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Daniel D. Sweeney[a]; Jeremy M. Slagley[a]; David A. Smith[a]
[a] Department of Systems and Engineering Management, Air Force Institute of Technology, Wright-Patterson AFB, Ohio

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Insertion Loss of Noise Barriers on an Aboveground, Full-Scale Model Longwall Coal Mining Shearer

Daniel D. Sweeney, Jeremy M. Slagley, and David A. Smith

Air Force Institute of Technology, Department of Systems and Engineering Management, Wright-Patterson AFB, Ohio

The U.S. mining industry struggles with hazardous noise and dust exposures in underground mining. Specifically, longwall coal mine shearer operators are routinely exposed to noise levels at 151% of the allowable daily dose, and approximately 20% exceed regulatory dust levels. In the current study, a partial barrier was mounted on the full-scale mock shearer at the National Institute for Occupational Safety and Health Pittsburgh Research Laboratory. A simulated, full-scale, coal mine longwall shearer operation was employed to test the feasibility of utilizing a barrier to separate the shearer operator from the direct path of the noise and dust source during mining operations. In this model, noise levels at the operators' positions were reduced by 2.6 to 8.2 A-weighted decibels (dBA) from the application of the test barriers. Estimated insertion loss underground was 1.7 to 7.3 dBA. The barrier should be tested in an underground mining operation to determine if it can reduce shearer operators' noise exposure to below regulatory limits.

Keywords longwall mining, noise, sound barrier

Address correspondence to: Jeremy M. Slagley, AFIT/ENV BLDG 640, 2950 Hobson Way, Wright-Patterson AFB, OH 45433-7765; e-mail: jeremy.slagley@afit.edu.

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INTRODUCTION

Noise induced hearing loss (NIHL) is a permanent disabling condition caused by chronic exposure to high levels of noise. Hearing loss from excessive noise exposure is caused by degeneration of the nerve fibers associated with the hair cells of the inner ear.[1] Once the damage has occurred, the hair cells cannot regenerate.[2] Although it is commonly believed that hearing aids can be used to overcome the loss, if the loss is from nerve damage the hearing aid can only partially restore hearing ability.[3] Of the 10 million people who currently suffer from NIHL in the United States, nearly all of them have suffered that hearing loss as a result of occupational exposure. This represents one-third of the 30 million people in the United States who have been occupationally exposed to hazardous noise. In addition, NIHL increased 26% from 1971 to 1990 among individuals between 18 to 44 years old.[4]

The U.S. Occupational Safety and Health Administration (OSHA) mandates "when employees are subjected to (hazardous noise), feasible administrative or engineering controls shall be utilized."[5] While some engineering noise controls may require in-depth studies or complete redesign of an operation, other controls such as barriers or enclosures may be an effective low-cost solution to controlling hazardous noise.

The partial sound barrier is an effective, inexpensive engineering noise control that may often be disregarded because it is commonly believed it will not reduce sound levels in a semi-reverberant field. Driscoll and Royster[6] report that for a partial barrier to be effective, the receiver must not be located in a reverberant field. This statement may be misconstrued as meaning a barrier will not work in a semi-reverberant field. However, this is only true in a completely reverberant field. In a semi-reverberant field, the sound barrier may be effective if the direct noise path predominates over the reverberant path. Moreland and Musa[7] measured insertion losses in a semi-reverberant room at 1.2 m (4 feet) from the barrier ranging from 2 to 13 dB across eight octave bands. This study examined the use of partial and full barriers in a full-scale model longwall coal mining shearer facility.

METHODS

This case study modeled an underground coal mine longwall shearer operation, which is an operation that has traditionally been considered extremely reverberant. This model was chosen due to the extremes of the operating environment and the fact that shearer operators are routinely exposed to hazardous noise levels at 151% of the allowable daily dose.[8] The total room absorption (TA) of the full-scale longwall model was measured using a known sound power source to determine how reflective the room would be. The greater the contribution of reflected path noise over direct path noise, the less insertion loss would be expected from the barrier. Several barrier configurations were constructed and tested for noise reduction potential.

Test Location

The test was performed at an aboveground, full-scale model of a longwall shearer operation at the National Institute for Occupational Safety and Health Pittsburgh Research Laboratory Facility (NIOSH-PRL). The model has two steel cutting drums that rest on the simulated coal face, which is plywood over corrugated steel. The walkway is a narrow path similar to the area an operator would be working in underground. The shields above the walkway are plywood and steel and represent a moving support structure that would protect the operator from the ceiling caving in. Behind the walkway and shields is an open space of approximately 2 m in depth that is used to represent the "gob" area of the underground operation.

In longwall mining, the shearer cuts along the coal face, progressing forward into the face. The shields keep the mine ceiling from collapsing in on the worker. As the shearer moves, the shields move with it, allowing the mine ceiling to collapse behind the workers. The collapsed area is the gob space composed of loosely packed rock and earth. Point noise sources, measurement locations, and barrier placement were positioned as indicated in Figure 1.

Total Room Absorption Coefficient

An electronic buzzer with a known sound power level was used as a noise source to measure the test location's total room absorption (TA) coefficient. A series of octave band analyzer (OBA) measurements were taken for the test area with the buzzer operating continuously in the center of each area. The OBA measurements were used in Eyring's Eq. 1 to determine the average room TA for each octave.

$$L_p = L_w + 10\,\mathrm{Log}_{10}[(Q/4\pi r^2) + (4/TA)] \qquad (1)$$

where Lp is the sound pressure level, Lw is the sound power level of the source, Q is the directivity factor of the source, r is the distance from the source to the receiver, and TA is the total room absorption.[2]

Sound Production and Measurement

A signal generator from a Norsonic type 830 real-time analyzer (Norsonic AS; Tranby I Lier, Norway) was connected to a Bogen Gold Seal Series GS3 250 pre-amplifier (Bogen Communications, Ramsey, N.J.) to provide pink noise to the test environment. The pre-amplifier was routed through a dbx 223XL crossover (dbx Professional Products; Sandy, Utah) that was connected to two QSC RMX-1450 amplifiers (QSC Audio, Costa Mesa, Calif.). The first amplifier was connected to two Peavey 115 loudspeakers (Peavey Electronics Corporation, Meridian, Miss.) for middle and high frequency output. The second amplifier was connected to two Peavey 118 subwoofers for low frequency output. Each set of speakers was connected in series with a second loudspeaker or subwoofer so that both the head drum and tail drum locations were noise sources. A 15.25-m, 12-gauge Live Wire speaker cable (Live Wire, Thousand Oaks, Calif.) connected the amplifier to the first set of speakers, followed by a 15.25-m-long 14-gauge Live Wire speaker cable from the first speaker to the next.[10]

The noise was measured using a Larson Davis Model 831 octave band analyzer (OBA) with PRM831 pre-amplifier and 377A20 1.3 cm (1/2 inch) diameter random incidence Type I microphone (Larson Davis, Provo, Utah). The OBA system was checked with a CAL200 acoustic calibrator (Larson Davis) before and after each test day. Measurements were taken with and without the barrier in place at the locations indicated in Figure 1. Locations were selected to represent the typical shearer operators' locations, including the center of shearer location, which is an occasional worker location during the

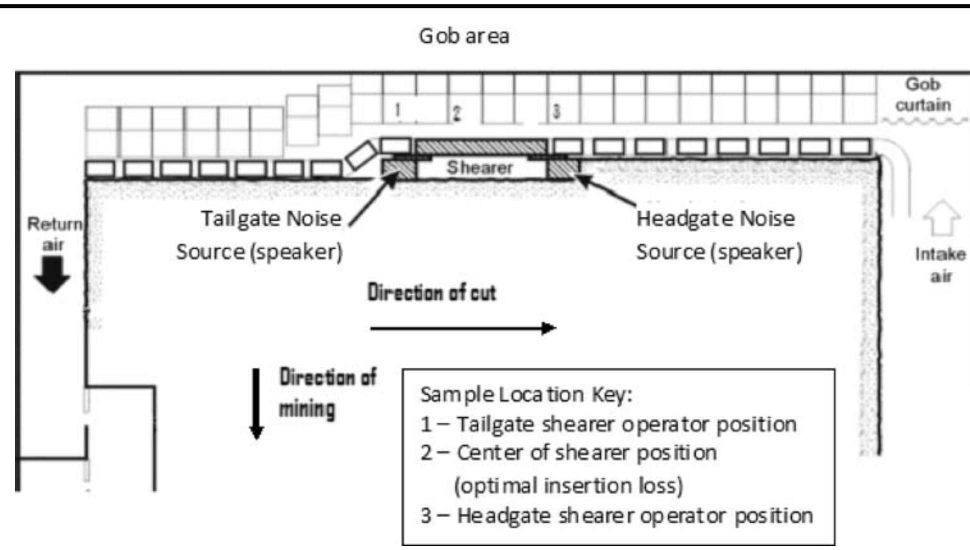

FIGURE 1. Full-scale model longwall shearer facility (Adapted from Ref. 9).

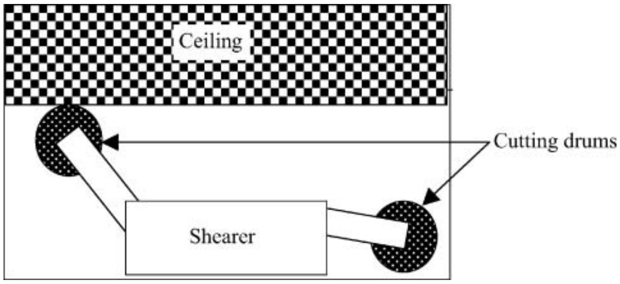

FIGURE 2. No barrier configuration (A) tested for noise reduction at the operator's position facing shearer (elevation view, NOT to scale).

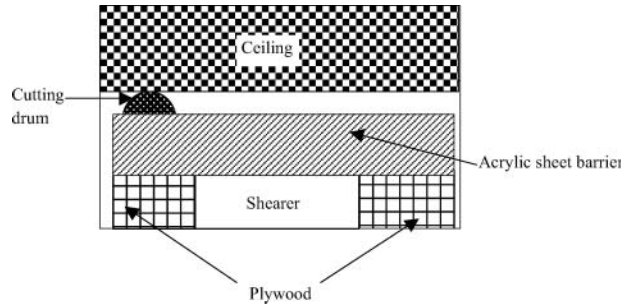

FIGURE 3. Simple barrier configuration (B) tested for noise reduction at the operator's position facing shearer (elevation view, NOT to scale).

process. The OBA was mounted to a tripod with its microphone 1.5 m above the ground, oriented parallel to the ground, at approximately 0° incidence to the sound source.

At each test location, three heights were measured, 132 cm from the floor to simulate the ear height of the fifth percentile female, 162.5 cm for the 50th percentile male, and 172.5 cm for the 95th percentile male.[11] All OBA measurements were taken as a 20-sec average sound pressure level and recorded as 1/1 octave band, 1/3 octave band, and A-weighted decibels (dBA) and repeated for n = 3 samples each.

Barrier Design

At the PRL test area, a partial barrier configuration and a full barrier (essentially a wall) were built and mounted on the shearer to test the effectiveness of each barrier for noise at the typical operator's position. A potential concern of a barrier mounted to the longwall shearer is the visibility of the cutting drum to the operators. To address this issue, clear acrylic sheeting was used to balance visibility and practicality with noise reduction. A thicker, sturdier barrier made of safety glass would be required in an actual underground operation, which may further increase noise reduction. In a single barrier configuration, thicker or denser material can have a higher transmission loss.[12] The greater the amount of barrier surface area, the greater the sound shadow for direct path sound waves will be, which should correspond to a greater sound reduction to the operator from direct path noise, as long as the barrier is between the receiver and the sound source. Because the shearer is mobile, the underground barrier either would have to have a gap between the top of the barrier and the ceiling or have a flexible portion near the top to allow for the changing ceiling height. This corresponds to the two tested configurations in this study.

The dimensions of the barrier were chosen for practicality in this experiment. It may be necessary to change the dimensions for underground operations. However, so long as the barrier is between the operator and the noise source, the barrier should effectively reduce the direct path sound waves contributing to the overall noise levels.

The shearer with no barrier and the two barrier configurations tested are shown in Figures 2, 3, and 4, respectively. The simple barrier was constructed of 1.22 × 0.61 m clear acrylic sheets with a thickness of 0.95 cm. Each sheet was mounted in series to a wooden frame that extended the full length of the shearer just beyond each cutting drum. The partial barrier left approximately a 0.6 m gap between the top of the barrier and the shield (Figure 3). The full wall was constructed by attaching rubber matt sheets to the top of the simple barrier to create a flexible seal that could adjust with the shield height as shown in Figure 4.

RESULTS

Absorption Coefficients

The results of the measured TA are shown in Table I. Low TA values indicate a more reverberant field. While a true TA cutoff for reverberant versus semi-reverberant fields does not exist, a comparison to the calculated underground mine TA suggests that the test area was more reflective than the expected underground operation. Therefore, the results indicate the PRL area is a fairly reverberant field and should give more conservative results (lower insertion loss estimates) to test the hypothesis that a partial barrier can be effective in a semi-reverberant field. The TA for the mine was calculated using the published absorption coefficient for coal for the face area multiplied by the estimated relevant surface area of the coal.[13]

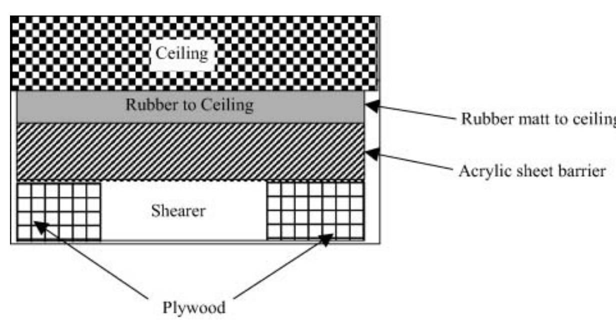

FIGURE 4. Full wall configuration (C) tested for noise reduction at the operator's position facing shearer (elevation view, NOT to scale).

TABLE I. Total Absorption Estimates (metric sabins)

Frequency:	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Estimated TA in longwall operation (m^2)	11.6	52	40.6	43.5	55.1	81.2	130.5
Full-scale shearer model TA (m^2)	17.3	14.8	11.6	4.4	7.0	23.6	9.4
Semi-reverberant test area TA (m^2) from Moreland and Musa[7]	105.5	88.6	87.9	55.7	110.0	124.3	93.7

Both the mine area estimate and the measured TA of the PRL facility were generally less absorptive than the semi-reverberant room used by Moreland and Musa.[7] However, since the PRL facility had the most reflective (lowest) TA, the insertion loss measured there should be lower than what could be achieved underground.

Barrier Tests

A full factorial model with interactions was developed to describe the performance of the different barrier treatments as given in Eq. 2:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_1 x_1 \beta_2 x_2 + \beta_2 x_2 \beta_3 x_3 + \beta_1 x_1 \beta_3 x_3 + \beta_1 x_1 \beta_2 x_2 \beta_3 x_3 + \varepsilon \quad (2)$$

where

y = the unweighted pink noise sound pressure level (dB)
β_0 = y-intercept
x_1 = barrier treatment (none, simple barrier, full wall)
x_2 = worker location (tailgate, center, headgate)
x_3 = microphone height (95% male, 50% male, 5% female)
ε = error

ANOVA analysis was performed on the full model using JMP software (v. 7.0; SAS, Inc., Cary, N.C.). The model was significant ($p < 0.0001$), but all interactions and the microphone height (x_3) were not significant, so those variables were removed. The model was then reduced to the following:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon \quad (3)$$

The results of the analysis of variance are given in Table II.

Multivariate analysis (Tukey's Honestly Significant Difference) revealed that the several levels of barrier treatment (x_1) and worker location (x_2) were all significantly different ($p < 0.05$). Further, the correlation of measurements to model prediction values had an R^2 value of 0.89.

The A-weighted results of the barrier treatments by worker location with insertion loss are given in Table III. Figures 5–8 show the unweighted and weighted frequency band results for the primary worker positions of headgate and tailgate. The major difference in insertion loss between headgate and tailgate seems to come from the greater degree of higher frequency content at the headgate position, which is more easily reduced by the barrier treatments.

The preceding section described the findings of the above-ground insertion loss study at PRL. The more interesting application question concerned what IL could be expected underground in an environment with different total room absorption.

Estimation of Underground Insertion Loss

The IL measured at the PRL facility is a combination of the direct and reflected path noise components of Eyring's equation.[2] Since the barrier treatments affect primarily direct path noise, the sound pressure levels would have to be deconstructed to determine the direct path component, apply the measured insertion loss, then reconstructed with the measured underground total room absorption coefficients. Hayden and Zechmann[14] estimated sound pressure levels in varied environments for hand tools. Since hand tools are generally operated at arm's length or less (<1 m), sound pressure levels are relatively close to sound power levels.

Once the sound power level is estimated tolerably, then the variables of Eyring's equation can estimate expected sound pressure levels in new environments. This method was investigated but was less useful because the source to receiver

TABLE II. ANOVA Results of Insertion Loss Model for Eq. 3, Pittsburgh Research Laboratory

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	4	770.92667	192.732	160.5471	<.0001
Error	76	91.23556	1.200		
C. Total	80	862.16222			

TABLE III. Full-Scale Longwall Barrier Insertion Loss Results, Pittsburgh Research Laboratory

	Treatment		
Worker Location	A None (dBA)	B Partial Barrier (dBA)	C Full Wall (dBA)
Headgate operator	94.5	88.5 (IL = 6.0)	86.3 (IL = 8.2)
Center of shearer	93.2	91.2 (IL = 2.0)	87.3 (IL = 5.9)
Tailgate operator	94.9	92.3 (IL = 2.6)	87.3 (IL = 7.6)

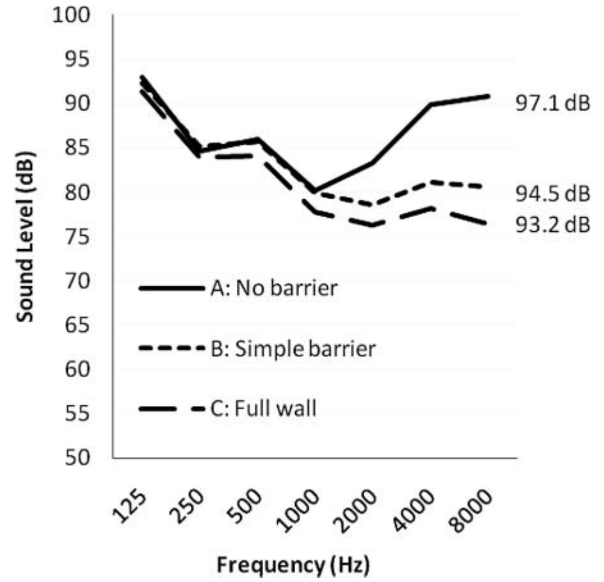

FIGURE 5. PRL facility frequency band unweighted levels for headgate position with barrier treatments.

distance was larger than 1 m, and since this study did not measure sound power levels, it was untenable to estimate underground sound pressure levels with great accuracy. Therefore, the insertion loss estimation method was simply to subtract the measured IL by octave band found at the NIOSH-PRL facility from a set of underground shearer noise recordings provided by the Mine Safety and Health Administration (MSHA) Physical and Toxic Agents Division. The estimated underground sound levels and insertion loss are given in Table IV.

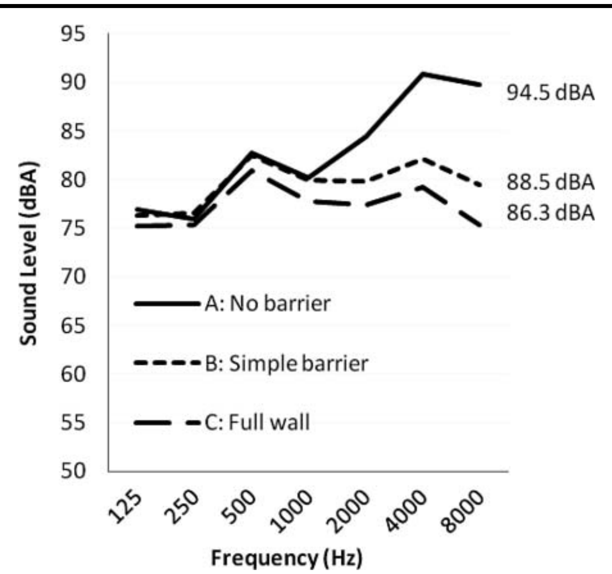

FIGURE 6. PRL facility frequency band A-weighted levels for headgate position with barrier treatments.

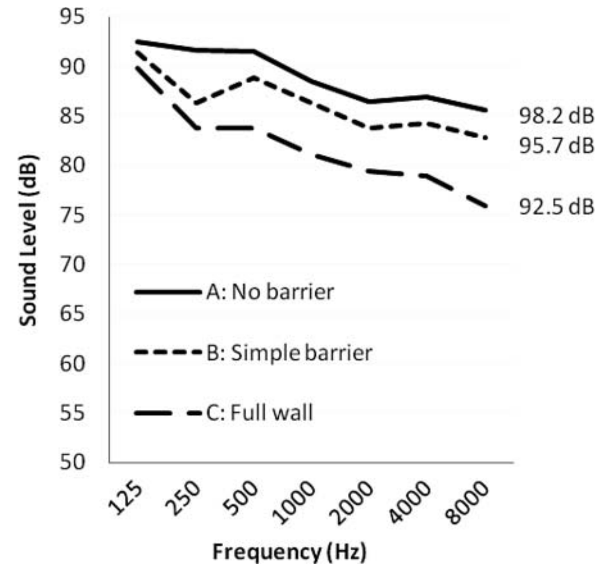

FIGURE 7. PRL facility frequency band unweighted levels for tailgate position with barrier treatments.

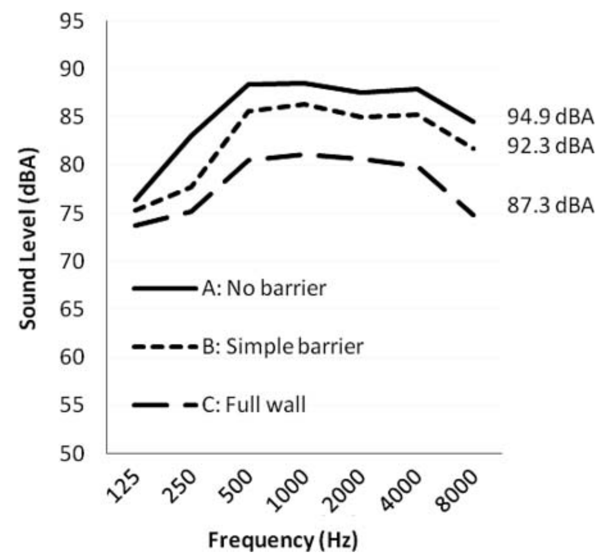

FIGURE 8. PRL facility frequency band A-weighted levels for tailgate position with barrier treatments.

TABLE IV. Estimated Underground Treatment Resultant A-Weighted Sound Pressure Levels

	Treatment		
Worker Location	A Recording (dBA)	B Partial Barrier (dBA)	C Full Wall (dBA)
Headgate operator	94.0	92.3 (IL = 1.7)	90.3 (IL = 3.7)
Center of shearer	94.0	92.7 (IL = 1.3)	89.0 (IL = 5.0)
Tailgate operator	94.0	91.5 (IL = 2.5)	86.7 (IL = 7.3)

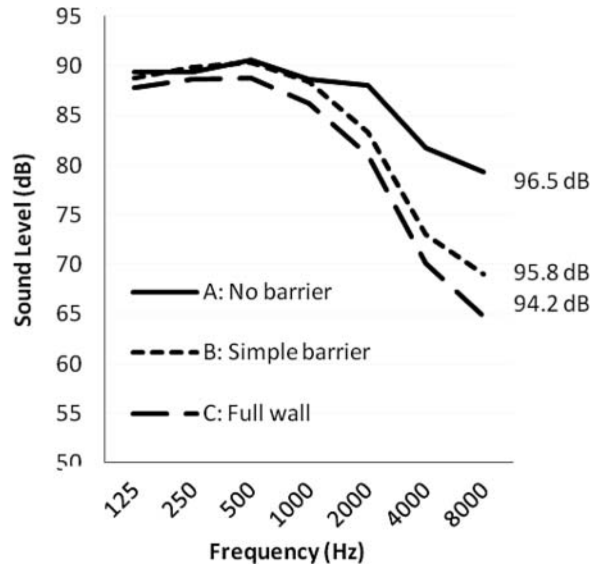

FIGURE 9. MSHA underground recordings estimated frequency band unweighted levels for headgate position with barrier treatments.

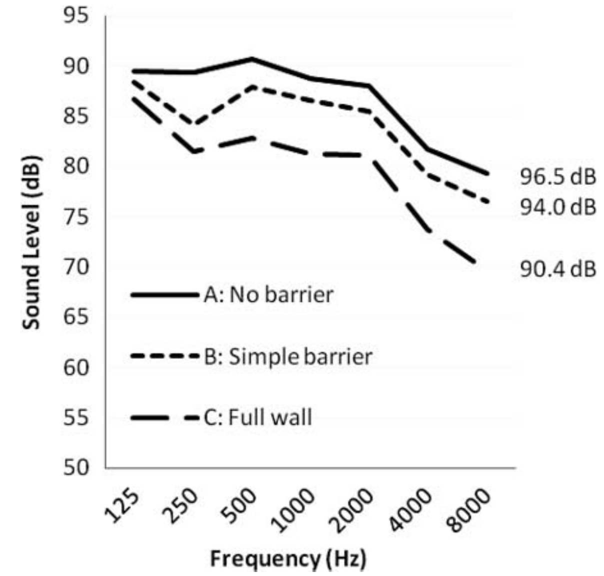

FIGURE 11. MSHA underground recordings estimated frequency band unweighted levels for tailgate position with barrier treatments

The marked difference in insertion loss between the PRL model and the underground estimation lies in the frequency distribution differences. Figures 9–12 show the expected underground octave band and overall unweighted and A-weighted levels from the two barrier treatments at the headgate and tailgate positions. The MSHA recordings indicated much more low to middle frequency energy, so that the relatively high insertion loss estimates from the PRL model study, which contained more high frequency noise, were not realized in the application to underground spectra.

DISCUSSION

According to the U.S. *Code of Federal Regulations*, Title 30, Part 62.130, "if during any work shift a miner's noise exposure exceeds the permissible exposure level, the

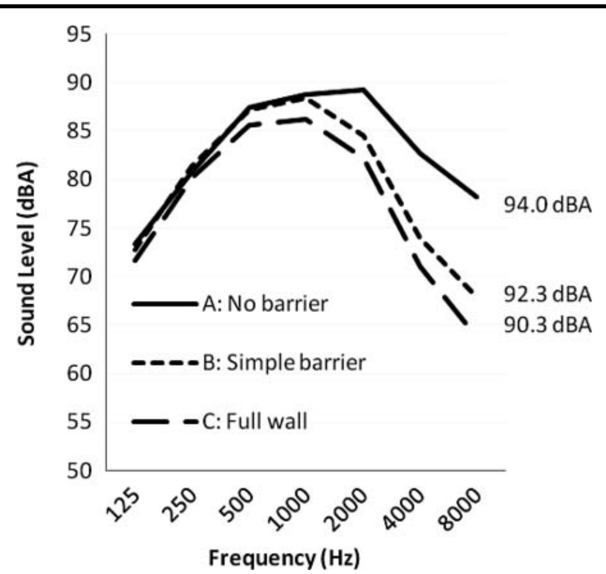

FIGURE 10. MSHA underground recordings estimated frequency band A-weighted levels for headgate position with barrier treatments.

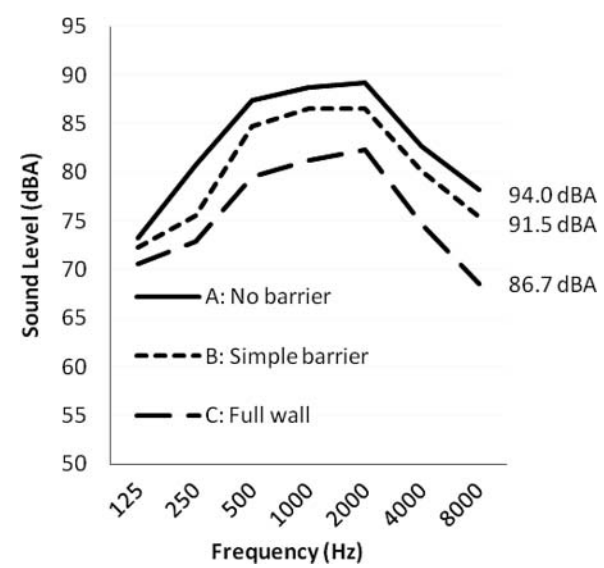

FIGURE 12. MSHA underground recordings estimated frequency band A-weighted levels for tailgate position with barrier treatments.

mine operator must use all feasible engineering and administrative controls to reduce the miner's noise exposure to the permissible exposure level."[15]MSHA gives further guidance that an engineering control is feasible if it reduces the noise exposure, is technologically achievable, and is economically achievable.[16] The MSHA guide also states that a 3-dBA reduction is generally considered to have reduced the noise, but the control may still be considered feasible if in combination with other controls, it achieves a minimum of 3 dBA.

Although the partial barrier did not meet the 3-dBA reduction criteria, it could be considered a feasible control and tested underground during an actual longwall operation given the following adjustments: (1) the barrier should be made of impact-resistant safety glass and be hinged for ease of cleaning and transport into and out of the mine shaft, and (2) the higher TA estimates underground should result in a higher insertion loss in actual use. When considering the NIOSH-PRL test facility was more reflective than the underground coal mine, a further reduction in noise may be expected in actual shearer operations. In addition, considering the underground adsorption test was performed in a coal shaft with four coal surfaces without the open gob space normally found behind the shearer during actual shearer operations, the reduction may be even greater because of the potentially higher absorption coefficient.[13] However, the additional absorption may be offset by the steel surfaces of the shields and shearer.

Both of the two different barrier configurations tested for noise reduction reduced the sound level to the operators. However, each barrier configuration had slightly different results. The simple barrier reduced noise at the operators' positions by 2.6 to 6.0 dBA. Although less practical for underground longwall mining, the full barrier (essentially, a wall) had the greater reduction of 7.6 to 8.2 dBA. This was due to the sound source being isolated from the operator by the wall, whereas the simple barrier had a noise flanking path directly over the top. This suggests that when possible in a semi-reverberant environment, even a simple wall isolating a sound source can achieve a high level of noise reduction.

In the underground operation where operators are routinely exposed to hazardous noise at 151% of the allowable limit (roughly 93 dBA equivalent continuous level) the two barrier configurations here may reduce the noise to levels close to or below the allowable limit, thereby reducing the frequency of NIHL.[8] The underground IL estimated that the simple barrier reduced noise at the operators' positions by 1.7 to 2.5 dBA. The less practical full barrier resulted in a greater estimated reduction of 3.7 to 7.3 dBA.

A second portion of this study included dust reduction with the barrier. Briefly, coal dust was generated at each cutting drum and measured at four positions along the walkway of the simulated shearer operation. The results from that portion of this study achieved as high as a 96% reduction in respirable dust levels.[17] Combining this with the noise reduction further warrants the testing of such a barrier underground.

CONCLUSIONS

A simulated, full-scale coal mine longwall shearer operation was tested to determine the feasibility of utilizing a barrier to separate the shearer operator from the direct path of the noise source during mining operations. In this model, noise levels were reduced by the application of a barrier. The barrier should be tested in an underground mining operation to determine if it can reduce the shearer operators' noise and dust exposure to below regulatory limits.

This research addressed a fundamental dilemma within industrial operations: by regulation, engineering controls are supposed to be the primary means of controlling an occupational exposure to within acceptable limits. Yet, because engineering controls are often regarded as complicated, expensive, and time consuming, industry typically favors personal protective equipment over a more permanent solution, which places the burden of protection on the worker. This research showed proof of concept that even basic noise engineering controls can be effective.

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REFERENCES

1. "Hearing Conservation Program, Veterans Compensation Chart, 2006." [Online] Available at http://chppm-www.apgea.army.mil/hcp/comp_reports.aspx (Accessed January 19, 2008).
2. **Bruce, R.D., S.A. Bommer, and C.T. Moritz:** Noise, vibration, and ultrasound. In *The Occupational Environment: Its Evaluation, Control, and Management,* S.R. DiNardi (ed.). Fairfax, VA: AIHA Press, 2003. pp. 434–493.
3. **Berger, E.H.:** Chapter 1: Noise control and hearing conservation: Why do it? In *The Noise Manual, Revised Fifth Edition,* E.H. Berger, L.H. Royster, J.D. Royster, D.P. Driscoll, and M. Layne (eds.). Fairfax, VA: AIHA, 2000. pp. 1–17.
4. "NIOSH Topic, Noise and Hearing Loss Prevention." [Online] http://www.cdc.gov/niosh/topics/noise/pubs/presentations/baltpres.pdf (Accessed January 19, 2008).
5. "Occupational Noise Exposure," *Code of Federal Regulations*, *Title 29*, Part 1910. 2008.
6. **Driscoll, D.P., and L.H. Royster:** Chapter 9: Noise control engineering. In *The Noise Manual, Revised Fifth Edition*, E.H. Berger, L.H. Royster, J.D. Royster, D.P. Driscoll, and M. Layne (eds.). Fairfax, Va.: AIHA, 2000. pp. 280–378.
7. **Moreland, J.B., and R.S. Musa:** The performance of acoustic barriers. In *Noise Control Eng. 1(2)*:98–101 (1973).
8. **Joy, G.J., and P.J. Middendorf:** Noise exposure and hearing conservation in U.S. coal mines —A surveillance report. *J. Occup. Environ. Hyg. 4*:(26–35) (2007).

9. **Rider J.P., and J.F. Colinet:** "Reducing Worker Exposure to Dust Generated During Longwall Mining. In *Proceedings of the Seventh International Mine Ventilation Congress, 2001*, S. Wasilewski (ed.). Krakow, Poland: Research & Development Center for Electrical Engineering & Automation in Mining EMAG, 2001. pp. 275–282.
10. **Sweeney, D.D., and J.M. Slagley:** "Passive Noise and Dust Control for Coal Mine Longwall Shearer." In *Proceedings of Noise-Con 2008,* Dearborn, Michigan, July 28–30, 2008. Institute of Noise Control Engineering, Indianapolis, Ind., *Vol. 117*:1 (2008). pp. 1421–1429.
11. **Annis, J.F., and J.T. McConville:** Chapter 1: Anthropometry. In *Occupational Ergonomics, Theory and Application*, A. Bhattacharya and J.D. McGlothlin (eds.). New York: Marcel Dekker, Inc., 1996. pp. 1–46.
12. **Uris, A.L., A. Lopis, and J. Llinares:** Technical Note: The influence of insulation thickness and number of layers of gypsum wall board on lightweight partition sound transmission loss. *Noise Control Eng. 49(5)*:238–240 (2001).
13. **Kovalchik, P, R. Matetic, S. Peng, and G. Cole.** Measurement method for determining absorption coefficients for underground mines. *Mining Eng. 59(11)*:59–62 (2007).
14. **Hayden, C.S., and E.L. Zechman:** Estimation of sound pressure level exposures from sound power level measurements of powered hand-tools. *Noise Control Eng. 55(4)*:379–389 (2007).
15. *"Occupational Noise Exposure," Code of Federal Regulations, Title 30,* Part 62.130, 2000.
16. **U.S. Deprtment of Labor (DOL), Mine Safety and Health Administration (MSHA):** *Compliance Guide to MSHA's Occupational Noise Exposure Standard*. Arlington, Va.: DOL, MSHA, 2000. p. 5.
17. **Sweeney, D.D., J.M. Slagley, D.A. Smith, and J.P. Rider:** Controlling dust exposure in longwall mining utilizing a simple barrier. *Mining Eng. 61(12)*:58–61 (2009).