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Exposure and area noise assessment of stone, sand, and gravel mining facilities

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ABSTRACT

Hearing conservation programs (HCPs) are required at mine sites where noise levels exceed the 85 dB(A) Mine Safety and Health Administration (MSHA) action level as an 8-hour time-weighted average. However, the success of implementing these programs likely varies, and little is known about barriers to full effectiveness. In this context, the National Institute for Occupational Safety and Health (NIOSH) is conducting research to increase the effectiveness of targeted hearing conservation program elements at surface stone, sand, and gravel (SSG) mining operations. As part of this project, an initial noise study at a collaborating surface SSG mine was conducted. The objective of this study was to help identify areas of high noise exposure in the following areas of interest: 1) automatic bagging, 2) manual bagging, 3) rotary drying, 4) palletizing, and 5) screening. To this end, noise levels were measured using a sound level meter on different grids at the areas of interest, and contour maps were developed. Also, a microphone array was used to identify dominant noise sources in the bagging stations. This paper provides a background of the noise exposure status at SSG mines, discusses the importance of increasing the effectiveness of hearing conservation programs, and then summarizes the results of this noise study in the form of contour maps and beamforming maps for the various areas of interest.

1   INTRODUCTION

Noise-induced hearing loss (NIHL) continues to be one of the most prevalent diseases in the mining industry. According to a study conducted by the National Institute for Occupational Safety and Health (NIOSH), in which over 1 million audiograms of workers in 31 industries were

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analyzed, hearing loss in the mining industry has the highest prevalence of 27% compared to the average prevalence of 18% in all other industries[1]. Within the mining industry, Mine Safety and Health Administration (MSHA) data shows more reportable cases of occupational hearing loss at stone, sand, and gravel (SSG) mines than at non-metal and metal mines. Furthermore, although both surface and underground SSG mines have the same incident rate of 2.5 cases per 10,000 miners, surface mines employ approximately 30 times more workers than underground mines[2]. In this context, NIOSH is approaching this problem from different fronts. On the one hand, NIOSH develops engineering noise controls for various types of mining equipment that are responsible for high noise exposures[3-5]. These controls reduce the noise generated by mining machines during operation and thus will reduce the incidence of hearing loss among machine operators in the long run. On the other hand, NIOSH is conducting research to identify and increase the effectiveness of targeted hearing conservation program elements. These programs are required at mine sites where noise levels exceed the 85 dB(A) level, which is MSHA's action level as an 8-hour time-weighted average. The current work is part of the latter approach, and one project objective is to identify areas of high noise exposure in surface stone, sand, and gravel mines, which constitute approximately 70% of all mines in the United States. This initial noise study focused on the following five areas of interest: 1) the automatic bagging area, 2) the manual bagging area, 3) the rotary drying area, 4) the palletizing area, and 5) the screening area. Previous case studies conducted by NIOSH focused on the sound level distribution outside the processing plant buildings[6]. However, the objective of this study was to assess the noise levels inside the plant buildings to get an understanding of the noise exposure of the operators that work in and transit through these areas. This information will be used to estimate the workers' noise exposure based on their task location and duration, and more generally, to understand and characterize the relationship between noise exposure and hearing loss, and to evaluate hearing loss risk among miners at surface SSG facilities.

2   MINE DESCRIPTION

The collaborating mine for this study is a surface stone, sand, and gravel mine. This mine consists of an open pit and a processing plant. At the pit, drilling, blasting and mucking are used to extract the rock; then, the rock is crushed, dried, and sent to the processing plant via a belt conveyor. There, the crushed rock is dried again and sent to the screening building. After being separated and processed into different sizes, the material is finally sent to the bagging building where the products are bagged into small, e.g. 22.7 kg (50-lb), bags and palletized, or bagged in bulk bags (also known as intermediate bulk containers). The mine extracts approximately 800,000 tons of rock per year, of which 650,000 tons are processed. Final products vary from 0.15-mm sand to 45-mm gravel. The mine employs approximately 35 people per shift and operates three shifts per day.

3   METHODOLOGY

For the initial noise study, area samples were collected using a Larson Davis LxT sound level meter on 1-meter and 2-meter spacing grids at a height of 1.5 meters from the floor in the areas of interest. A total of 461 samples was collected consisting of A-weighted equivalent continuous sound pressure level and 1/3-octave band A-weighted sound pressure levels. These data were used to generate the area noise maps and beamforming acoustic maps at both bagging stations. In addition, microphone array data were collected from the two bagging machines and a forklift.

4 RESULTS

4.1 Automatic Bagging Area

Figure 1 shows the automatic bagging machine in the background with the microphone array in the foreground. The bagging machine is run by one operator who inserts a new bag in each of the four feeder nozzles, and then the bag is filled, closed, and dropped onto a belt conveyor that takes it to the palletizing area. Figure 2 shows a schematic top view layout of the building where the automatic bagging machine is installed. This building may be divided into three adjacent areas: Area 1 is located towards the screening building; in this area bulk bags are temporarily stored on pallets. There are also three large storage bins (hoppers) for bulk bagging located in this area. Area 2 is where the actual automatic bagging machine is located. There are also an enclosed control room and a test station in this area. The operator in the enclosed room monitors the rotary dryer as well as the test station. Area 3 has offices, a bathroom, and a compressor room. Also in area 3, an overhead conveyor transports the bags from the automatic bagging machine to the palletizing area. These three adjacent areas are of interest because of the high traffic of operators.
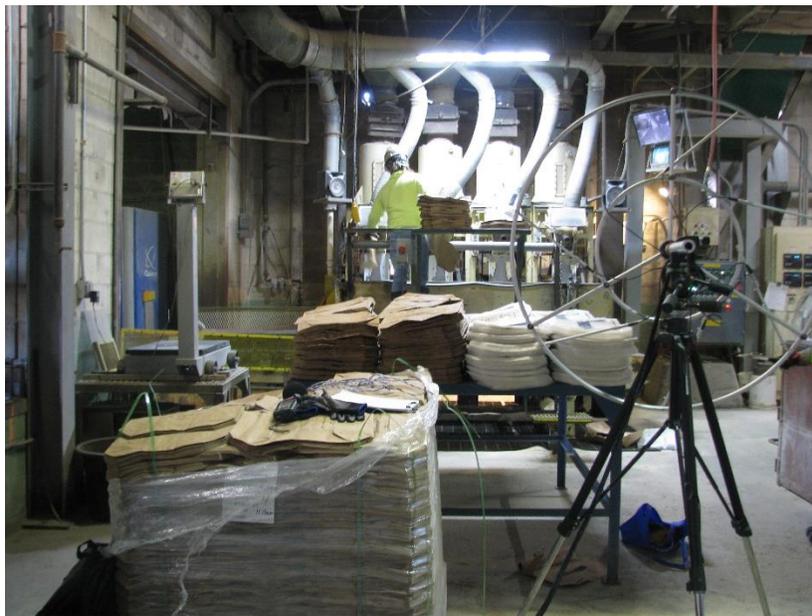
Fig. 1 - Automatic bagging machine and operator in the background, with the microphone array in the foreground.
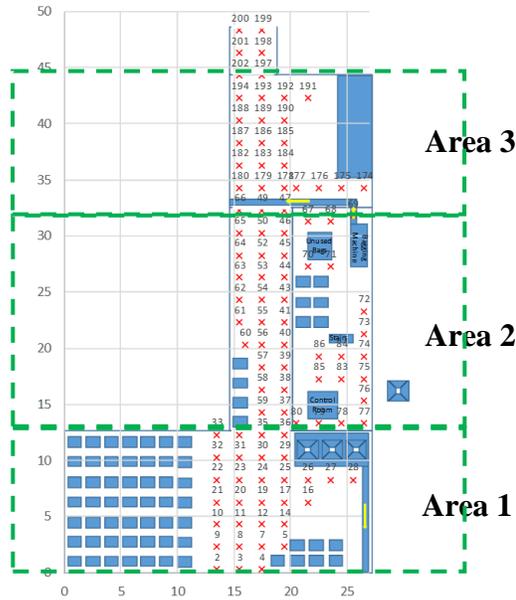
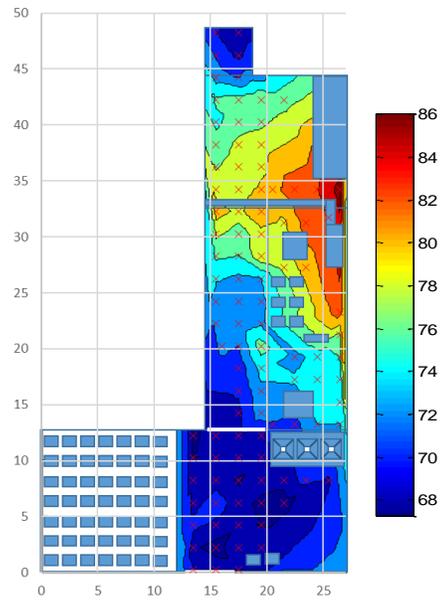*Fig. 2 - Top view layout of the building where the automatic bagging machine is installed (distance, m).*

Fig. 3 - Overall sound pressure level distribution in the automatic bagging building (L_{eq}, dB(A)).

Figure 3 shows a contour map of overall sound levels in the automatic bagging area. From this figure, it can be seen that the highest levels of sound are located near the automatic bagging machine. Figure 4 shows the one-third octave band spectra of the noise measured in front of the automatic bagging machine. This figure shows that significant levels of noise are radiated at 160 Hz and between 630 Hz and 2,000 Hz.
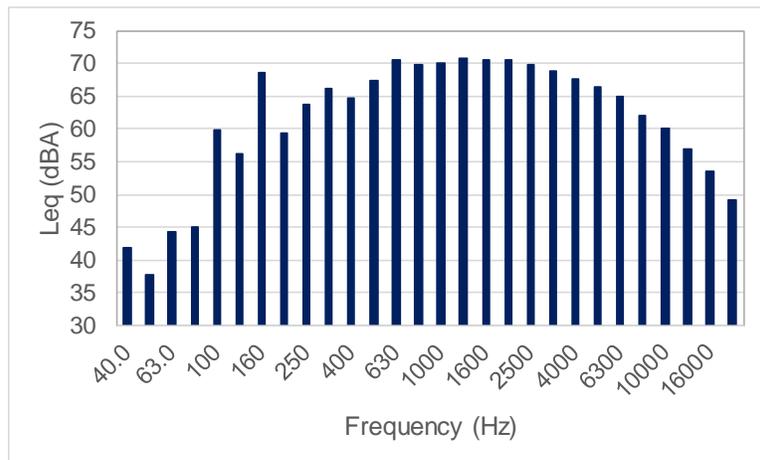

Fig. 4 - One-third octave band sound pressure level measured at the automatic bagging machine.

Figure 5 shows the acoustic maps for the automatic bagging machine in operation. These maps correspond to the one-third octave bands with the highest noise levels, as shown in Figure 4. From these maps, it can be seen that the automatic bagging machine radiates noise at high frequencies, i.e. above 1,250 Hz. However, at low frequencies, i.e. below 1,250 Hz, the noise comes from a source adjacent to the automatic bagging machine. In this adjacent area to the bagging machine, a

belt conveyor transports the bags from the automatic bagging machine to the palletizer. Figure 6 shows the acoustic maps of an inclined segment of this conveyor. From these maps, noise sources at 630 Hz and 800 Hz can be seen at some of the conveyor rollers. However, Figure 6c shows a noise source located behind a column on the right side of the picture. In this location, a room houses an air compressor that supplies air to the automatic bagging machine. It is suspected that this compressor is responsible for the low frequency noise, i.e. less than 1,000 Hz.
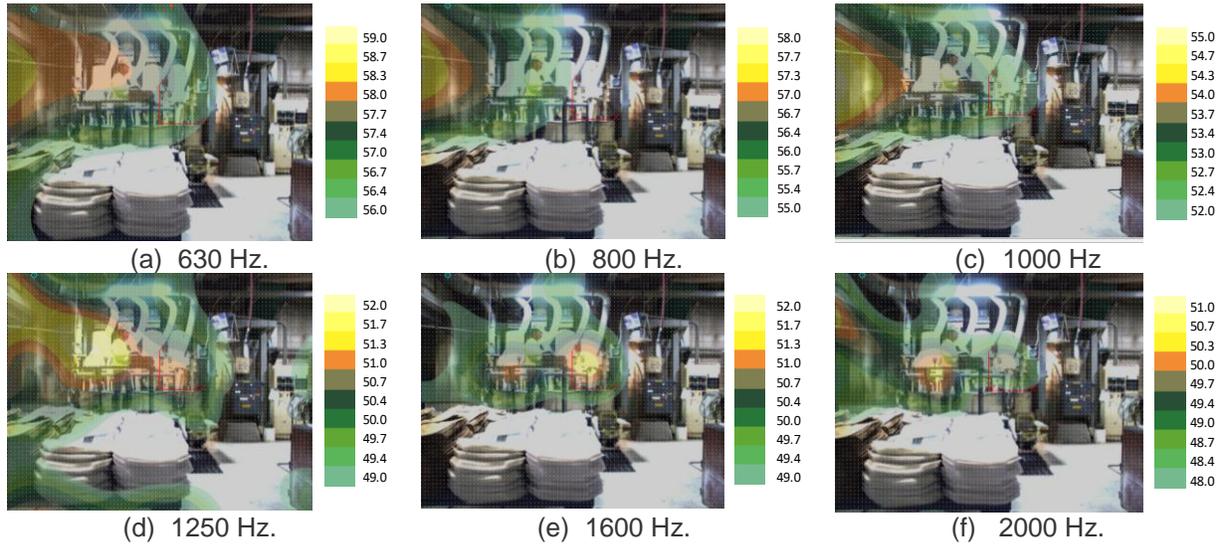

| (a) 630 Hz. | (b) 800 Hz. | (c) 1000 Hz |
| (d) 1250 Hz. | (e) 1600 Hz. | (f) 2000 Hz. |

Fig. 5 - Acoustic maps showing noise sources in the automatic bagging area.
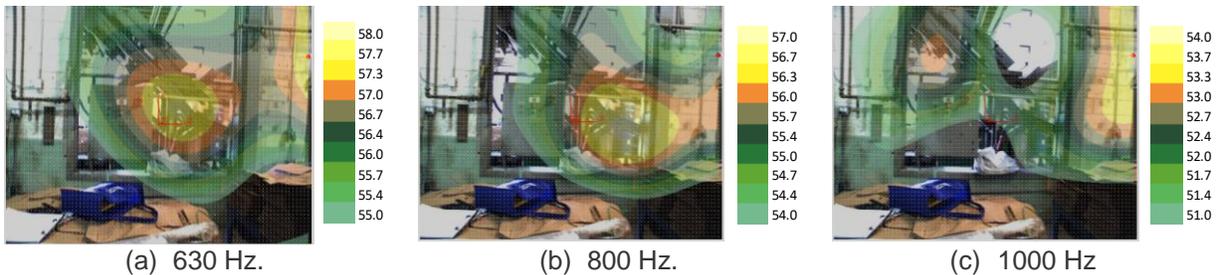

| (a) 630 Hz. | (b) 800 Hz. | (c) 1000 Hz |

Fig. 6 - Acoustic maps showing noise sources in the belt conveyor rise going from the automatic bagging machine to the palletizer area.

4.2 Manual Bagging Area

Figure 7 shows a photo of the manual bagging area. This area consists of a rectangular room 14.5-meters long by 9-meters wide, adjacent to the storage building. The bagging machine is used to bag large size aggregate (from 1.2 mm to 45 mm). One operator and the operator's helper run the machine. The operator inserts an empty bag into the feeder; then, when the bag is filled, seals the bag and drops it onto a small belt conveyor. The helper is located at the other end of the conveyor; he picks the bags from the conveyor and stacks them in a rotary table that self-adjusts its height as it is loaded with bags. This self-adjusting mechanism prevents the helper from bending their back to lower the bags, reducing injury risks. Also shown in Figure 7 are a ventilation fan

mounted on the wall and a belt conveyor that transports material to an upper hopper located above the bagging machine.

Fig. 7 - Manual bagging machine and a wall ventilation fan on the top right corner.

Figure 8 shows a schematic top view layout of the room where the manual bagging machine is installed, and the points where data were collected. Figure 9 shows a contour map of overall sound levels in the manual bagging area. From this figure, it can be seen that the highest levels of sound are located in the vicinity of the bagging machine itself. Figure 10 shows the one-third octave band spectra of the noise measured at the manual bagging machine. This figure shows that significant levels of noise are radiated between 1600 Hz and 4,000 Hz.
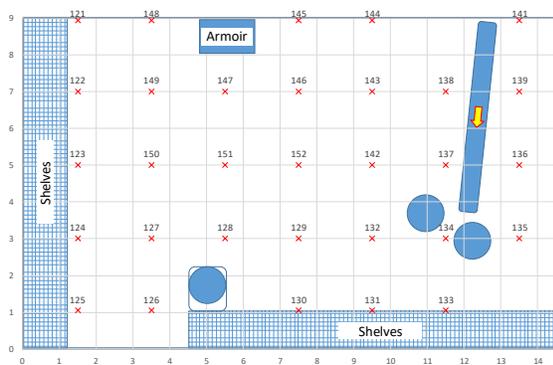

Fig. 8 - Top view layout of the manual bagging machine room (distance, m).
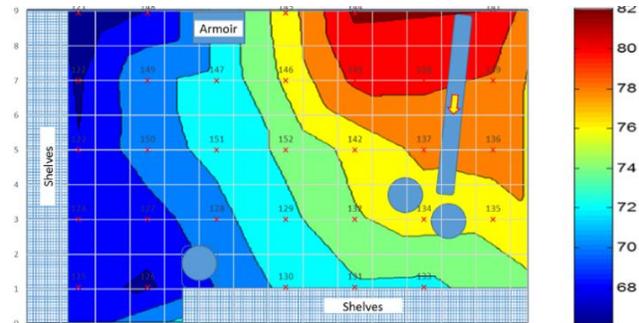

Fig. 9 - Overall sound pressure level distribution in the manual bagging machine room (L_{eq}, dB(A)).
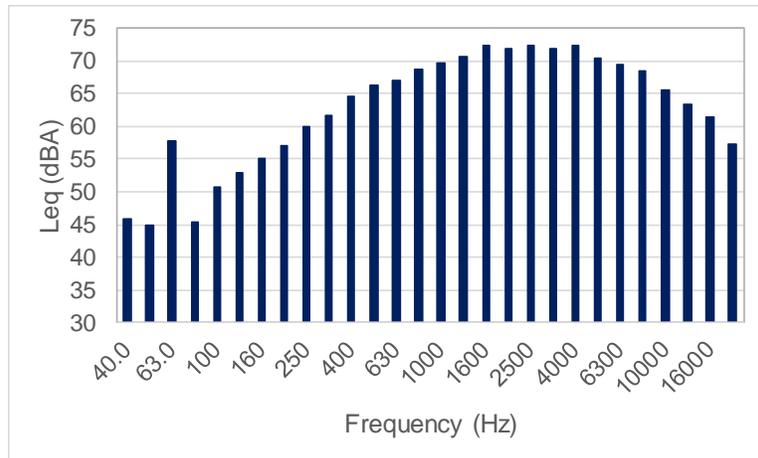
Fig. 10 - One-third octave band sound pressure level measured at the automatic bagging machine.

Figure 11 shows the acoustic maps for the manual bagging machine in operation. These maps correspond to the one-third octave bands with the highest noise levels, as shown in Figure 10. From the acoustic maps, three noise sources can be distinguished: 1) the hopper located above the bagging machine, radiating noise at 630 Hz and at 800 Hz; 2) the ventilation fan radiating noise at 1,000 Hz, and 3) the bag filling mechanism, radiating noise at frequencies at and above 1,250 Hz.
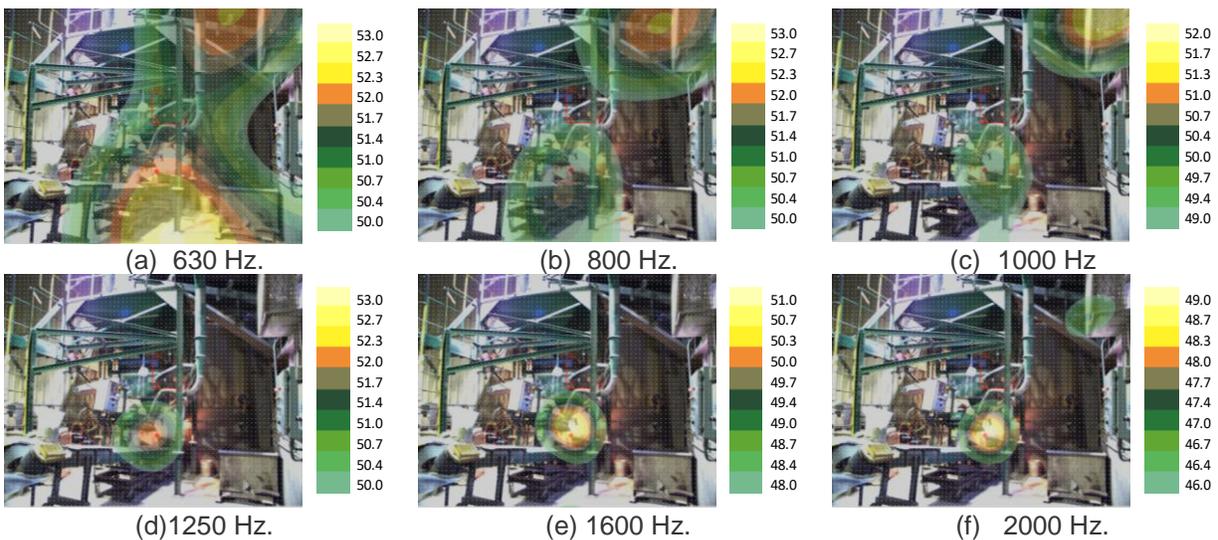

(a) 630 Hz.   (b) 800 Hz.   (c) 1000 Hz

(d) 1250 Hz.   (e) 1600 Hz.   (f) 2000 Hz.

Fig. 11 - Acoustic maps showing noise sources in the manual bagging area.

4.3 Palletizing Area

This area is located between the automatic bagging area and the storage building. The main noise sources in this area consist of the palletizing machines and the belt conveyor that transport the bags into the palletizer. This conveyor is fitted with pneumatic actuators that stop and run the conveyor intermittently, to rotate and accommodate bags in the pallets.

Figure 12 shows a schematic overview layout of the area next to the palletizer where noise samples were collected. This area consists of a passage between the automatic bagging area (on the right side) and the storage/manual bagging areas (on the left side). Figure 13 shows the overall noise map for this area. From this figure, it can be seen that the highest noise levels are located at

the center of this area. This location corresponds to the actual automatic palletizer itself, which rotates the bags and stacks them into pallets.
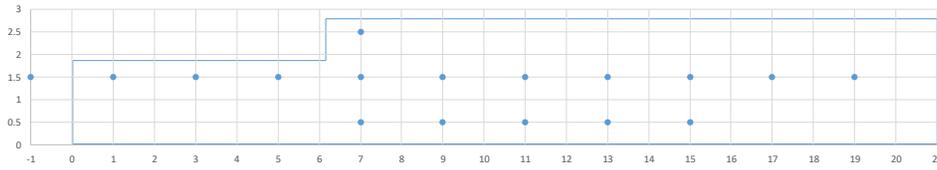

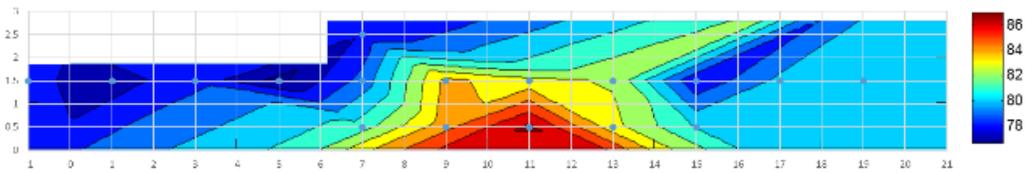*Fig. 12 - Schematic layout of the palletizing area (distance, m)*

Fig. 13 - Overall sound pressure level distribution at the palletizing area (L_{eq}, dB(A)).

4.4 Rotary Dryer

The rotary dryer is used to dry large aggregate before it is sent to the manual bagging machine or to the inside storage bins for bulk bagging. It is located in a 14-meter by 9-meter room, adjacent to area 1 and area 2 of the automatic bagging room. The room has a 4.5-meter wide door opening as shown in Figure 14. Noise data collected for this room yielded the map shown in Figure 15. Also, some measurements were conducted outside the room next to the door opening. From Figure 15, it can be seen that the highest noise levels are present near the center of the drum at 93 dB(A). However, outside the opening, levels dropped to around 84 dB(A).
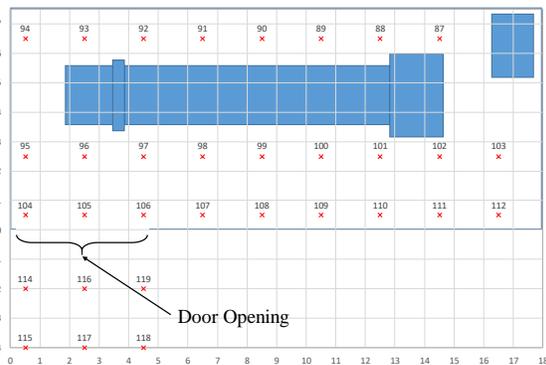

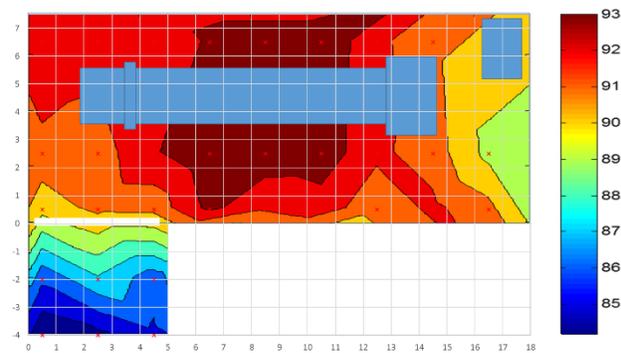*Fig. 14 - Top view layout of the rotary dryer room (distance, m).*

Fig. 15 - Overall sound pressure level distribution for the rotary dryer room (L_{eq}, dB(A)).

4.5 Screening Building

This building has five levels. The crushed rock arrives in this building via a conveyor, and it proceeds through the various screens until it reaches the first floor from where it is transported to the bagging building. There is one operator who periodically conducts maintenance and inspection on the various screens. During a shift, this operator usually conducts three visits to the screening building; two out of the three times, he conducts cleaning tasks of the various screens, spending around 30 to 45 minutes per visit. The rest of the time this operator monitors the activities from a control room located on the first floor, adjacent to the main building. Noise level samples were collected on each floor, as shown in Figure 16. However, since the space for the operators is reduced, as shown in Figure 17, contour maps were not prepared. Instead, the maximum, minimum, and the mean equivalent continuous sound pressure levels on each floor was obtained. Table 1 summarizes these values for each floor. Noise samples were also collected in the operator's control room, and they are also shown in Table 1. Table 2 lists the mean sound pressure level near each of the various noise sources present in this building. From this table it can be seen that the highest noise source is a periodic compressed air release in the first floor, reaching levels of 100 dB(A).
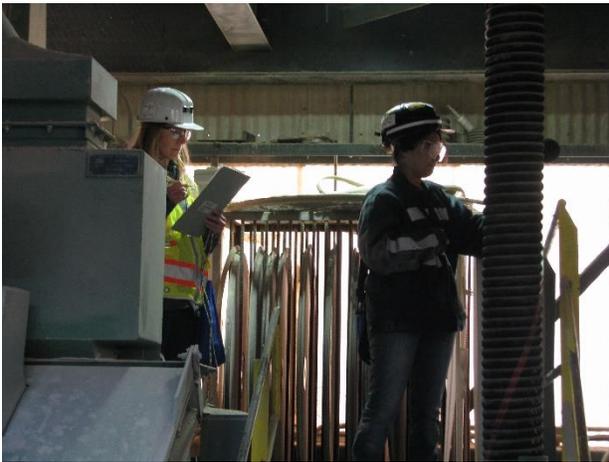
Fig. 16 - Data collection in the screening building.

Fig. 17 - Screens in parallel on the second floor of the building.

Table 1. Maximum, minimum, and average sound levels on each floor of the screening building, dB(A).

Floor	Room	Minimum	Maximum	Range	Mean	Standard Deviation
1	Screen Building	83.3	100.0	16.7	85.9	3.4
	Control Room	-	-	-	60.9	-
2	Screen Building	84.9	95.0	10.1	87.0	1.8
4	Screen Building	86.3	92.0	5.7	88.1	1.0
5	Screen Building	87.4	91.2	3.9	89.0	0.9

Table 2. Average sound pressure levels measured at each of the various noise sources in the screening building, dB(A).

Floor	Description	Mean L_{Aeq}
1	Outside of Control Room with the shaker running	93.0
	Compressor air release (periodically)	100.0
	Conveyor	84.4
2	On the platform next to the screeners	86.3
	On the middle of stairs	87.2
	On the middle of the aisle between 2 screeners	87.9
4	Compressor	89.6
	Screener	88.9
5	Motor	89.9
	Screener	89.0

5 DISCUSSION

Of the various areas of interest surveyed in this study, the automatic and manual bagging areas have the highest worker traffic. During a normal shift, there are two operators for the automatic bagging machine and the palletizer. These operators switch positions every four hours. There is also one operator in the control room in Area 2 (shown in Figure 2). This operator monitors the rotary dryer drum and obtains three to four samples of the product being bagged per day in the shaker test station. Finally, three forklift operators move the pallets in and out of this area. Therefore, there are usually six workers that receive a noise dose from the automatic bagging area.

At the manual bagging area there are usually two, and on occasion up to three, operators—with one operator at the bagging machine, one at the end of the conveyor belt stacking and palletizing the bags, and the third operator moving the pallet to the wrapping machine and then to the storage building. These operators usually switch positions every two hours. Therefore, there are up to three workers who accumulate their daily noise dose in the manual bagging area.

In contrast to the two bagging areas where up to nine operators accumulate their daily noise dose, the screening building and the rotary dryer room have the least traffic of workers. There is only one operator who monitors the screening building operation and conducts periodic checks. During a normal day, this operator usually conducts three visits to the screening building; for two out of the three visits, he performs cleaning of the screens for 30 to 45 minutes on each visit. Similarly, only one operator monitors the rotary dryer drum. This operator is located in an enclosed control room in Area 2 of the automatic bagging building and spends less than one hour in the vicinity of the rotating drum, conducting an inspection, during a normal shift.

6 CONCLUSION

An initial noise study was conducted by NIOSH researchers in a stone, sand, and gravel processing plant. The objective of this study was to assess the noise levels in five areas of interest. This study is part of a larger project to increase the effectiveness of targeted hearing conservation program elements at surface stone, sand, and gravel mining operations.

Noise area maps were obtained in four of the five areas of interest. In addition, beamforming acoustic maps were also generated at the two bagging stations. These area maps and beamforming maps show the locations with the highest noise levels and the location of noise sources, respectively. From this study, it was found that high noise levels are present in the vicinity of the automatic bagging machine. In this area, the dominant noise sources at frequencies of less than 1,000 Hz are a compressor that supplies air to the automatic bagging machine, and curved and incline conveyors that transport bags from the automatic bagging machine to the palletizer. At frequencies above 1,000 Hz, the automatic bagging machine itself is the dominant noise source. During a normal shift, approximately six operators work in this area. At the manual bagging machine, low frequency (less than 1,000 Hz) noise sources are the storage hopper located above the bagging machine and a ventilation fan installed in the wall near the bagging machine. At high frequencies (greater than 1,000 Hz), the bagging machine itself is the dominant noise source. During a normal shift, there are generally two operators, and sometimes up to three operators, working in this area. Finally, both the rotary dryer room and the screening building are each monitored by one operator located in an enclosed control room. The screening building operator spends between 1:30 to 2:15 hours inside the building conducting maintenance to the screens, and the rotary dryer operator spends less than one hour in the vicinity of the rotating drum.

The results from this study will be used to further understand and characterize the relationship between noise exposure and hearing loss and to evaluate hearing loss risk among miners at surface stone, sand, and gravel facilities.

7   ACKNOWLEDGEMENTS

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