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Dynamic assessment of ground support schemes: insights from comprehensive full-scale testing

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Abstract

Rock ejection from dynamic loading poses significant risks in underground mining and tunnelling operations. In order to mitigate these risks and ensure a safe working environment, surface support systems such as steel mesh are crucial in containing any rock failures or ejections. This research presents findings from a comprehensive test series conducted in Walenstadt, Switzerland to assess the effectiveness of ground support schemes using different types of steel mesh and bolts under dynamic conditions. The test rig was designed to apply large amounts of energy to various support systems with different bolt patterns and mesh types at full scale. The behaviour of the systems was analysed using load cells, high-speed video analysis and accelerometers.

Different set-ups with typical reinforcement elements have been tested, where the focus has been on developing a test method which reflects a realistic load transfer scenario. For that purpose, tests with different energy levels have been carried out and analysed. The main objective of the tests has been to investigate the energy dissipation of specific support elements if tested in a full system. Based on that, energy dissipation ratings (in kJ/m^2) in different areas of the complete scheme can be assessed. Varying the impact energies allows investigation of the increasing load distribution in the scheme and helps to identify residual capacities and residual safety after a dynamic event. This will help to develop a design concept for site-specific ground support schemes.

In summary, this paper offers significant insights into the load-bearing characteristics of typical ground support schemes under dynamic conditions and highlights the crucial role of a system-based approach in their design. The outcomes of the comprehensive test set-up and advanced analysis of various impact scenarios can aid in the development of more efficient and effective surface support systems, as well as a suitable design concept, ultimately resulting in safer and more productive mining operations.

Keywords: *ground support testing, mesh overlap, full-scale tests, chain-link mesh*

1 Introduction

Surface support interacts with rock reinforcement elements to create an integrated ground support scheme (Potvin & Hadjigeorgiou 2020). In this context, surface support connects the reinforcement elements to resist surface deformation and prevent rock blocks from falling or ejecting, such as fragmented and loose rock between the bolts and other reinforcement elements. Furthermore, it is commonly observed that bolts will fail first in large dynamic events. In this type of scenario it is important that the surface support, such as mesh, can transfer the loads to the reinforcement elements surrounding the failure area and generate a system capable of retaining ground deformations (Figure 1) from significant inward movement of the rock mass surrounding an excavation (Villaescusa et al. 2013).

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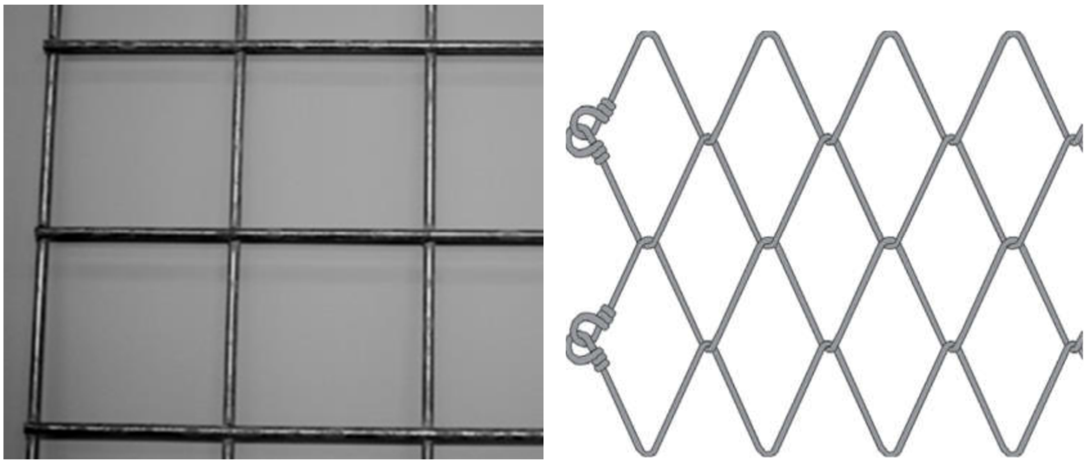
Figure 1 Significant damage to ground support and excessive deformation at Lapa gold mine

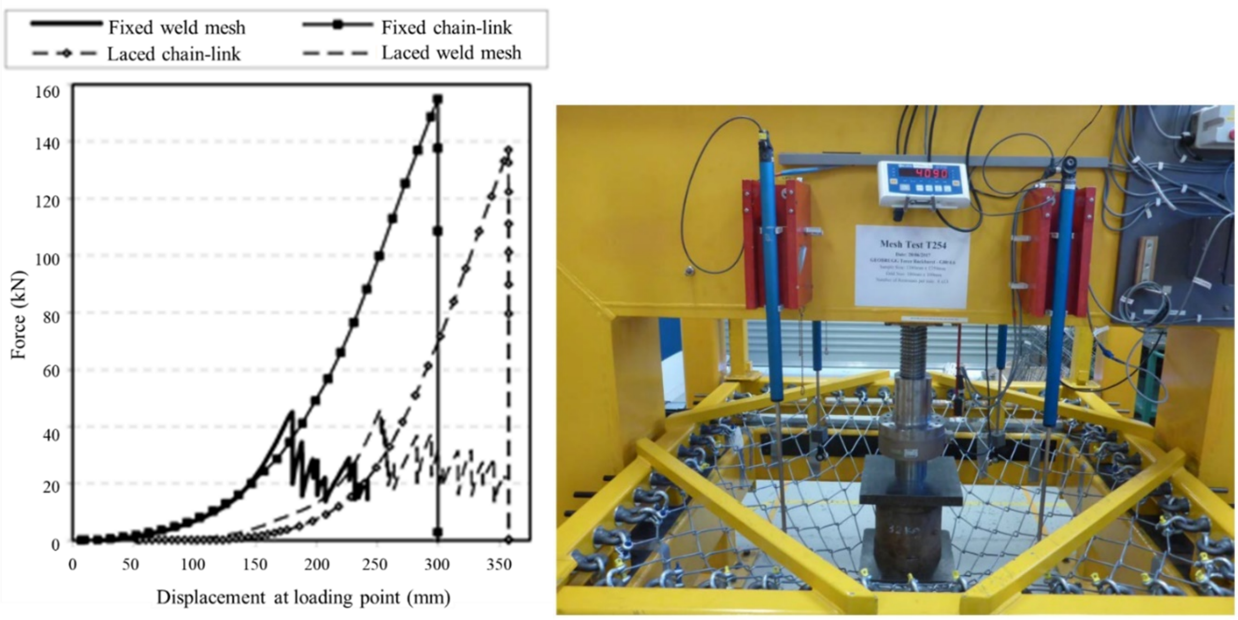
The primary types of mesh used in underground mining are welded wire mesh and chain-link mesh (Figure 2). Welded mesh is made from metal wires that are spot welded together in an orthogonal pattern. Typically this mesh uses 5 or 5.6 mm steel wires with a 100 mm aperture, offering enhanced weld strength. It is favoured in some mines due to its ease of installation with mechanical bolters and jumbos (Potvin & Hadjigeorgiou 2020). In contrast, chain-link mesh features a woven wire design, providing greater deformation capacity. The wires in chain-link mesh are generally thinner than those in welded mesh sheets. The efficiency of mechanical installation has been significantly enhanced by using specialised equipment and drill boom attachments which allow the mesh to be simultaneously unrolled from one boom and bolted to the walls with the other (Coates et al. 2009; Potvin & Hadjigeorgiou 2020). Improvements in chain-link mesh have focused on using higher quality steel with increased tensile strength and a diamond-shaped pattern, as well as enhancing installation systems for greater efficiency.



(a) (b)

Figure 2 (a) Welded wire mesh; (b) High-tensile chain-link mesh

Eriksson (2020) conducted a series of load tests on welded mesh and found that its load-carrying capacity is approximately proportional to the amount of wires the loading plate is catching. The study concluded that the load-carrying capacity of welded wire mesh ranges from 15 to 45 kN (for 5.6 mm wire with a 100 × 100 mm aperture) at displacements between 250 and 450 mm. Research conducted at the Western Australian School of Mines (WASM) by Morton et al. (2007) examined the load deformation characteristics of mesh under different restraint configurations (fixed or laced at the ends). The load displacement tests revealed that high-tensile chain-link mesh has a higher load-carrying capacity compared to welded mesh, attributed to its greater deformation capability and resistance (Figure 3).



(a) (b)

Figure 3 (a) Load deformation capacity of welded and chain-link mesh; (b) Quasi-static tests at the Western Australian School of Mines

2 Comparing welded wire mesh and high-tensile chain-link mesh

The investigation consists of two different large-scale field tests and various laboratory tests.

2.1 Test set-up

In order to reach the required impact energy, the block with a weight of 9,380 kg was lifted to the defined drop heights of 5.67 m by means of a crane and released with a remote control (Figure 4).

Figure 4 Test stand before release

2.1.1 Coordinate system

The used test field coordinate system is as follows (seen in the flight direction of the block in Figure 5):

- + X – positive left
- + Y – positive backwards
- + Z – positive upwards.

The origin (zero-point) of the coordinate system is in the middle of the concrete floor where the block hits the floor.

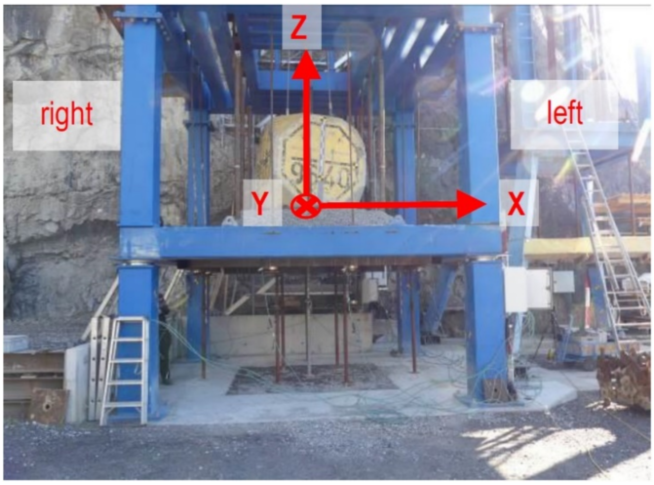


Figure 5 Coordinate system

2.1.2 Data acquisition

The following electronic instrumentation was used for measurements during the test.

Table 1 Instrumentation

Measuring point	Engineering data	Frequency	Filter	Measuring direction
Block: acceleration	Triaxial accelerometer, 2,000 g	20 kHz	CFC 60	x, y, z
Anchors: load	Load cells, 750 kN	4.8 kHz	CFC 1802	z
Supports: load	Load cells, 750 kN	4.8 kHz	CFC 180	z
Posts: load	Load cells, 750 kN	4.8 kHz	CFC 180	z
Block: displacement	High-speed camera	500 Hz	N/A	z
Concrete floor: deformation	3D laser scan	N/A	N/A	x, y, z

The measuring equipment was triggered manually and synchronised by evaluation of data plots (abrupt change of acceleration/force)

2.1.3 Load measurement

2.1.3.1 Anchors

To measure the loads on the nine anchors during the impact, nine load cells were installed directly on the abutment of the anchors (Figure 6). The loads were measured relatively (pre-tension loads not considered) by DTC AG (Independent Test Institute, Dynamic Test Center AG, Route Principale 127, 2537 Vauffelin, Switzerland).

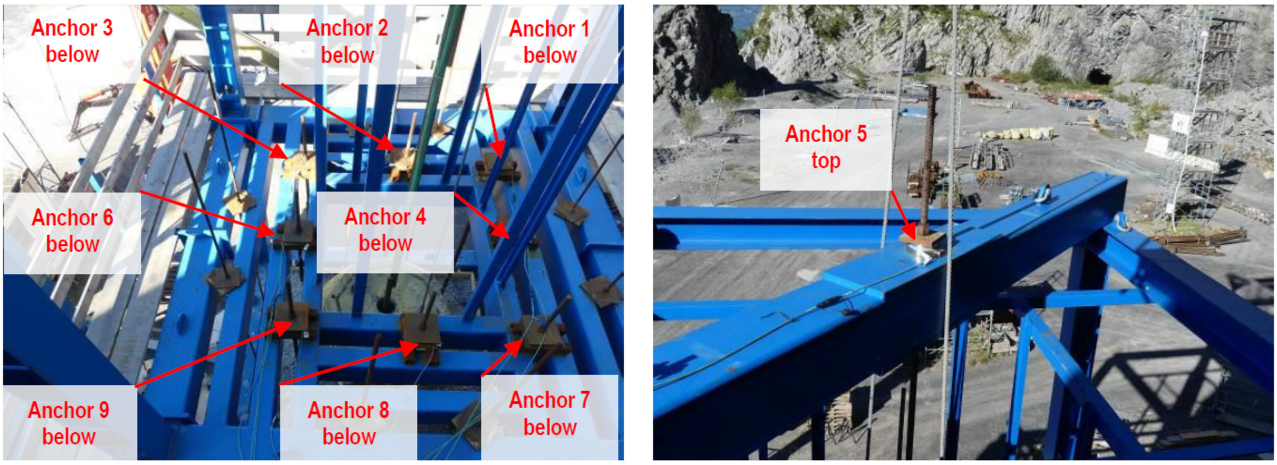


Figure 6 Load cell positions

2.1.3.2 Supports

To measure the loads transferred for the ground support scheme on the support structure during the impact, eight load cells were installed below support beams surrounding the simulated ground support scheme (Figure 7). The loads were measured relatively (pre-tension loads not considered) by DTC AG.

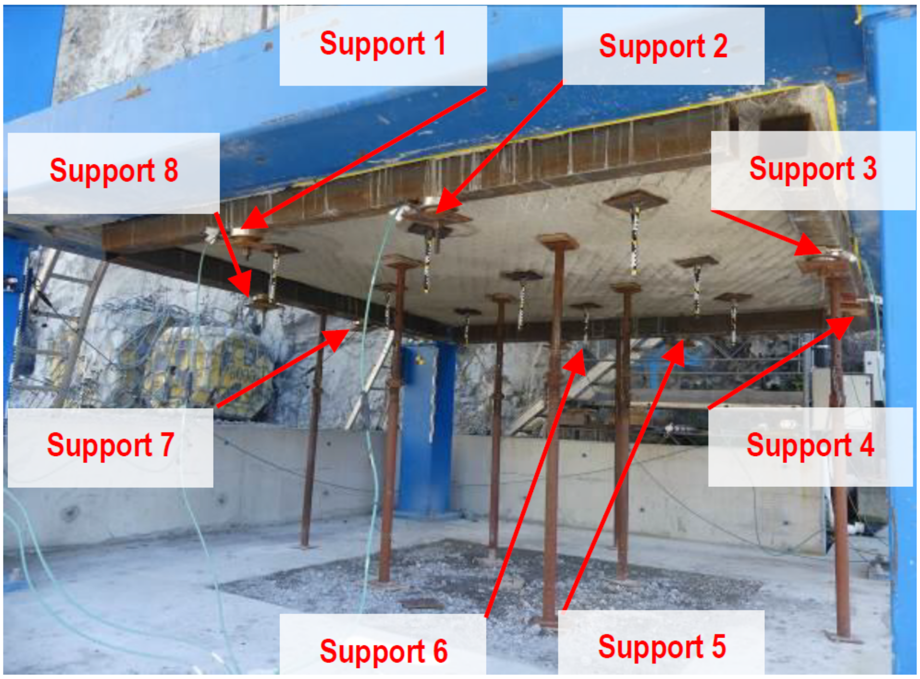


Figure 7 Load cell position supports

2.2 Full-scale test with welded wire mesh 100 × 100 × 5.6 mm

An impact test on a full-scale ground support scheme was conducted at the test site of Walenstadt (Switzerland) in November 2023. The ground support consisted of a 100 mm-thick shotcrete slab reinforced with welded wire mesh comprising 5.6 mm wire with a minimum tensile strength of 500 MPa and a 100 mm mesh aperture. The welded wire mesh was sprayed in with shotcrete at minimal coverage (shotcrete fill-in) (Figure 8), and the overlap of the sheets of mesh were placed at the bolts next to the impact centre. The shotcrete and welded wire mesh were supported by nine 20 mm-diameter resin-encapsulated rebar rockbolts with a decoupled length of 1.00 m, set inside steel tubes. The steel tubes were cut at 1 m lengths to simulate the fracture in the rock mass which lays within the 1.00 m decoupled length. This set-up permits the bolt to plastically deform before rupture.

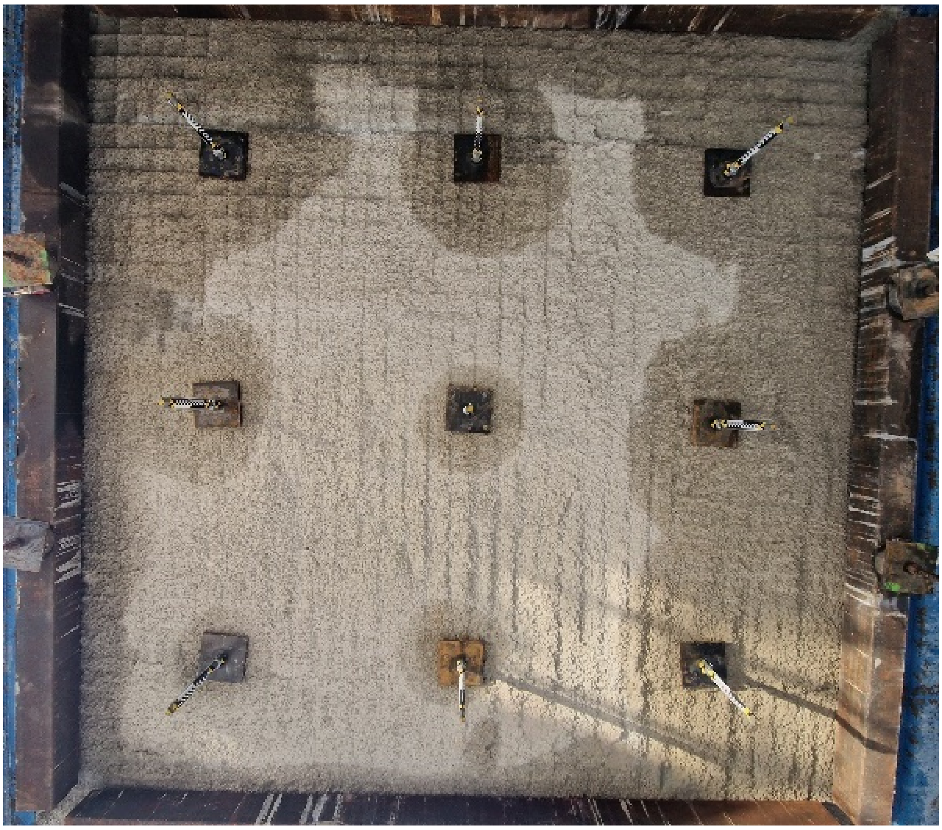


Figure 8 Configuration of welded wire mesh test

The test block made from concrete has a vertical hole in the centre which allows a fully central drop onto the bolts/plate arrangement in the centre. To distribute the impact load to all support elements, a layer of cemented aggregate fill with a height of 600 mm was used as simulated rock mass (Figure 9).

Figure 9 Simulated rock mass with 600 mm cemented aggregate fill

The test block with a weight of 9,380 kg was dropped down onto the simulated rock mass from a height of 5.66 m to reach an input energy of 521 kJ. The block was restrained by the simulated ground support but the welded wire mesh ruptured and failed. The central bolt failed (Figure 10) at an elongation of 90 mm.

Figure 10 Failed centre bolt and ruptured mesh after testing

2.3 Full-scale test with high-tensile chain-link mesh 80/4.6

A second test was conducted on 21 September 2022 using high-tensile chain-link mesh in place of the weld mesh (Villaescusa et al. 2023). The ground support in the test consisted of a shotcrete slab of 100 mm MINAX 80/4.6 chain-link mesh with a minimum tensile strength of 1,770 MPa and an aperture of 80 mm (inner circle of the diamond). The mesh was sprayed in with shotcrete with a minimal overburden (shotcrete fill-in). The shotcrete and MINAX 80/4.6 mesh were supported by nine 20 mm-diameter resin-encapsulated rebar rockbolts with a decoupled length of 1.00 m, set in steel tubes. The full set-up can be seen in Figure 11.

Figure 11 Walenstadt test set-up with high-tensile chain-link mesh, before lifting the test block

The 9,380 kg test block was dropped onto the simulated rock mass from a height of 5.67 m to reach an input energy of 522 kJ. The block was completely stopped and restrained by the ground support scheme. The centre bolt ruptured at an elongation of 75 mm (Figures 12 and 13).

Figure 12 Post-test MINAX 80/4.6 central bolt detail

(a) (b)

Figure 13 (a) Post-test MINAX 80/4.6 overview; (b) Detail of stretched mesh

2.4 Test results on each system

The full-scale tests quantified the performance of the high-tensile chain-link mesh 80/4.6 versus a 5.6 mm welded wire mesh under dynamic loading in the area of the mesh. The welded wire mesh failed when subjected to an impact energy of around 520 kJ, while the chain-link mesh 80/4.6 was able to withstand the same load and dissipate and distribute the energy without failure. The accelerometer data showed a short peak up to 110 g for the welded wire mesh set-up at the impact of the block (Figure 14) and acceleration in the range of 10 g until 100 ms for the chain-link mesh configuration, and the peak at impact reached over 160 g while the residual acceleration was around 10 g until 100 ms. The impact of a solid concrete block onto a rigid hard surface will create an impact shock resulting in very high acceleration values, such as 110 or 160 g. Even though the set-up has been consistent, the variation could have occurred due to the imperfections of the surface of the block and the surface of the impacted concrete.

The configuration of the wires in the chain-link mesh can be stretched and deformed even though the high-tensile wire is not very ductile. The specific diamond shape and the links make the high-tensile chain-link mesh flexible under load. This allows the chain-link mesh to deform, which dissipates the impact energy and prevents rupture.

A significant difference in the results is visible in the measured loads of the supports. A peak of 650 kN has been measured in the test with the welded mesh configuration while 320 kN has been the measured load in the MINAX configuration (Figure 15). This is a result of the higher flexibility of MINAX compared to a sprayed-in weld mesh configuration.

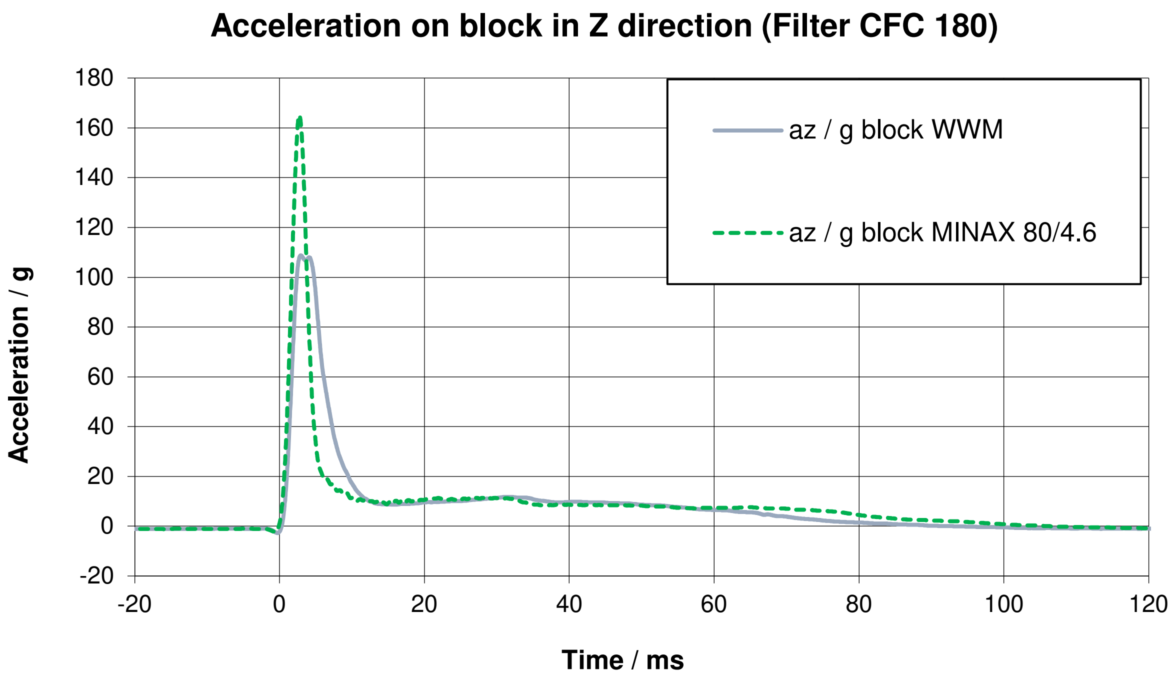


Figure 14 Acceleration of block for welded mesh (blue) and MINAX 80/4.6 (green)

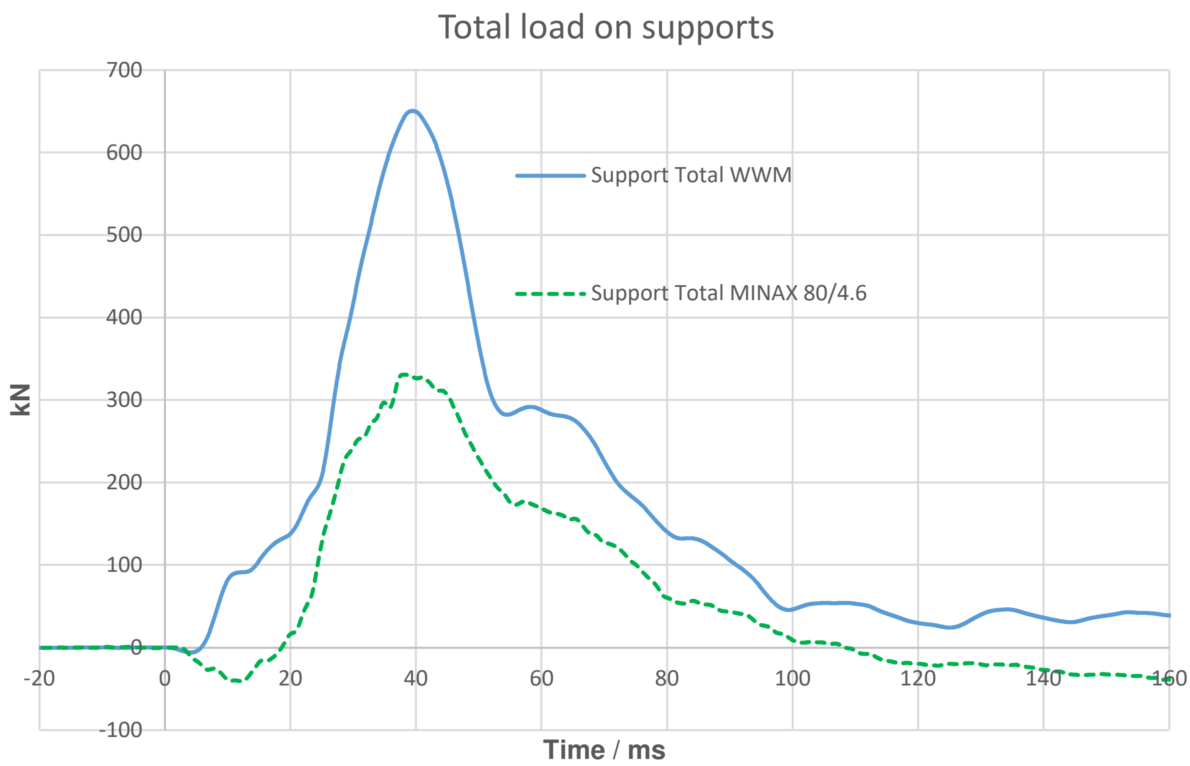


Figure 15 Total load on supports

Comparing the dynamic behaviour of the impacting block shows the significant difference between the two systems (Figure 16). The deformation energy (dissipated energy after impact) of both tests are very similar, while the deformation of the more flexible MINAX system is 23 cm compared to 19 cm for the welded mesh system. This results in the failure of the welded mesh system as the straight wire does not allow the deformation to dissipate the energy.

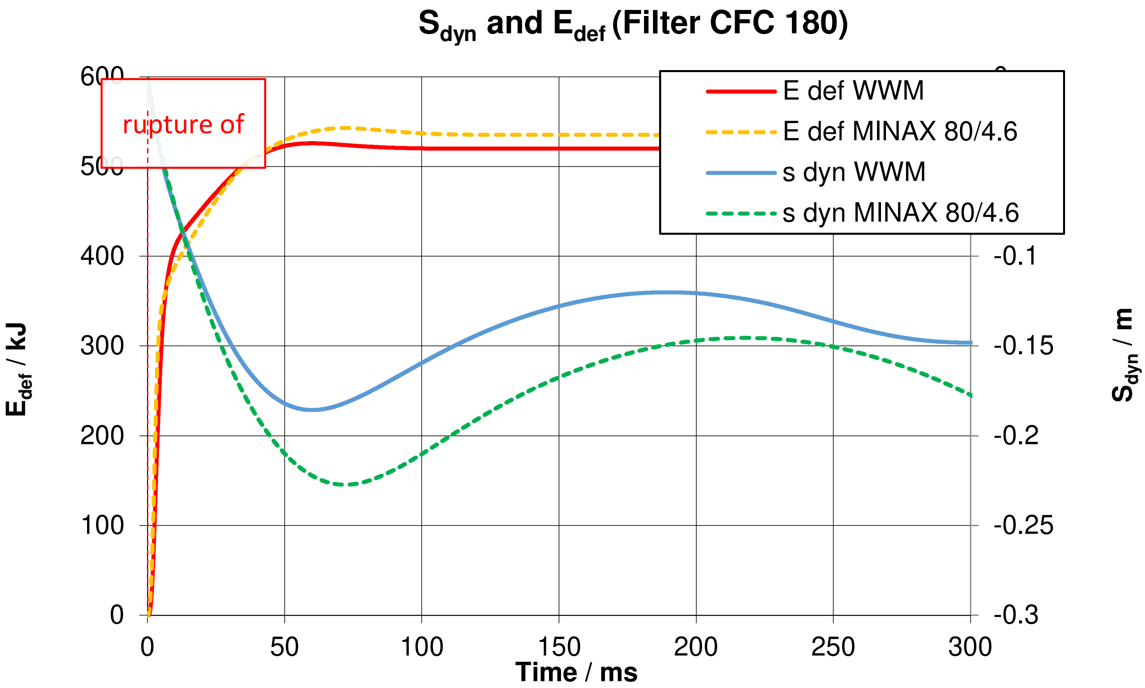


Figure 16 Deformation energy and dynamic displacement of block in z direction

Comparing the measured anchor loads reveals very similar loading across the bolts, demonstrating the reproducibility of the test set-up (Figure 17). The observation of almost identical loads in the anchors while a failure occurs in one system highlights the importance of the strength and flexibility of the screen mesh.

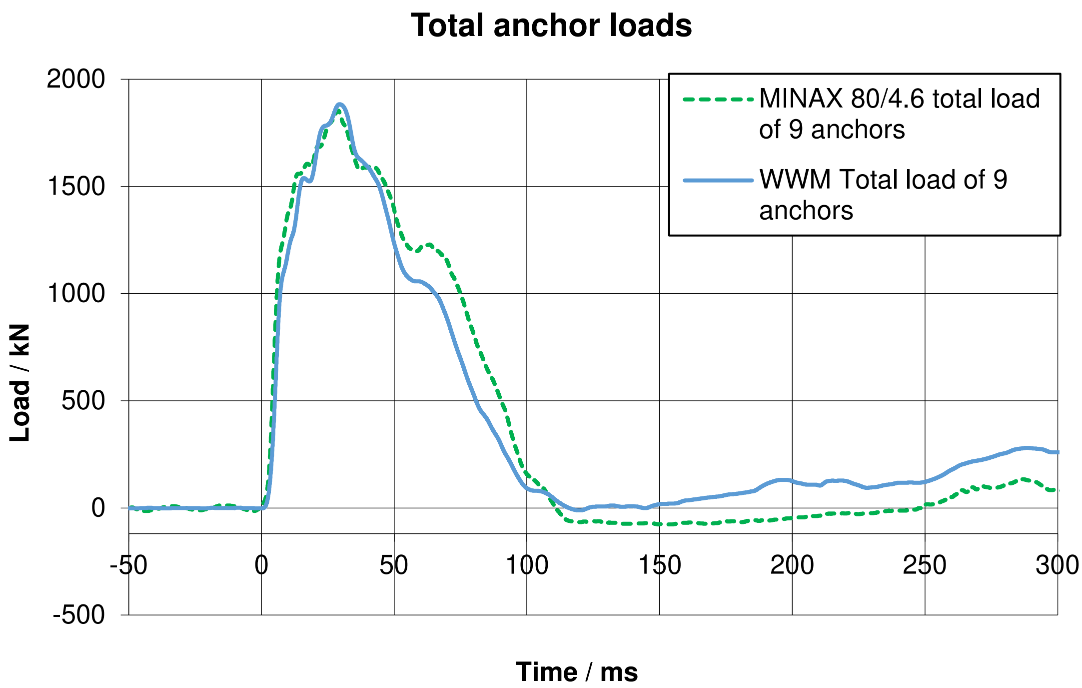


Figure 17 Total loads in all nine anchors during impact

3 Conclusion

The presented test set-up is suitable to dynamically test full-scale ground support schemes with up to nine reinforcement elements. The surface support can consist of 3.9 × 3.9 m shotcrete or mesh-reinforced shotcrete. The impact on a simulated rock mass with a test block allows the load transfer to the ground support scheme. By using cemented aggregate fill a repeatable test method was developed.

The tests showed that the stiff reinforcement elements are loaded first and, when the first bolt is ruptured, the load must be transferred to the surrounding bolts through the surface support. For that purpose the surface support must be strong enough to sustain large deformations without rupturing. The two tests carried out on the similar load level showed that that welded wire mesh was not able to transfer the loads, and ruptured in the centre without deforming in the adjacent sections. The high-tensile chain-link, on the other hand, transferred the loads, dissipated the energy over a larger area and did not rupture.

The test results of two typical ground support schemes suggest that the majority of the energy must be dissipated by the reinforcement elements without deforming too much. In order to keep a scheme from unravelling, the surface support must also be able to dissipate significant energy and follow the full deformation without rupturing and disintegrating.

It is proposed to execute more tests on this new test site, with typical ground support schemes of nine reinforcement elements and attached surface support. A database for ground support schemes can be added to thanks to their repeatable set-ups.

References

Coates, R, Brown, S, Bucher, R & Roth, A 2009, ‘Fully mechanised installation of high-tensile chain-link mesh for surface support in tunnels’, in PM Dight (ed.), *SRDM 2009: Proceedings of the First International Seminar on Safe and Rapid Development Mining*, Australian Centre for Geomechanics, Perth, pp. 165–172, https://doi.org/10.36487/ACG_repo/902_15

Eriksson, F 2020, *Assessment of Static Performance of LKAB’s Welded Mesh: Laboratory Testing and Analysis*, master’s thesis, Luleå University of Technology, Luleå.

Morton, E, Thompson, A, Villaescusa, E & Roth, A 2007, ‘Testing and analysis of steel wire mesh for mining applications of rock surface support’, in L Ribero e Sousa, C Olalla and NF Grossman (eds), *Proceedings of the ISRM 11th International Congress on Rock Mechanics*, vol. 2, Taylor & Francis, Oxford, pp. 1061–1064

Morton, EC, Thompson, AG & Villaescusa, E 2009, ‘The performance of mesh, shotcrete and membranes for surface ground support’, in M Diederichs & G Grasselli (eds), *ROCKENG09: Proceedings of the 3rd CANUS Rock Mechanics Symposium*, paper 4022.

Potvin, Y & Hadjigeorgiou, J 2020, *Ground Support for underground mines*, Australian Centre for Geomechanics, Perth.

Villaescusa, E, Thompson, AG & Player, JR 2013, ‘Static and dynamic testing of welded and woven mesh for rock support’, in Y Potvin & B Brady (eds), *Ground Support 2013: Proceedings of the Seventh International Symposium on Ground Support in Mining and Underground Construction*, Australian Centre for Geomechanics, Perth, pp. 187–196, https://doi.org/10.36487/ACG_rep/1304_11_Villaescusa

Villaescusa, E, Thompson, AG, Windsor, CR & Player, JR 2023, *Ground Support Technology for Highly Stressed Excavations: Integrated Theoretical, Laboratory, and Field Research*, 1st edn, CRC Press, Boca Raton, https://doi.org/10.1201/9781003357711