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Vertical load capacities of roof truss cross members

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ABSTRACT

Trusses used for roof support in coal mines are constructed of two grouted bolts installed at opposing forty-five degree angles into the roof and a cross member that ties the angled bolts together. The load on the cross member is vertical, which is transverse to the longitudinal axis, and therefore the cross member is loaded in the weakest direction. Laboratory tests were conducted to determine the vertical load capacity and deflection of three different types of cross members. Single-point load tests, with the load applied in the center of the specimen and double-point load tests, with a span of 2.4 m, were conducted. For the single-point load configuration, the yield of the 25 mm solid bar cross member was nominally 98 kN of vertical load, achieved at 42 cm of deflection. For cable cross members, yield was not achieved even after 45 cm of deflection. Peak vertical loads were about 89 kN for 17 mm cables and 67 kN for the 15 mm cables. For the double-point load configurations, the 25 mm solid bar cross members yielded at 150 kN of vertical load and 25 cm of deflection. At 25 cm of deflection individual cable strands started breaking at 133 and 111 kN of vertical load for the 17 and 15 mm cable cross members respectively.

1. 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 [1]. 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 [1].

It may be true that the roof usually only needs a "little help" to prevent falls and that if the bottom 30 cm of the roof is held, then the rest will stay up [1]. 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 travel way 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 [2–4]. 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.

2. 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

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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 27–36 kN. With the two anchor bolts installed at 45° angles, the vertical capacity ranges from 190 to 250 kN for each bolt with a theoretical combined load capacity of 380–510 kN.

Tests of the three different types of roof truss cross members were conducted in the Mine Roof Simulator (MRS), located at the Pittsburgh site of the National Institute of Occupational Safety and Health (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 25 mm-diameter threaded bars, 17 mm-diameter cables, and 15 mm-diameter cables. The length of the specimens was 4.9 m and the maximum vertical deflection that could be applied was 45 cm. A 220 kN 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 Fig. 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, 2.4 m 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 Figs. 2 and 3. The shoes were mounted to the MRS fixtures using pieces of 25 mm 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°. The angled bolts showing the damage from shear caused by the tension in the cross member during a test are shown in Fig. 4.

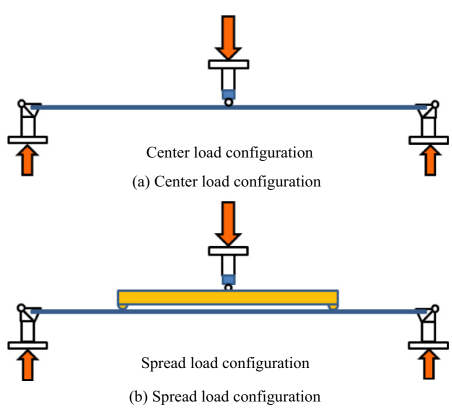

Fig. 1. Test configuration diagrams.

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

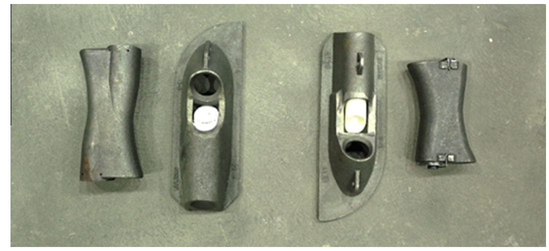

Fig. 3. Shoes and dog bones for 17 mm cable (l) and 15 mm cable (*r*).

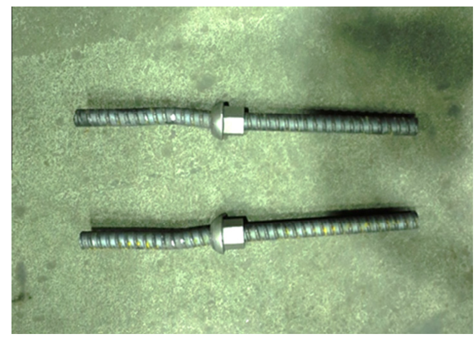

Fig. 4. Angled bolts showing shear damage caused by the tension in the cross member.

The tensions on the threaded bars at the beginning of the tests were 5 and 10 tons. These forces were generated by applying either 340 or 680 N m of torque to the nuts at the dog-bone connection. The tension on the cable specimens were either 23 or 46 kN. These forces were applied by a tensioning jack before the tests. The tension for all of the spread load tests was 45 kN.

2.1. 25 mm 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 25 mm-diameter threaded bar at the quarter points. The yield stress of the bar was achieved at about 98 kN of vertical load after 42 cm of convergence for the single-point load configuration.

For the eight-foot spread-load configuration, the average vertical load at the yield strength of the bar was about 147 kN at 25 cm of deflection. The stiffness of the spread-load tests from 15 to 25 cm of deflection is about 8.9 kN/cm. The results from both of these load configurations are shown in Fig. 5.

2.2. 17 mm-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

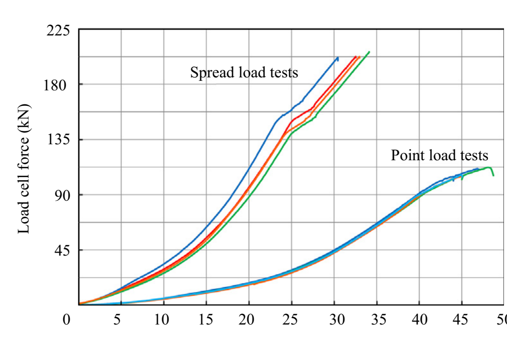

Fig. 5. Test results from the 25 mm-diameter threaded bar tests.

the 17 mm-diameter cables at the quarter points. The yield stress of the cable was not achieved, even after 45 cm of convergence for the single-point load configuration. The maximum load reached about 89 kN.

For the eight-foot spread-load configuration, the load when strands of the cable began to break was about 133 kN at 25 cm 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 15 to 25 cm of deflection is about 8.9 kN/cm. The results from both of these load configurations are shown in Fig. 6.

2.3. 15 mm-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 15 mm-diameter cables at the quarter points. The yield stress of the cable was not achieved, even after 45 cm of convergence for the single-point load configuration. The maximum load reached about 67 kN.

For the 2.4 m spread-load configuration, the maximum applied load was about 111 kN at 25 cm of deflection. The stiffness of the spread-load tests from 15 to 25 cm of deflection is about 6.7 kN/cm. The results from both of these load configurations are shown in Fig. 7.

2.4. Finite element modeling

Finite element models (Fig. 8) of the two load cases for each specimen were developed in ANSYS. 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.

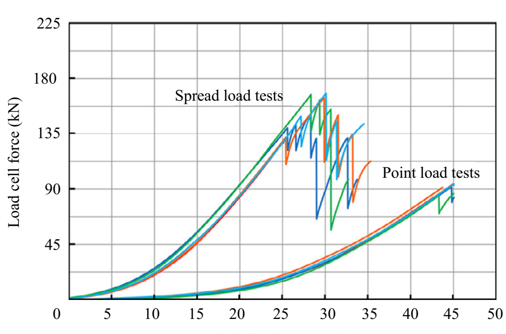

Fig. 6. Test results from the 17 mm-diameter cable tests.

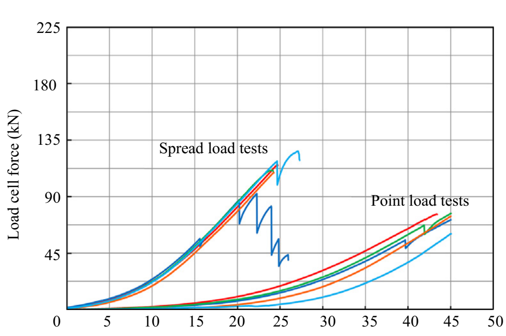

Fig. 7. Test results from the 15 mm-diameter cable tests.

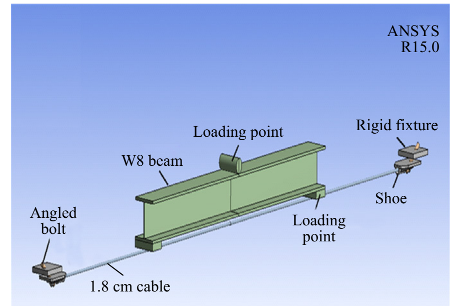

Fig. 8. Finite element model for spread-load configuration.

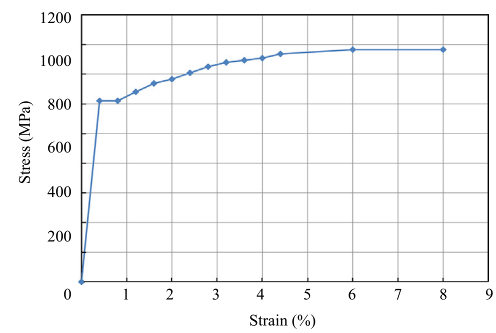

Fig. 9. Stress–strain relationship of bar material.

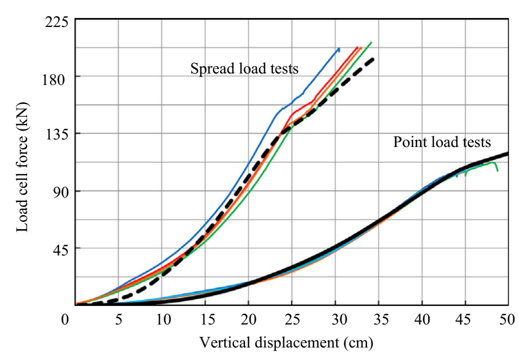

Fig. 10. 25 mm diameter bar tests with finite element model results shown as heavy black lines.

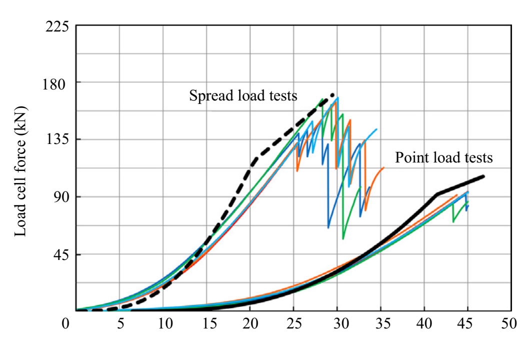

Fig. 11. 17-mm-diameter cable tests with finite element model results shown as heavy black lines.

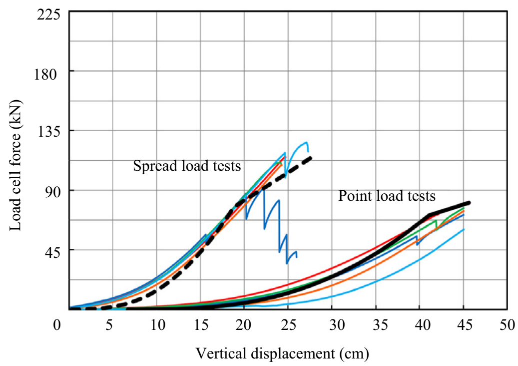

Fig. 12. 15-mm-diameter cable tests with finite element model results shown as heavy black lines.

Both material and geometrical non-linearity were considered in the models. The modulus of elasticity and Poisson's ratio of the bar material are 204 GPa and 0.3, respectively. The stress–strain relationship of the bar material is shown in Fig. 9. The yield and breaking loads of the 17 mm diameter cable are 300 and 340 kN, respectively. The yield and breaking loads of the 15 mm diameter cable are 235 and 258 kN, respectively. The yield and breaking strains of the cables are 1% and 3.5%, respectively. The calculated modulus of elasticity of the 17 mm and 15 mm diameter cable materials are 156 and 167 GPa, respectively. The Poisson's ratio of the cable is 0.3.

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 40 mm, and for the beam load case the factor was 34 mm. The test results with the adjusted model results are shown in Fig. 10.

For the single-point load condition on the cable specimens, the addition of 62 mm 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 appropriately adjusted model results are shown in Figs. 11 and 12.

3. Conclusions

The yield loads of the cross members for the spread-load tests on the 25 mm diameter bars were 147 kN, the 17 mm diameter cables were 133 kN and for the 15 mm diameter cables were 111 kN. The deflection at yield was about 25 cm. The maximum vertical stiffness of the cross members between 15 and 25 cm of deflection ranges from 8.9 kN/cm for the 25 mm diameter bar and 17 mm diameter cable to 6.7 kN/cm for the 15 mm diameter cable.

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