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Short Communication

The Use of Noise Dampening Mats to Reduce Heavy-Equipment Noise Exposures in Construction

Sabah Saleh*, Susan Woskie, Anila Bello

Department of Work Environment, University of Massachusetts Lowell, Lowell, MA, USA

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ABSTRACT

The performance of sound barriers was evaluated to determine their technical effectiveness and practicality in reducing noise exposures to operating engineers in construction. Commercially purchased sound dampening mats (SDMats) were installed inside three heavy-equipment engine compartments. Sound pressure levels (SPLs) were measured before and after installing the SDMats while the equipment was on idle and full-throttle settings where it normally operates. SPLs inside the heavy-equipment operator cabs were significantly reduced by 5.6–7.6 dBA on the full-throttle setting following installation of the SDMats ($p < 0.01$). The evaluated engineering control intervention was simple to install, affordable, and substantially reduced the engine noise reaching the heavy-equipment operator, potentially reducing reliance on hearing-protection devices to protect construction workers from noise exposures.

1. Introduction

Exposure to elevated levels of noise in construction has been documented since the 1960s and 1970s [1,2], yet it remains a major hazard in modern construction sites. Recent estimates suggest that more than half a million construction workers are exposed to harmful noise [3,4]. A study of four construction trades reported that 40% of workers were exposed to noise levels exceeding 85 dBA [5]. Noise-induced hearing loss is common in construction work [6], limiting workers' ability to hear high-frequency sounds, understand speech, and communicate with others [3,5]. Exposure to noise has also been associated with stress [7], hypertension [8], and cardiovascular disease [9,10].

Heavy-equipment and power tools contribute the majority of noise on construction sites. Noise levels generated by power tools ranged from 87 dBA to 115 dBA, whereas heavy-equipment noise ranged from 80 dBA to 120 dBA [1,2,5,11]. As a result, noise exposures can vary between construction trades. Workers with lower exposures include carpenters and heating, ventilation, and air conditioning installers; by contrast, workers operating cranes and bulldozers were reported to have mean exposure level of 93 dBA and 105 dBA, respectively [6,12,13]. The Occupational Safety and Health Administration (OSHA) permissible exposure limit is 90 dBA (29 CFR 1926.52), whereas the American Conference of Industrial Hygienists has a noise threshold limit value of 85 dBA.

Reducing noise exposure to acceptable levels can be best achieved using engineering controls. However, effective noise-reducing engineering controls are often difficult to implement in construction sites due to changing environment and intense use of equipment [6]. Some engineering controls, such as equipment maintenance and replacing defective parts, such as a damaged muffler, are easier to implement than others like purchasing new quieter equipment. Nevertheless, the National Institute for Occupational Safety and Health (NIOSH) has recommended the purchase of newer, quieter hand tools (Buy Quiet Program) [14], and newer models of heavy equipment are commonly equipped with enclosed cabs that effectively reduce operator noise exposure. Neitzel et al [5] reported that operator average noise exposure was 85.2 dBA in open cab heavy equipment and 79.6 dBA in similar heavy equipment with an enclosed cab. However, for many contractors, replacing older heavy-construction equipment likely to produce higher levels of noise with newer quieter equipment is not financially feasible. As a result, hearing-protection devices (HPDs) have been widely recommended to reduce construction worker noise exposure [15–17]. However, HPDs have been shown to be ineffective in reducing noise exposures due to low or irregular use

* Corresponding author. Department of Work Environment, Kitson Hall, Room 200, University of Massachusetts Lowell, 1 University Avenue, Lowell, MA 01854, USA.
E-mail address: Sabah_Saleh@student.uml.edu (S. Saleh).

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during high exposure periods [15,18]. Thus, studies have recommended further research on the development and introduction of practicable engineering controls that can reduce noise levels at construction sites [15–17].

Sound barriers and sound absorbers (e.g., panels, curtains, or partitions) are an engineering control solution that can be used to reduce noise levels. Commercially available sound dampening mats (SDMats) can be installed in different parts of heavy-equipment vehicles to reduce the emission of engine noise into the operator compartment. In construction, operating engineers (OEs) drive and operate heavy equipment for relatively long periods. To date, no studies are available in the peer-reviewed literature on the use of SDMats to reduce heavy-equipment noise levels. This study evaluated the technical effectiveness and practicality of using SDMats as an intervention to reduce exposures to OEs in construction.

2. Materials and methods

The study was conducted at Training Center for Local 4 of International Union of Operating Engineers in Canton, MA, USA. The Training Center provides apprenticeship training to heavy-equipment OEs in areas such as hoisting, excavation, and maintenance. Dedicated mechanics provided mechanical services to the on-site heavy equipment. All SDMat installation on the heavy equipment was done at the Training Center workshop.

Several types of heavy equipment were available in the Training Center ranging from large cranes to small asphalt rollers. Three priorities were used for selecting heavy equipment suitable for testing the noise-reducing intervention. First, noise level at heavy-equipment operator seat exceeded 80 dBA. Second, design of the engine compartment was large enough to allow for installing the SDMats. Third, the engine compartment had few, relatively small, ventilation openings. Engine ventilation openings allow for air movement and could not be covered by the SDMats.

Initial sound pressure level (SPL) measurements and engine compartment design review of 18 pieces of heavy equipment resulted in selection of a Dynapac asphalt roller (Dynamic, Atlas Copco, Nacka, Sweden), PSI M413XT grader (PSI, Pavement Services, Inc., Madison, SD), and American 998 crane (American Crane Corporation, Wilmington, NC) for installation of the SDMats. All three pieces of heavy equipment generated high noise levels, especially in the range over 1,000 Hz, and had distinctly different engine compartment designs to allow us the opportunity to evaluate the technical effectiveness and practicality of using the SDMats in a variety of equipment. The asphalt roller engine compartment was located in front of the open seat of the operator, the grader engine compartment was located behind the glass-enclosed operator cab, and the crane had a large engine chamber next to glass-enclosed operator cab (Fig. 1).

The research team evaluated several types of SDMats based on their advertised noise dampening level, the frequencies of maximum attenuation, flexibility, ease of installation, thickness, and heat-resistance capability. SDMats are advertised under different names such as noise barrier material, sound deadening, and noise barrier composites. The SDMats selected for this study were manufactured by Technicon Acoustics (Concord, NC, USA) and sold by West Marine (Watsonville, CA, USA) under the name WEST MARINE Noise Control Barrier Material for use in boats to reduce engine compartment noise levels. This mat has some deadening (vibration reduction) capability but it was primarily a sound absorbing material, with its highest attenuation in the 1,000–4,000 Hz range. These SDMats were made of two layers of open-cell polyurethane foam separated by high-density polyvinyl chloride vinyl flexible sheet. The inner side of the SDMats was coated with an adhesive layer that could be attached to a metal surface. The exterior layer was covered with thin film of Mylar reinforced with elastomer-coated fiberglass providing additional surface heat protection, resulting in the material being fire retardant up to 107.2°C (225°F). West Marine sold the SDMats in 81 cm × 114 cm (32 in × 45 in.) rolls with either 1.3 cm (0.5 in.) or 2.5 cm (1 in.) thickness.

Fig. 1. The engine compartment location relevant to operator seat in three heavy-equipment machines.

Installation of the SDMats was a two-phase process. First was the removal of engine oil and dust from the engine compartment metal surfaces, because these contaminants reduce the adhesive strength of the SDMats after installation. Second was cutting and attaching the SDMats' adhesive side to the cleaned metal surface and in some cases using mechanical hanging pins for thicker mats. Fig. 2 shows SDMats covering the metal walls of the grader and roller engine compartments; additionally, SDMats were installed on the crane engine door leading to operator cab.

A 1.3-cm (0.5-in.) thick SDMat was used to cover a majority of metal surfaces inside the roller engine compartment. Where spacing allowed, a second layer of 1.3-cm (0.5-in.) thick SDMat was added. In total, approximately 5.6 m^2 (60 ft^2) of SDMats were used for a cost of US$500. Installation work was carried out by two mechanics and lasted an entire 8-hour work shift. A single layer of 1.3-cm (0.5-in.) thick SDMat was installed on the grader. It was not possible to add another layer of SDMats due to limited space inside the engine compartment. Approximately 4.6 m^2 (50 ft^2) of SDMats were installed covering the front, top, and both sides of the engine compartment for a cost of US$420. Installation work lasted an 8-hour work shift and was carried out by two mechanics. Unlike the grader, the crane engine compartment was large enough and allowed the installation of 2.5-cm (1-in.) thick SDMats. However, a second layer of SDMats was not used due to the added weight. Approximately 3.4 m^2 (36 ft^2) of SDMats, costing US$350, were installed by two mechanics during an 8-hour work shift. The SDMats were installed on the engine compartment door that connects to operator cab, and on a portion of the operator cab wall.

SPLs were measured before and after installing the SDMats using a Type I sound-level meter (Model LxT; Larson Davis, Depew, NY, USA) in A-weighting mode, as well as collecting octave-band settings. Sound-level meter calibration was performed before and after each set of measurements. SPL measurements were made for each of the three pieces of heavy equipment on idle and full-throttle settings. Heavy equipment is set on idle when it is kept running, but not being used, and on full throttle while being operated. Full throttle is the more common operating setting and it generates higher noise levels compared with the idle setting. Noise measuring was conducted in an empty yard in the Training Center to prevent interferences by other equipment or the reflection of noise from adjacent building walls. Real-time SPL measurements were taken at the operator seat for approximately 8 minutes at 1-second time intervals. The first and last 30 seconds of measurements were not included in the analysis to account for SPL changes caused by the opening/closing of the heavy-equipment cab door, therefore, for each test, 6 minutes of the SPL measurements were used. SPL measurements were focused on source reduction and subsequent reduction in noise levels at the operator position. However, these SPL measurements do not represent 8-hour time-weighted averages because that will depend on the highly variable work pattern of each day on a construction site. After each SDMat installation, the Training Center mechanic was interviewed to collect information to aid in evaluating the advantages and disadvantages associated with the intervention. The mechanic provided information on the length of time it took to install the SDMats and any difficulties in installing the SDMats.

For each SPL measurement session lasting 6 minutes, PROC AUTOREG in SAS version 9.2 (SAS Institute, Cary, NC, USA) was used to evaluate stationarity and adjust the variance estimates to account for the autocorrelation structure. This enabled statistical testing of the difference between the preintervention and postintervention SPLs [19].

3. Results

For each piece of heavy equipment, four sets of SPL measurements were collected on four different settings: idle preintervention, idle postintervention, full-throttle preintervention, and full-throttle postintervention. The data from all tests are stationary and autocorrelated with a lag of 1. The autocorrelation-adjusted standard error, which increased by 20–30%, was used in

Fig. 2. Grader and roller engine compartments with sound dampening mats (SDMats) installed. In addition, crane engine room with SDMats installed on the door leading to operator cab.

the *t* test to determine whether the preintervention and postintervention noise levels were significantly different.

SPL was reduced for all three pieces of heavy equipment after installing the SDMats (Table 1). The roller SPL was significantly reduced by 12.3–7.6 dBA on idle and full-throttle settings, respectively. In addition, the grader postintervention SPL was significantly reduced by 4.6–7.1 dBA on idle and full-throttle settings, respectively. Similarly, the crane postintervention SPL was significantly reduced by 5.3–5.6 dBA on idle and full-throttle settings, respectively.

Heavy-equipment SPL octave-band levels were measured before and after the intervention on the full-throttle setting (Fig. 3). The highest intensity SPL was recorded at 1,000 Hz for the crane and roller. The grader had a predominant frequency at 500 Hz. The highest SPL attenuation was achieved at the middle frequencies (1,000 Hz and 2,000 Hz) for all three types of heavy equipment. The roller SPL was reduced by 11.2 dBA at 1,000 Hz and 11.5 dBA at 2,000 Hz. The grader SPL was reduced by 8.1 dBA at 500 Hz, 8.5 dBA at 1,000 Hz, and 11 dBA at 2,000 Hz. Similarly, the crane SPL was reduced by 5.6 dBA at 1,000 Hz, 6.1 dBA at 1,000 Hz, and 6.4 dBA at 2,000 Hz.

Table 1
Heavy-equipment preintervention and postintervention sound pressure levels

Heavy equipment	Setting	SPL mean (SE)* (dBA)		*t* Test *p*
		Preintervention**	Postintervention**	
Roller	Idle	83.1 (0.044)	70.8 (0.022)	0.001
	Full	90.5 (0.076)	82.9 (0.045)	0.001
Grader	Idle	83.2 (0.023)	78.6 (0.033)	0.001
	Full	95.6 (0.033)	88.5 (0.048)	0.001
Crane	Idle	80.8 (0.075)	75.5 (0.062)	0.001
	Full	99.2 (0.024)	93.6 (0.021)	0.001

* The mean sound pressure level and standard error.
** $N = 360$ representing 360 seconds of real-time SPL measurements.
SPL, sound pressure level.

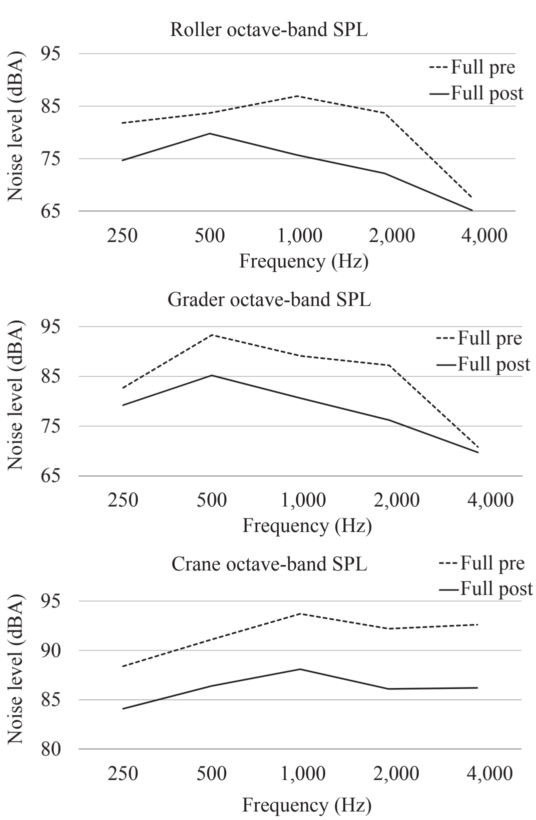

Fig. 3. Preintervention and postintervention octave-band levels for all heavy-equipment machines on the full-throttle setting. SPL, sound pressure level.

4. Discussion and conclusion

Noise exposures are a common hazard at construction sites. The difficulty of implementing effective engineering controls has led to a high dependency on the use of HPDs, even though studies suggest that HPD use is inconsistent and ineffective, resulting in significant noise-induced hearing loss among construction workers. There is a real need for inventive noise engineering controls in construction. Research to practice initiatives for noise reduction in construction has been limited. NIOSH has explicitly recognized and recommended eliminating or reducing noise at its source. The use of SDMats falls in line with NIOSH Prevention through Design (PtD) strategy, which recommends "Engineering out" hazardous noise before exposure occurs. PtD recognizes that noise-reduction measures, such as SDMats, can protect workers' hearing, improve productivity, and lower costs associated with workers' compensation claims from hearing loss [20]. This case study evaluated the effectiveness of SDMats in reducing noise level of heavy-construction equipment. Data collected from three types of heavy equipment, fitted with the intervention, showed promising results. The SPL was reduced on both idle and full-throttle settings for all of the heavy-equipment types, although most heavy-equipment machines are operated on full throttle. The reduction of 5.6–7.6 dBA on full throttle for these types of heavy equipment is a substantial decrease, bringing two of the three below the OSHA permissible exposure limit of 90 dBA. This result shows that the SDMats were technically effective in reducing heavy-equipment noise levels and will make a substantial contribution to reducing noise exposures to both the operator and nearby construction workers.

The octave-band analysis took a closer look at the intervention noise attenuation at different frequencies. The aim was to identify the range of frequencies that contributed the most to the overall exposure and to evaluate the frequencies at which the highest noise attenuation was achieved. Analysis showed that all three pieces of heavy equipment generated the highest SPLs centered on the middle frequencies. In addition, our analysis showed that the intervention was effective in reducing the SPLs at those middle frequencies. When contacted, the SDMats manufacturer provided detailed specifications, which included noise-attenuation testing for their product. According to their product specifications, the SDMats have better noise attenuation at 1,000–4,000 Hz frequencies compared with 125–500 Hz frequencies, as is expected for most noise barriers. The manufacturer can modify the SDMats design to alter the frequencies that will have the highest noise attenuation. Such custom-made SDMats will be more expensive and require extended manufacturing time compared with standard commercially available SDMats.

This study has some limitations. First, the intervention was tested on only three types of heavy equipment using one type of SDMat. The three types of heavy equipment had diverse engine compartment designs, which was a strength of the study, however, additional testing is needed in a wider range of equipment using a variety of SDMat types. A second limitation was that personal dosimetry data were not collected, therefore no evaluation was made on how effective the intervention was in reducing the daily time-weighted average exposure of OEs. However, conducting this type of validation is difficult in the real world, where construction conditions are constantly changing from day to day, because these variable conditions could also impact daily noise exposures making preintervention and postintervention comparisons difficult.

This study also has some strengths. The standard commercially available SDMats used in this study cost less than US$500 in materials for each piece of equipment. The Training Center mechanics reported that SDMat installation was fairly simple and was only limited by the space available within the engine compartment, illustrating that this type of engineering control can be easily and simply installed by contractors who own their own equipment. However, in a large specialized workshop, the heavy-equipment engine could be removed to allow for more space to install the SDMats in the engine compartment. This might allow for thicker layers of SDMats to be installed and result in higher noise attenuation. Finally, the mechanics believe that the SDMats could be installed in most types of heavy equipment used in construction and they reported that after up to 1.5 years of use, the SDMats are still in place and do not require any repairs.

Conflicts of interest

The authors have no conflicts of interest to declare.

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