

FULL-PANEL SCREEN TESTING: MORE REALISTIC BUT WHAT CHANGES?

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ABSTRACT

How representative are partial-panel screen tests of the in situ response of screen to roof and rib deterioration and displacements? Can a more representative procedure that tests up to two full screen panels improve the utilization and effectiveness of screen as a roof and rib support? This paper details a new full-panel screen test procedure and the initial results. The full-panel test frame was designed to test a 2.4 by 3.6-meter screened area with bolt spacing as small as 0.3-meter increments. The initial design included up to 6 screen pull points, but additional locations can be added to produce a more uniform loading. The test frame was developed to capitalize on the capabilities of the Mine Roof Simulator (MRS) at the Pittsburgh Mining Research Division (PMRD) of the National Institute for Occupational Safety and Health (NIOSH). The initial tests included a baseline test of a partial panel (1.22 by 1.22-m screen section) using the original 1.52 by 1.52-meter test frame, a 1.22 by 1.22-meter screen section test in the new full-panel test frame, and two tests of 2.4 by 3.6-meter screened area in the full-panel test frame. The 1.22 by 1.22-meter screen section tests in the full-panel test frame produced a peak load 6% higher and a yield load 30% lower than the partial-panel (original) test frame. The multiple pull points of the full-panel frame produced variable yield, peak, and intermediate loads, but on average were lower than the single pull-point tests.

INTRODUCTION

Roof and rib surface support has become a major component of the stability and safety of underground coal openings in the past 15 years. The use of screen, either metal or synthetic, has proven to decrease the injuries of underground coal miners. By 2005, there were 466 injuries in the United States caused by roof skin failures, with numerous mines not employing roof screen. In contrast, in 2015 there were 175 injuries caused by roof skin failures, with at least some of the reduction due to the increased use of roof screen. A continued effort to increase the utilization of screen in areas of underground coal mines where workers are traveling and working can reduce these injuries even further. To aid in this effort, the testing of various screen types under various loading and attachment conditions is required. Past testing efforts have primarily consisted of partial-panel testing in a laboratory setting.

Laboratory testing of roof screen, both metal and composite, has been conducted in several ways by researchers, manufacturers, and other entities. The primary focus on the testing has been evaluating weld integrity of 1.22 by 1.22-meter screen section tests of various screen types utilized in mining (Dolinar, 2006; Dolinar, 2009; Tannant, 2001). There have also been several efforts at numerical simulation of the screen and screen/rock interactions (Murali et al., 2006; Shan et al., 2014). A few full-panel tests were performed with one pull or loading point in the center of the screen panel (Shan et al., 2014).

As most previous efforts have mentioned, the only true way to evaluate the capabilities of screen is to conduct full-panel testing. Single wire strand, weld, and partial-panel (1.22 x 1.22-m) tests as well as numerical modeling only provide insight into the actual response of full-panel screen. A new test frame and procedure have been developed at PMRD to conduct various loading, anchoring, and material testing.

FULL-PANEL TEST METHOD

In order to conduct full-panel screen testing, a new test frame had to be designed to accommodate full-panel sheets of screen. A reasonable correlation with partial-panel and full-panel testing is needed to justify using the full-panel test procedure that will allow for actual evaluation of the loading and anchorage scenarios encountered in underground mining environments. Another important capability of the new full-panel test frame is to have flexibility in bolt placement as well as screen loading points. Finally, the full-panel test method needed to be as repeatable as the previous partial-panel testing.

Test Frame Components

The new full-panel test frame consisted mostly of I-beams (W12 x 50) with various connectors to attach it to the Mine Roof Simulator (MRS) floor, as well as various connectors and loading fixtures that attach to the MRS roof and screen.

The frame attached to the MRS floor consisted of two long (5.2 m) I-beams, two medium length (2.14 m) I-beams, and multiple small length (0.71 m) I-beams to allow for the anchor points to the screen. *Figure 1* shows the two long I-beams and are representative of all the I-beams used to build the full-panel frame.



Figure 1. Image of the W12x50 I-beams with the 2.5-cm holes spaced every 30.5 cm.

The I-beams were attached to each other using a 2.54-cm flat bar, 10.2-cm by 1.27-cm thick angle iron, 1.9-cm hex cap screws, 1.9-cm nuts, 1.9-cm washers, 1.2-cm hex cap screws, 1.2-cm nuts, and 1.2-cm washers. Then, 2.54-cm holes were drilled in the I-beams at least every 30.5 cm.

The loading or pull points (*Figure 2*) were attached to the MRS roof with 1.9-cm, grade-100 chain, anchor shackles, and eye bolts. The loading and pull points consisted of various sized I-beams, bolt plates (typically 30.5-cm square), or 33-cm bells. Between the MRS roof and the pull fixture, there is a load cell monitored by the MRS control system. These load cells were either 89- or 222-kN cells with 0.09- to 0.22-kN accuracy.



Figure 2. Loading or pull points with bolt plate and load cell during composite screen test.

Figure 3 shows the anchor that attaches the pull point to the MRS roof. This design allows for rotation and translation of the anchor to ensure alignment to the central loading on the bolted screen areas, as well as off-centered loading if deemed appropriate to replicate an actual loading condition of the surface control product.



Figure 3. Image of the roof anchor, chair, and anchor shackle used to attach the pull point to the screen being tested.

General Design and Test Procedure

The full-panel test frame (Figure 4) that was designed with the capability of testing a 2.4-m x 3.6-m welded roof screen area was installed in the Mine Roof Simulator (MRS). A 1.22-m bolt spacing was used to attach the screen to the frame. Load was applied to the center of each bolted area, using either a 30.5-cm-square load plate or a 33-cm-diameter bell. A total of six load pull locations were used for this series of tests. With the MRS capabilities, the screen could be displaced up to 51 cm. The pull tests were conducted in displacement control with a displacement rate of 5.1 cm/min.

The screen loading was measured using an 89-kN or 222-kN load cell attached to the pull chains with an accuracy of ± 0.09 kN or ± 0.22 kN, respectively, and the screen displacement was monitored using a Temposonics magnetostrictive linear-position sensor with a ± 0.25 -mm accuracy. This test data was recorded at a sampling rate of 5 Hz.

The bolts securing the bearing plates and the wire mesh to the frame had a 1.9-cm diameter and were placed on a 1.22-m x 1.22-m pattern. The bearing plates were 15.2-cm x 15.2-cm, grade 4 with a 0.8-cm thickness. The load reaction frame was constructed from W12x50 steel beams. In order to limit slippage of the screen, the nuts

on the bolts were torqued to 203 N-m to generate approximately 66 kN of load on each bearing plate.



Figure 4. Test frame with the six-pull-point scheme with 1.22-m bolt anchor spacing.

Flexibility of Full-Panel Testing Frame

The full-panel test frame was designed with the intent of testing various types of screens used for roof and rib support in underground coal mining. A secondary goal was to be able to test any screen type materials used in the mining industry. This also includes various screen anchor spacing geometries (replication of the bolt locations in mine setting) and loading points within the screen section. The final design allowed for variable bolt anchoring spacing from 0.3 to 2.44 m in both directions. This provided for realistic roof and rib support spacing.

Another area of design variability is within the loading application points. The system was designed to be able to move the centroid of the loading point, as well as modify the area and magnitude of the loading contact. To accomplish these goals, the system was designed with rotatable anchor points in Figure 3. Another necessary component was the chain and shackles allowing for attachment to various load fixtures. The roof pull points were designed to be adjustable in position to apply a centralized load to the area between bolts as well as an eccentric loading with respect to the bolt anchor points. Currently, we have limited the pull points to six, but more could be added to the system if desired in the future. Figure 5 shows a shakedown test conducted to ensure that the planned capabilities were incorporated into the design prior to conducting actual testing.

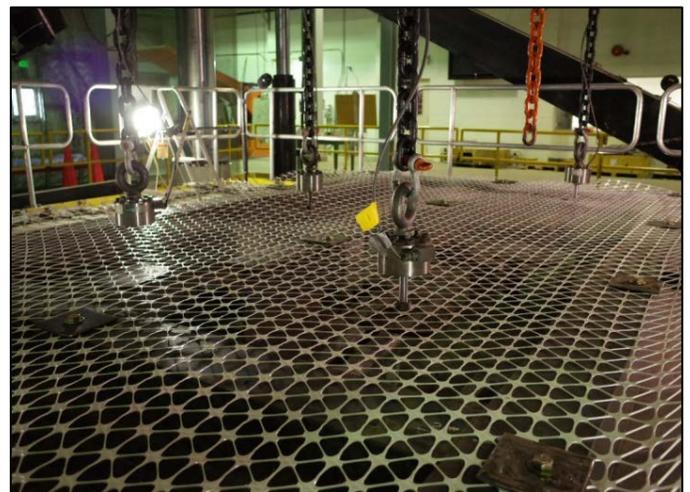


Figure 5. Image showing shakedown testing utilizing three loading points and the standard 1.22-m bolt anchor spacing.

The final manipulation of the testing frame was to vary the sequence of loading points in “time.” The “real-world example” of this is when the roof or rib sags at different locations at different times. This could be accomplished in several ways using the newly developed full-panel test rig. The first option is to simply apply different-length chains to the various pull points. The second option would be to add a “buffer” spring between the pull fixture and the MRS roof anchor.

Experimental Design

The experimental design consisted of two phases. The first phase was the baseline comparison tests between the partial-panel test frame and full-panel frame. Test type1 was a 1.52 x 1.52-m section of screen anchored on 1.22-m centers in the partial-panel test frame and loaded with a single pull point. Test type2 is the same as test type1, except that it is performed on the new full-panel test frame. Test type3 is performed on the full-panel test frame with two 1.35 x 3.9-m screen panels anchored on 1.22-m centers and loaded with 6 pull points centered in between each bolted area. The two panels of screen in test type3 are overlapped by 30.5 cm along the long axis and are anchored every 1.22 m about the same axis.

The second phase, aimed at assessing repeatability, included two different tests, each conducted four times. The first test (type2) was designed to replicate original NIOSH screen testing procedures (Dolinar, 2006; 2009) using the new larger (full-panel) test frame. It consisted of a 1.22 by 1.22 meter spacing with a single pull point using a rounded edge bolt plate located in the center. The second phase two test (type3) was 6 pull points in the full-panel test frame using two screen panels loaded over a 2.4 m x 3.6 m area. The screen panels anchored on a 1.22 m spacing.

All tests included in this paper were tested using a displacement rate of 5.1 cm/min. The loading fixture used for all of the tests was the rounded-corner, 30.5-cm roof bolt plate. Weld and wire breaks were counted with photographic documentation as well.

RESULTS

The results for both phase 1 and 2 include the load-displacement data for each test, as well as the weld and wire failures.

Phase 1 Results

For the testing using the partial-panel test frame of a single 1.52-m-square section of screen (type1), the load-displacement curve showed a yield load of 8 kN at 251 mm. Figure 6 also shows the measured peak load of 10.5 kN at 496 mm of displacement.

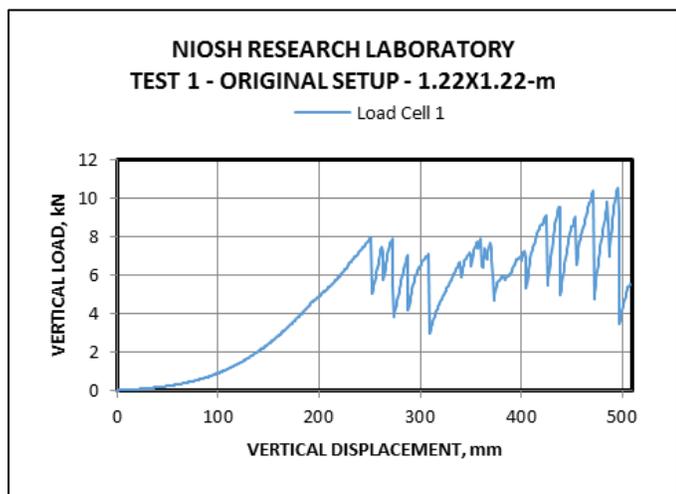


Figure 6. Displacement versus load for welded wire mesh using the original test setup.

The test replicating the original 1.22 by 1.22-m test (type2) on the new full-panel test frame resulted in a yield load of 5.6 kN at 224 mm of displacement. As can be seen in Figure 7, the measured peak load is 12.3 kN at 390 mm of displacement.

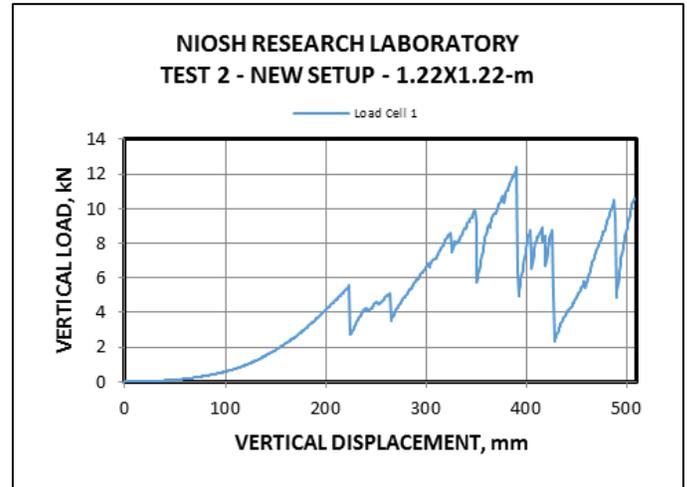


Figure 7. Displacement versus load for welded wire mesh using the large-scale frame replicating the original setup.

The results for the two (type3) tests on a 2.4 m x 3.6 m area of roof screen were relatively similar in terms of the average yield load, peak load, and associated displacements. The range of yield and peak loads varied from 2.9 to 7.6 kN and 6.2 to 16.2 kN, respectively. The average yield load was 4.1-kN at 165-mm of displacement, whereas the average peak load was 9.7 kN at 475 mm of displacement. The values for the second test can be seen in Figure 8.

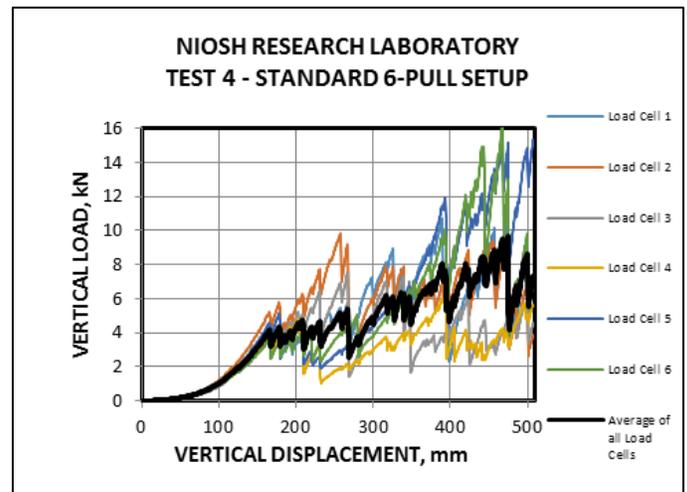


Figure 8. Displacement versus load for the 6-pull-point test showing all 6 load cells and the average response.

Slips, weld breaks, and wire breaks were monitored in addition to the load-displacement results during each test. The 2.4 x 3.6-m tests produced two to four times the amount of slips, weld breaks, and wired breaks as can be seen in Figure 9.

Phase 2 Results

The results of phase two include four 6-pull-point tests on a 2.4 x 3.6-m section of roof screen (type3) and four tests on 1.22 x 1.22-m screen sections (type2) all in the full-panel test frame.

Figure 10 shows the results of a 6-pull-point (type3) test. The load versus displacement for each of the 6-pull-points and the average of the 6-pull-points are shown. The peak load for this test occurred at load cell location 1 with 18 kN at just over 500 mm of displacement. The average load from all six loading locations is just over 10 kN at just under 500 mm.

The four type2 tests on a 1.22 x 1.22-m screen section, produced relatively similar results for the peak and yield loads and their corresponding displacements. Figure 11 shows that the peak load

ranged from 6.3 to 8.0 kN and the yield load ranged from 10.3 to 12.7 kN.

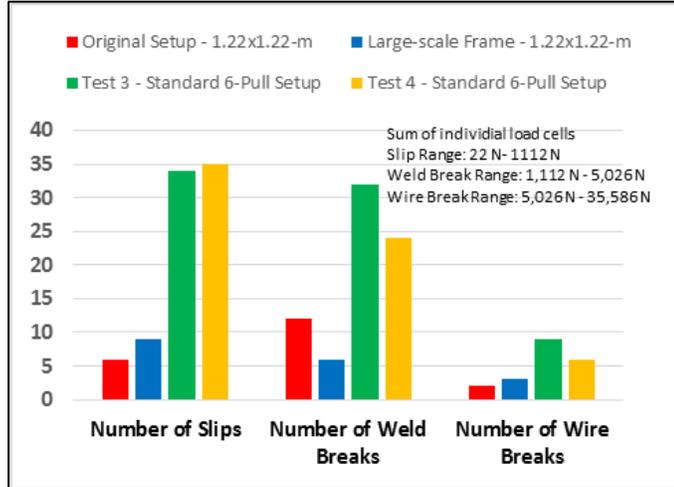


Figure 9. Comparison of slips, weld breaks, and wire breaks for phase 1 tests.

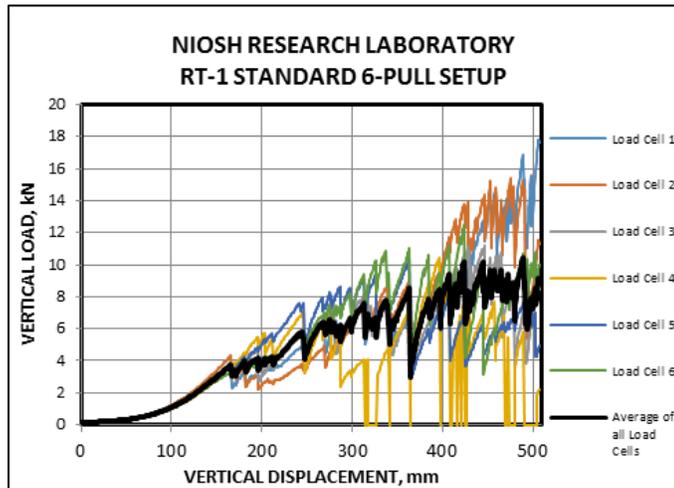


Figure 10. Displacement versus load results for a sample 6-pull-point test of the repeatability testing, including the average of all load cells.

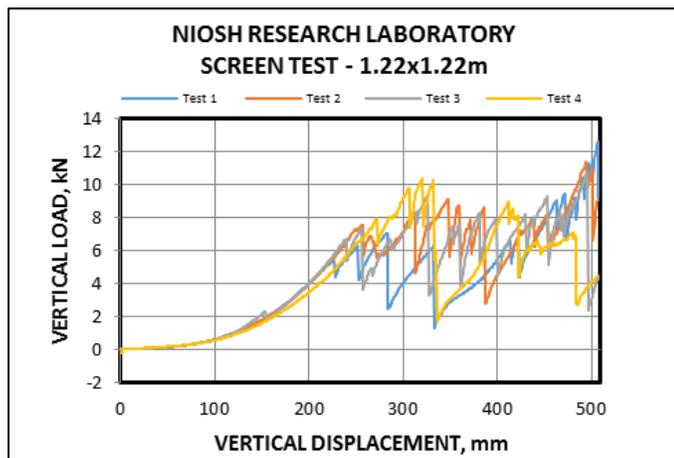


Figure 11. Displacement versus load for all 4 of the large frame 1.22 x 1.22 meter tests (type2).

The average, maximum, and minimum performance characteristics at the yield and peak loading are shown in Table 1 for the six load cells for the 2.4 x 3.6-m section of roof screen and average

performance characteristics for the smaller 1.22 x 1.22-m screen sections.

Table 1. The yield and peak characteristics of the 6-pull-point and 1.22 x 1.22-m tests. Load, displacement, and stiffness for the average, minimum, and maximum.

	6-pull-point - Yield			6-pull-point - Peak		
	Load	Displacement	Stiffness	Load	Displacement	Stiffness
Average of all Tests/Load Cells	5.7	206.9	0.25	13.3	452.2	2.07
Maximum of all Tests/Load Cells	10.0	298.2	0.35	20.0	506.5	3.98
Minimum of all Tests/Load Cells	3.5	166.1	0.19	8.8	353.3	0.92
	1.22 x 1.22-m - Yield			1.22 x 1.22-m - Peak		
	Load	Displacement	Stiffness	Load	Displacement	Stiffness
Average of all Tests	7.1	255.0	0.28	11.3	454.3	1.10

The counts of slips, weld breaks, and wire breaks are summarized in Figure 12. For the 6-pull-point tests on the 2.4 x 3.6-m section of roof screen, the total number of slips, weld breaks, and wire breaks are presented. For the 1.22 x 1.22-m tests, the values represent a single load cell.

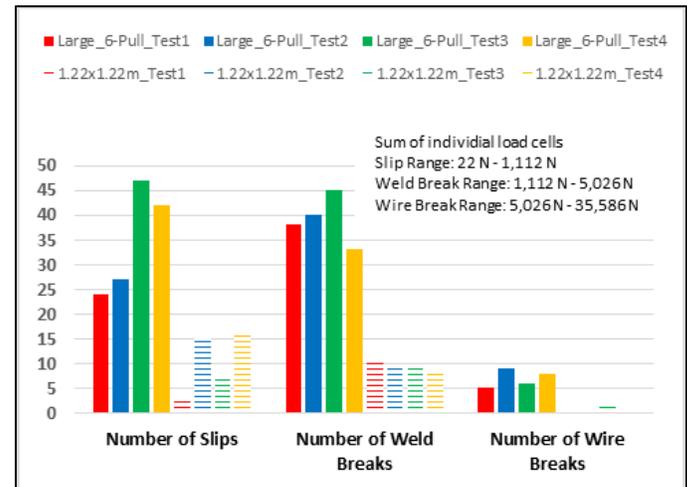


Figure 12. Comparison of slips, weld breaks, and wire breaks for the 8 repeatability tests.

DISCUSSION

The phase 1 testing with the smaller test frame showed that the 1.22 x 1.22-m (type1) tests produced a slightly higher yield load and lower associated stiffness than 1.22 x 1.22-m (type2) and 2.4 x 3.6-m (type3) screen section tests with the larger full-panel test frame. The peak load was slightly lower with a higher associated stiffness for the 1.22 x 1.22-m (type1) test compared to the 6-pull-point (type3) test in the larger full-panel load frame. These differences are most likely associated with variations in the steel and welds on the welded wire screen as opposed to the impact of the size of the test frame.

The phase 2 testing produced relatively repeatable results for the larger 2.4 x 3.6-m tests when you look at the average of all load cells. The yield load, displacement, and stiffness varied by less than 10%, while the peak load, displacement, and stiffness varied by as much as 12% for the (type3) 6-pull-point tests. For the 1.22 x 1.22-m (type2) tests in the larger full-panel frame, the yield load, displacement, and stiffness varied by as much as 27%, while the peak load varied by less than 22%. For all tests in the larger full-panel frame, the slips, weld breaks, and wire breaks were much more variable than the load and stiffness behavior.

The increased repeatability observed with the larger screen tests that encompass six bolted areas compared to a single bolted area test

suggest that the full-panel screen testing is more representative of the in situ performance of the screen. The average yield load for the 6-pull-point tests were about 20% lower than the 1.22 x 1.22-m tests. However, the maximum yield load for the 6-pull-point tests were about 25% higher than the 1.22 x 1.22-m tests; indicating that a single bolted section performance may not be representative of the full panel screen performance.

The repeatability results of the 6-pull-point tests are welcomed results given credence to using the larger, full-panel test frame to conduct testing that is more representative of the installed screen loading conditions.

This includes varying bolt spacing, varying loading conditions, different anchoring systems, and various surface skin control products. Furthermore, the more conservative response of the screen should provide a larger margin of safety in assessing screen performance and design considerations.

The end outcome of the test frame will be a better understanding of the skin control products' capabilities, the products' interactions with other support members, and ultimately optimized design.

DISCLAIMER

The findings and conclusions in this report are those of the author(s) and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company or product does not constitute endorsement by NIOSH.

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