Performance Characteristics for Large Sections of Welded Wire Screen With Multiple Pull Patterns

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ABSTRACT

From 2011–2016, there were 1,511 documented injuries, including 7 fatalities, from ground falls in underground coal mines in the United States. The majority of these ground-fall injuries were not caused by a major roof collapse, but from falls of smaller rocks from the immediate roof. Roof screen can significantly reduce the number of these injuries and has been widely used in underground coal mines for surface control. Because of the potential of reducing ground-fall injuries, the National Institute for Occupational Safety and Health (NIOSH) is further evaluating the performance characteristics of welded wire screen as used in underground coal mines by conducting a laboratory testing program using the Mine Roof Simulator (MRS) in Pittsburgh, PA.

The load-displacement characteristics of an 8-ft x 12-ft panel of 8-gauge welded screen were evaluated using a newly designed, large laboratory screen test frame with multiple load pull locations. This screen was tested in a configuration that simulates current installation practices in U.S. coal mines. In this study, the effects of varying the number and position of the load pull location on the screen performance were evaluated. Ultimately, the type of information obtained in this and similar studies can be used to aid in developing wire roof screen design criteria and to assist mine operators in the selection and use of roof screen in underground mines.

INTRODUCTION

The large majority of ground-fall injuries are caused by falls of smaller rocks from the immediate roof. Various controls are currently being used in mines to control this surface rock, including the use of wire roof screen. In mines where wire roof screen has been installed, injuries from rock falls have been reduced dramatically (Robertson and Hinshaw, 2001). Roof screen has the potential to prevent hundreds of injuries caused by the fall of small rocks between permanent roof supports (Compton et al., 2007). Because of this potential for reducing ground-fall injuries, the National Institute for Occupational Safety and Health (NIOSH) is evaluating the performance characteristics of welded wire screen as used in underground coal mines by conducting a laboratory testing program in the Mine Roof Simulator (MRS) in Pittsburgh, PA.

Previous tests to evaluate the performance characteristics of various types of screen have been conducted by the University of Alberta (Tannant, 2001). In this study, the load-displacement properties of welded wire, chain link, and expanded metal mesh were measured by performing full-scale pull tests. A flat steel plate was pulled through a screen test sample that was bolted to a special test frame while the pulling force and mesh displacement were measured. These tests established the general load-displacement behavior of the screen. Peak load capacities and stiffness were determined for each screen type, showing how welded wire mesh has a much stiffer initial loading response, whereas chain link and expanded metal mesh have large displacement capabilities and exhibit significant post-peak ductility.

Three-dimensional (3D) numerical modeling has also been used to evaluate the performance characteristics of roof screen (Murali, Rusnak, and Honse, 2006). Numerical modeling provides an alternative approach in deriving the load-displacement characteristics of roof screen with reasonable accuracy up until the initial yield load point. After the yield point, the complexity of the failure mechanism is problematic to model due to the difficulty in determining if the load shed events were due to wire slippage or the failure of the weld, wire, or any combination of these factors. Based on a 3D numerical model parametric study, load-displacement responses were evaluated by nonlinear numerical models, which showed the importance of boundary conditions at the bearing plates. With most of the load capacity being carried by the wires that are directly under the bearing plates, screen stiffness and yield load capacity could be obtained by ensuring the maximum possible number of wires are securely held by the bearing plates.

In previous NIOSH studies, laboratory tests were conducted to develop performance characteristics that could be used in the evaluation of welded wire screen (Dolinar, 2006; 2009). In these studies, the wire size and configuration, bearing plate loads, and bolt spacing were varied, using a laboratory test frame capable of varying bolt spacing from 4 to 5 feet with four bolts used to attach the screen to the frame. In these studies, the screen capacities were altered by the bearing plate size and load surface type. Also, the screen performance was affected by slippage at the bearing plates.

NIOSH also previously studied and evaluated the performance characteristics of an 8-ft x 12-ft panel of 8-gauge welded screen, using a large laboratory test frame with multiple load pull locations (Batchler, 2018). The screen was tested in a configuration that simulates the installation of roof screen in U.S. coal mines. The effects of the displacement loading rate, load pull surface geometry, and roof channel on the screen load-displacement characteristics were evaluated.

An Australian study measured the load-displacement response of two different wire screen designs from large-scale pull tests (Shan, Porter, and Nemcik, 2014) and compared them to numerical modeling. Large-scale pull tests were performed on welded screen sections measuring 4.25-ft x 12-ft and 5-ft x 13-ft, using a single dome plate instead of the usual flat steel plate. The load-displacement curves derived from the numerical modeling were similar to the full-scale laboratory tests, with only slight differences due to the model not being able to replicate the slippage of the screen under the bearing plates.

In the current NIOSH study, the performance characteristics of an 8-ft x 12-ft panel of 8-gauge welded screen was evaluated using a large laboratory test frame with multiple load pull locations. In this study, the effects of varying the number and position of the load pull location on the screen performance were evaluated. Ultimately, the type of information obtained in this and similar studies can aid in developing design wire-roof-screen criteria and in assisting mine operators in the selection and use of roof screen in underground mines.

TEST FACILITY AND PROCEDURES

A test frame (Figure 1) was installed in the Mine Roof Simulator (MRS) that was designed with the capability of testing a full panel of 8-ft x 12-ft welded roof screen. A 4-ft bolt spacing was used to attach the screen to the frame. Load was applied to the center of each bolted area, using a one-foot-square load plate. Up to 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 20 in. The pull tests were conducted in displacement control with a displacement rate of 2 in/min.

Figure 1. Test frame setup used to test the six-load-pull-location welded screen. Bolt spacing was 4 ft x 4 ft.

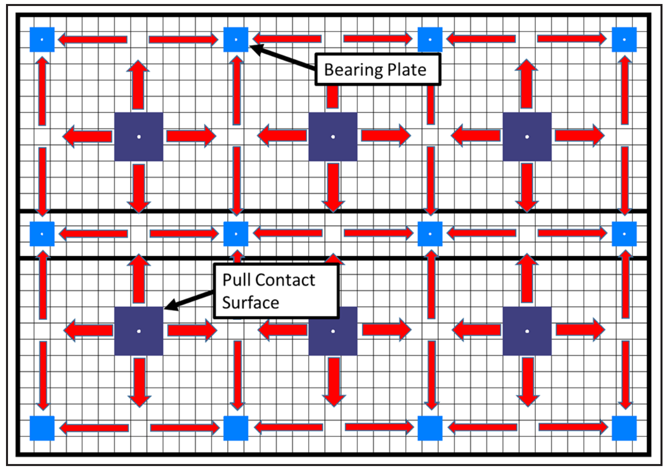

Figure 2. Schematic of screen test configuration with square bolting pattern with respect to the screen. The arrows indicate the load transfer directions from the pull plates to the bearing plates.

The screen loading was measured using a 20,000-lb or 50,000-lb load cell attached to the pull chains with an accuracy of ± 20 lb or ± 50 lb, respectively. The screen displacement was monitored using a Temposonics magnetostrictive linear position sensor with a ±0.01 in 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 0.75-in diameter and were placed on a 4-ft x 4-ft pattern. The bearing plates were 6-in x 6-in, 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 150 lb-ft to generate approximately 15,000 lb of load on each bearing plate.

The screen was placed in a rectangular configuration with respect to the test frame and bolts (Figure 2). This is similar to a typical installation in an underground coal mine. With this arrangement, load was transferred from the load pull areas to the bolt and bearing plates by the screen. The welded screen positioned on the reaction frame was sized to include a one-mesh square (4-in) extension beyond the bolts on all sides.

WELDED WIRE SCREEN

One of the most common roof screen designs used in U.S. coal mines is an 8-gauge wire, welded into a 4-in x 4-in spacing or aperture with a nominal wire diameter of 0.161 in. There are currently no standards for the properties of welded wire screen used in mines. The requirements for the strengths of the wire and weld are those developed for concrete reinforcement and are associated with ASTM specifications related to that application. According to these ASTM requirements, the weld strength in pounds-force should not be less than 35,000 multiplied by the nominal area of the wire in square inches when tested in accordance with the designated ASTM tests (ASTM A-497-99, 2004). The area of the 8-gauge wire

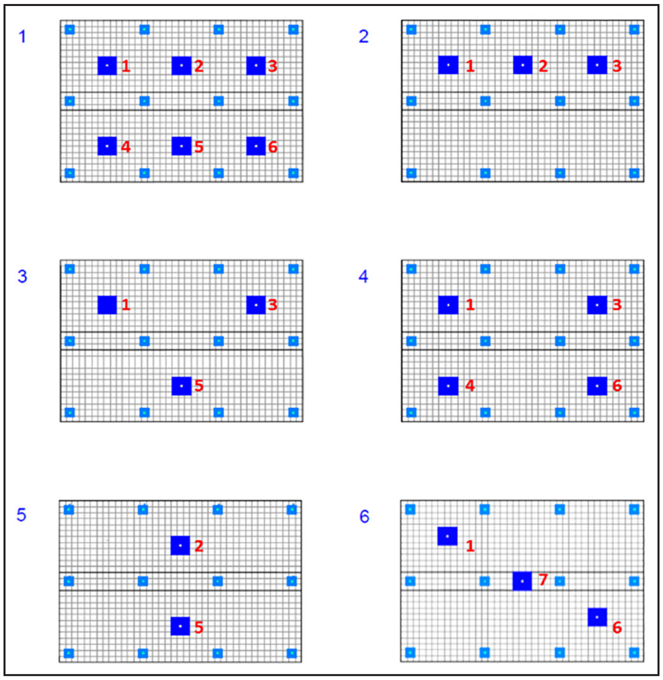

Figure 3. The various configurations of the test layouts for this series of tests and pull locations for each load cell.

is 0.0201 in^2, resulting in a minimum weld strength of 710 lb with a calculated shear stress strength of 530 lb. The tensile stress of wire must exceed 75,000 psi (ASTM A-823-97A, 2004; Dolinar, 2006).

EXPERIMENTAL DESIGN

In this series of tests, the test setup varied using multiple load pull locations. Research was conducted on the effects of varying the number and position of the load pull location, and the screen performance was evaluated.

A schematic of the screen test configurations with the bearing plate bolting pattern and various pull locations is shown in Figure 2. This figure shows arrows to indicate the primary load transfer directions along the wires from the loading plate to the bolted bearing plates. This bolt pattern is consistent with the typical installation currently used in underground coal mines. With this test configuration, the loading is transferred from the load area through the corresponding screen wires crossing the loading plate, then largely to the perpendicular wires that directly connect to the bearing plates (Dolinar, 2006). Figure 3 shows the various configurations of the test layouts and pull locations for this series of tests. The loading is measured with a load cell at each of the pull locations.

TEST RESULTS

Six different test configurations were evaluated during this study, as shown in Figure 3.

A representative load-displacement curve for one of the tests is shown in Figure 4. The test data was analyzed to determine the average of the pull points for the peak load, stiffness at peak load, yield load, and stiffness at yield load (Table 1). The yield load is identified as the point where there is a significant change in behavior from a general elastic screen response to inelastic

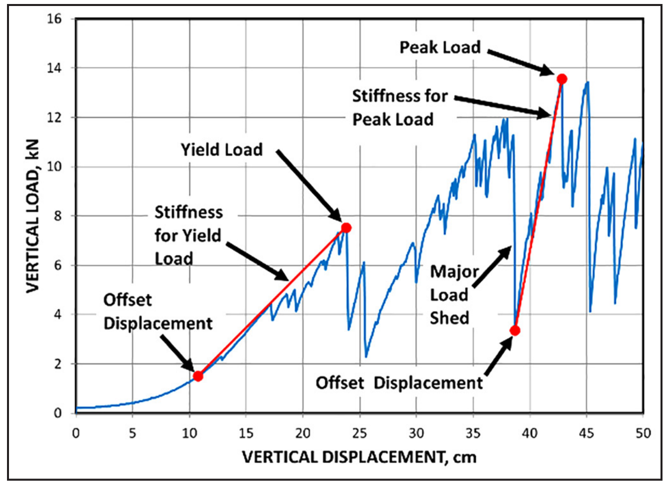

Figure 4. Load-displacement curve for a test on a welded screen, showing key parameters used to evaluate the screen performance.

behavior during the initial screen loading. Generally, the yield load is determined by the first major load shed event. Calculated screen stiffness related to the yield load was determined based on the slope of the line from the yield load to a 20% offset displacement (see Figure 4). After the yield load point is reached, there is often a loss of load caused by some form of significant screen damage. Slippage at the bolted interface produces a jagged load response, whereas permanent damage from either wire or weld breakage is seen as a large, sharp load drop. This screen slippage or damage is categorized as a load shed event. The peak load is the maximum load capacity of the screen. It is generally preceded and followed by a load shed event, indicating that some form of failure has occurred. Similarly, the peak load stiffness is calculated from the load reduction due to a major load shedding event prior to the restoration of load leading to the peak load.

The weld shear strength for an 8-gauge wire used in screen fabrication is 530 lb. For the wire screen, a baseline shear value of 250 lb was selected based on the shear strength of a weld break for a single weld break, which tends to occur mostly at the bearing plates. The load shed was shared between two separate pull locations. Unlike weld breaks, wire breaks generally occur at or near the loading plate with the loading response confined to a single (4-ft x 4-ft) screen area and measured by only one load cell. Consequently, the wire break limit was based on the 1,130-lb shear strength of an 8-gauge wire at a single location. Slippage and weld breaks and wire breaks produce an increased deflection or softening of the screen loading behavior. A load shed event is then sorted into one of three categories based on the magnitude of the load shed: (1) wire slip event, 15–250 lb, (2) weld break event, 250–1,130 lb, or (3) wire break event above 1,130 lbs.

EVALUATION OF TEST RESULTS

Six different pull point configurations were evaluated in the full-scale laboratory test. In evaluating the impact of these parameters, the stiffness, yield, and peak load averaged from the load points were analyzed. After the yield load occurs, screen performance behavior is dominated by load shed events caused from the slippage of the screen under the bearing plates or the failure of the wires from weld or wire breakage. The change in screen performance

Table 1. Results of the welded screen tests conducted in the Mine Roof Simulator (MRS). Values are averages for each test series.

Test Configuration	Number of Pull Points	Stiffness at Yield Load	Stiffness at Peak Load	Yield Load Capacity	Peak Load Capacity
		kips/in	kips/in	kips	kips
1	6	0.245	1.914	1.251	2.862
2	3	0.285	1.589	1.222	2.539
3	3	0.354	1.689	1.735	3.860
4	4	0.266	2.019	1.594	2.949
5	2	0.304	1.537	1.287	4.455
6	3	0.468	1.772	1.754	3.873

characteristics relative to the stiffness, yielding, and peak capacity was analyzed for the various test parameters.

Stiffness

Screen stiffness is a measure of how quickly the screen system develops its load carry capacity in relation to the load caused from roof skin or surface fall. Stiffness is an important factor in designing screens because, as a passive structure, the load resistance is only developed through the loose rock from the skin fall.

The stiffness for each of the six different pull point configurations were evaluated (see Figure 5). The load at the individual pull points was applied, using either a combination of 2, 3, 4, or 6 pull point locations. A 4-ft bolt spacing was used to attach the screen to the frame. Load was applied to the center of each bolted area, using a one-foot-square load plate, except for the sixth configuration, where the pull point was applied between the center bolted area (see Figure 3).

The individual stiffness for each of the pull point locations during each setup configuration test was analyzed, and the results are shown in Figure 5. On average there was a 9%–44% increase in average system stiffness of the screen using the different setup configurations. The observed variability in the stiffness capacity is likely attributed to the position of the pull points, the boundary conditions at the multiple load pull points, and the test frame reactions of the bolted plate. When compared to the results of the first and sixth test configurations, shown in Table 1, the loading stiffness prior to yielding increased by 248% and peak loading by 49% when analyzing the center load cell (#7) from the sixth setup configuration compared to the average yield loading stiffness from the first setup configuration. This can be explained because, when using the sixth setup configuration, the center load was applied at a closer distance to the bearing plate, causing the increased stiffness (Figure 3).

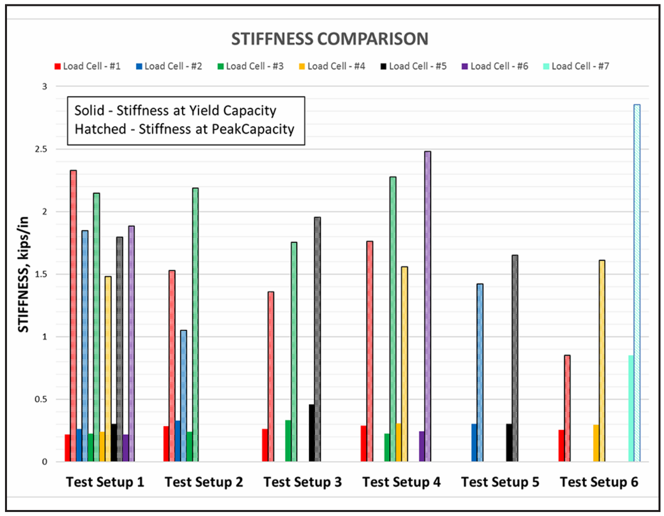

Figure 5. The individual stiffness values for each pull point for all six test configurations.

Yield and Peak Load Capacities

Table 1 displays the yield and peak load capacity for each of the pull locations using the six different test setup configurations. The average screen yield and peak load capacity using the six setup configurations ranged from 1.068–1.754 kips and from 2.539–4.455 kips, respectively. Observed from this data, the impact from the number and location of the pull points directly affects the yield and peak load capacities of the screen. From these tests, it was observed that, if the pull point locations were unaffected from the proximity of other pull point areas, the load capacity of the screen would be higher. In other words, the performance capacity of the screen would be improved if the sections of the screen around the pull point area were not also under load. For example, Table 1 shows an increase in average yield and peak load capacities by 39% and 35%, respectively, when comparing the first and third test setup configurations. However, when compared to the first and second test configuration setup, there was only a minimal change with the average yield and peak load (2% and 11%, respectively). When using the second screen layout configuration, the screen performance behavior allows the entire load capacity of the three pull points to be transferred through only one side of the test frame. This means that, essentially, the first test layout configuration is repeated using the same amount of wires to transfer load per pull point. The second side of the test frame does not have any pull point contact and does not develop any load. The third configuration, while still only using three pull points, spreads the load contact transfer over a larger area of the test frame. Therefore, the load capacity is shared through a larger number of wires and is less affected by the other pull point areas, thus allowing for a larger average load capacity per pull point.

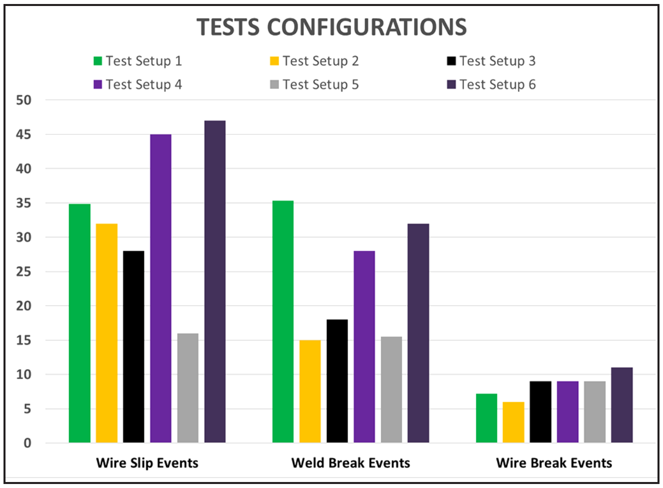

Figure 6. Amount and type of load shed events for each test configuration.

The largest individual pull point occurrence was the center load cell (#7) for the sixth setup configuration with the yield and peak load capacity of 1.938 and 5.716 kips, respectively. This was due to proximity of the pull point location to the center bearing plates.

Load Shed Events

The screen performance behavior for each of the six different test setup configurations was also assessed by evaluating the number of load shed events that occurred from either a wire slip, weld break, or wire break. A load shed event is defined as a sudden drop of load capacity greater than 5 lb. Figure 6 shows the number of wire slips, weld breaks, and wire breaks per test for each test parameter. Each load shed event was sorted into one of three categories: (1) wire slip event, 5–250 lb, (2) weld break event, 250–1,130 lb, or (3) wire break event, above 1,130 lb.

Changing the location and number of pull point contacts affected the amount of load shed events. From the results in Figure 6, using less load pull point locations showed a decrease in weld break events. For test configurations two, three, and five, there were 49%–58% less weld break events. However, the number of wire breaks were similar for the test series one through five with a change of plus or minus two wire break events.

Figure 6 shows an increased total number of load sheds when using the sixth setup configuration. This, again, is due to the location of the #7 load cells and the proximity to the center bearing plates. The increase load sheds are a result of the shorter distance (9.6 inches closer) to the bearing plates compared to the other test configurations. The load-carrying wires allowed for a higher load-carrying capacity, while allowing for more load shed events than when using the other test configurations.

CONCLUSIONS

Laboratory tests were performed to evaluate the load-displacement characteristics of an 8-ft x 12-ft panel of 8-gauge welded screen. In this study, the effects of varying the number and position of the load pull location on the screen performance were evaluated. The screen capacities were measured with respect to yield and peak load and the associated stiffness. The screen damage and impact on performance was analyzed with regard to wire slips, weld breaks, and wire breaks.

The study analyzed the effect of varying the number and position of the load pull points on the system stiffness of wire screen. On average, there was a 9%–45% increase in average system yield stiffness of the screen using the different setup configurations.

Also observed from this data was the impact from the number and location of the pull points on the yield and peak load capacities of the screen. The general trend is an increase in average load capacity when the test configuration allowed the unloaded section of the screen to contribute to the overall load capacity of the loaded sections of the screen. This can specifically be observed when comparing test configurations two and three, which resulted in over a 40% increase in average yield and peak load capacity.

This study also analyzed the effect of changing the location and number of pull point contacts affecting the amount of load shed events. It was observed from the data that using less load pull point locations and increasing the distances between load pull points could result in over 58% decrease in weld break events. Therefore, the placement and number of load pull points can significantly affect the screen capacity and performance.

Ultimately, the type of information obtained from these tests can be used to aid in developing wire roof screen design criteria and in assisting mine operators in the selection and use of roof screen in underground mines.

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