APPLIED STUDIES

Construction Noise: Exposure, Effects, and the Potential for Remediation; A Review and Analysis

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More than one-half million construction workers are exposed to potentially hazardous levels of noise, yet federal and state Occupational Safety and Health Administration (OSHA) programs provide little incentive to protect them against noise-induced hearing loss. Construction noise regulations lack the specificity of general industry noise regulations. In addition, problems that characterize the construction industry, such as worker mobility and the large proportion of small businesses, make implementing hearing conservation measures more difficult. The apparent severity of exposure depends greatly on the measurement method, with the 3-dB exchange rate almost always showing higher average exposure levels than the 5-dB (OSHA) rule. Construction workers demonstrate hearing threshold levels that generally conform to those expected in manufacturing. The prevalence of hearing protection device (HPD) use among U.S. construction workers is very poor, partly because of perceived difficulties in hearing and understanding speech communication and warning signals. In addition, masking by noise of necessary communication and warning signals is of particular concern in construction, where recent research demonstrated the association between fatalities and the failure to hear reverse alarms. Judicial use of HPDs is of the utmost importance, along with avoiding overattenuation, selecting HPDs with uniform attenuation, and using noise-attenuating communication systems when possible. A successful hearing conservation program in British Columbia can serve as a model for the United States, with a long-standing positive safety culture, a high percentage of HPD use, improvement in average hearing threshold levels over the last decade, and a centralized record-keeping procedure, which helps solve the problem of worker mobility. However, controlling construction noise at the source is the most reliable way to protect worker hearing. U.S. manufacturers and contractors should benefit from the activities of the European Community, where noise control and product labeling in construction has been carried out for more than 20 years.

Keywords: construction workers, hearing conservation, noise exposure

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The fact that U.S. construction workers are exposed to hazardous levels of noise and sustain significant hearing impairments is not news. That these impairments are at least as great as would be expected from an industrial population became evident during the 1960s and 1970s.[1,2] Estimated numbers of construction workers exposed to potentially hazardous levels of noise range from about half a million to 750,000.[3,4] In 1988 the National Institute for Occupational Safety and Health (NIOSH) recommended that the Occupational Safety and Health Administration's (OSHA's) noise regulation, including the hearing conservation provisions, be extended to construction workers as well as to other occupations not then covered.[5] A 1995 conference jointly sponsored by NIOSH and the National

TABLE I. Construction Employment Data (1995) and NIOSH Estimates (1981–1983) of Numbers Exposed at or Above 85 dBA (Adapted from Hattis[4])

SIC	Industry Description	1995 1000s Employees	NIOSH % Exposed >85 dBA[A,B]
152	Residential builders	609	12
154	Nonresidential builders	567	12
161	Highway and street construction	223	27
162	Other heavy construction	526	17
171	Plumbing, heating, and air conditioning	712	7
172	Painting and paper hanging	179	20
173	Electrical work	593	13
174	Masonry, stonework, and plastering	409	8
175	Carpentry and floor laying	219	32
176	Roofing, siding, and sheet metal	208	11
177	Concrete work	248	40
179	Miscellaneous special trade contractors	548	14
Total (in 1000s)		5041	

[A]Percentages were rounded to the nearest integer.
[B]Total number exposed >85 = 754,174.[4]

Hearing Conservation Association identified construction workers as an "underserved" population.[6]

In the United States there are separate noise regulations for construction (29 CFR 1926.52 and 1926.101) and general industry (29 CFR 1910.95). The permissible exposure limits (PEL) and requirements for noise control are essentially the same, an 8-hour time-weighted average exposure level (TWA) of 90 dBA with a 5-dB exchange rate between allowable duration and noise level. Engineering or administrative controls are required to be implemented above this level, and hearing protection devices (HPDs) must be issued and worn when exposures exceed the PEL. Both regulations require hearing conservation programs (HCPs) for overexposed workers, but there are two essential differences: (1) the noise regulation for general industry requires the initiation of HCPs at an action level of 85 dBA, whereas the construction regulation does not use an action level; and (2) the general industry regulation gives detailed requirements for noise exposure monitoring, audiometric testing, (HPDs), worker training and education, and record keeping, whereas the construction regulation (1926.52) has only a general requirement for "continuing effective hearing conservation programs" above the PEL. Construction regulation 1926.101 merely mandates the use of hearing protection above the PEL and requires insert devices to be fitted or determined individually by "competent persons."

Current enforcement of these noise regulations is not rigorous, particularly in construction. Neither the noise reduction nor the hearing conservation provisions are well enforced in construction. For example, of more than 18,000 federal construction inspections during fiscal year 1998, only 63 inspections were conducted for the noise regulations, resulting in a total of 79 citations.[7] Lack of enforcement characterizes state as well as federal programs. Even those states that have adopted the general industry noise regulation for construction, such as the state of Washington, have failed to enforce the hearing conservation provisions.

Part of the problem has been a perceived lack of information about the noise exposures of construction workers, although several studies have been conducted over recent decades in the United States and Canada. A more salient reason for the lack of activity in this area is the impracticality of the usual approaches to HCPs in the construction arena. Mobility among construction workers, short periods of employment, and the consequent difficulty in record keeping and follow-up present daunting obstacles. This report attempts to address these issues and offer possible solutions.

NOISE EXPOSURE LEVELS OF CONSTRUCTION WORKERS

Evidence of Overexposure

Several studies conducted in the 1960s and 1970s indicated that construction workers were overexposed. In the early 1980s NIOSH estimated the numbers of workers in various occupations, including construction, exposed to noise levels above 85 dBA.[8] Table I gives the estimated percentage of workers in various construction trades exposed to noise levels above 85 dBA. Although the percentages were derived in the early 1980s, the data on numbers of employees in the various trades has been updated to 1995.[4]

The highest percentages of overexposed workers occur in highway and street construction, carpentry, and concrete work. Of the approximately 5 million construction workers in 1995, the total number exposed to noise levels of 85 dBA and above was about 754,000. Because NIOSH sampled noise levels rather than exposures, these are not TWAs, and the actual numbers would be somewhat lower when using TWA, but these numbers are useful for ranking the extent of the hazard by trade and to estimate the upper bound of the total number exposed.

Studies of Noise Exposure in Construction Workers

Recent studies have supplemented the earlier ones with noise dosimetry, providing a more precise and comprehensive picture of construction workers' exposures. Table II, containing information from Sinclair and Haflidson,[9] shows average daily noise exposures of construction workers by type of construction. The authors obtained samples of up to 5 hours in 27 construction projects during 1991–1992, which, due to the repetitive nature of the work, they considered representative of a full shift. They measured according to the proposed Ontario Noise Regulation, which specifies a 3-dB exchange rate.[10] TWA sound levels using the 3-dB exchange rate

TABLE II. Average Noise Exposure Levels (Daily L_{eq}) by Type of Construction (Adapted from Sinclair and Haflidson[9])

Type of Construction	Number Samples	Average dBA[A]	Range dBA[A]
Residential	7	93	87–96
Roads/bridges	16	93	84–100
Shop work[B]	26	95	85–104
Maintenance	2	95	91–97
ICI[C]	23	96	81–108
Sewer/water	17	99	85–108
Plant work[D]	6	101	87–106
Power station	6	108	93–113
Total	103	99	81–113

[A]Rounded to the nearest integer
[B]Shop work = work in a contractor's fabrication shop.
[C]ICI = industrial, commercial, or institutional.
[D]Plant work = work in a construction contractor's plant.

are sometimes referred to as "equivalent continuous sound levels" or L_{eq}. Of the 103 workers sampled, the average noise exposure level was approximately 99 dBA.

Table III, also from data gathered by Sinclair and Haflidson,[9] shows daily average noise exposure levels by trade, activity, or equipment. The authors caution that in many cases the samples are too small to state definitively which sectors of construction have the greatest risk, but, in their words, "the magnitude of the problem is obvious."[(p. 459)] From Table III it is clear that boilermakers and iron workers, at least those studied here, are heavily exposed, with average exposure levels of 108 and 105 dBA, respectively. The authors concluded that pneumatic tools were largely responsible.

In another Canadian study, Legris and Poulin[11] reported on the noise exposure of heavy equipment operators and laborers. The data were collected in Quebec in the late 1980s and the measurements used a 5-dB exchange rate. The average duration of the work shift was 9.5 hours with a range of 8–12 hours, and the data were normalized to an 8-hour shift. Of the 250 samples taken, 65 were from laborers and 185 from heavy equipment operators.

TABLE III. Average Noise Exposure Levels (Daily L_{eq}) by Trade, Activity, or Equipment (Adapted from Sinclair and Haflidson[9])

Trade, Activity, or Equipment	Number of Samples	Average dBA[A]	Range dBA[A]
Install rebar	2	89	88–90
Carpenter	3	90	82–94
Mason	14	91	84–97
Framer	7	93	87–96
Sprinkler	6	94	86–97
Forming	5	94	87–97
Refractory	2	95	91–97
Sheet metal	17	96	85–104
Ironworker	2	105	98–108
Boilermaker	6	108	93–113
Paver	6	90	84–92
Front-end loader	2	90	87–92
Scraper	5	90	88–91
Curb machine	3	93	86–96
Roller	2	98	93–100
Crane	3	99	95–102
Dozer	6	102	85–108
Heavy equipment	4	90	86–94
Gravel plant	4	102	88–106
Other	4	88	81–90
Total	103	99	81–113

[A]Rounded to the nearest integer

TABLE IV. Average Daily Noise Exposure Levels (8-Hour TWA) of Heavy Equipment Operators and Associated Laborers in dBA (Adapted from Legris and Poulin[11])

Operator or Task	Mean TWA	SD	Range
Heavy-duty bulldozer	99	5	91–107
Vibrating road roller	97	4	91–104
Light-duty bulldozer	96	2	93–101
Asphalt road roller	95	4	85–103
Wheel loader	94	4	87–100
Asphalt spreader	91	3	87–97
Light-duty grader	89	1	88–91
Power shovel	88	3	80–93
Laborers	90	6	78–107
Crawler crane >35 ton			
Noninsulated cab	97	2	93–101
Crawler crane <35 ton			
Noninsulated cab	94	3	90–98
Insulated cab	84	3	80–89
Rubber tired cane >35 ton			
Noninsulated cab	84	5	78–90
Insulated cab	74	9	59–87
Rubber tired crane <35 ton			
Insulated cab	81	4	77–87
Truck-mounted crane	79	2	76–83
Tower crane	74	2	70–76

Table IV gives 8-hour average noise exposure levels for heavy equipment operators and laborers according to Legris and Poulin. The authors explained the variations in exposures by such factors as the location and type of muffler, amount of time the equipment was idling or under load, the power rating of the engine, and the nature of the task. Of particular importance were the presence or absence of an insulated cab and the design of the equipment. Note the 10-dB difference between insulated and noninsulated cabs and the 13-dB difference between crawler and rubber-tired cranes weighing more than 35 tons with noninsulated cabs.

The results of another, smaller study of operating engineers and laborers are in general agreement with those of Legris and Poulin. Greenspan et al.[12] found 8-hour TWAs ranging from about 68 to 103 dBA, with a mean TWA of 89 dBA, although five of the eight samples were above 90 dBA. The study should not be considered conclusive because of the small sample size (N=8) and the wide range of exposures, but it gives a clear example of the benefits of noise reduction in machinery design. The 68-dBA exposure was achieved in a Caterpillar 980 front-end loader with an enclosed, sound insulated cab.

Data from the Worker Compensation Board of British Columbia[13] are also in general agreement with the above data, although such factors as occupations, sample sizes, and the exchange rate vary from study to study.

Several factors make it difficult to draw comparisons between these kinds of studies. First, the exchange rate has an effect, with the 3-dB exchange rate almost always producing higher exposure levels than the 5-dB exchange rate. Second, the length of the work shift, of course, increases the exposure level; and third, the amount of time each worker spends on each piece of equipment also has an effect.

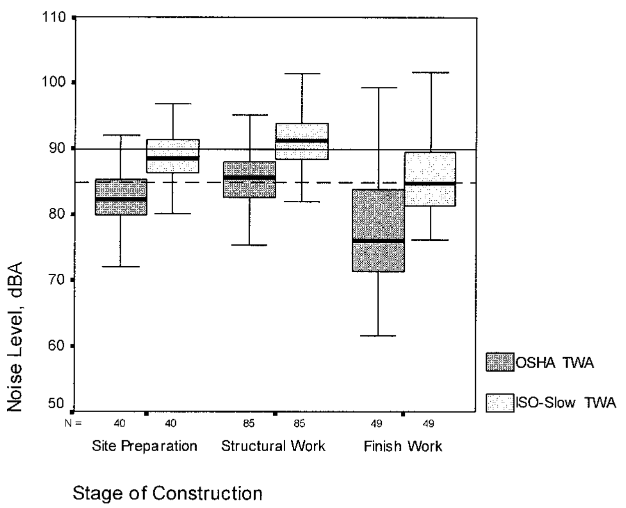

FIGURE 1. Comparison of OSHA and NIOSH/ISO TWAs by site stage of construction. Reprinted from Neitzel et al.[14] with permission of the first author.

Effect of the Exchange Rate

Varying and intermittent noise environments are typical of the construction industry, unlike many manufacturing industries in which the noise is relatively continuous. Much of the construction process takes place outdoors, without the reverberant buildup typical of factories, and it is often characterized by the high-level short-duration sounds of hand tools. When noise from heavy equipment predominates, however, the sound tends to be more continuous. Thus, the differences between measurements using the 3- and the 5-dB exchange rate become more pronounced as the type of construction moves from site preparation, which involves much use of heavy equipment, to finishing work involving carpentry and the use of hand tools.

Neitzel, Seixas, and their colleagues at the University of Washington measured the noise exposure levels of 133 carpenters, laborers, ironworkers, and operating engineers with data-logging dosimeters.[14,15] They found that using the 5-dB exchange rate ("OSHA TWA"), 13% of their samples exceeded the 90-dBA criterion and 40% exceeded the 85-dBA criterion. Using the 3-dB exchange rate ("ISO-slow TWA"), 45% exceeded the 90-dBA criterion and 80% exceeded the 85-dBA criterion. These large differences, according to stage of construction, are presented graphically in Figure 1.[14] The boxes represent the range of noise exposure between the 25th and 75th centiles, the brackets show the entire range of exposures, and the horizontal lines within the boxes represent medians. One can see that the differences are larger in finish work than in site preparation and structural work. The authors found the differences to be statistically significant for both finish work and structural work, although not for site preparation.

Figure 2, also from Neitzel et al., compares noise exposure levels using the 3- and 5-dB exchange rates by construction trade. The differences are smallest for the operating engineers and greatest for carpenters, but they are also substantial for ironworkers and laborers. In this case all of the differences were significant at the 0.05 level. The authors found an overall difference between the 3- and 5-dB exchange rates of about 7 dB.

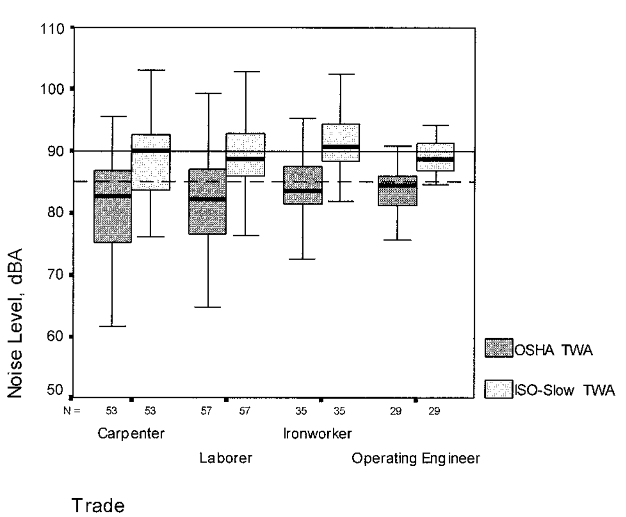

FIGURE 2. Comparison of OSHA and NIOSH/ISO TWAs by trade. Reprinted from Neitzel et al.[14] with permission of the first author.

TABLE V. Median 1-Min Sound Levels in L_{eq} by Equipment/Tool (Adapted from Neitzel et al.[14] Using Additional Data Supplied by Neitzel[16])

Tool Name	Tool Drive Type	Minutes	Median dBA	SD dBA	Range dBA
Air compressor	pneumatic	255	96	11.2	70–114
Backhoe	gasoline	1908	86	6.0	70–108
Bulldozer	gasoline	494	89	8.2	70–104
Chipping gun	pneumatic	1151	93	13.1	70–120
Chopsaw	electric	631	80	8.6	70–106
Crane	electric	3059	78	7.7	70–110
Forklift	gasoline	3727	85	5.8	62–125
Hand hammer	mechanical	4443	85	8.0	56–110
Jackhammer	pneumatic	267	104	11.4	70–112
Lejeune gun	pneumatic	390	89	8.4	70–120
Truck	gasoline	970	78	8.0	70–123
Welding torch	other	1923	84	8.9	70–118

Relative Hazard of Construction Equipment

Because construction workers often use several different pieces of equipment, Neitzel and Seixas developed a method by which the average noise contribution of the various tools and equipment could be assessed. Table V gives "1-min sound levels" of construction equipment. This term represents an average of the 1-min dosimeter readings in L_{eq} (3-dB exchange rate) that came from periods when workers reported using a particular piece of equipment. For example, there was a total of 255 min during which workers reported using an air compressor, and the median sound level, integrated during each 1-min period, was 96 dBA, with a range of 70 to 114 dBA and a standard deviation of 11.2 dBA. The large standard deviations for most pieces of equipment reflect the variations of sound levels and conditions of use.

These 1-min average noise levels do not represent noise doses or 8-hour time-weighted exposures, but they do provide a means for estimating the relative hazard of the various pieces of equipment. The reason they may be somewhat lower than measurements taken with a sound level meter is that they tend to incorporate some amount of time when the equipment is either idling or actually turned off. Although it would be useful to have data on additional types of equipment, as well as various models of the

TABLE VI. Job Specialties Showing Incidence of Hearing Loss (Adapted from Ohlin[25])

Job Title	No. Audiograms in Specialty	No. with Hearing Loss[A]	Percentage with Hearing Loss[A]
Crane operator	116	38	33
Welder	602	176	29
Carpenter	811	214	26
Engineering equipment operator	340	84	24
Wood worker	258	61	24
Motor vehicle operator	983	185	19
Electrician	495	92	19

[A]HTLs greater than an average of 25 dB at 1000, 2000, and 3000 Hz.

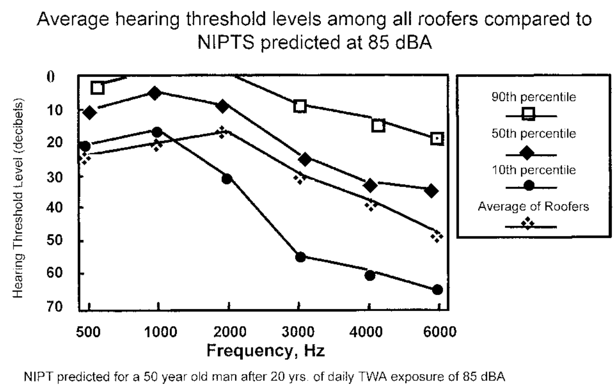

FIGURE 3. Average hearing threshold levels among roofers compared with those of a hypothetical 50-year-old population exposed to 85 dBA for 20 years as predicted by ISO 1999 using Annex B. Reprinted from Schneider and Tennenbaum[27] with permission of the first author.

same type of equipment, these data show that pneumatic tools, such as jackhammers and chipping guns, pose a greater risk than those powered by other means.

Chemical and Combined Exposures

In recent years there has been a substantial increase in information on the adverse auditory effects of chemicals, especially when combined with high levels of noise. OSHA estimates nearly one million construction workers are occupationally exposed to lead,[17] a substance known to be ototoxic.[18,19] Solvents, such as toluene and xylene, have been implicated as causes of occupational hearing loss, and, particularly when combined with noise, appear to exacerbate the hazard to hearing.[20–23] In a report on construction laborers, Burkhart et al.[24] placed toluene and xylene high on the list of hazardous chemicals and physical agents in terms of estimated number of exposed workers. Until more details are known about the combined exposures of construction workers, the existing data in this area should be used as added incentive for diligence in protecting workers, both from noise and from potentially hazardous chemicals.

HEARING THRESHOLD LEVELS OF CONSTRUCTION WORKERS

Although there is not nearly as much information on hearing threshold levels of construction workers as there is on noise exposure levels, fortunately, some data do exist. Studies as early as the 1960s and 1970s pointed out the problem. LaBenz et al.[1] measured the hearing of 66 operators of earth-moving vehicles and found considerably more hearing loss than in a population not exposed to noise for all age groups. Kenney and Ayer,[2] with more sophisticated audiometric equipment, measured hearing threshold levels of 33 sheet metal construction workers who regularly used hand-held power tools. They found noise-induced threshold shifts that were significant for every age group and greatly exceeded expected hearing threshold levels for the older age groups.

Ohlin[25] prepared an inventory of civilian job specialties giving the number and percentage of workers in each specialty with hearing loss, defined as hearing threshold levels (HTLs) greater than an average of 25 dB at 1000, 2000, and 3000 Hz. The list, found in Table VI, includes several jobs that are associated with construction activity.

Waitzman and Smith[26] performed a multivariate regression analysis based on the combined data from the Public Health Service and Health Examination Surveys of 1960–1961 and 1971–1975. The authors divided industrial workers into three categories: construction, manufacturing/mining, and other. They found that the construction category showed the greatest amount of hearing loss for all degrees of severity and at all ages, demonstrating the magnitude of the problem in construction and indicating that the onset of noise-induced hearing loss starts early. The relative risk for blue-collar construction workers was three times that of white-collar workers. In addition, white-collar construction workers also had more hearing loss than their counterparts in other industries.

A recent study of hearing loss among 66 roofers was conducted by Schneider and Tennenbaum.[27] Subjects completed a questionnaire that included information on other hazards, such as exposure to vibration, fuels, thinners/solvents, paints, glues, lead, extreme heat, and extreme cold, as well as information on hypertension and shooting habits. The average age was 48 years with 20 years on the job. Subjects reported that they generally worked slightly more than half time and they wore hearing protection infrequently (2 always, 7 often, 11 sometimes, and 46 never). The only confounding variables that showed an effect were hypertension and shooting. The authors adjusted the data for shooting by using only the right ear of the 18 subjects that reported use of weapons.

Figure 3, from Schneider and Tennenbaum,[27] shows the average hearing threshold levels of roofers compared with the median, 90th, and 10th centiles predicted by ISO 1999 for the same age group exposed for 20 years to average levels of 85 dBA. The roofers' hearing threshold levels fall between the median and 10th centiles of the ISO prediction.

Two factors might cause these thresholds to be overestimates of the true hearing thresholds of roofers. First, the audiometric room was quiet but not soundproofed, which would be likely to produce elevated thresholds in the low and middle frequencies, although lack of soundproofing is unlikely to affect thresholds above 1000 Hz, where the major differences manifest. Secondly, a self-selection bias could occur because these subjects were volunteers at a convention. The bias could, however, work the other way in that some roofers might not volunteer because they did not want to confront the fact of hearing loss. One factor that would cause these thresholds to be underestimates is that they are part-time exposures that are compared with full-time exposures in

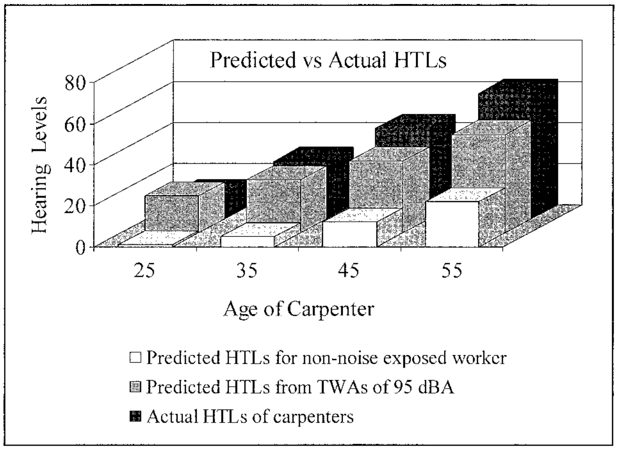

FIGURE 4. Predicted compared with actual hearing threshold levels at 4000 Hz for carpenters. Reprinted from Stephenson[28] with permission of the author.

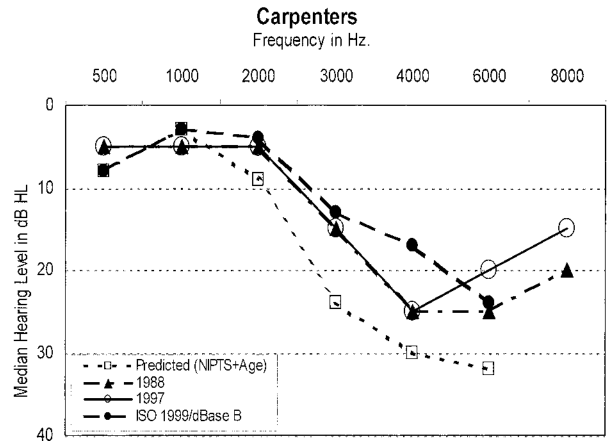

FIGURE 5. Hearing threshold levels of British Columbia carpenters (triangles, 1988; open circles, 1997) plotted against a population not exposed to noise (closed circles) and predictions of expected hearing threshold levels due to average measured exposures of carpenters of L_{eq} 91.3 dBA (dashed line). Reprinted from Gillis and Harrison[29] with permission of the first author.

the ISO method. Thus, to the extent that other roofers work longer hours their hearing losses could be more severe.

Figure 4, from Stephenson,[28] shows predicted compared with actual hearing threshold levels at 4000 Hz for carpenters. The data were collected by NIOSH personnel at a convention, so once again, self-selection may have introduced a bias, either to higher or lower hearing threshold levels. The results are interesting, however, because the author compares mean hearing levels of carpenters with a control group not exposed to noise (Annex A of ISO 1999 or ANSI S3.44, which comprises hearing threshold levels of an ontologically normal [highly screened] population) and to median hearing levels predicted by ISO 1999 (or ANSI S3.44) of persons exposed to average daily levels of 95 dBA for the same age groups. One can see that the carpenters' hearing threshold levels are considerably greater than those of the subjects not exposed to noise in all age groups, and worse than the 95-dBA populations in the older age groups. These data would indicate, to the extent that this is a representative sample, that the exposures of carpenters equal or exceed an average L_{eq} of 95 dBA.

Undoubtedly, the most comprehensive HCPs for construction workers are those of the Worker's Compensation Board (WCB) in British Columbia. Figure 5, supplied by the WCB, shows HTLs of carpenters dating from 1988 and 1997.[29] These HTLs are plotted against a population from ISO 1999 Annex B (hearing threshold levels listed in Annex B of ISO 1999 [and ANSI S3.44] are for an unscreened population in an industrialized country) not exposed to noise and predictions of expected hearing threshold levels (noise-induced permanent threshold shift plus age) calculated from the measured exposures of a group of 63 carpenters in British Columbia. The carpenters' data are for the right ear and Annex B data are for the better ear, although any effect caused by this difference should be minimal. The average exposure of the measured group was an L_{eq} of 91.3 dBA. One can see that the carpenters' HTLs were slightly worse than that of the population not exposed to noise but somewhat better than the predictions based on ISO 1999. Also, there is a slight improvement between the measured thresholds in 1997 and those from 1988 in the 6000- and 8000-Hz frequencies.

Figure 6 shows the same kind of data for equipment operators.[29] The ISO 1999 estimates of HTL are based on the measured noise exposures of 46 workers with an average L_{eq} of 91.6 dBA. Once again the 1988 HTLs are worse than those of the control population not exposed to noise and better than would be predicted according to the ISO standard. HTLs of the 1997 population, however, mimic the nonexposed curve and are substantially better than would be predicted by the average exposure level of a similar group of equipment operators. The reasons for these improvements are most likely attributable to the success of HCPs, which will be discussed further in the following sections. It is possible that some of the improvements may be due to the learning effect, an artifactual improvement in HTLs that occurs when people take several audiometric tests over a period of time. However, one cannot dispute the large differences between HTLs of these workers and the HTLs that would be predicted from their noise exposures.

HEARING PROTECTOR USE AMONG CONSTRUCTION WORKERS

Prevalence of Use

The use of HPDs by U.S. construction workers has been notoriously poor, although it has improved slightly in recent years. For example, a 1967 study of occupational health in California noted that HPDs were not considered practical because of heat, dust, dirt, and lack of washing and fitting facilities on job sites.[30] This attitude was probably typical of construction in the United States until fairly recently. Even today, the use of HPDs in construction is not widespread. Greenspan et al.[12] found that only one individual out of the group of operating engineers and laborers they studied used HPDs, and this individual reported that he already had a hearing loss. Most of the group was older than 50 years and most reported that HPDs interfered with communication.

Table VII gives estimated numbers of workers exposed to noise levels of 85 dBA and above in various segments of the construction industry and the reported percentage using HPDs. The numbers of exposed workers are based on NIOSH estimates from 1981–1983, updated to reflect 1995 construction employment data.[4] The percentages are based on NIOSH observations from

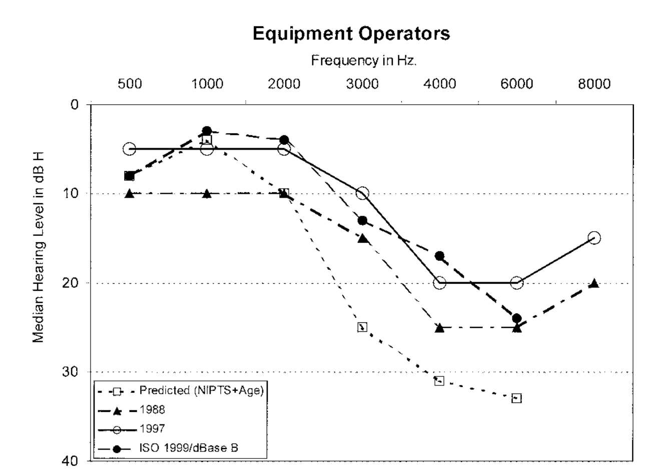

FIGURE 6. Hearing threshold levels of British Columbia equipment operators (triangles, 1988; open circles, 1997) plotted against a population not exposed to noise (closed circles) and predictions of expected hearing threshold levels due to average measured exposures of equipment operators of L_{eq} 91.6 dBA (dashed line). Reprinted from Gillis and Harrison[(29)] with permission of the first author.

1981–1983. One should keep in mind that the numbers exposed include all of those exposed to levels, not TWAs, of 85 dBA and above. Even so, the percentage observed using HPDs is quite low, and virtually nonexistent in certain trades.

The information in Table VIII summarizes the prevalence of HPD use according to various studies. In their survey of operating engineers, carpenters, and plumbers/pipefitters, Lusk and her colleagues found that overall, 24% of those surveyed never used HPDs when exposed to high levels of noise, and only 5.3% always wore them when exposed.[(32)]

By contrast, the majority of British Columbia construction workers regularly used HPDs, even in 1988, when hearing conservation efforts were formally initiated in construction. According to Harrison,[(33)] British Columbia has required the use of HPDs since 1967, and a positive safety culture has existed there since the early 1970s, when hard hats and HPDs were fairly widely accepted. Enforcement of hearing conservation requirements was stepped up in the early 1970s, mainly in the forestry industry, but compliance appeared to spread into other sectors at that time. The widespread use of HPDs by 1988 is likely to be the primary reason for the better-than-expected hearing threshold levels of the carpenters and equipment operators shown in Figures 5 and 6.

Practical Considerations

The need for construction workers to communicate with each other is as great or greater than in most manufacturing industries. This is particularly true of personnel operating heavy and mobile equipment, such as loaders, dozers, and cranes, as well as personnel on the ground or in structures who need to communicate with them. Unless these workers are fitted with effective two-way or multiway communication systems, HPDs are likely to be viewed as a hindrance to communication and the perception of warning signals. This is especially true of workers who have already incurred a noise-induced hearing loss.

Most of these noise-induced hearing losses occur in the frequencies above 1000 Hz, which is the area most critical for the understanding of speech. Unfortunately, HPDs attenuate most effectively in this same frequency range. Consequently, spoken communication and indeed many warning signals become more difficult to perceive and understand when the person with noise-induced hearing impairment wears HPDs. There is a considerable body of research indicating that persons with noise-induced hearing loss are at an increased disadvantage in the perception of speech and warning signals when they wear HPDs.[(34)]

By contrast, a recent laboratory study of the effects of HPDs and hearing loss on the ability to perceive a common back-up signal indicated that persons with fairly severe losses could still detect a common reverse alarm at a signal-to-noise ratio of 0 dB.[(35)] These results are not definitive, however, because of the small size of the experimental population and because the subjects had no additional demands on their attention. It does suggest that even hearing-impaired persons wearing HPDs are able to perceive warning signals under certain favorable conditions.

There is also a body of research on listeners with normal hearing that shows that the use of HPDs can actually improve the perception of speech and warning signals in high-noise conditions. This is especially true when the noise is continuous. It appears that the point at which HPDs no longer provide an advantage for normal-hearing listeners is between about 80 and 90 dBA.[(34)]

However, much of construction noise tends to be intermittent or varying. Intermittent noise, which is typical of carpentry and

TABLE VII. Estimated Numbers of Workers Exposed at or Above 85 dBA and Percentage Using HPDs (NIOSH Percentage Estimates [1981–1983] Using 1995 Construction Employment Data. Adapted from Hattis[(4)])

SIC	Industry Description	NIOSH Est. No. Exposed >85 dBA	Reported % Using Hearing Protection
152	Residental builders	75,500	1
154	Nonresidental builders	66,300	15
161	Highway and street construction	60,400	11
162	Other heavy construction	90,500	44
171	Plumbing, heating, and air conditioning	52,700	16
172	Painting and paper hanging	35,100	0
173	Electrical work	74,100	0
174	Masonry, stonework, and plastering	33,500	11
175	Carpentry and floor laying	70,700	0
176	Roofing, siding, and sheet metal	22,300	3
177	Concrete work	98,500	19
179	Miscellaneous special trade contractors	74,500	35
Total		754,100	avg. 15%

TABLE VIII. Summary of Prevalence of HPD Use According to Various Studies

	1988	1998
NIOSH (NOES) (1981–1983)[A]		
Highway and street construction, 11%		
Carpentry and floor laying, 0%		
Plumbing, heating, and air conditioning, 16%		
Overall average, 15%		
Lusk et al.[31]		
Operating engineers, 49%		
Carpenters, 18%		
Plumbers/pipefitters, 32%		
Overall average, 33%		
British Columbia WCB[29]	1988	1998
Equipment operators	74%	90%
Carpenters	49%	77%
Electricians	55%	87%
Laborers	64%	64%
Truck drivers	46%	73%
Welders	76%	94%
Overall average	56%	75%

[A]Examples from Table VII

finishing operations, is characterized by large differences in sound level and periodic interruptions at relatively low levels. Varying noise, which is more typical of the heavy equipment noise generated during site preparation, is characterized by ample differences between maximum and minimum levels, but low-to-moderate levels in between are present for a considerable amount of time.[36,37] Although HPDs may benefit communication during high noise periods, they are likely to be an impediment during the periods of intermittency when noise is below 80–90 dBA, and yet construction workers need to communicate and hear warning sounds during these periods.

This problem would suggest the need for HPDs that can be easily put on and taken off, such as muffs or semiaurals. There are, however, drawbacks to both of these protectors in the construction environment. First, muffs are sometimes incompatible with hard hats and safety glasses. Some muffs can be worn with the headband under the chin, but this position may be awkward. Muffs that are actually attached to the helmet are a popular alternative, but the attenuation is not always as great as with standard muffs because of difficulties in proper orientation and fit. The temple bars of safety glasses will often break an earmuff's seal and attenuation will be reduced. Semiaurals may be useful as they are very easy to don and doff, but workers often find them uncomfortable and dislike the effects on the perception of their own voices due to the "occlusion effect" they sometimes generate.[38]

Interestingly, most workers in the British Columbia program, where the rate of use is highest, prefer to wear earplugs rather than earmuffs or semiaurals. In 1997, 64% of the construction workers reported using plugs, 13% used muffs, 1% used a combination of plugs and muffs, and 22% used no HPD. The use of plugs in British Columbia has greatly increased since a previous survey in 1981, and the use of muffs has decreased.[39]

Earplugs also have their disadvantages, aside from the fact that they require more time and effort to put on and take off than muffs or semiaurals. User-molded plugs, which have become by far the most popular type of plug, require clean hands to roll down and insert. The dust and dirt typical of construction sites can become imbedded in the plug and therefore a possible hygiene problem.

Localization of the sound source can be very important in construction. Workers need to be aware of warning signals, shouts from co-workers, and back-up alarms from moving vehicles. Both plugs and muffs degrade the ability to localize in the horizontal plane (left-right) and muffs have a devastating effect on localization in the vertical plane.[34,40,41] This fact has particular implications for the safety of iron workers and others who depend on communication in the up-down dimension.

It is true that hearing loss itself degrades the ability to localize[42] and to perceive speech and warning signals,[34] and one of the best ways to prevent hearing loss is the effective use of HPDs. This presents a difficult paradox because one is reluctant to generate safety problems in the effort to reduce an adverse effect on both safety and health.

The most recent noise regulation in British Columbia, which applies to construction as well as general industry, requires the posting of noise hazard areas when average exposure levels exceed 85 dBA (L_{eq}) or peak sound levels exceed 135 dBA. Employers must supply HPDs and workers must wear them in areas that have been posted.[43] This would presume that construction workers would be obliged to wear HPDs during the quiet periods and in noise levels between 80 and 90 dBA, even if they should pose a safety hazard. The regulation does state, however, that workers must wear HPDs "in accordance with instructions provided by the employer." Hopefully, employers would see fit to allow, even encourage workers to remove protectors when noise levels drop below about 85 dBA, but such flexibility on the part of both contractors and workers may not be easy to achieve. Employers often have the idea that bigger is better, and seek out HPDs with the most attenuation, regardless of an employee's noise environment and job needs. This practice can lead to overprotection, when too much attenuation can prevent workers from hearing sounds that are necessary to their job performance and safety. HPDs with only mild or moderate levels of attenuation can be quite adequate, as long as they are worn properly.

The British Columbia noise regulation requires certain selection criteria for HPDs, which are based on the Canadian Standards Association Standard, Z94.2–94, "Hearing Protectors" and its appendix. These criteria include communication demands on the worker as well as the worker's hearing ability and daily noise exposure.[43] The requirements should have the effect of encouraging employers not to overprotect.

In the United States the ANSI standard (S12.6) for estimating the attenuation of HPDs has recently been revised to include a subject-fit protocol (Method B) in addition to the traditional experimenter-fit method (Method A).[44] Using the new subject-fit procedure results in noise reduction ratings (NRRs) that are somewhat lower, but considerably more realistic than those derived by the earlier method, which is still printed on the HPD's package. U.S. employers should be encouraged to use the newer Method B values whenever available, and to understand that they are more reflective of real-world use. In other words, employers should understand that hearing protector attenuation needs to be adequate but not excessive, and that overkill is a bad idea.

Regardless of whether HPDs improve or interfere with the perception and identification of warning sounds in specific cases, many construction workers believe that they will be a hindrance and therefore resist wearing them. A survey of carpenters' attitudes showed that nearly 50% believed they would be unable to hear warning sounds when wearing HPDs, and an additional 17% was unsure.[45] This problem calls not only for improved training, but an educated sensitivity on the part of those who dispense and supervise the wearing of HPDs.

Potential Solutions

Over recent decades, certain HPDs have been developed with speech communication and warning signal detection in mind. They may be classified as passive attenuators, attenuators aided by electronics, and communication systems. (For a comprehensive review of technology advances in HPDs, see Casali and Berger.[46])

Passive attenuation is characteristic of conventional plugs and muffs that do not use electronic systems. An example of a relatively new passive device is the Ultra 9000 (Aearo Co. Indianapolis, Ind.), a level-dependent earmuff that uses a valve system to achieve low levels of attenuation in low noise levels, with substantial attenuation in impulsive noise conditions.[47] Although this muff provides somewhat less attenuation in the low frequencies than in the middle and high frequencies, the slope between 500 and 8000 Hz is relatively flat (when worn correctly), which is desirable for speech communication. Other earmuffs without the level-dependent characteristic are currently being marketed for their communication advantages. An example is the Bilsom NST (Bacou-Dalloz Inc., Reading, Pa.), which has a relatively uniform attenuation between 250 and 6000 Hz.

Another promising development in the passive category are the ER-15 and the ER-25 plugs (Etymōtic Research, Elk Grove Village, Ill.). The former provides a uniform attenuation of approximately 15 dB throughout nearly the entire frequency range, and the latter 25 dB of attenuation, although it rolls off slightly in the low frequencies. According to Killion et al.,[48] the acoustics of the ER-15 plug were developed to mirror the natural response of the open ear while providing some amount of attenuation. It has become known as the "musician's earplug" because of its popularity among musicians, who require spectral "fidelity." Because its official NRR is only 7 dB, it is not appropriate for all occupational uses. The ER-25, however, does provide more attenuation, with an NRR of 16. The major drawback to these HPDs is that they must be custom molded to the user's ear, which adds considerably to the cost.

There are some conventional earplugs that attempt to achieve a flat attenuation at much lower cost. For example, Aearo's Ultratech plugs, with NRRs of 12 or 16 dB, are premolded plugs that have a slope of only 10 dB between 125 and 8000 Hz when worn correctly. Even though the NRRs of these devices are not as impressive as the 25-to-30 dB of many other HPDs, their attenuation would be sufficient for many construction activities, as long as they are inserted and worn properly.

There are two types of earmuffs that employ electronics. One uses noise cancellation to achieve attenuation. The other uses amplification to permit the passage of low and moderate levels of sound, maintaining a constant level at the ear. It then acts as a passive attenuator at high levels. An example of the latter is the Peltor Tactical 7-S (Aearo Co., Indianapolis, Ind.). This type of HPD offers promise of protection against high-level impulses superimposed against a background of relative quiet.[46]

Noise canceling earmuffs use electronics to generate an "antinoise" signal that reduces incoming noise levels by 20 dB or so in the low frequencies. An example of this HPD would be the ProActive 3000 muff (Noise Cancellation Technologies Inc., Stamford, Conn.), with an NRR of 21 dB assessed in the passive mode. These devices are useful mainly in environments characterized by high levels of low-frequency noise, where C-weighted levels exceed A-weighted levels by at least 10 dB. Because the electronics take up considerable room in the earcup, they cannot achieve as much passive attenuation as certain other protectors. However, they can produce a flatter attenuation curve when the active noise reduction feature is activated by boosting attenuation in the low frequencies and they can also reduce the troublesome masking properties of low-frequency noise. As of 1989, at least seven different companies had working models of active noise reduction headsets using noise cancellation technology,[49] but that number is probably lower today. Cost is a drawback, with prices ranging from $150 up to $1000 per set.[46]

It appears that there has been little laboratory or field testing of speech recognition with either type of electronically aided muffs. These HPDs may indeed be of benefit to speech communication and warning signal detection, but further evaluation is indicated before they are relied on in situations when speech communication is critical.

Communication headsets, however, have been used successfully over the years when communication at a distance is necessary. Although they cost anywhere from $200 to over $600, the expense can be more than offset by the benefits of clear and necessary communication. Noise cancellation may be used in these devices as an added benefit in the reduction of low-frequency noise, as in the Aviation Headset X (Bose Corp., Framingham, Mass.). Passive attenuating muffs may be plugged into existing radio systems, or self-contained units are also available for communication at distances of up to 2 miles. Several companies manufacture HPDs as communication headsets, with NRRs ranging from 21 to 29 dB.[50]

With the passage of the Americans with Disabilities Act in 1990, it is within reason to speculate that employers, including construction contractors, may need to provide workers who have hearing losses with HPDs that are suited to their communication needs, both in terms of spoken communication and the perception of warning signals.[51]

Clearly, the only practical, long-term solution to the many problems of hearing protector use in construction is noise control, both in the design and manufacture of construction equipment and at the construction work site.

AUDIOMETRIC MONITORING/ RECORD KEEPING

Audiometric testing is of little value unless serial audiograms can be compared, threshold shifts detected, and measures taken to halt the progression of noise-induced hearing loss. Single audiograms may indicate hearing loss, but unless a series of audiograms imply an occupational cause, the process is only one of documentation rather than conservation of hearing.

Barriers to Successful Audiometric Monitoring and Record Keeping

There are several reasons why meaningful audiometric testing and the proper keeping of records are difficult in the construction industry. These include (1) mobility of construction workers, (2) the temporary and seasonal nature of employment, (3) the small size of construction companies, and (4) the prevalence of self-employment.

The Center for the Protection of Workers Rights has compiled a substantial amount of information about the construction industry and its workers from the Bureau of Labor Statistics, the Bureau of the Census, and other sources, which can illuminate these issues.[52]

Mobility. Depending on the size and nature of the project, construction workers may work for one company for only a matter of weeks or months, or up to many years. The average duration, however, is less than in the manufacturing industries. Job tenure in construction also depends on whether an employee belongs to a union. In 1993 the median job tenure in construction for union employees was 5 years and for nonunion employees, 3 years.[52, chart 20b] However, nearly 80% of construction employees are not unionized.[52, chart 14a)

Temporary and Seasonal Nature of Employment. Temporary unemployment is common among construction workers, and seasonal breaks are particularly common in the northern states. Unemployment ranges from 5 to 10% higher in construction than in the general population[52, chart 20c] and the rate of failure in construction companies has been consistently greater than in other industries as a whole.[52, chart 11a]

Small Size of Construction Companies. Small businesses are less likely to conduct audiometric testing, and those with 10 employees or fewer are generally exempt from record-keeping requirements. Nearly 82% of construction establishments have less than 10 employees and less than 1% have more than 100 employees.[52, chart 3c]

Prevalence of Self-Employment. Construction workers who are self-employed are less likely to be part of an employer's safety and health program, and are unlikely to have their own hearing tested. About 2 million of the estimated 5 million construction workers list themselves as self-employed, and 75% of these are unincorporated.[52, page 21]

Potential Solutions

Centralized Systems

British Columbia. The most successful HCP for construction workers is the program conducted by the Worker Compensation Board (WCB) of British Columbia. One measure of its success can be seen in the better-than-expected hearing threshold levels of construction workers and the improvements between the thresholds in 1988 and those measured in 1997. The examples given in Figures 5 and 6 are representative of all of the trades measured.[29] This program has the advantage of being centralized in the WCB, which is supported from fees taken out of the worker compensation premiums of British Columbia employers.

The program has been in effect for construction workers since 1987, when audiometric tests were initiated, and since then tests have been conducted annually. An updated noise regulation specifies a PEL of 85 dBA, a 3-dB exchange rate, a peak sound level limit of 135 dBA, and engineering controls above these limits whenever practicable.[43] Noise exposure monitoring and training and education are required at an action level of 0.5 (an L_{eq} of 82 dBA), but these latter requirements are not rigorously enforced in the construction industry.[53]

The WCB trains and certifies all technicians, who then provide audiometric testing, training, and counseling to construction workers. Audiometric information, including a medical history, is collected by the technicians on an optical-read form and scanned onto a WCB mainframe. In addition, workers carry with them a ''WorkSafe'' card, which contains a record of their hearing test, the date of the test, and boxes in which the technician may check whether the worker has received an explanation of the results, a fit test of hearing protection, or whether the requirement to wear HPDs has been discussed. Workers are advised to show the card at the next test in one year. The regulation requires also that the employer maintain, ''in a manner acceptable to the board,''[sec. 13.120] a record of the hearing tests for each worker as long as the worker is employed by that employer.[43]

Information about noise control and other aspects of hearing conservation is made available to employers through a WCB newsletter as well as through the technicians. Roberts[53] reports that compliance with the regulations is fairly good in heavy construction, commercial building, and road construction, but poorer in housing construction and among small-business contractors (which is not surprising). Also, because the regulation requires hearing tests ''not later than 6 months after the start of employment,''[sec. 13.116] workers on short jobs are likely to be overlooked.

European Programs. Bygghälsan, the Swedish Foundation for Industrial Safety and Health in the Construction Industry, was founded in 1968. Its support was generated by assessing contractors for fees based on hours worked, and, like the British Columbia program, provided a central repository for hearing test data and other types of information. Its activities in recent years have been severely curtailed because of government cutbacks. The CPWR Chart Book, however, does contain data showing the decreased prevalence of ''severe high-tone hearing loss'' in Swedish construction workers between 1971–1974 and 1986–1990.[52, chart 40c]

In Germany, Arbeitsmedizinischer Dienst, state-run occupational health centers assist small companies with audiometric testing and the retention of audiometric records.[54]

Requirements of Other OSHA Regulations. Welch and Roto[55] report that of the 21 OSHA regulations requiring medical monitoring, 13 apply to construction. Both lead and asbestos have their own construction versions, although lead is, at this time, a final interim rule. The lead standard, 29 CFR 1926.62, requires a full medical examination when blood-lead or air sampling levels exceed certain criteria. The asbestos standard, 29 CFR 1926.1101, requires medical monitoring for all employees who are exposed above the PEL or an ''excursion limit'' for a combined total of 30 days or more per year. A medical exam must be given at least annually. It should include pulmonary function tests and may include a chest X-ray at the discretion of the physician. An exam is not required if records show that an employee has been examined within the past year.

The general industry regulation for hazardous waste operations, 29 CFR 1910.120, also requires medical examinations, and the revised respirator standard, 1910.134, requires physician clearance for workers to wear continuous-flow respirators. These standards also apply to construction.

Employers, including construction contractors, are required to ensure that these tests are performed and must pay for them. The problem is that the many complex characteristics of construction mentioned above (mobility, seasonal and short-term nature of the work, prevalence of self-employment, etc.) work against efficient medical monitoring programs, especially the keeping of records. OSHA's record-keeping rules, which have the same provisions for construction as for general industry, limit the requirements for short-term employment and for companies with 10 or fewer employees, except in cases of fatalities or multiple hospitalization accidents. Clearly, great numbers of construction workers are falling through the cracks.

Even for those companies that would be responsible for keeping records of medical monitoring, the question remains as to what to do when employees move on. The construction regulation for access to medical records (29 CFR 1926.33), which is identical to the general industry regulation (29 CFR 1910.1020), states that employers need not retain records after an employee's termination, but may simply give the records to the employee, provided that the employee has not worked there for more than 1 year.

But the question of effective follow-up remains open, especially in the case of audiometric testing, which is so dependent on the comparison of serial audiograms. There appears to be little experience with effective records management for construction employees for any health hazard outside of British Columbia. The one exception may be joint labor-management programs.

Joint Programs. Several of the unions whose members perform construction work have negotiated medical monitoring, testing, and training programs through the collective bargaining process. Examples of these are ironworkers, painters, carpenters, laborers, and sheet metal workers. All of these unions have centralized funds used mainly for training, but that also pay for some medical testing, such as asbestos exams, lead, and clearance for working with hazardous waste.[56]

A good example of this type of program is the MOST (Mobilization Optimization, Stabilization, and Training) program run by the boilermakers union.[57] The program covers drug, pulmonary function, and respirator fit testing, as well as safety glasses and safety training for some 20,000 boilermakers at this time, and it will soon involve 26,000 construction workers in Michigan. In addition, it is now open to all crafts in the nation. One of its most interesting aspects is the Employee Verification System, the ability of employers to call in to the program headquarters and obtain information on pulmonary function levels, as well as the dates on which all testing and training occurred. The program used to include full medical exams, including audiometric testing, but that segment was discontinued due to expense.

Unfortunately, there is no evidence in the United States of joint labor-management programs for construction workers that include audiometric testing and record keeping.

Even though these joint programs may be very successful, there are two principle disadvantages. First, union members are understandably reluctant to pay for medical monitoring and training when OSHA regulations have mandated these as employer responsibilities. Even though it is actually the employer who pays, workers may be reluctant to use collective bargaining to achieve benefits that are their right by law. The second and most obvious disadvantage is that 80% of the construction work force is not organized and therefore would not benefit from this type of arrangement.

There is no reason, however, why contractors could not pay into a fund for purposes of medical monitoring, including audiometric testing and record keeping, which would be managed by a public or private agency. This fund would then cover all construction workers, whether or not they were unionized.

State-Run Programs. There are, in fact, some states that have adopted OSHA's hearing conservation amendment for construction workers. For example, the State of Washington's Department of Labor and Industry is divided into a worker compensation section and an occupational safety and health section, the latter having jurisdiction over noise regulations. However, there has been virtually no enforcement or compliance with the construction noise standard, so merely adopting the federal hearing conservation standard for construction workers is not necessarily the answer unless the state is willing and able to enforce it.

It appears that the best solution would be a program like that of the WCB. Here, a centralized agency, in this case the WCB of the Province of British Columbia, not only keeps the records but trains the technicians, ensures follow-up, and provides quality control. This function could be carried out within the United States by state agencies, such as health departments.

There is a program called the Adult Blood Lead Surveillance program, funded by NIOSH and the Centers for Disease Control and Prevention, in which 26 states keep a register of the effects of lead and other heavy metals. These data are generally used for epidemiological purposes, but in some cases for individual follow-up. In New York, for example, all blood lead levels are sent to the State Department of Health and high levels can trigger follow-up phone calls to lead-exposed individuals.[58] In addition, some states have cancer or silicosis registries.

Although a state-run program is likely to be the most efficient solution for HCP elements such as audiometric testing and record keeping, these programs are always susceptible to the whims of state legislatures or federal funding sources. The perfect solution is elusive.

Credit-Card Type Storage Devices

Contemporary technology could make the problem of construction worker mobility somewhat more tractable. These devices, like optical cards, may be carried in one's wallet and are capable of storing considerable amounts of information. Evidently they are already being used for documenting safety training. According to Stephenson,[59] any audiometer that can communicate with a personal computer (which is a great many audiometers nowadays) can handle these devices. All that is needed is the appropriate software and a special drive. NIOSH has this capability at this time.

An example of the effective use of these "smart" cards is the program that allows travelers to cross the U.S./Canadian border by inserting a card encoded with the individual's fingerprint into an optical reader. According to a press release issued by Canon USA in 1995, these cards can store the equivalent of 1600 pages of text or other digital data, and they are already widely used in the health care field as a portable clinical record.[60] No doubt the technology has advanced considerably since then.

NOISE, HEARING LOSS, AND ACCIDENTS IN CONSTRUCTION

Accidents in Construction

Traditionally there has been a high rate of occupational injuries in the construction industry. Sweeney and her colleagues collected the following data from the Bureau of Labor Statistics and various other sources:[61] Construction workers represent 6.5% of the work force, but 18% of the fatal injuries occur in construction. After mining and agriculture, construction ranks third for workplace fatalities and injuries. The leading causes of construction fatalities include falls (31%) and transportation incidents (27%). Contact with or being struck by an object and musculoskeletal disorders account for more than 50% of all traumatic injuries. Construction workers are twice as likely as the average worker to be killed by a motor vehicle, and 40% of worker fatalities from motor vehicle accidents are pedestrians. Nearly 2000 machine-related deaths in construction occurred between 1980 and 1992 and in nearly one-third of the cases the worker was struck by a moving mobile machine. Laborers (23.5%) and operating engineers (22.6%) accounted for nearly half of the machine-related deaths.

Possible Contribution of Noise and Hearing Loss

There is little objective information linking noise exposure or hearing loss with accidents specific to construction, but common sense would suggest that many of these accidents might have been prevented had workers been able to perceive warning shouts or signals. The high incidence of fatalities from being struck by objects, of transportation incidents, and the frequency of fatal accidents from moving machines (especially with pedestrians as victims) all suggest a breakdown in communication.

Noise and hearing loss have been implicated in studies of other industries. For example, noise and hearing loss were found to be accountable for 43% of the injuries in a shipyard setting.(62) The authors considered other possible causes, such as alcohol consumption, cigarette smoking, and the use of earplugs, and found that alcohol consumption was the only significant factor besides noise and hearing loss. It appears that the authors controlled for age and job hazard.

Zwerling et al.(63) assessed the likelihood of occupational injuries in a large sample of workers drawn from the National Health Interview Survey. These workers had listed themselves as having some kind of preexisting impairment: visual or hearing impairment, back conditions, upper or lower extremity conditions, diabetes, epilepsy, and arthritis. The authors found that the highest risk of job-related injuries came from workers having sensory impairments with odds ratios for blindness of 3.21, deafness 2.19, hearing impairment 1.55, and visual impairment 1.37 (which was not statistically significant). Of the seven occupational groups studied, laborers represented about 8% of the total cohort, and approximately 36,000 in this group (13%) were construction laborers.(64) The remainder of the group included material handlers, as well as operators of various kinds of vehicles and equipment, some of whom might also be considered construction workers. The category titled laborers was one of three blue-collar categories, the others being mechanics/repairers, and operators/assemblers. The odds ratio for injury among laborers was 4.16, the highest of any of the groups.

Another study of a large industrial population compiled accident data from factories over a 2-year period.(65) The authors found that the frequency of accidents and illness-related absences increased with increasing noise exposure levels for both men and women. The relationship between noise exposure and accidents was significant for men but not for women. Unfortunately, it can be very difficult to control for the hazardous nature of various jobs in this kind of study, and it is possible that high levels of noise may be related to jobs that are inherently hazardous.

Reverse Alarms

In recent years there has been some attention to the questionable effectiveness of back-up alarms in mobile machinery. A study by Laroche et al.(66) demonstrated that the audibility of back-up alarms on dump trucks is compromised because of the ineffectiveness of their acoustic signals. Laroche and Lefebvre(67) traced 22 fatalities to faulty back-up alarms in the Province of Quebec over a 15-year period. Table IX provides an updated version of these data, giving the cause of each accident and comments about noise levels and the back-up alarm specific to each situation.(68)

Laroche and Lefebvre(67) concluded that there are at least five principle causes for these types of accidents: (1) hearing loss among construction workers, (2) high noise levels on some sites, (3) worker attentional demand or complacency, (4) inadequate placement of alarms, and (5) deficient acoustic features of the alarms.

The adverse effect of hearing loss should be self-evident, as with high noise levels, because they both would degrade the ability to perceive back-up alarms as well as warning shouts. Worker attentional demand from complex tasks or stimuli could cause the failure not so much to hear but to attend to the warnings produced by back-up alarms (see review of this subject by Suter, Ref. 34, Chapter 4). Inattention caused by habituation also could reduce the ability to react appropriately to the sound of warning alarms.

Laroche and Lefebvre(67) reported that placement of the back-up alarm is often problematical. For example, some owners position the alarm underneath the vehicle to protect it against weather, which placement has an attenuating effect. With regard to deficient acoustic features, the authors found that most back-up alarms produce pure-tone signals around 1400 Hz or modulations of two neighboring sounds, 1250 and 1350 Hz. Reflections of these sound waves on the ground or diffraction by the sides of vehicles have the effect of reducing or even canceling them before reaching the listener. Within spaces of less than a few inches, Laroche and Lefebvre found variations in sound pressure level of more than 15 dB behind vehicles. Finally, the use of a pure tone in the 1500–3000 Hz range is not efficient for purposes of auditory localization.(69)

There are several reasonable solutions to these problems. First would be to prevent hearing loss through noise control, the judicial use of HPDs, and training. Second, noise levels on the construction site should be reduced through the manufacture and purchase of quieter equipment and the proper maintenance of all noise-producing equipment. Third, workers should be trained in the awareness of warning signals as well as all aspects of hearing conservation. Fourth, back-up alarms should be placed for optimal reception by the intended listener. Fifth, greater attention should be given to the workers' sound environment and sound propagation in the design of the alarm, as well as the psychoacoustics of audition. Laroche and Lefebvre(67) caution that back-up alarms should not emit just one pure tone because of the considerable risk of sound cancellation, but instead should produce several frequencies in the 500 to 2000 Hz range that are not harmonically related.

In optimal conditions the sound level of an alarm should exceed the background noise by 10–15 dB. However, this can pose a problem to the residents neighboring construction sites, who often complain about the noise of back-up alarms. A partial solution could be found in the form of an auto-adjusting alarm, which senses noise in the environment and adjusts its signal to a level 10 dB above that of the background noise. An example is the Starmatic 63–000 (Star Warning Systems Co., Avon, N.Y.), an auto-adjusting back-up alarm, with a range of 87–112 dB.

One final recommendation came from a safety workshop attended by laborers, and that is that personnel backing heavy vehicles should use an additional worker as a "spotter."(56) This worker is presumably in a place where the operator can see him or her, and it is important that the worker is trained and alert because Laroche and her colleagues found that the "signalman" was sometimes the one who was fatally hit.(66)

NOISE CONTROL IN CONSTRUCTION

There is a considerable amount of information available on the control of noise in the various aspects of construction, and a detailed discussion of this topic is beyond the scope of this report. A brief overview, however, would be useful. Noise control solutions include the efficient operation and maintenance of construction equipment, retrofit of existing equipment, and the design of quieter new equipment.

Feasibility

It appears that noise reduction in most construction sites and for most construction equipment is feasible. Although some tools will still require the use of HPDs for adequate protection, there is a great deal that can be done. Figure 7, from the Bureau of Mines,

TABLE IX. Deadly Accidents Involving Heavy Vehicles and Noise (After Laroche et al.;[69] Updated, Expanded Version Translated into English Provided by Laroche[68])

Case No.	Date of Accident	Employee	Vehicle Involved	Cause of Accident	Comments
1	08-29-91		tow truck		noise level exceeded alarm
2	06-02-88	splitter/operator (aluminum co.)	forklift	poor visibility, plus backup alarm not detected	
3	04-28-88	water system installer	dump truck (?)	backup alarm not detected	poor synchronization of maneuvers
4	09-04-87	flag person (construction site)	dump truck (10 wheeler) backup alarm: DAP	backup alarm not detected	alarm: 90 dBA; noise from streamroller: 87 dBA
5	07-01-87	quality control attendant (construction site)	dump truck (10 wheeler) Kenworth 1974	backup alarm not detected	backup alarm in front of the 2 back axles and directed toward the left. alarm : 80–85 dBA; noise: 105–107 dBA
6	01-09-87	flag person (construction site)	dump truck (10 wheeler)	misjudgment by worker	alarm level greater than noise levels
7	08-08-86	marine docker	forklift	backup alarm not detected, plus driver's vision obstructed	noise: 84–96 dBA; alarm: +2 dBA
8	08-15-85	flag person (road repair)	5-ton truck backup alarm: DAP 50	backup alarm not detected, plus poor planning of operations	noise: 92 dBA; alarm: 75 dBA
9	11-21-83	shipping and receiving clerk (interior site of a pharmaceutical co.)	delivery truck	noise from truck was not detected	high noise level because of construction
10	10-06-82		loaded dump truck, Mack 76 (10 wheeler) (28,800 kg)		poor judgment or noise level same as alarm
11	09-24-82	docker (port)	road hauler	noise from hauler was not detected	high noise level, poor lighting; one-way circulation
12	09-17-82		10 wheeler dump truck		alarm was not functioning, high noise level
13	01-20-82	general foreman (James Bay site)	loaded cement mixer (82,000 kg)	backup alarm not detected	alarm: 83 dBA at 1 ft noise: 107 dBA at 3 ft
14	11-23-81	welder (railroad)	grinder, LORAM	horn was not detected	horn: 97 dBA welding noise: 90.5 dBA
15	08-10-81		loader		lack of good work method, no backup alarm
16	12-06-78	garbage collector assistant	garbage truck	backup alarm or noise not detected (?)	surrounding noise greater than truck noise
17	08-21-78	flag person (road repair)	dump truck (10 wheeler) Ford 8000	backup alarm not detected	noise level greater than alarm
18	01-08-76	digger operator (Miron)	dump truck (8 wheeler) (10 tons)	noise from truck was not detected	no backup alarm
19	12-29-75	flag person (snow removal)	leveler	noise from leveler was not detected	no backup alarm
20	07-08-75	flag person (steel works site)	dump truck (19 tons)	noise from truck was not detected	worker was walking with his back to the truck
21	08-14-75	crane operator	platform type tow truck	noise from truck was not detected	no backup alarm

TABLE IX. Continued

Case No.	Date of Accident	Employee	Vehicle Involved	Cause of Accident	Comments
22	07-08-75	truck driver (road repair)	dump truck (7 tons)	noise from truck was not detected, also subject was very close to the back of the truck	high noise level
23	03-18-75	pedestrian (construction site)	dump truck	noise from truck was not detected	high noise level, no backup alarm
24	03-12-75	engineer (road excavation)	loader (2.5 tons)	noise from loader was not detected	high noise level

gives examples of how noise control could be applied to surface mining machines, several of which are used in construction.[70] Note the dramatic reductions achieved in haulage trucks, front-end loaders, and graders. Although some of these noise problems may have been mitigated in contemporary equipment, undoubtedly many have not yet been sufficiently quieted.

Maintenance

One of the least expensive and most rewarding noise control practices is the proper operation and maintenance of equipment. This includes keeping noisy operations away from workers who are not involved in that process, lubricating parts, keeping saw blades sharpened, and replacing worn bearings and other parts as needed. It also involves keeping the doors and windows of noisy vehicles closed to the extent possible to protect the operator from the engine and exhaust noise. Like any vulnerable part, noise control measures, such as gaskets and mufflers, need to be maintained and replaced when necessary to provide the desired attenuation.

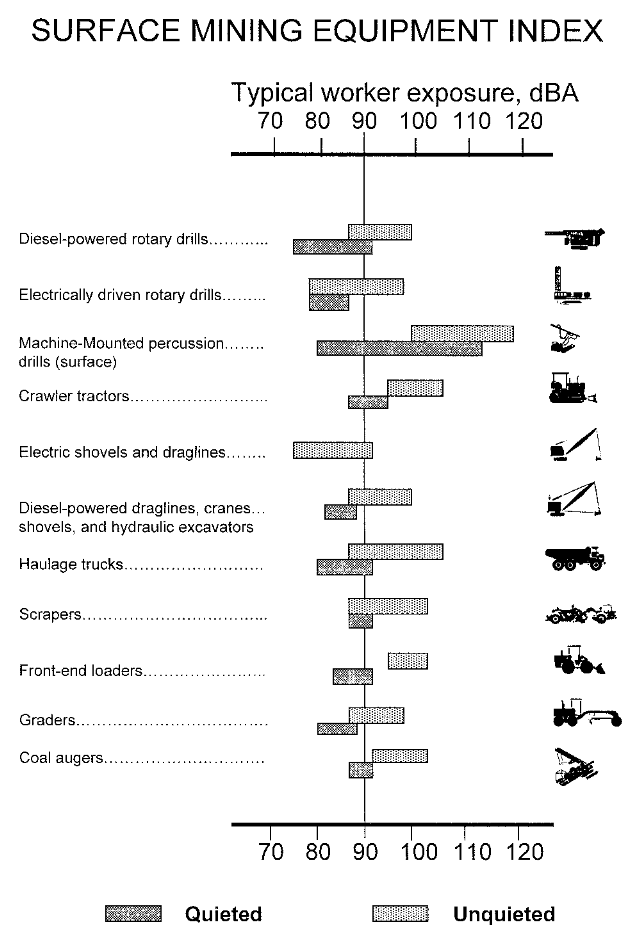

FIGURE 7. Examples of how noise control may be applied to surface mining equipment, some of which is used in construction. Reprinted from Bartholomae and Parker,[70] U.S. Bureau of Mines publication.

Retrofit

Retrofit applications, such as those advocated in the Bureau of Mines Handbook,[70] include installing mufflers, enclosing and insulating the cabs of noisy vehicles, and enclosing parts of noisy machines. Table X, from Schneider et al.[51] lists types of construction equipment and suggested retrofit controls. The authors give references for each control measure. For example, they cite a report by the Society of Automotive Engineers, which found that changing from an inadequate to a better muffler could make a difference of 1–3 dB, and installing a muffler where one had been lacking could make a difference of 10–12 dB.[71]

There may be times when retrofits yield only small improvements in noise level and HPDs are still necessary to prevent hearing loss. Researchers at the Mine Safety and Health Administration found that retrofit controls tend to reduce high-frequency noise more readily than low-frequency noise, often resulting in differences between C-weighted and A-weighted noise levels that exceed the nonretrofit condition, even though A-weighted levels had been reduced.[72] Although this finding should not discourage the use of retrofit measures, it does provide additional support for choosing HPDs with good low-frequency attenuation and careful training in their effective use.

Design

The most efficient and economical stage at which to control noise is in the design phase. This is true both in the design of a potentially noisy work space and in the design of equipment. For example, changes in the pathways of ductwork can reduce fan noise,[73] and changing low-frequency jet noise to high-frequency can make it easier to control.[74]

At an Environmental Protection Agency (EPA) hearing many years ago, George Diehl, an acoustical engineer with the Ingersoll-Rand Co. (Woodcliff Lake, N.J.), reported on a "whisperized" air compressor, in which the noise level had been reduced from 110 dBA to 85 dBA.[75] At that time the company was also working on noise from rock drills (pavement breakers and jackhammers), and had reduced the noise between 8 and 10 dB, while simultaneously reducing vibration. Mr. Diehl also discussed another type of demolition tool called a "hobgoblin," which was

TABLE X. Noise Controls for Construction Equipment (from Schneider et al.[51])

Equipment	Noise Controls
Pile driver	Enclosure, muffler
Stone cutting saw	Noise control pad with water
Handheld impact drills	Reduction of reflected sound
Circular saw blades	15° tooth angle, new tooth configuration, slotted saw blades, viscoelastic damping
Pneumatic tools	Muffler
Pavement breaker/Rock drill	Muffler, enclosure of cylinder case and front head, moil damping
Portable air compressor	Muffler, acoustic enclosures
Bulldozer	Cab-liner material, enclosure, sound absorption in canopy, sealing of all openings
Wheeled loader	Absorption of sound cooling air route
Vibratory roller	Flexible mounting for pump compartment
Joint cutter	Antivibration mounting fixtures

mounted on a backhoe. Because it was hydraulically operated it had no air exhaust, and therefore, the major source of noise was reduced. He reported that it could do the work of 10 to 24 regular paving breakers while producing considerably less noise.[75] It appears that this kind of push for the control of construction noise in the United States has diminished, but it continues to progress in Europe.

There is, however, an interesting innovation being developed called the Raptor (Brookhaven National Laboratory, Upton, N.Y.), a machine that fractures concrete by firing steel nails from silencer-equipped guns. It is reported to work more rapidly than the conventional jackhammer, does not rely on an air compressor, and the noise level is projected to be below 80 dB.[76]

Resources

There are many such reports on noise control solutions in the construction industry. Some of them are consolidated in booklets or a series of articles. In addition to the sources cited by Schneider et al.,[51] the following are some examples.

Mining Machinery Noise Control Guidelines, 1983, a Bureau of Mines Handbook.[70] This publication contains information on the noise levels of surface and underground mining equipment, some of which is used in construction, particularly in the site preparation phase of large construction projects. For each piece of equipment the booklet lists typical noise levels, along with recommended treatments, quieted noise levels, costs in dollars and labor in hours, and the availability of treatments. These descriptions include sources for commercially available noise control products and materials, technical reports on the development and demonstration of noise control treatments, and case histories.

Noise Control, Proceedings: Bureau of Mines Technology Transfer Seminars.[77] This book of proceedings contains specific articles covering some of the same types of information as above, with more text.

Constructional Noise: A Survey of Noise on Building Sites, Bygghälsan, Stockholm.[78] This booklet gives octave band and A-weighted noise measurement data for more than 30 examples of construction noise sources, along with information on the work operation, cause of the noise, and suggested control measures for each type of equipment or setting. Although these data are more than 25 years old, many are undoubtedly still applicable. It includes comments about controls and the need for hearing protection.

Noise Control: A Guide for Workers and Employers, U.S. Department of Labor.[79] Although this guide pertains to general noise problems and their solutions, some of the principles of noise control also apply to construction. It was originally published by the Swedish Work Environment Fund, translated, then edited and adapted by OSHA.

"Noise Control: Principles and Practice," published in *Noise News International* between June 1994 and June 1999, form a series of 15 articles by Stig Ingemansson, the original author of the Swedish guide previously cited.[80] The articles represent an edited and updated version of the older guide.

Many papers and articles on noise control, some of which deal with construction, are available in the publications of the Institute of Noise Control Engineering, which has headquarters in Poughkeepsie, N.Y. These include *Noise Control Engineering Journal, Noise News International,* and the proceedings of annual conferences, both U.S. and international.

In addition to the preceding suggestions, there are other publications, such as those cited by Neitzel and Seixas:[15] Alfredson and May,[81] Kessler,[82] and Mulholland and Attenborough.[83]

EPA

The Office of Noise Abatement in the U.S. EPA, which functioned between 1972 and 1982, made significant efforts to control noise in the general environment, including construction noise. Funding for the program was terminated in 1982 by the Reagan administration, and the office was closed. However, the statutory requirements still stand because Congress has never rescinded them: the Noise Control Act of 1972 and the Quiet Community Act of 1988 (P.L. 92–574, 1972 as amended at U.S.C. 4901–4918, 1988).

Of interest in the area of construction are the regulations for medium- and heavy-duty trucks, air compressors, and regulations for the existing motor carrier fleet. These regulations are still in effect but are not being enforced. Two pieces of construction equipment, pavement breakers and rock drills, were identified as major sources of noise and set on the path toward regulation, but were "disidentified" when the program closed in 1982. The agency also considered the regulation of wheel and crawler tractor noise emission. The Noise Control Act required EPA to regulate the labeling of products that emitted or reduced noise, but EPA only promulgated one regulation in this category, the attenuation of HPDs.

A considerable amount of information about construction noise was generated by the agency, most of which is listed in EPA's *Bibliography of Noise Publications.*[84] Some titles pertaining to construction noise are listed in Appendix A. In addition, EPA has microfilmed much of the materials from the Office of Noise Abatement, and many of its contractor reports are still obtainable.

EUROPEAN STANDARDS AND DIRECTIVES

Activities of the European Community

Undoubtedly the most interesting developments in noise standards and regulations are currently occurring in the European Community (EC), now known as the European Union (EU). With the economic unification of European countries, the effort to harmonize existing standards and to develop a unified approach to new standards has been taking place for nearly two decades. There are now a great many European standards and directives in the field of noise measurement, effects, permissible limits, and control, including some that are specific to construction.

Although publications in this area tend to use the terms "standard" and "directive" interchangeably, the word "standard" is usually applied to measurement procedures or proposals set forward by consensus groups such as the International Organization for Standardization (ISO) or the International Electrotechnical Commission (IEC). The term "directive" usually applies to an order issued by the Council of the European Community (CEC), and this order is generally mandatory for implementation by the member states of the EU.

The EU speaks in terms of the "old approach" and the "new approach" to the issuance of directives. The old approach, taken prior to 1985, applied to one product at a time and was very time-consuming. The new approach resembles enabling legislation, in that these directives apply to broad categories of products. Under the new approach, the CEN prepares nonmandatory technical specifications, the purpose of which is to assist manufacturers in the design of products so that these products will meet mandatory directives. Although the new approach was followed for directives issued in 1985 and thereafter, directives issued under the old approach still apply. Some of the old approach directives are being revised, and some new directives are still being issued under the old approach.[85]

Construction Directives

One of the earliest directives issued by the EC specified measurement methods for determining the A-weighted sound power levels of construction plants and equipment.[86] This directive was followed in 1984 by several specific directives,[85] which stipulated measurement methods and permissible sound power levels for air compressors (84/553/EEC; 85/406/EEC), tower cranes (84/84/534/EEC), welding generators (84/553/EEC; 85/407/EEC), power generators (84/536/EEC; 85/408/EEC), and concrete breakers and picks (84/537/EEC; 85/409/EEC). In 1986 the EC issued a directive on hydraulic and rope-operated excavators, dozers, loaders, and excavator-loaders (86/662/EEC; 89/514/EEC). Several of these directives have been revised (indicated by the second date). Tables 3–8 in Ref. 85 present a summary of the sound power level limit values for the construction equipment listed above. The permissible sound power levels range from 100 dBA to 118 dBA, depending on size, weight, and type of equipment. (One needs to keep in mind that the sound power level can be some 25 dB greater than the sound pressure level at the operator's position.)

1986 Directive to Protect Workers Against Noise

In 1986 the CEC issued directive 86/188/EEC "on the protection of workers from the risks related to exposure to noise at work."[87] This directive required all employers to reduce TWA noise exposure levels (using the 3-dB exchange rate) to 90 dBA or "to the lowest level reasonably practicable, taking account of technical progress and the availability of measures to control the noise, in particular at source."[article 5-1] This means that employers must reduce noise to levels below 90 dBA whenever "reasonably practicable."[article 5-2] Other measures, such as information and training, the provision of HPDs, and hearing testing must be instituted at an L_{eq} of 85 dBA. Those countries comprising the EC were required to have regulations that conformed to the CEC directive, or were at least as stringent, by January 1, 1990. Article 8 of the directive states that the design, building, and/or construction of new plants must comply with the 90-dBA exposure limit, and tools or machines that expose workers to daily average levels greater than 85 dBA must provide adequate information "about the noise produced in conditions of use to be specified."

Machinery Directive

In 1989 the CEC issued the Machinery Directive, under the procedures of the new approach.[88] This directive, 89/392/EEC, requires manufacturers of a wide variety of machines, including many that are used in construction, to make noise reduction an integral part of machinery design by implementing state-of-the art design methods.[85] Manufacturers must include information on noise levels when any machinery exceeds exposure levels of 70 dBA or 130 dBC at the operator's work station, or when sound power levels exceed 85 dBA.[88] Both the sound pressure and sound power level information are to be based on durations representative of the typical work-cycle of the machine. Noise emission information must be included in the instruction handbook of the machine (for the user's benefit) and in the technical information describing the machine (for the benefit of the purchaser.)

Since the promulgation of the machinery directive, several safety standards have been issued specific to certain machines. These standards contain a description of the hazard, the safety objectives to be achieved, measures for reducing the hazards, test methods to establish compliance, and user information. Lazarus and Zimmerman[89] present a discussion of these standards, along with some of their limitations.

Draft standard EN 1746 gives the noise provisions that should be included in machine safety standards: the identification of a machine's main noise sources; reference to principles of low-noise design, along with examples of design for noise control; a compilation of ranges of noise emission values; and the development of information necessary for user instructions to allow for low-noise operation. The authors report that the majority of "framework" standards necessary for the preparation of machine-specific safety standards already exist for noise, but they need to be developed further and adapted to the practical problems of manufacturers and operators. For example, typical operating conditions still need to be agreed on and differences between the conditions specified in the standards and actual use need to be resolved.[89]

Labeling

Another interesting provision of the machinery directive is its requirement for compliant machinery to carry the "CE" mark. An amendment to the machinery directive gives the form in which the CE mark is to be displayed (93/68/EEC). In addition, the construction noise directive (79/113/EEC) requires manufacturers to display labels in the form of plates showing either the sound power level (L_{WA}) or sound pressure level (L_{pA}) at the operator's position. The specifications for these labels are shown in Figure 8.

There is an ISO standard pertaining to the noise labeling of

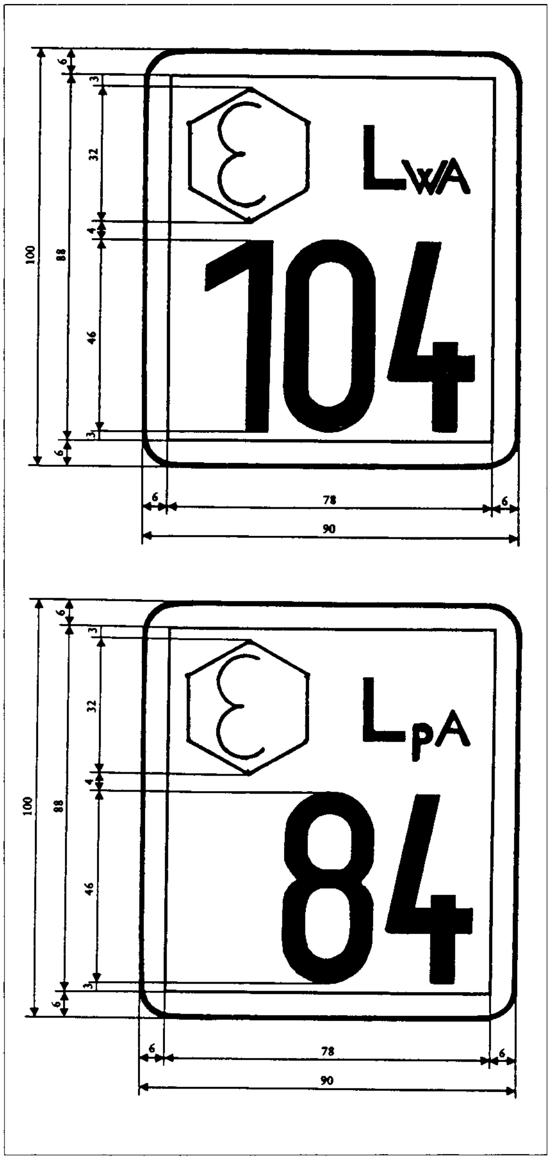

FIGURE 8. Models of plates showing the sound power level (L_{WA}) and sound pressure levels (L_{pA}) at the operator's position required by the European Community's construction noise directive (79/113/EEC). Reprinted from Higginson et al.[85] with permission from *Noise News International.*

machinery and equipment, ISO 4871.[90] This standard prescribes the labeling of machines, or families of machines, with the A-weighted sound power level in more than one mode of operation, preferably the mode resulting in the highest value. Although the labeled sound power level may be useful for deciding which machine to purchase, it gives relatively little information on the worker's exposure in actual use.

A draft American National Standard is currently being prepared by an ANSI working group[91] that adopts the provisions of ISO 4871, with the addition of a series of annexes. Proposed Annex E gives the option of including A-weighted sound pressure levels and C-weighted peak sound pressure instead of or along with sound power levels. A proposed modification to Annex B gives examples of declarations for both sound power level and sound pressure level in the "idle" and "operating" modes. It is important to remember, however, that the operating mode means under load but not necessarily in actual working conditions, as in the case of a tool contacting a work piece.

Evaluation of Noise Limits and Labeling Requirements

The success of these programs is bound to be variable because enforcement of the EC directives is carried out by the individual member states, some of which are likely to be more zealous than others. Also, the problems raised above by Lazarus and Zimmerman have been mentioned by other researchers. Kyttala and Airo[92] found that although a majority of the hand-held power tools they surveyed carried noise declarations (labels), the authors questioned whether the information provided would apply to the tools as they were being used. They found that the declared noise levels were usually lower and sometimes considerably lower than those measured in actual use.

Irmer and Fischer-Sheikh Ali[93] pointed out that the primary purpose of the machinery noise directives was to enhance the functioning of the common market by eliminating trade barriers. Thus, noise limits were set high enough so that very few products would be excluded from the market. They maintain that setting an easily achieved upper limit for construction equipment removes any pressure to produce products with lower noise emission levels. They do mention, however, that the EC has recently published a proposal on the noise emission of equipment used outdoors, which will replace existing directives and revise existing noise limits in such a way as to give a higher priority to environmental concerns like construction noise.[93,94]

INCENTIVES FOR QUIET

Disincentives of the Last Two Decades

With the demise of EPA's Office of Noise Abatement in 1982 and along with it the regulatory program for construction equipment, the incentive for noise control has declined. This is true of equipment manufacturers as well as contractors. Some small incentive has been supplied by municipalities and local groups seeking to mitigate the noise exposure of communities, but the noise abatement capabilities of local governments were adversely impacted by the closing of the national noise office. Within the last few years there has been a rekindling of interest in environmental noise abatement, both on the national and local levels, but Congress has still not seen fit to appropriate funds for the implementation of the Noise Control Act. There are now two self-sustaining national organizations concerned with noise abatement: the Noise Pollution Clearinghouse and the League for the Hard of Hearing. There also has been considerable media attention to the problem in recent years, as well as increased interest in local ordinances throughout the nation.

Efforts to control noisy products and workplaces have been severely curtailed by OSHA's compliance directive of 1983,[95] which effectively raised the PEL to a TWA of 100 dBA and discouraged noise control even above that level due to extremely permissive enforcement procedures.[96] To the extent that manufacturers of construction equipment concerned themselves with the prospect of noise regulation from either EPA or OSHA, that incentive has disappeared.

FIGURE 9. The "Blue Angel" label. Reprinted from Irmer and Fischer-Sheikh Ali[93] with permission from *Noise News International.*

The Blue Angel Program

Europe, however, does provide some incentive for noise reduction by the manufacturers of construction machinery, even in the United States. First, there are the directives for noise limits and labeling, with which American manufacturers must comply if they wish to sell their products on the European market. The advent of the ANSI standard on labeling of machinery for noise could possibly encourage U.S. manufacturers to reduce product noise levels, even though the standard will not be mandatory.

The most promising development is Germany's "Blue Angel" program, which could have beneficial spillover for construction workers in the United States and which could also be used as a model in this country. The Blue Angel refers to a program for the voluntary designation of products as favorable to the environment. It was developed in Germany in 1977 and is flourishing today. The program's two main purposes are to assist customers in the choice of products and to encourage manufacturers to develop and market environmentally friendly products. Figure 9 shows the Blue Angel label with the environmental logo of the United Nations, the inscription "Umweltzeichen" (environmental label) above, the words "weil lärmarm" (because low-noise) below, and the words "Jury Umweltzeichen" (Environmental Label Jury) underneath.

Blue Angel awards for low-noise construction equipment were established in 1988. Irmer and Fischer-Sheikh Ali[93] reported that more than 40 companies had applied for the award with about 200 products displaying the label. Differences in sound levels between the existing noise limits in EC directives and those emitted by the Blue Angel products range from 5 to 14 dBA. In the early days of low-noise construction equipment the Federal Environmental Agency gave some financial support to interested manufacturers, but the authors report that the Blue Angel proved to be a good advertising tool and financial incentives are no longer needed.

Some local governments in Germany have given preference to Blue Angel construction products and are allowing them to be used in noise-sensitive areas, where the use of noisier products would be proscribed. Irmer and Fischer-Sheikh Ali[93] also mention that the number of non-German applicants is steadily increasing, with about 15% of the Blue Angel manufacturers coming from outside Germany. A 1997 publication of the German government gives an overview of construction machinery bearing the Blue Angel label.[97] The Caterpillar Co. is one of 14 manufacturers of excavators, with four types of machines displaying the Blue Angel. Their sound pressure levels range from 72 to 77 dBA. Of the 12 manufacturers of loaders, Caterpillar manufactures six models with sound pressure levels ranging from 68 to 78 dBA. Other products listed include compressors, power generators, welding generators, paver-finishers, concrete mixers, and tower cranes. Additional products and companies are undoubtedly certified today. Current information on the Blue Angel program is available at http://www.blauer-engel.de.

Buy Quiet Programs

EPA's Office of Noise Abatement and Control initiated an ambitious Buy Quiet program during the 1970s.[98] Its purpose was to leverage the multibillion dollar public sector market to buy quiet products. This would be done by organizing government purchasing cooperatives and working through professional purchasing organizations. The agency's program included the Government Services Administration, the National Institute of Governmental Purchasing, the National League of Cities, and various federal, state, and local purchasing agencies and cooperatives.

The EPA's Buy Quiet program consisted of four parts: (1) a series of conferences to develop quiet product purchase descriptions, (2) local Buy Quiet programs in which governments and purchasing cooperatives agree to buy quiet products as an ongoing activity, (3) a data bank for quiet purchasing operated by the National Institute of Governmental Purchasing, and (4) demonstrations of quiet products loaned by the EPA to local governments. Bids were evaluated on the basis of both noise level and price. In 1981, 64 governments had either committed themselves to a Buy Quiet program or were considering doing so.

EPA's Buy Quiet program had a short life because the agency was closed in 1982. At present there are no data on the number of government agencies (federal, state, or local) with these kinds of programs, but it is likely to be relatively few.

There is evidence, however, that these programs may continue in some places. Haag[99] reported that the 1987 edition of the National Fire Protection Association (NFPA) Standard on Fire Department Occupational Safety and Health Program contained noise specifications. Section A-5–8.1 stated that "new fire apparatus should provide maximum sound requirements that would allow members to ride in those vehicles without hearing protective devices. A maximum limit of 85 dBA without audible warning devices and 90 dBA with warning devices in operation is recommended."[99, p. F-22]

CONCLUSIONS

Approximately one-half million construction workers are exposed to hazardous levels of noise. Studies of construction workers' HTLs in the United States reflect excessive exposure, and it appears that the onset of noise-induced hearing loss starts early and continues throughout the career.

The prevalence of HPD use in the U.S. construction industry is very poor and only recently has begun to improve. Anxiety concerning the ability to perceive and understand warning signals and communication is an important factor in resisting HPDs, and research over recent years supports the validity of this anxiety. In British Columbia, however, the use of HPDs is significantly higher than in the United States, which is related to the success of its overall HCP. Today's broad range of HPDs, with several models designed specifically to mitigate the problems of hearing and understanding communication and warning signals in noise, points toward the necessity of careful selection and fitting of HPDs.

Audiometric testing in industry is of virtually no value unless serial audiograms can be compared. The problem of audiometric record keeping is especially difficult in construction because of the mobility of construction workers and the small size of many construction companies. Some kind of centralization, such as that found in the British Columbia program, would appear to be the best solution. Credit card storage devices or "smart cards" could make audiometric record keeping considerably more efficient for mobile employees because workers could easily carry them from job to job.

Although there has been relatively little investigation into the effects of noise, hearing loss, and HPDs on accidents in the construction industry, the existing research, along with evidence from studies of other industries, demonstrates the likelihood of adverse effects in construction. There are several steps that can be taken to reduce this hazard.

Noise control is the most effective way to prevent noise-induced hearing loss in construction, and very possibly reduce the incidence of serious accidents. Although maintenance and retrofit are viable approaches, control at the design stage is most desirable. Considerable information in this area is available, although some of it may be dated.

European standards and directives have focused attention on noise emission in European countries. These directives, which limit noise exposure and mandate labeling and provision of information, must provide some incentive to manufacturers, even though these requirements need to be made more relevant to the workplace in some cases.

Incentives for noise control on construction sites in the United States have diminished over the last two decades. The most likely reasons are the closing of EPA's Office of Noise Abatement and the issuance of OSHA's compliance directive for general industry, which effectively raised the PEL to 100 dBA. European directives may provide some incentives to U.S. manufacturers, especially in the form of programs like Germany's Blue Angel. Governmental Buy Quiet programs could also provide some incentive for noise control.

RECOMMENDATIONS

Professionals in industrial hygiene and hearing conservation should make every effort to control excessive noise on construction sites through the purchase of quieter equipment, as well as retrofit and proper maintenance of existing equipment. These efforts would not only conserve hearing but also aid in the prevention of noise-related accidents and fatalities.

Training programs should be developed for workers and contractors that include the importance of communication in the construction workplace, the dangers of overfitting HPDs, and how to tailor HPDs to communication needs. Contractors should be warned that they may have to spend more money on HPDs than they anticipated to ensure worker safety and efficiency, as well as the prevention of noise-induced hearing loss.

Manufacturers of reverse alarms and other warning devices should be encouraged to design their products for maximum audibility in the noise conditions most typical of their use, and to be perceived and understood by workers with noise-induced hearing loss, workers wearing HPDs, and workers under varying degrees of attentional demand. Contractors should be encouraged to purchase warning devices that are suitable for the work environments for which they are intended.

Pressure should be brought to bear on OSHA to move as rapidly as possible to extend the general industry noise regulation, including its amendment for HCPs, to cover construction workers. Although sections of the regulation would need to be tailored specifically to construction, it appears that the necessary knowledge and technology are available.

The agency should also be encouraged to rescind its instruction of Nov. 8, 1983, CPL 2–2.35 and all references to a TWA of 100 dBA in its directives and manuals. This policy was not subject to public notice and comment and provides a powerful disincentive for noise control and the conservation of workers' hearing in all industries, including construction.

Additional noise measurement data are needed on the sound levels of various types of construction equipment and various models within the same type. These data would facilitate the identification of low-noise and high-noise equipment, both for OSHA to assess the technological capabilities of the industry and for the sake of contractors who wish to purchase quieter equipment.

Consideration should be given to the identification and use of a centralized agency (or agencies) in which audiometric test results could be kept on a permanent basis.

The use of "smart cards" to store and transfer audiometric data should be further investigated.

A noise control database for the construction industry needs to be developed. It should include noise sources and levels, recommended treatments, quieted noise levels, estimated costs, and the availability of materials for treatments. The database should be made available electronically as well as on paper, and should be targeted to contractors, worker representatives, professionals in industrial hygiene and noise control, and federal and state compliance officers.

Government agencies should make financial and technical assistance available to organizations that could renew interest in Buy Quiet programs.

Organizations within the United States should obtain information about and publicize the achievements of all companies that currently display Germany's Blue Angel label for quiet equipment.

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