Open pit mine rockfall protection

Highly flexible catch fences and high performance drape mesh systems for rockfall protection in open pit operations
ABSTRACT

Rockfall hazards in open pit applications mainly occur in steep open pit walls due to aggressive pit design, in flat walls without berms while following shallow dipping ore bodies or locally on batter level. Areas with high damage potential such as decline portals or haulage ramps are especially hazardous. Dangers from falling rocks have to be reduced as much as possible. The protection systems to cope with such hazards from the manufacturer Geobrugg which are described in this paper are highly flexible and consist of high-tensile steel components. They are field tested and are thus rated with a certain energy absorption capacity. In order to get impact velocities and energies, a rockfall simulation is run, utilising actual slope characteristics. This study deals with three case studies of rockfall protection systems recently implemented in Western Australia. The first study describes a portal protection fence, the second one a ramp protection fence and the third one a high-performance drape system with impact section.

INTRODUCTION

From a global point of view rockfalls in open pit mines mainly occur in steep open pit walls due to aggressive pit design or in bermless flat walls while following shallow dipping ore bodies. Locally, rockfalls can take place on a batter level, with rocks falling out of the crest or the batter itself and reaching the next berm. In areas with a high danger potential such as portals, ramps, escape ways or exhausts, adequate measures have to be taken to reduce this risk to the work force and infrastructure. To cope with such hazard, different strategies and solutions can be implemented such as increasing berm width, building windrows, installing drape mesh or rockfall barriers.

Rockfall barriers have the advantage that if a stable foundation can be achieved, it is possible to effectively protect the area below the fence without the need to access onto the berm and without enlarging berms. This is mainly an interesting solution due to the fact that the overall angle is not affected or can be developed even steeper.
In order to be able to absorb energies in the range of 100 to several thousand kJ, it is necessary to install flexible systems which gradually slow the rocks. Systems made of steel beams, sleepers or wire ropes are too stiff and thus induce large forces on the barrier during the impact. Due to the non-linear behaviour of flexible rockfall barriers it is still not possible to design them on paper only; they still have to be tested “one on one”.

The Swiss company Geobrugg is a leading supplier of rockfall protection systems. Geobrugg gained experience in this field over decades and has implemented hundreds of projects worldwide. The systems are all field tested to determine the energy absorption capacity. The projects described here were installed by Rock Engineering, a ground support specialist company based in Perth.

**HIGH-TENSILE WIRE MESH**

The main element of the protection systems presented in this paper is the high-tensile chain-link mesh called TECCO. The mesh was developed by Geobrugg not only for static applications such as slope stabilization but for dynamic applications such as rockfall protection catch fences or for use as drape mesh as well. Both the static and dynamic performance of the mesh is proven by independent testing and applications.

The mesh is made of high-tensile steel wire with a diameter of 4 mm and a tensile strength of 1770 MPa. Furthermore, this high-tensile wire has an excellent shear resistance. The mesh is diamond shaped and the wires at the selvedge are bent over and double twisted in such a way that this connection is as strong as the mesh itself. The mesh is produced in rolls and can be manufactured in widths up to 4 m and in tailor-made lengths.

*Figure 1: Geometry of the TECCO mesh*
The static strength of the mesh was determined in several laboratory testing programs by Torres (2002) at the University of Cantabria in Santander, Spain. The characteristics of the mesh are summarized in the table below:

Table 1: Properties of the TECCO mesh G80/4 mm.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearance diameter</td>
<td>80 mm</td>
</tr>
<tr>
<td>Wire diameter</td>
<td>4 mm</td>
</tr>
<tr>
<td>Wire strength</td>
<td>1770 MPa</td>
</tr>
<tr>
<td>Breaking load of a single wire</td>
<td>22 kN</td>
</tr>
<tr>
<td>Tensile strength longitudinal</td>
<td>200 kN/m</td>
</tr>
<tr>
<td>Tensile strength transversal</td>
<td>80 kN/m</td>
</tr>
<tr>
<td>Weight</td>
<td>2.6 kg/m²</td>
</tr>
</tbody>
</table>

The tests of Torres (2002) further showed that there is no unravelling of the mesh once a wire failed. The tests were executed with a wire cut before testing the longitudinal strength. The test panel reached the same breaking loads with or without a cut wire.

**DYNAMIC TESTING OF THE MESH**

Several dynamic testing programs were carried out with the TECCO mesh on the test site of the Swiss Federal Institute of Forest, Snow and Landscape (WSL) in Walenstadt, Switzerland. The tests were executed by Geobrugg under supervision of WSL.
The testing facility consists of a steel frame construction with a crane installed above, with a remotely controlled release hook. In the test frame mesh panels of up to 4 m x 4 m can be put in place at a height of 5 m above ground. The tests are executed by using concrete boulders of different sizes released from a predetermined height (up to 65 m). Load cells are put in place under the frame and in the support ropes and two high-speed digital video cameras (250 frames/sec) record the impact sequence.

Sennhauser (2002) executed several 50 kJ tests in late 2002 with a 2 m x 4 m panel of TECCO mesh. The impact energy was achieved by releasing smaller blocks from greater heights and also larger blocks from lower heights. The mesh stopped all the blocks and consequently showed the performance to easily absorb 50 kJ. The braking distance was in the order 1.5 m.

The mesh did not show any damage. It was slightly deformed but there were no broken wires (see figure 4). Trials with multiple impacts in the same location of the mesh proved that the mesh is able to absorb at least two impacts of 50 kJ. Due to the very short braking distance, the forces in the support infrastructure get naturally quite high. But since these forces are known, it is possible to dimension ropes, posts and anchorage.
In addition to rockfall testing, Geobrugg also carried out field tests with high performance drape mesh. In these trials TECCO mesh was used with wire diameters of 3 mm and 4 mm. In order to simulate the impact of a block into the mesh while sliding down behind the curtain, the mesh curtain was installed with an angle of 30° between the mesh and rock face and then the blocks were released into it (mirrored situation). Figure 5 shows such a test with 1730 kg free falling from 5 m into the drape mesh.

By using this setup it was possible to determine the capacity of the mesh and this makes it possible to dimension a drape mesh system. The results are summarized in figure 6.

Compared to other mesh products, the TECCO mesh has the advantage that its properties and performance are very well established (statically and dynamically).

**ROCKFALL SIMULATION**

In order to determine energy requirements in a specific case, special software is needed. The potential block sizes can be estimated by site visits but the impact velocities and kinetic energies have to be simulated. In the simulation described here the software is called ROCKFALL and was developed by Spang (1995) in Germany.

Firstly, the cross section of the simulation has to be defined and split in slices with different properties such as dynamic and static friction, damping factors, rolling resistance and surface roughness. All these values are defined probabilistically with standard deviations. The blocks can be chosen as spheres or, more realistically, as cylinders.

The simulations calculate the trajectories of the blocks by using the laws of kinematics and linear and triangular momentum. The movement of the rocks can be bouncing, rolling, sliding or toppling. The iterations are repeated until the block strikes a protection structure or comes to a complete stop. Figure 7 shows the cross section and the calculated trajectories of case study 1.
Since the characteristics of the ground conditions follow certain distributions, there is for every block a different trajectory and there is a distribution for impact energies and bouncing heights as well. The software is able to plot these distributions and by considering them, it is possible to choose a rockfall barrier with a certain capacity within a chosen level of confidence. Figure 8 shows the energies and bouncing heights according to the trajectories of figure 7.

By field testing the rockfall barriers, the energy absorption capacities can be determined, and by executing rockfall simulations of a specific site, its demand of energy absorption capacity can be evaluated.
CASE STUDY 1: PORTAL PROTECTION

Portals are key elements for underground operations and thus the risk that a portal could be blocked has to be kept as low as possible. For that reason most portals are highly reinforced and supported with bolts, mesh and shotcrete. If there are no stability problems in the wall but the danger of rocks falling out of the face or crest above, a rockfall catch fence above the portal can be an effective and cost-efficient alternative to meshing or shotcreting the wall.

A first application of this kind was realised at the 10140 portal in the Kanowna Belle Gold Mine near Kalgoorlie in Western Australia. Since this portal is not the main portal to the operation and is used at the moment just to access a fan and pumps, it was an ideal location for a first test installation. The requirements for the catch fence were to stop falling rocks, to be installed easily and quickly and to be maintenance free.

The maximal block size was identified to be about 30 to 50 kg falling out about 40 m above the portal. The according rockfall simulation (see figure 7) showed that a maximum velocity of 20 m/s has to be expected which results in a maximal kinetic energy of 10 to 15 kJ. A system height of 3 m was regarded as being sufficient.

To meet the requirement of a maintenance free fence, a chevron type design was chosen. The basic idea is that the falling rocks hit the catch fence and are rejected to one or the other side of the portal.

The fence consists of 5 posts made of thick steel tubes which were grouted into the rock by using large but short airleg holes (65 mm diameter). In order to reduce bending moments in the posts, the post heads are anchored back to the face by retaining ropes. These ropes are connected to eyebolts which were grouted into the rock. To hold the mesh in place and carry the loads to the posts, wire ropes were attached to the posts as can be seen in figure 10. Finally the TECCO mesh is assembled to the support ropes by using shackles.
The installation of the fence took place in June 2003 and took five days for a two men crew. Firstly the holes were drilled and the posts and eyebolts grouted in. Afterwards the retaining ropes were attached to the eyebolts by using wire rope clamps and then the support ropes were added to the posts. The mesh was prepared in such a manner that it was possible to put it on the centre post and be released on both sides. After the fixation of the mesh by shackles, the retaining ropes were attached to the post heads and then tensioned.

This type of portal protection proved to be an effective and cost-efficient protection system and can be a real alternative to extensive meshing or shotcreting. This makes it not only feasible for permanent portals but especially for temporary ones. Besides portals, further applications can be the protection of escape ways, exhausts or adits.

The energy absorption capacity of this design is in the range of 20 kJ. For higher energies the high-tensile mesh has to be combined with stronger infrastructure and then energies up to 50 to 100 kJ are achievable. For even higher energies systems with ring nets are available with absorption capacities of up to 5'000 kJ.
CASE STUDY 2: CATCH FENCE

As mentioned above, engineered catch fences are a feasible and designable measure to protect people and infrastructure from the hazard of falling rocks. This case study deals with a catch fence which was installed along a ramp in the Fimiston Superpit of Kalgoorlie Consolidated Gold Mines in Kalgoorlie, Western Australia.

The area to be addressed here is an old, filled stope of about 20m in width, which was exposed. Rocks at the crest above it threatened to fall out and hit the haul ramp, endangering heavy transport and light vehicles alike. In order to deal with this hazard, a 24m long and 4m high catch fence was considered. The energy absorption capacity was determined to be in the order of about 50 kJ.

The implemented system consists of 5 universal columns with a post spacing of 6 m. These posts are 3 m long and are connected to heavy duty steel tubes which were introduced in 165 mm diameter holes. The tube to column join sat one meter above finished ground level.

In this bottom part of the fence a 1 m high windrow was considered to get
the 4 m system height together with the 3 m high mesh. In order to be able to anchor the cables in solid rock, all the anchors are placed on both sides of the filled stope and not into it.

The posts are anchored back to the slope by using wire ropes and twin-strand cable anchors with a loop at the surface. These anchors have the advantage of a flexible head and are thus insensitive to shear. The mesh is held in place by a top and a bottom support rope as well as vertical ropes along the posts.

The installation of this catch fence was done in December 2003 and took 3 days for a two man crew. After drilling the holes, the tubes and cable anchors were put into place and grouted in. Universal columns were then bolted to the tubes and tie back and support and ropes attached and tensioned back. Mesh was then fixed to support ropes by weaving the top and bottom ropes into the chain link of the mesh. Mesh was then connected to the vertical ropes with rope clamps. The windrow was filled in just prior to the area being reopened to passing traffic.

This example shows that it is easily possible to install a quite strong catch fence without need of access to a batter. The catch fence will protect the ramp in this area from potential falling rocks.
CASE STUDY 3: HIGH-PERFORMANCE DRAPE MESH SYSTEM

Chain Draping of chain-link mesh over crests and batters of open pit walls is a common practice to hold small rocks back and if they fall out to slow and guide them down to the berm. Under some circumstances standard mild steel chain-link mesh is not strong enough to fulfil these objectives and high-tensile mesh such as TECCO has to be considered.

One of these cases occurred at the Mt Keith Nickel operation North of Leinster in Western Australia. A large berm was developed to protect the ramp underneath it from falling rocks coming from the pit wall above. Concern arose however, as there was one location where a large part of this berm was lost and falling rocks had to be expected to pass it and reach the ramp. Since the ramp is the lifeline of the operation, adequate measures had to be taken.

Figure 15: Location where the berm was lost

In order to cope with this hazard a high performance drape mesh system was designed to stop rolling rocks in the area of the lost berm and to guide these rocks safely down to a catchment area beside the ramp. The system was dimensioned for about 200 kJ and an impact velocity of 10 m/s which equates to maximal block sizes of about 1.5 m³ or 4'000 kg. The mesh rolls are 3 m wide and 30 m long.

Since the drape mesh has to function as a catch fence at its top end, a construction with steel posts and support ropes had to be considered. The 5m high universal columns were connected to steel tubes which were grouted into 165 mm diameter holes. The length of the grouted-in tubes was 5 m as well due to the ground conditions. The support rope is held at the post heads and is anchored at both sides to the rock by using twin-strand cables with a loop at the surface. The TECCO mesh rolls are attached to the support rope and connected to each other by using flexible wire rope.
The installation of the drape system was completed in late 2003 and took 5 days with a 3 man crew. Firstly the holes were drilled and then the posts and cable anchors inserted and grouted in. Afterwards the support rope was introduced and attached to the loop anchors with wire rope clamps. Finally the mesh rolls were attached to the rope and released in three stages as lifts were made, developing the batter.

It is important that the mesh does not reach the ground and stops 1 to 2 m above it to avoid accumulating of material at the bottom of the mesh.

This kind of application is a possible solution for situations were standard draping is not strong enough or where mesh is needed with a tested and determined capacity. Examples of such situations are old, badly filled stopes or bad rock conditions with rocks regularly falling out of the batter.
CONCLUSIONS

The described case studies prove that flexible rockfall protection barriers and high performance drape mesh systems have to be considered as an option to cope with rockfall hazards in open pit operations.

Rockfall barriers can not only be used to protect local areas from the danger of falling rocks but also as part of pit design optimization. For the first type of application mainly availability and quick installation is important. For the second application such as reducing berm width, double benching or bermless designs, the costs of the system and the saved mining costs (strip ratio) and potential to reach additional ore have to be compared economically.

The current technology allows the design of catch fences with high-tensile mesh for rockfall energies from 20 to 100 kJ and rockfall barriers with ring nets for energies from 250 to 5'000 kJ. These systems are engineered and one to one tested.

Consequently, it is possible to dimension sound rockfall protection systems by using rockfall simulation software and considering field tested systems and as described in this paper.

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