

Vertical Load Capacities of Roof Truss Cross Members

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ABSTRACT

Trusses are primarily used as passive roof supports in coal mines. They are constructed of three main parts: two grouted bolts installed at opposing forty-five degree angles into the roof so that they are anchored over the ribs and a cross member that ties the angled bolts together. There is also hardware used to assemble these components. The capacities of the angled bolts are typically 30 to 40 tons and the tensile capacity of the cross member is also 30 to 40 tons. Importantly, the direction of the immediate roof loading on the cross member is unlike the direction of the loading on the angled bolts. The load on the cross member is transverse to the longitudinal axis instead of along it, and therefore the cross member is loaded in the weakest direction.

Previous tests conducted on truss systems applied loads such that the increasing tension in the two diagonal bolts increased the tension in the horizontal cross member, resulting in a stiff response. By contrast, if the load is applied directly to the cross member, which then transmits those forces to the diagonal bolts, it results in a much softer response.

Based on this difference, laboratory tests to apply transverse loads and measure the vertical load capacity of three different types of cross members were conducted using the Mine Roof Simulator (MRS) located at the National Institute for Occupational Safety and Health (NIOSH) in Pittsburgh. The length of the samples was about 16 feet. Single-point load tests, with the load applied in the center of the specimen were conducted to verify the performance of the test arrangement and the finite element models. Double-point load tests, with a span of eight feet, were also conducted. This arrangement replicates the performance of the cross members with a distributed load. Both of these test arrangements were conducted on one-inch-diameter threaded steel bars and 0.7-inch-diameter cable and 0.6-inch-diameter cable cross members.

For the single-point load configuration, the yield of the one-inch bar was nominally 22 kips of vertical load, achieved at 17 inches of deflection. For both sizes of the cable cross members, yield was not achieved even after 18 inches of deflection. Peak vertical loads were about 20 kips for the 0.7-inch cables and 15 kips for the 0.6-inch cables. For the double-point load configurations, the one-inch

bar cross members yielded at 33 kips of vertical load and 10 inches of deflection. The 0.7-inch-diameter cable cross members broke strands at 30 kips of vertical load and 10 inches of closure, and the 0.6-inch-diameter cable cross members broke strands at 25 kips of vertical load and 10 inches of closure. Finite element models of each of the six different configurations were developed and show the variation of the vertical capacity of the cross members and the difference of the behavior of the bar versus the cables.

BACKGROUND

The roof of a coal mine normally sags or bulges downward some small amount immediately after the room is mined as the in situ stress is relieved. This small amount of convergence normally slows as the ground stabilizes and as the stress redistributes around the mine opening (White, 1968). Roof bolts are installed to form a stiff beam in the strata by clamping layers together and increasing the resistance of the bolted section to shear and bending forces. Unfortunately, this clamping tension can create voids near the top of the bolt anchor which can weaken the attachment of the roof beam to stronger layers of rock above.

Beam formation is how the self-supporting capacity of the roof can be maximized. There are two factors that are most important to the successful application of this method. The first is to ensure the maximum thickness of the roof beam, by adding the lowest layers of the roof to it. This is accomplished by the standard bolting pattern. The second is to eliminate or reduce tensile forces in the roof caused by elongation from bending of the roof beam. This can be accomplished by the installation of roof trusses where the cross member tension can reduce or eliminate tensile forces that exist in the roof (White, 1968).

It may be true that the roof usually only needs a "little help" to prevent falls and that if the bottom 12 inches of the roof is held, then the rest will stay up (White, 1968). But roof support must provide the strength, stiffness, and stability to match the weight of the entire roof that may need support. The truss arrangement of bolts, cables, or bars, when added to the standard roof bolt pattern, can meet the requirements to support the roof and this can be accomplished without obstructions in the travelway or restrictions to ventilation airflow.

Previous tests conducted on complete trusses applied the vertical force to a beam, such that the angled bolts applied tension to the cross member (Oldsen, 1997) (Stears, 1988) (Mangelsdorf, 1979). This method of simulation eliminates deflection of the cross member and therefore, measures a large proportion of the vertical load capacity from the angled bolts. But to monitor the field performance of trusses, the tension in all three legs, along with the roof sag must be measured. This study measured the vertical capacity of the cross members by applying transverse loads directly to them. This method of simulation causes the cross member to deflect which then transfers the vertical load to the angled bolts.

LABORATORY TESTING

Roof trusses are constructed of three main parts: two grouted bolts installed into the roof at opposing forty-five degree angles so that they are anchored over the pillar and a cross member that ties the ends of the angled bolts together. There is also hardware to assemble these components. The capacity of each component is typically in the range of 30 to 40 tons. With the two anchor bolts installed at forty-five degree angles, the vertical capacity ranges from 21 to 28 tons for each bolt with a theoretical combined load capacity of 42 to 56 tons, or 84 to 112 kips.

Tests of the three different types of roof truss cross members were conducted in the MRS, located at the Pittsburgh site of NIOSH, to measure the vertical capacity of this single component. The increase in the vertical load is the result of the increase in tension caused by deflection of the cross member. The types of cross members tested were one-inch-diameter threaded bars, 0.7-inch-diameter cables, and 0.6-inch-diameter cables. The length of the specimens was sixteen feet and the maximum vertical deflection that could be applied was eighteen inches. A 50-kip load cell was attached to the center fixture and was used to measure the total force required to deflect the specimens.

Two different configurations were used for the tests in the MRS as shown in Figure 1. The first configuration was for the single-point load in the center of the specimen and the second configuration used a reinforced section of a W8 beam to apply the load at two locations, eight feet apart. The first arrangement was conducted to verify the properties of the material and the second arrangement, with the spread load at the quarter points of the cross member, was chosen because it approximates the condition where the load on the cross member would be uniformly distributed.

The ends of the specimens were attached to shoes that were made for each product as shown in Figure 2 and Figure 3. The shoes were mounted to the MRS fixtures using pieces of 1-inch-diameter threaded bar and a piece of a bar shoe cut to fit onto the top of the fixtures so that the threaded bar simulated the angled bolts installed at 45 degrees. The angled bolts showing the damage from shear caused by the tension in the cross member during a test are shown in Figure 4.

The tension on the threaded bars at the beginning of the tests were 5 and 10 tons. These forces were generated by applying either 250 ft-lbs or 500 ft-lbs of torque to the nuts at the dog-bone connection. The tension on the cable specimens were either 2.5 tons or 5.0 tons. These forces were applied by a tensioning jack before the tests. The tension for all of the spread load tests was 5.0 tons.

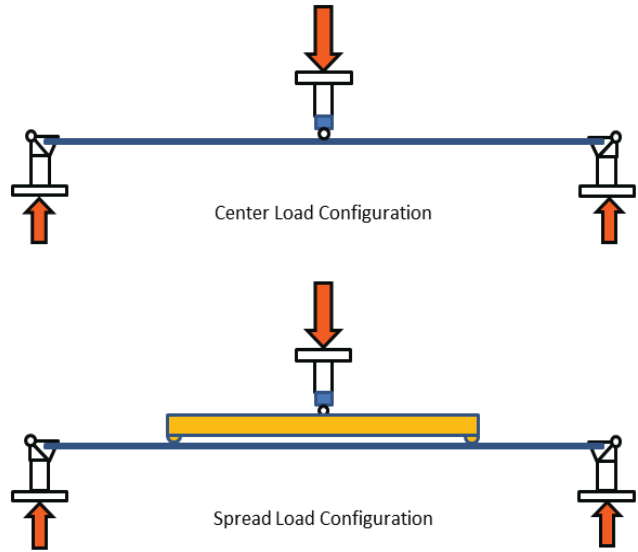


Figure 1. Test configuration diagrams.



Figure 2. A bar shoe and a shoe cut for the top of the fixture.



Figure 3. Shoes and dog bones for 0.7-inch cable (l) and 0.6-inch cable (r).

One-Inch-Diameter Threaded Bar Tests

Five tests were conducted with the single-point central load and four tests used the eight-foot-long beam to apply the load to the one-inch-diameter threaded bar at the quarter points. The yield stress of the bar was achieved at about 22 kips of vertical load after 17 inches of convergence for the single-point load configuration.

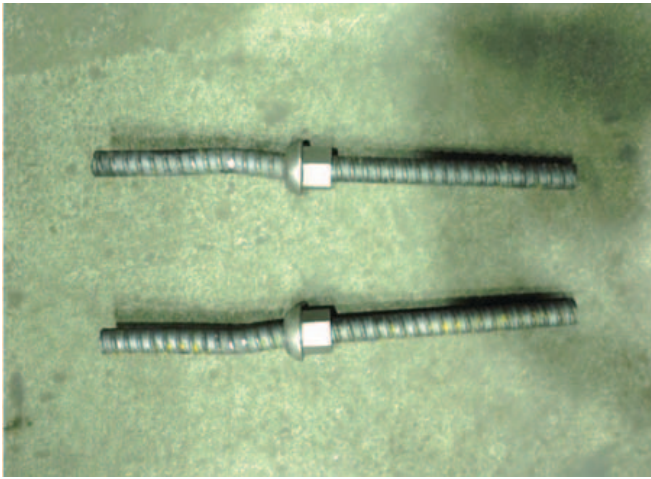


Figure 4. Angled bolts showing shear damage caused by the tension in the cross member.

For the eight-foot spread-load configuration, the average vertical load at the yield strength of the bar was about 33 kips at 10 inches of deflection. The stiffness of the spread-load tests from 6 to 10 inches of deflection is about 5.0 kips/inch. The results from both of these load configurations are shown in Figure 5.

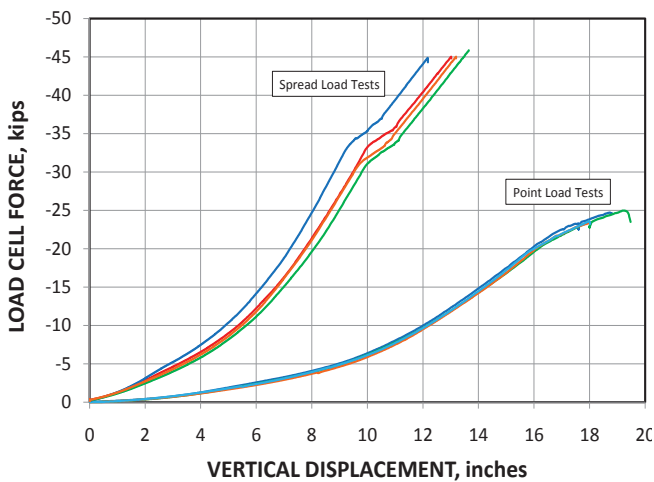


Figure 5. Test results from the one-inch-diameter threaded bar tests.

0.7-inch-Diameter Cable Tests

Five tests were conducted with the single-point central load and five tests used the eight-foot-long beam to apply the loads to the 0.7-inch-diameter cables at the quarter points. The yield stress of the cable was not achieved, even after 18 inches of convergence for the single-point load configuration. The maximum load reached about 20 kips.

For the eight-foot spread-load configuration, the load when strands of the cable began to break was about 30 kips at 10 inches of deflection. The tensile failures of the strands mainly occurred

near the end of the load beam, but sometimes occurred near the shoes. The stiffness of the spread-load tests from 6 to 10 inches of deflection is about 5.0 kips/inch. The results from both of these load configurations are shown in Figure 6.

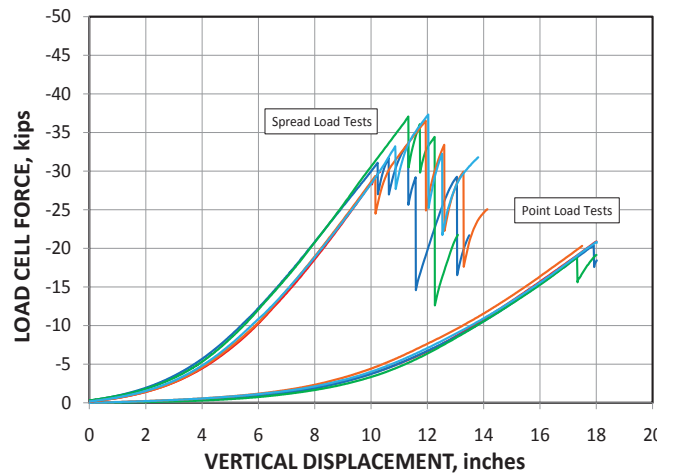


Figure 6. Test results from the 0.7-inch-diameter cable tests.

0.6-inch-Diameter Cable Tests

Five tests were conducted with the single-point central load and five tests used the eight-foot-long beam to apply the load to the 0.6-inch-diameter cables at the quarter points. The yield stress of the cable was not achieved, even after 18 inches of convergence for the single-point load configuration. The maximum load reached about 15 kips.

For the eight-foot spread-load configuration, the maximum applied load was about 25 kips at 10 inches of deflection. The stiffness of the spread-load tests from 6 to 10 inches of deflection is about 3.75 kips/inch. The results from both of these load configurations are shown in Figure 7.

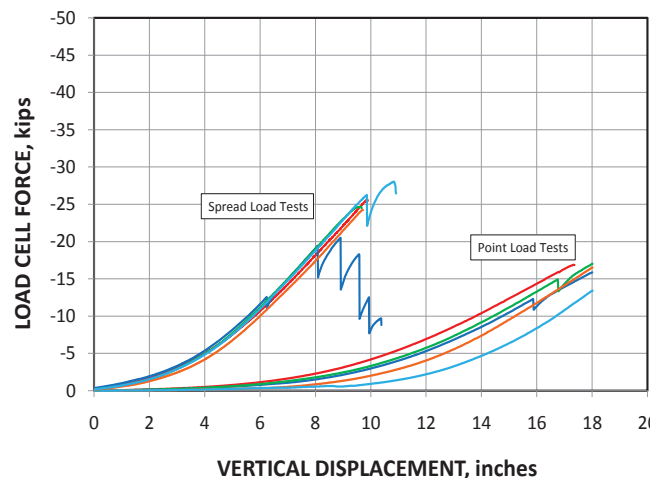


Figure 7. Test results from the 0.6-inch-diameter cable tests.

Finite Element Modelling

Finite element models (Figure 8) of the two load cases for each specimen were developed in ANSYS¹. The models used a rigid fixture at each end of the specimen, but the fixtures were allowed to rotate to replicate the bending of the truss shoes. This characterization forced the model to be stiffer than the actual test conditions. In addition, the cables were modeled as single solid rods with a cross-sectional area equal to the steel area of the cables and without a dog bone, which also made the cable models much stiffer than the test specimens because of the elimination of the cable lay and the wedge grips.

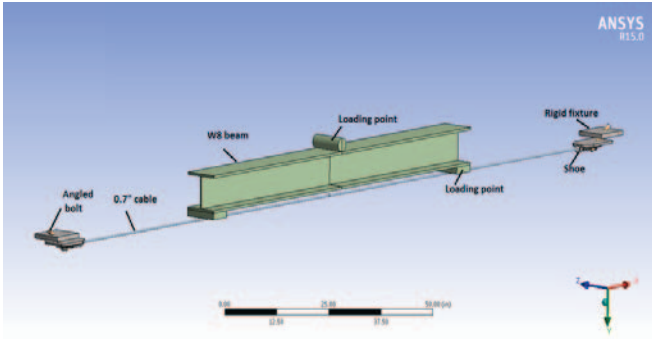


Figure 8. Finite element model for spread-load configuration.

Both material and geometrical non-linearity were considered in the models. The modulus of elasticity and Poisson's ratio of the bar material are 29.7×10^6 psi and 0.3, respectively. The stress-strain relationship of the bar material is shown in Figure 9. The yield and breaking loads of the 0.7-in diameter cable are 68.6 kips and 76.2 kips, respectively. The yield and breaking loads of the 0.6-in diameter cable are 52.74 kips and 58 kips, respectively. The yield and breaking strains of the cables are 1% and 3.5%, respectively. The calculated modulus of elasticity of the 0.7-in and 0.6-in diameter cable materials are 22.6×10^6 psi and 24.3×10^6 psi, respectively. The Poisson's ratio of the cable is 0.3.

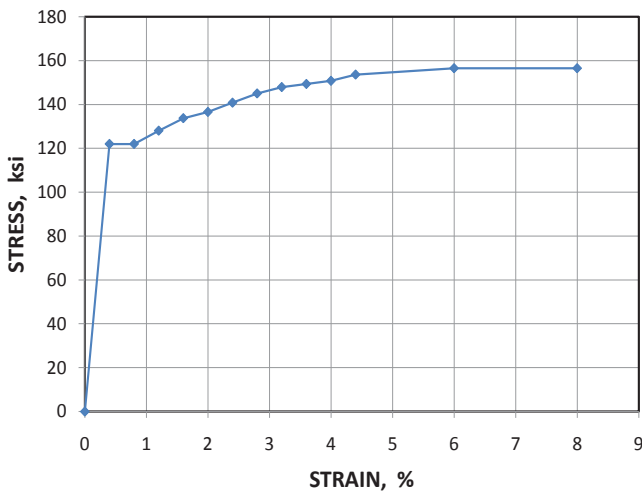


Figure 9. Stress-strain relationship of bar material.

For the bar specimen tests, the angle bolts had the same torque applied as the connector on the cross member. The shoes sliding on the fixtures, the angle bolts shearing due to the tension in the cross member, and the lateral deflection of the MRS end support fixtures required that a 'pull-in' factor be included to make the models fit the data from the tests. For the single-point load case the deflection factor was 1.60 inches, and for the beam load case the factor was 1.35 inches. The test results with the models are shown in Figure 10.

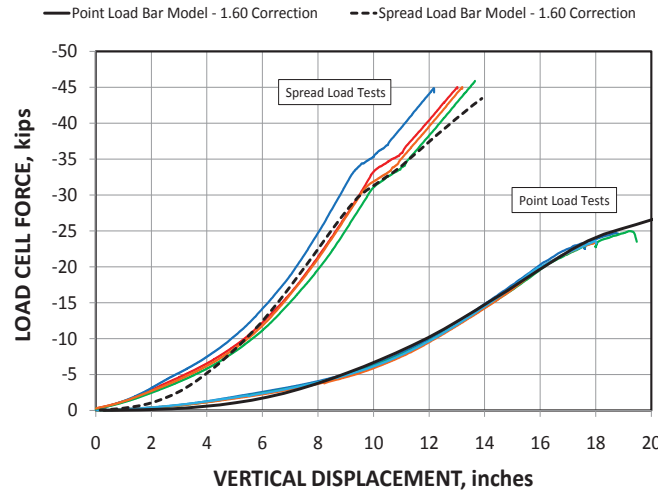


Figure 10. One-inch diameter bar tests with finite element models.

For the single-point load condition on the cable specimens, the addition of 2.5 inches to the recorded vertical deflection aligned the model results with the test data, and for the spread-load models, no adjustment was necessary. The charts showing the cable specimen test data with the models are shown in Figure 11 and Figure 12.

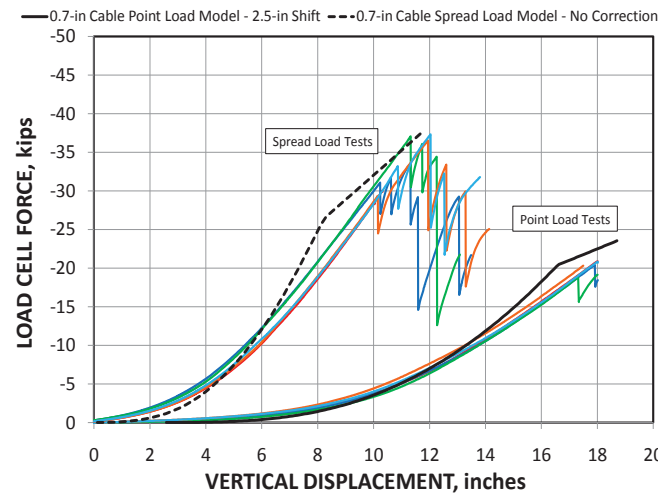


Figure 11. 0.7-inch-diameter cable tests with finite element models.

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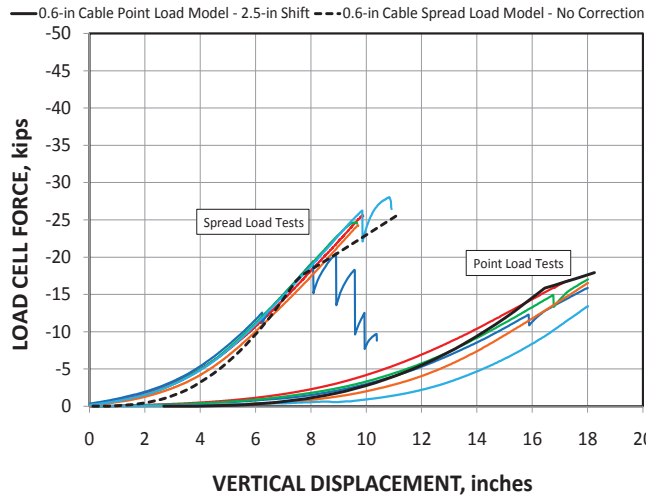


Figure 12. 0.6-inch-diameter cable tests with finite element models.

CONCLUSIONS

The yield loads of the cross members for the spread-load tests on the one-inch diameter bars were 33 kips, the 0.7-inch diameter cables were 30 kips and for the 0.6-inch diameter cables were 25 kips. The deflection at yield was about 10 inches. The maximum vertical stiffness of the cross members between six to ten inches of deflection ranges from 5.0 kips/inch for the one-inch diameter bar and 0.7-inch diameter cable to 3.75 kips/inch for the 0.6-inch diameter cable.

(Endnotes)

1 Mention of a trade name or product does not imply endorsement by the National Institute for Occupational Safety and Health.

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