The Limited Scope of Some Static Support Systems in the Mitigation of Rockburst Events

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ABSTRACT

The mine's economic life is dynamic by nature. Some factors that create this scenario are the need to recognize new exploitation areas, the evolution of the mineral prices and the development of new technologies to access them. The dynamics of mining development, especially in the underground environment, changes significantly as the stages unfold. In many cases the final solution differs greatly with the initial. The frequent presence of new conditions and factors often cause the mine to develop in a quasi-permanent transition stage, which could be characterized by the generation of dynamic micro-seismic events that could cause rockburst damage in some specific areas. Although they may be infrequent, these dynamic events can have an important adverse impact on mine safety and causes serious losses. Also, changes in the production schedule during exploitation could be a big issue if the problem is not effectively addressed.
When the transition of the mine to an active micro-seismic environment begins as an unforeseen scenario, it is frequent to use static ground support systems as they are readily available. Traditionally, the support systems used are reinforced shotcrete with a middle layer of Welded Standard Wire Mesh (WSWM) and Chain Link Standard Wire Mesh (CSWM) of reduced gauges, i.e. wires less or equal than 4 mm in diameter. Although, this support system is used to control static instability problems, there is no good reference of its energy absorption capacity under dynamic load conditions, creating uncertainty in the effectiveness of controlling rockburst events. These support systems are analyzed at the present paper, testing the reinforced shotcrete layer with 4 mm diameter of WSWM and CSWN under dynamic load. Additionally, the influence of the use of high tensile strength steel wire in the meshes (HSWM) compared to the previous ones, is analyzed to assess the scope in controlling rockburst events and keeping the safety of underground environment.

INTRODUCTION

As part of the natural cycle of a mining operation, exploration campaigns are carried out with the aim of incorporating more resources and reserves to increase the economic life of the mine. This implies an expansion of the mine's infrastructure towards the lateral limits and also in depth. In this process, unforeseen conditions may be found, which are often addressed during their execution. These new conditions may go through initial microseismic activity processes and the onset of rockburst instability problems (Figure 1a). The lack of strategies to control the unforeseen microseismic activity and the need to continue with the exploitation and development programs, forces field engineers to employ rock support systems that are developed for the control of static stability problems. this solution is an attempt to control the unexpected dynamic problem that can sometimes work properly, but the lack of knowledge of the energy capacity of the reinforcement system constitutes an important risk and makes almost impossible to determine the vulnerability of the excavation.

In order to design an effective support system which stands against rockburst problems in a dynamic environment, it is necessary to determine the source that originates micro seismic activity, the failure mechanism, the damage mechanism and the energy involved in the failure. This information is compared to the energy capacity of the rock support to asset the factor of safety or the vulnerability of the supported excavation.

The objective of this study is to determine the energy and dynamic load capacity of the support systems commonly used in mines with static instability problems. This reinforcement system consists of a 10 mm thick layer of shotcrete reinforced with different kinds of metallic meshes embedded in the middle of the shotcrete layer. Figure 1 clearly shows the application of this type of rock support as a restitution of the support damaged by an isolated rockburst event in a tunnel of the El Porvenir Mine in Peru.

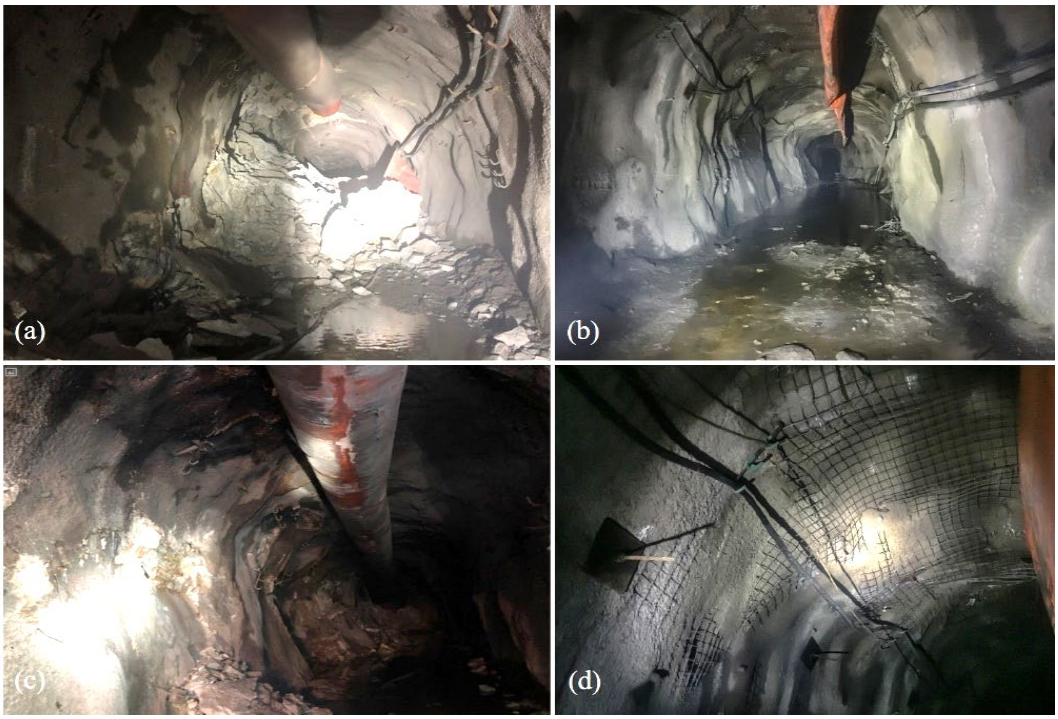

Figure 1. Example of an isolated rockburst event and the restitution of the damaged support system by a reinforced shotcrete with embedded metallic mesh. El Porvenir Mine

The Shotcrete and the Rock Support System

Several theories were developed to understand the behavior of the shotcrete as a reinforcement system. Norcroft (2006) considers a membrane and beam behavior for the stabilization of the rocky mass on the surface of the excavation that can explain the six failure mechanisms suggested by Barrett & McCreath (1995) based on adhesion loss, flexural failure, direct shear, punching shear, compressive failure and direct tensile failure. More than one mechanism may be present in static instability problems and depend on the mechanical response of the rock mass to the induced stresses. On the other hand, although the complexity of the loads developed in the reinforcement system by a rockburst event, it is reasonable to consider the punch shear mechanism as a response of the shotcrete to a dynamic load (Drover & Villaescusa, 2015). The shotcrete in conjunction with the action of tendons are considered a kind of reinforcement system since it transfers the surface load generated on its surface to the rock mass trough the anchoring element.

Studies Performed on Surface Reinforcement Elements

The metal mesh performs the function mainly of surface support in underground mining and also as a concrete reinforcement launched for stability control of excavations conventionally with static instability problems. The most widely used gauges in mining range from No. 6, No. 8 and No. 10 gauges BWG (Birmigham Wire Gauge), which represents diameters of 5,156 mm, 4,191 mm and 3,404 mm respectively. On the other hand, the use of meshes with standard wires of gauge N°8 is an attractive alternative due to the cost-resistance ratio and the ease of handling due to its relative low weight.

A good reference on the capacity of the reinforcement elements is the study carried out in Villaescusa et al. (2013). This study summarizes the results of energy capacity of mesh panels with different wire diameters or gauges subjected to static and dynamic loads, using the concept of moment transfer. The most common diameters in the study were 5.6 mm. The series of tests reported energy absorption capacities between 2 and

3 kJ for welded meshes of 5.6 mm in diameter and up to 14 kJ for high resistance woven meshes with diameters of 4 and 5 mm. The displacements reported in the tests range from 170 mm to 450 mm for welded and high tensile chain link mesh respectively. Although true, the results reported by the trials described in Villaescusa et al. (2013) are a good starting point to have an idea of the capacity that a reinforcement system composed of reinforcement of shotcrete with mesh, the certainty of the load capacity of a system cannot be efficiently determined by the response of the elements of that system separately (Stacey, 2012).

Shotcrete Capacity Under Static Conditions

Morgan et al. (1989) tests various configurations of reinforced shotcrete panels with electro-welded meshes and synthetic fibers. The welded meshes used for the reinforcement of the shotcrete panels have a diameter of 4.1 mm and 4.8 mm equivalent of 8 gauges and 7 gauge in the BWG scale. This study shows in detail the load deflection curves where the energy capacity of the system can be efficiently calculated. Also, in other study carried out in Cengiz & Turanli (2004), different panels of shotcrete reinforced with metallic meshes, synthetic fibers and metallic fibers are tested using the EFNARC standard, emphasizing the energy absorption capacity in quasi-static loads. Morton et al. (2009) performs static tests on large-scale shotcrete panels to determine energy absorption capacity, the tested shotcrete types include panels reinforced with welded mesh, metallic and synthetic fibers. The reported results indicate that the energy capacity of the shotcrete reinforced with welded mesh is higher than the energy reported by the shotcrete with fibers. In addition, the displacement at the loading point of the shotcrete with welded mesh is greater than the other panels. Stacey et al. (1995), also performed static tests on shotcrete panels with different thicknesses in areas of 1 m^2, reinforced with wire mesh. The overall result of these tests delivers average energy capacities of 4 kJ/m^2 5.5 kJ/m^2 and 9 kJ/m^2. Some other studies, also described in Morton et al. (2009) deal with the strength of shotcrete subjected to static loads and its energy capacity, these are Fernandez Delgado (1977), Holmgren (1976), Little (1985), Kirsten and Labrum (1990), Kirsten (1992), Tannant and Kaiser (1997) and Kaiser and Tannant (2001).

Although those studies are very complete and carried out following strict procedures, the static energy calculated has little representativeness of the dynamic capacity of the systems.

Shotcrete Capacity Under Dynamic Conditions

Dynamic conditions were tested in surface reinforcements with different configurations, such as Villaescusa et al. (2016) where different reinforcement systems composed of bolts and welded wire meshes and chain linked meshes are tested, generating a good basis in understanding the lower limit of energy capacity that a reinforcement system can have if it is comprised by an element described in the study.

Kaiser et al. (1996) reports a series of drop tests on shotcrete panels reinforced with welded mesh #6 gauge, the mass used for the tests is 565 Kg and is thrown from different heights up to a maximum of 4 m. The energy determined in the tests indicates greater capacity for dynamic conditions than for quasi-static conditions. In this regard, the authors indicate that the components of the test device helped the energy dissipation (Kaiser et al. 1996) and, this possibly overstates the energy capacity reported in the drop tests. The energy capacity of the shotcrete panels determined by the tests is 15 kJ/m^2 when rigid anchors are used. On the other hand, the authors suggest energy capacities that exceed 25 kJ/m^2 if the reinforcement system is combined with dynamic bolts of at least 10 kJ/m^2 of capacity.

Ortlepp and Stacey (1997) Reports dynamic tests on shotcrete panels with 25 MPa of nominal resistance, with surfaces of 1.6 x 1.6 m and 100 mm thick. These panels are reinforced with welded wire mesh of 100 mm aperture and 4 mm diameter of wire, synthetic fiber and metal fiber. The shotcrete panels were suspended with 4 bolts spaced at 1 m, these tests deliver energy capacities of 15.4 kJ 15 kJ and 12.5 kJ on average respectively. The data provided in the related study (Ortlepp and Stacey, 1997) are of utmost importance, however, the energy capacity reported for the shotcrete panel reinforced with welded mesh comes from a single drop test, which does not constitute enough data to determine the variability that the reinforcement system can have.

Finally, the data summarized in the mentioned studies is summarized in Figure 2.

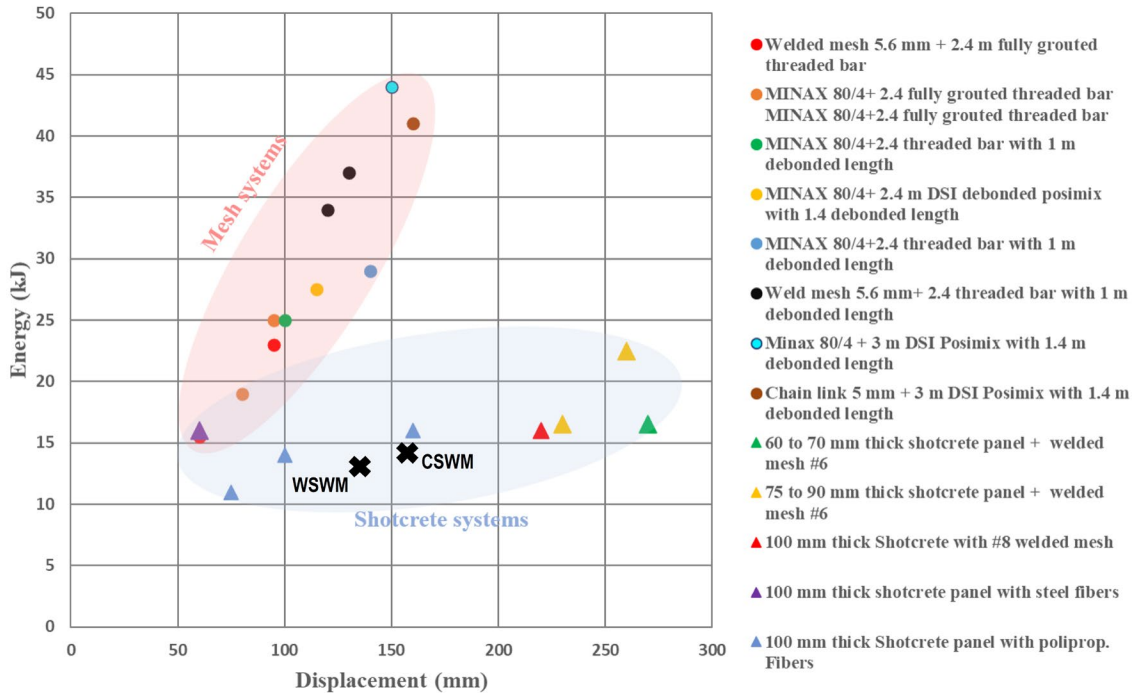

Figure 2. Energy vs displacement of several support systems tested under dynamic loads (Villaescusa et al. 2016; Kaiser et al. 1996; Ortlepp and Stacey, 1997). Tests made in the present study are presented as cross markers.

DYNAMIC IMPACT TESTS IN REINFORCED SHOTCRETE

This section describes the methods used to assess the capacity of the static support system used for dynamic problems described earlier. Five rockburst impact tests were performed in the middle of the shotcrete panel, with three different designs of embedded metallic mesh, (Welded Standard Wire Mesh WSWM gauge #8, Chain Link Wire Mesh CSWM gauge #8, and high tensile strength wire mesh HSWM gauge #7 and gauge #11). The tests were carried out at the test facility "Lochezen" in Walenstadt – Switzerland. The drop test device is described in Brändle et al. (2019).

The dynamic load is applied by dropping a concrete block with a weight of 6280 kg from a height or 0.48 m. The acceleration of the concrete block was measured using a three-axis accelerometer placed on top of the block. Figures 3 show the used test field coordinate system is as follows (seen in flight direction of the block): X: positive left, Y: positive backwards, Z: positive upwards. The origin (zero-point) of the coordinate system is in the middle of the shotcrete panel, where the block hits the panel.

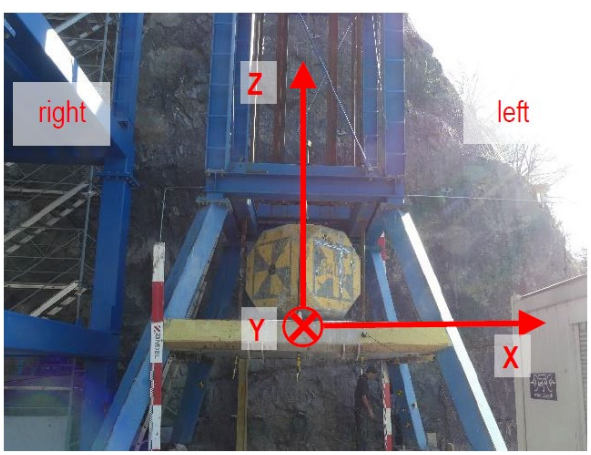

Figure 3. Used coordinate system

Also, the forces acting on the rock bolts during the tests were detected using load cells installed directly on the top ends of the anchors, the location of the anchors is given in Figure 4 (a),(b). Lastly, four stationary digital high-speed cameras were used for visual documentation of the test and to evaluate the displacement of the block.

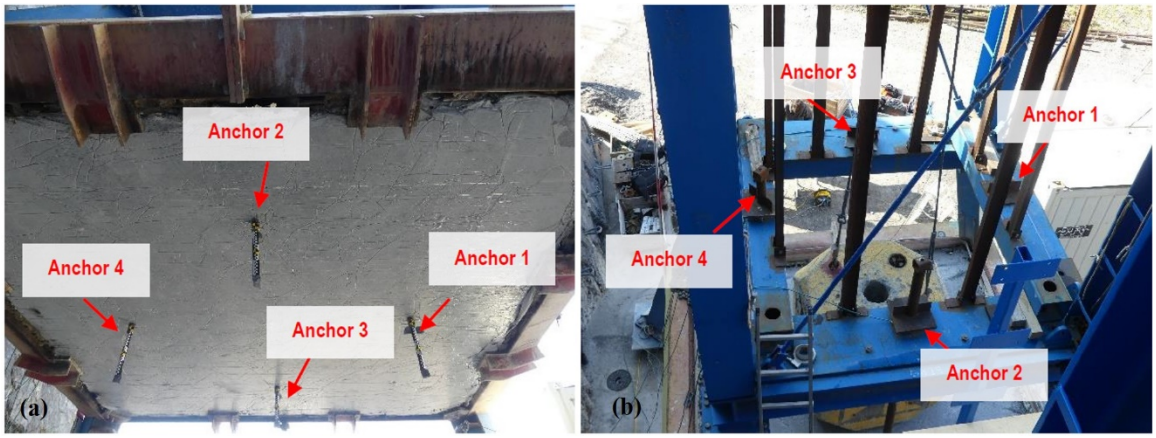

Figure 4. Location of anchors (a) View from below (b) View from above

Rock Support Setup

The three ground support systems tested consists of 100 mm thick layer of shotcrete with fibers. Two panels are comprised of 40 N/mm2 of UCS, one panel is reinforced with the CSWM (MFI3500-100) and the other panel are reinforced with HSWM (one panel with MINAX 80/3 and the other panel with MINAX 80/4 and MINAX 80/4.6). Lastly, one panel with UCS of 50 N/mm2 shotcrete is reinforced with WSWM #8 gauge. Each panel covers an area of 3.6 m x 3.6. Four rockbolts with a diameter of 22 mm and made of A630 steel grade, arranged in a square pattern of 1.4 m x 1.4 m, support the internal layer of metallic mesh in every single panel. The fixation is a single nut and plate per rockbolt. All rockbolts are cement grouted in a steel tube and have a debonded length of 70 cm from the collar. The scheme of the support system is showed on Figure 5.

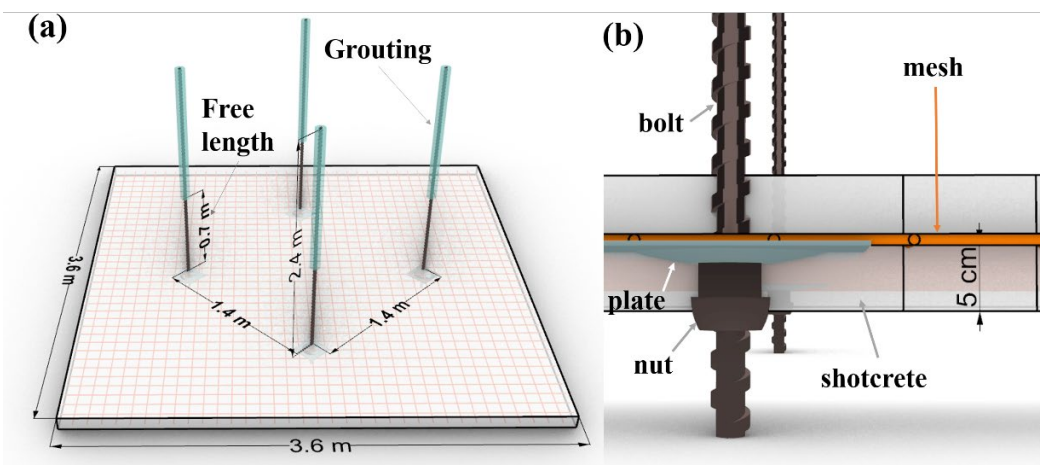

Figure 5. Rock support scheme (a) bolt distribution in the shotcrete panels (b) section of the tested panels

Tests Results and Analysis

Between 2020 and 2021, the three full-scale tests were performed with an impact energy of 30 kJ (Figure 6). A concrete block of 6280 kg was dropped down from a height of 0.48 m onto the shorcrete panels. The block has caused the violent failure of 2 panels with the standard wire meshes (WSWM and CSWM) causing a displacement of 0.14 m and 0.16 m in the moment of the failure respectively.

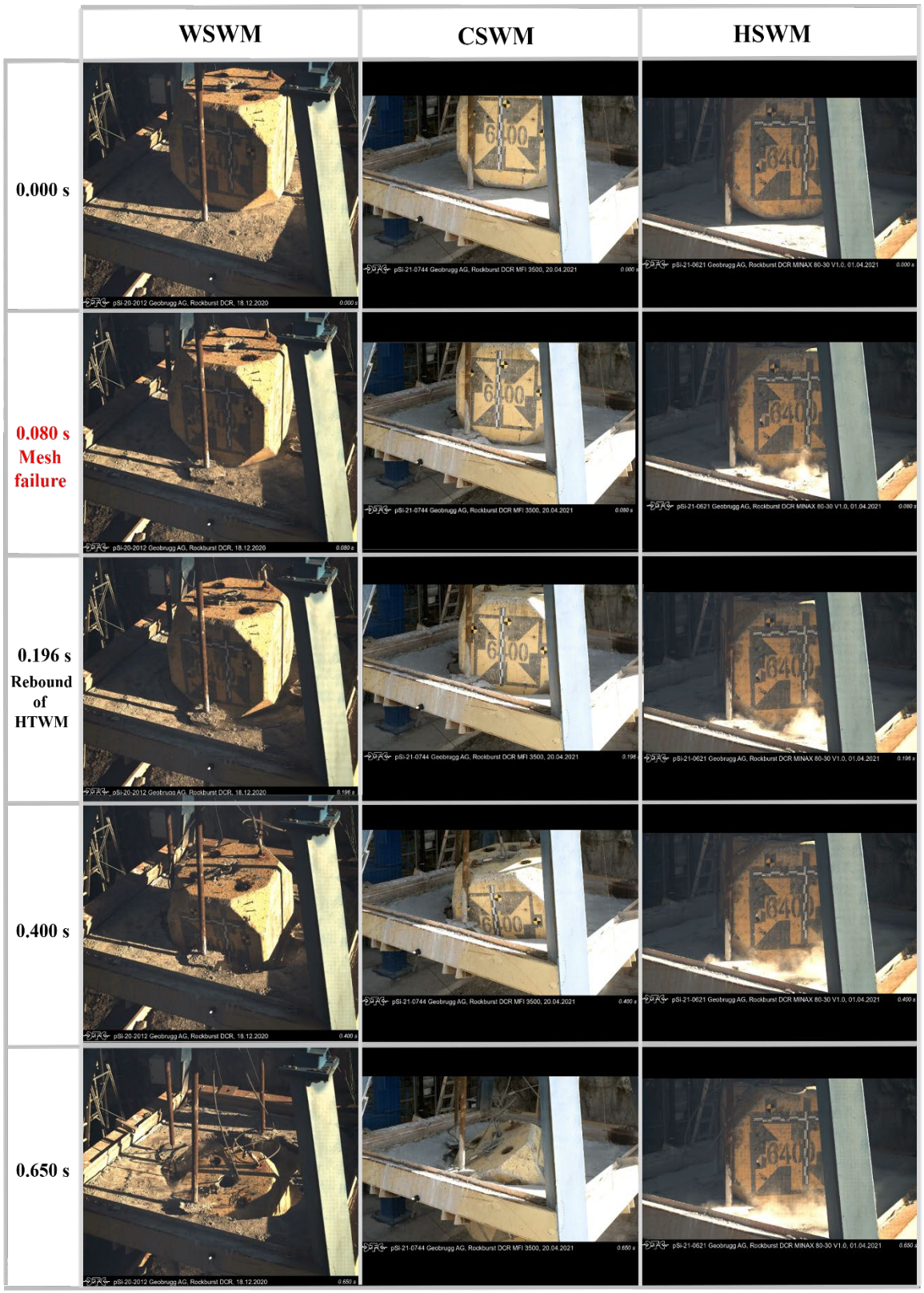

Figure 6. Impact Sequences of the drop test on three different reinforces shotcrete. The figure shows first impact and the failure of the panels reinforced with WSWM and CSWM,

On the other hand, the shotcrete panel with the HSWM completely restrained the concrete block, causing a maximum displacement of 0.15 m. The results are summarized in Table 1. And the moment of the rupture is presented in Figure 6, along with the sequence of impact on the three reinforced shotcrete panels.

Table 1. Results of the performed impact tests

	pSi-20-2012	pSi-21-0621	pSi-21-0744
Panel	Shotcrete WSWM	Shotcrete HSWM	Shotcrete CSWM
Weight of block (kg)	6280	6280	6280
Drop height (m)	0.48	0.48	0.48
Kinetic energy at impact (kJ)	30	30	30
Deformation energy kJ	26	33	28
Block got restrained	No	Yes	No

The Figure 7 below shows the result of the 3 tests. As in the tests of CSWM and WSWM the mesh failed, the deformation energy of this tests is calculated until the time point where the mesh ruptures. As noted in table 1 the deformation energy of the block is higher than the impact energy, due to the additional potential energy of the displacement of the block after the first contact. Time point 0 describes the first contact of the block with the shotcrete (see Figure 5).

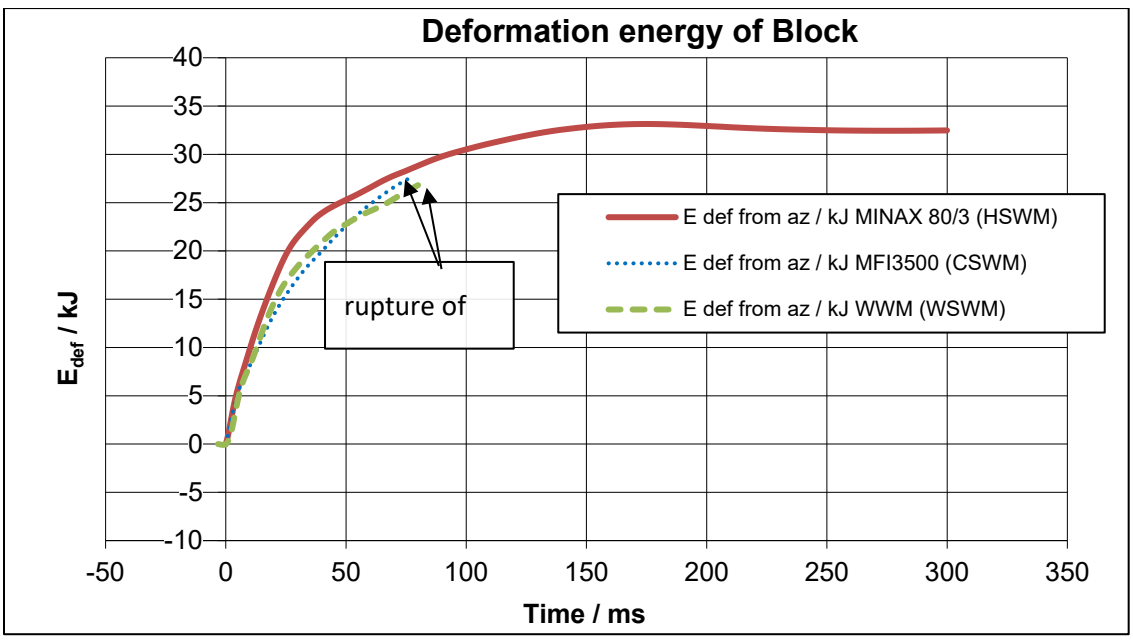

Figure 7. Energy of deformation vs time measured in the three tests

Load cells measured the occurring load in the anchors during the impact. However, at the test with HSWM and CSWM the load cell on anchor no.1 was not working. For the analysis and comparison just the anchor forces of anchor 2; 3 and 4 have been used in Figure 8. The loads measured show a 25% higher load transfer of the HSWM to the anchors compared to WSWM and 37% higher compared to the CSWM. The load transfer of the WSWM into the bolts is around 17% higher compared to CSWM.

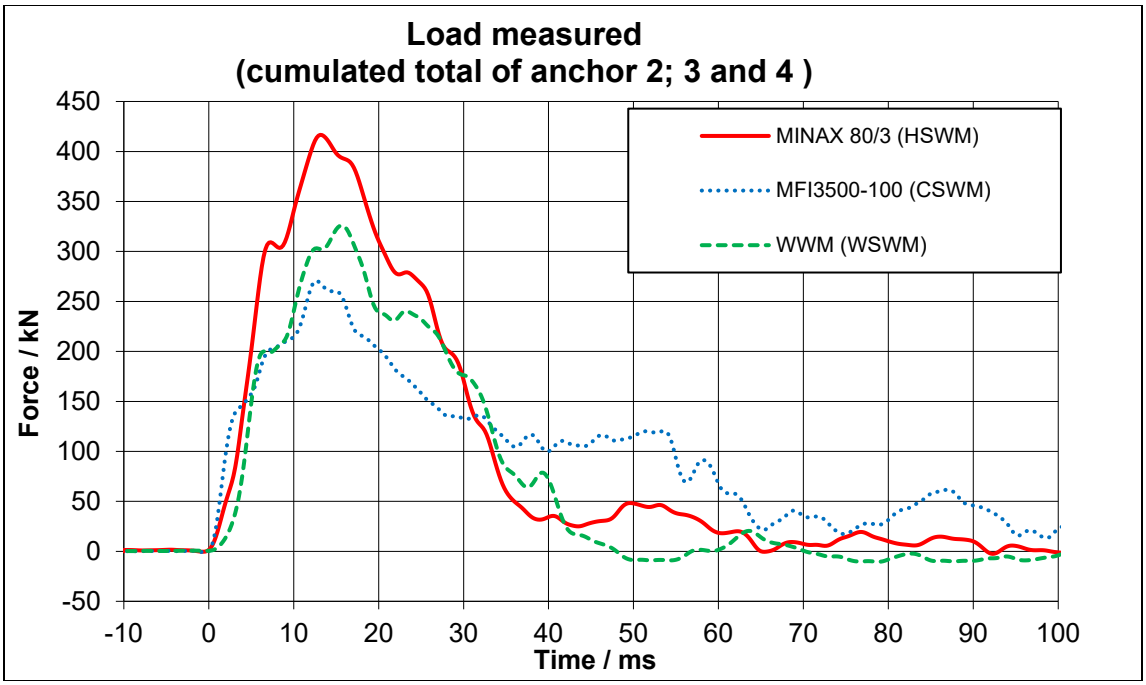

Figure 8. Cumulative loads measured by load cells placed in the anchors. The total load in the HSWM is 25% higher than the loads in the WSWM test, and 37% higher than CSWM tests

The dynamic displacement in Figure 9 of the block complies with the measured loads. As the displacement curve is flatter it indicates a faster deceleration which also indicates a higher resistance of the simulated ground support.

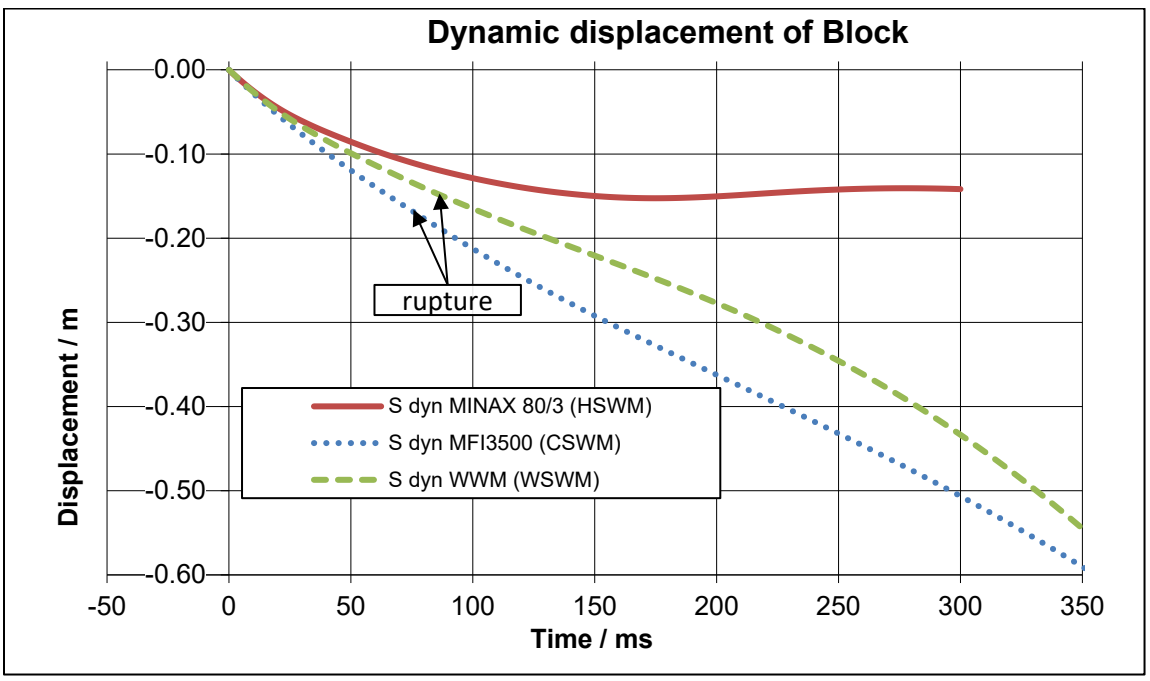

Figure 9. Dynamic displacement vs time determined in the tests

CONCLUSION

These 3 tests have been conducted to compare the different types of materials which are used in ground support systems in Peru at this time. As an energy of 30 kJ is not seen as an overestimated possible event from the authors, one can see there are some limits for the use of WSWM or CSWM in areas with a ground support demand of min. 30kJ. As the tests with WSWM and CSWM caused a failure of the ground support, an estimation of the dissipated energy was possible and therefore an estimation of the max. possible energy this system can dissipate. For the HSWM however cannot be said what the maximum would be from these tests.

The energy dissipation reported in the tests of the present study have a similar magnitude of energy per square meter reported in Kaiser et al. (1996) and Ortlepp and Stacey (1997); even though, the tests reported has different geometric configurations and different bolt spacing. A good reference to see the variation in the capacity of the systems under different bolt spacing is Ortlepp & Swart (2002). However, the major difference falls on the use of the debonded length of the rock bolts used in the present study wich apparently do not provide energy dissipation capacity to the system.

The measurement of forces in the rockbolts show that the load transfer from panels with WSWM and CSWM to the rockbolts are less than the load transfer from the panel with HSWM. This may be due to the fact that failure occurs at the connection point between the shotcrete panels and the rockbolts. This break at the connection point is more noticeable in the shotcrete with CSWM.

The graph in figure 7 shows that the HSWM high-strength steel mesh, works in rational way, unlike the other two meshes in comparison. The HSWM can transmit most of the stresses to the bolt system, leaving no be a simple element of containment, to become a protagonist of the support system as a clear load transmission tool.

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