and is shown in Figure 6. This applies only for high-tensile chain-link mesh. It does not apply for mild steel chain-link mesh, as the individual wire does not have the required strength to lock itself in.



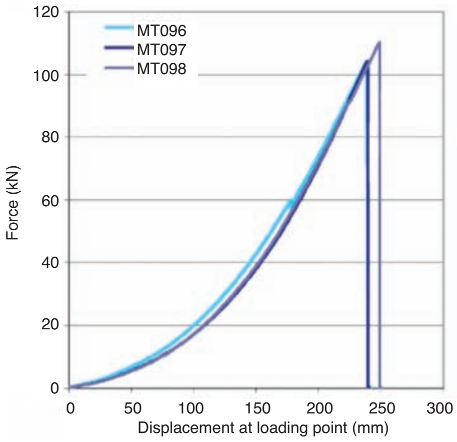
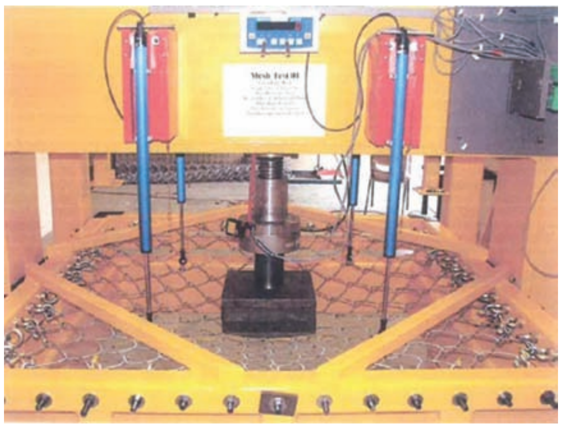


Figure 3—Measured forces in the anchorages for the high-tensile steel wire mesh G80/4



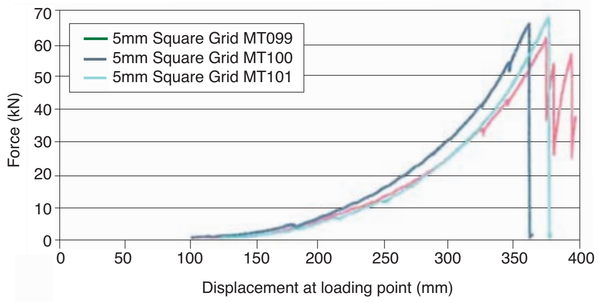


Figure 4—Measured forces in the anchorages for the 5 mm wire diameter heavy mild steel chain-link mesh

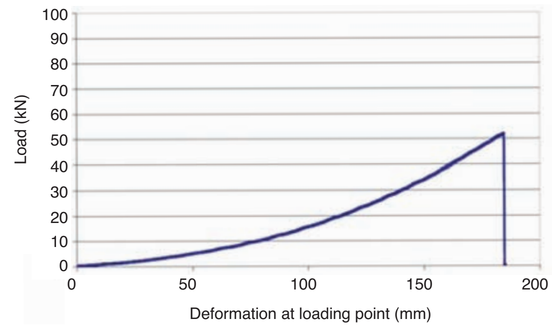


Figure 5—Measured forces in the anchorages for the high-tensile steel wire mesh G80/3

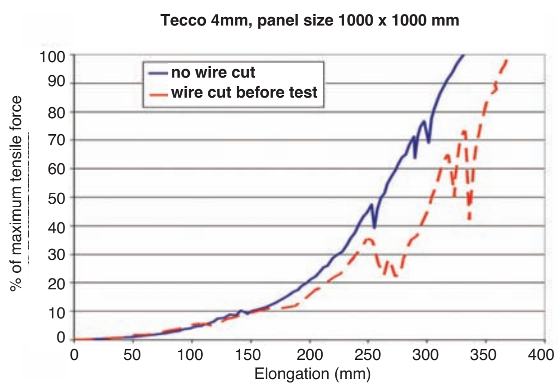


Figure 6—Static tests of a high-tensile steel wire mesh which show no unravelling test

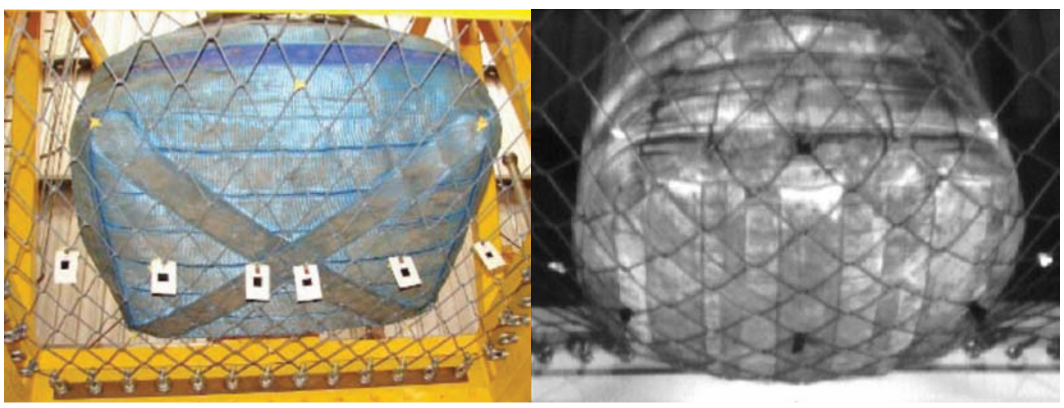


Figure 7—View from underneath of the test arrangement before the impact of a 1000 kg mass (left) and photo from the high-speed video camera after impact (right)

Dynamic testing

The G80/4 mesh was tested at the dynamic testing facility of WASM (Player *et al.*[5]) by using a momentum transfer method (see Player *et al.*[6]; Thompson *et al.*[7]). The mesh panel is installed in a loading frame and a steel weight can be dropped onto the mesh from different heights. The rebound of the loading frame is stopped by buffers while the loading mass impacts the mesh sample without separation.

This test arrangement simulates the situation with installed mesh in tunnels. The dynamic test apparatus is instrumented with high-speed video cameras, load cells, and accelerometers.

Figure 7 shows images from a camera and a high-speed video camera before and after a mass of 1 000 kg (bag with mill steel balls) hits the high-tensile chain-link mesh. The mesh deforms with the applied load and transfers the forces to the boundary. The boundary conditions are fixed to have comparable and repeatable results.

It was established that the high-tensile chain-link mesh G80/4 is able to absorb energies of up to 12 kJ in such a configuration. This is equal to stopping a rock mass of 1 000 kg that was accelerated to 4.9 m/s. This value represents the energy absorption of the mesh only, and does not include any absorption by the rock mass or the yielding bolts.

Welded wire mesh (wire diameter 5.6 mm and 100 mm wire spacing) showed energy absorption capacities up to 2 kJ in the same test setup.

Numerical model

For the numerical model, we sought an algorithm that was capable of handling large deformations and dynamic impacts. A code was chosen that is based on a discrete finite element method (FEM) and a model of rope and truss elements. In order to simulate dynamic impacts, Newton's second law is applied together with the material properties of the single components ('time-stepping'). The software FARO ('falling rock') was developed by the Swiss Federal Institute of Technology ETH and the Swiss Federal Research Institute WSL (Volkwein *et al.*[8]).

Figure 8a shows the static mesh tests executed by Roth *et al.*[4] with the mesh and a bolt pattern of 1 x 1 m where the mesh was loaded with a steel frame. These tests were used to calibrate the numerical model. It became possible to perform dynamic simulations and assess forces, failure modes and deformations of the different components with the calibrated FEM model.

With the numerical model of a ground support system with high-tensile steel wire mesh, it is possible to simulate the dynamic response of any setup and loading. More precise information about FARO load modelling and different kind of possibilities for boundary modeling can be found in Volkwein.[9] Input parameters can be adjusted to specific project parameters and the bolt pattern and maximum deflections can be determined.

This makes designed ground support schemes for dynamic loading theoretically possible. It is very important to have a support system where the support components have matching capacities. The calibrated numerical model makes it possible to connect different bolt types with the high-tensile steel wire mesh and determine if they work together under given conditions. Since there is always a load concentration on the bolt plates, higher loads could be achieved by using special plates able to grab more wires, like the spike plate shown in Figure 2.

Installation of high-tensile chain-link mesh underground

The difference between the installation of welded mesh and the installation of chain-linked mesh is due to the stiffness of the products. The welded wire mesh is relatively stiff and is delivered and applied in sheets. The roll of chain-link mesh is stiff only in one direction but flexible in the other, and therefore has to be installed in a different way to welded wire mesh.

Therefore a new method was conceived, comprising a mesh handler to unroll the mesh and hold it onto the surface of the tunnel while it is pinned to the rock with the second jumbo boom. The main objectives were the speed and safety of the installation in order to comply with the targets of modern mining both in terms of safety and economics.

Fully mechanized installation of chain-link mesh with the MESHA® installation handler

An automated roll mesh handler for the application of high-tensile chain-link mesh was developed and successfully tested in Australia and Switzerland for the installation of support in underground workings. The handler, called MESHA® installation handler, is compatible with all standard multi-boom jumbo drilling equipment, and applies mesh from a cassette system. The handler with the mesh roll is on the one boom and the drill/bolter mounted on the other boom of the jumbo (Figure 9). The application of the high-tensile mesh and installation of split-sets or bolts occur simultaneously.

The handler is manipulated from the cabin of the drill to pick up a roll of TECCO® or DELTAX® mesh, minimizing manual handling. The mesh can then be positioned on the walls and backs for bolting, using the drilling component of the opposite boom.

The system reduces manual handling and personnel exposure during the installation process, reduces support cycle times, enables the mesh to follow the rock surface contours more closely—reducing unravelling/bagging of material in voids. No personnel are exposed to unsupported ground, due to the ability of the jumbo to pick up the mesh roll cassette with the manipulator arm.

In situ installation trial at Gold Fields South Deep, general experience

From the results obtained, the following comparison between conventional wire mesh installation and wire meshing using the MESHA® installation handler as well as DELTAX® wire mesh developed by GEOBRUGG could be formulated (Table II)

It was assumed that the MESHA® installation handler did not influence the drilling time. It is assumed that in future

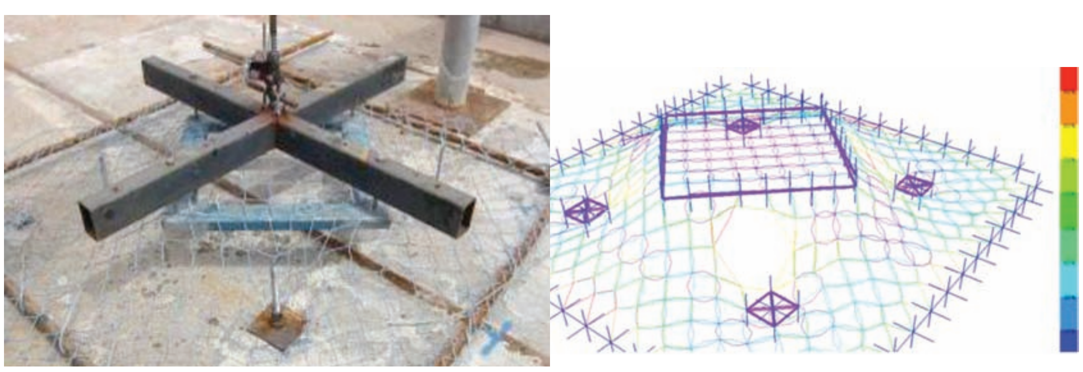


Figure 8—Static mesh tests (left) and the calibration of the numerical model (right)

Figure 9—A 2,3 m wide handler mounted on a twin boom jumbo (left) and a MESHA® installation handler mounted on a jumbo boom picks up the roll of mesh auto-matically (right)

Table II

Conventional meshing vs. MESHA® installation handler (Tonkin[10])

	Conventional (after 10 shifts)	MESHA® installation handler (estimated af-ter 1 trial)	MESHA® installation handler (assuming 30% time reduction)
Effective support considered	12.6 m^2	24 m^2	24 m^2
Expected number of drilled holes	17	35	35
Drilling	02:21 min	02:33 min	02:33 min
Preparation	00:58 min	00:48 min	00:48 min
Attachment	03:29 min	01:30 min	01:25 min
Total	06:48 min/m^2	04:51 min/m^2	04:46 min/m^2
Hangingwall support	1:25:47 h per shift	1:56:24 h per shift	1:54:24 h per shift
Sidewall support	70 min per shift	Included	Included
Total	2:35:47 h per shift	1:56:24 h per shift	1:54:24 h per shift
Time saved per shift	-	39:23 min/m^2	41:23 min/m^2

the same drilling pattern as the one used in conventional sheet meshing will be used. To ensure that the same support standards were used for sheet wire meshing and the MESHA® installation handler, it was included that 10 split sets be installed on either side of the sidewall, using the same method as for those installed in the hangingwall. The accuracy of the information may be limited by the following factors:

- The attachment times are estimates
- This was the operator's first time using the MESHA® installation handler
- Different drill rigs were used during the conventional and MESHA® installation handler
- Hangingwall conditions between relevant workplaces (South shaft, 87, 1 west and Twin shaft, 94, 3 west) differ.

During the trial the operator stated that the MESHA® installation handler seemed to be more effective than conventional meshing and there was no damage noted to the Deltax® G80/3 mesh after blast.

A number of issues have been raised, as listed in Table III together with proposed solutions and actions taken as a result of the trial.

Conclusions

After successfully testing the high-tensile chain-link mesh under both static and dynamic conditions, it was shown that this kind of mesh is suitable for ground support in potential rockburst areas and also in high-deformation ground conditions. In contrast to shotcrete or fibrecrete, the rock remains visible for inspection by geotechnical personnel. With the use of the MESHA® installation handler, this new type of mesh can be installed easily and more quickly than welded sheets of mesh.

It is evident that wire meshing contributes largely to the number of hours spent at the face and therefore, also the need for crews to spent time underground. This is unnecessary, as it is evident that a large amount of time can be saved, according to the key performance indicators pertaining to the MESHA® installation handler and the trial data obtained from the MESHA® installation handler. It can be concluded that both the high-tensile chain-link mesh and its fully mechanized installation can significantly increase the safety of mining personnel, the quality of the installed ground support, and the speed of mining development.

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Table III

MESHA® installation handler, issues and actions

Issue	Cause & proposed action	Action taken
Spindle with mesh was pushed out of the gripper.	Too much pressure from unrolling wheels. Locking the grippers with pins will prevent this.	Pins will be supplied together with MESHA® installation handler.
	The black protection wrap around the gripper is not resistant enough for underground conditions. Closing the gripper with a solid plate will improve this.	Some R&D work is done to design and mount such plates.
It was difficult to slide in the spindle through the delivered rolls of mesh.	The cardboard spindles on which the mesh is supplied were not resistant enough for outside storage (especially impact of water).	In future mesh will be supplied on plastic spindles.
Some operators had difficulty installing claiming the mesh was to flexible.	Mesh stretching is in fact a good property as the mesh can be installed close to the rock profile. It is important to keep the mesh under tension by using the mesh to achieve the best results. With practice and training this problem can be overcome.	
Whilst no operating problem was faced it was mentioned that the total weight of the MESHA® installation handler and mesh could negatively impact on the good operation of the boom (rollover weight).		Geobrugg AG and Rock Australia will do some R&D work and analyse how to further reduce the weight of the MESHA® installation handler.

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