tion energy of 52.7 for $0.123 < x < 0.175$, and 62.74 kJ/mol for $0.175 < x < 0.219$. The reaction order with respect to partial pressure of H_2 was calculated as 0.971 ± 0.013. The SEM analyses of roasting product further verified the presence of sintered structure, which could be the primary reason for diffusion being a controlling mechanism. ■

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Analysis of steel prop supports subjected to vertical and lateral loading

Khaled Mohamed and Timothy Batchler
CDC NIOSH, Pittsburgh PA, USA
*Corresponding author emails: kmy1@cdc.gov, avy4@cdc.gov

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Standing supports have been used in coal mines for decades to enhance roof support capability. Occasionally, standing supports are used to resist the lateral movement of spalled ribs. Researchers from the National Institute for Occupational Safety and Health (NIOSH) are conducting a testing program for standing supports to investigate the effect of lateral loading on their vertical loading capacities and the factors affecting their lateral loading capacities. The Mine Roof Simulator (MRS) was used to determine the response of steel props to vertical and horizontal loadings. Finite element models (FEMs) were developed and verified using the tested steel props. Prop models were used to study the effect of a range of roof and floor materials — gray shale, shale and claystone — on the critical buckling loads of the steel props.

Background

Over the past decade, rib falls resulted in 16 fatalities, representing over 50 percent of the ground-fall fatalities in U.S. underground coal mines. Statistical analyses on the fatality cases resulting from underground coal pillar rib falls from 2010 to 2019 show that more than 70 percent of the accidents occurred during the development loading [1]. More recently, falls of rib or face led to all three of the ground-fall-related fatalities in 2018 and 2019.

The design of rib supports in U.S. underground coal mines is based primarily on local practices and experience rather than on the engineering design process. Current rib supports fall into two main categories: (1) rib control based on intrinsic supports and (2) rib control based on external supports. Prop-type standing supports sometimes could be the only choice to stabilize fractured ribs. When prop supports are used for rib control, it is important that they be secured in such a manner that a hazard is not created because of dislodged supports. Ignoring the importance of lateral loading capacity of standing support as a factor that could determine the stability of standing supports could lead to serious outcomes.

Problem description and methodology

The performance characteristics of steel props were studied under vertical and lateral loading conditions. FEMs were then developed using the tested steel props. The models were used to answer the questions of how the boundary conditions and the spatial location of the lateral load along the support affect its lateral loading capacity.

Fig. 1 Vertical load capacity test setup for steel props.

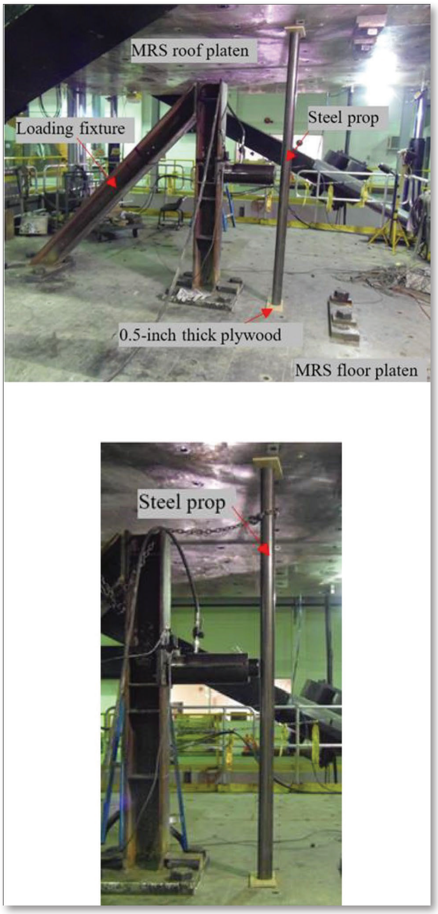

Fig. 2 Setup for lateral load capacity tests.

Full-scale testing for steel props. *Vertical load capacity tests.* This study conducted full-scale buckling and lateral loading testing for steel props under vertical loading. The steel prop was placed in the MRS with full roof and floor contact to establish uniform loading on the support. To simulate the convergence of the mine roof and floor, the convergence of roof and floor platens continued until the prop became unstable. Figure 1 shows the buckling failure of a square 8-ft prop. Buckling failures generally occurred near the mid-height of the prop as shown in Fig. 1.

Lateral load capacity tests. The testing of steel props for lateral load capacity was also conducted in the MRS. Like the vertical test, the steel prop was placed with full roof and floor contact. A lateral loading fixture attached into the floor platen of the MRS (Fig. 2) was used to apply lateral loading on tested props.

Finite element models for the tested steel props. FEMs were created and compared with the MRS results. The ANSYS [2] FEMs were developed to simulate the loading and deformation behaviors of the steel props. The prop model successfully calculated the critical buckling load for the tested prop with an error of 6 percent at maximum.

Figure 3 shows the deformed shape of the modeled prop compared with the prop after testing. It shows that the deformed shape of the prop model is very similar to the deformed shape of the tested steel prop.

Discussion

Factors affecting lateral load capacity of steel props. Finite element modeling successfully calculated the lateral loading capacity for tested steel props. The prop models were then used to study the effects of a range of roof and floor materials — gray shale, shale, and claystone — on the critical buckling loads of the steel props. For example, the maximum prop support load with claystone rocks boundary conditions was about 60 percent compared to the steel boundary. However, the prop response became insignificant at large roof-to-floor convergence (about 0.6 in.).

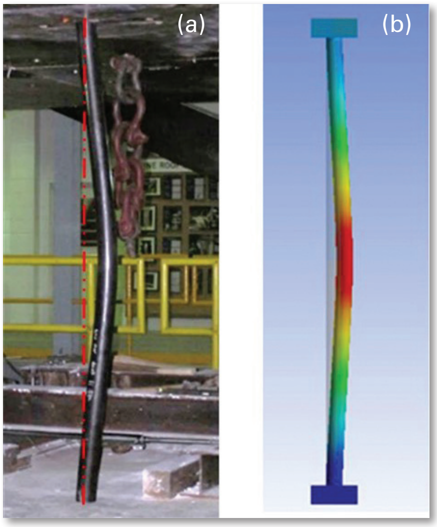

Fig. 3 Deformed shape of prop: (a) loaded vertically, compared with (b) FEM model.

Several models were also developed where the lateral loading was applied at various heights along the prop. The smallest resistance to the lateral loading capacity of the support was observed when the load was applied at the mid-height of the steel prop, while the highest was observed around 10 percent of the prop height.

Conclusions

- The tested steel props failed due to buckling in the process of plastic deformation.
- The modeled elastic stiffness of the steel props setting up against the claystone rocks has a reduced stiffness about half of that tested in the MRS.
- The modeled maximum support load with claystone roof and floor rocks was about 60 percent of that obtained by the MRS test.
- For slight lateral displacement, less than 0.5 in., the greatest lateral loading capacity was observed when the lateral load was applied near prop ends, at about 0.1 prop height. For great lateral displacement, more than 4 in., little effect was seen of the position of lateral loading on the lateral loading capacity. ■

Disclaimer

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

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