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"소음주의구역 (Noise Perimeter Zones)" - 고속도로 신설 공사 건설 현장에서의 소음 노출 저감을 위한 새로운 체계적인 방법

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"Noise Perimeter Zones" – A New Systematic Method for Noise Exposure Reduction in Highway Construction Sites

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이 연구에서는고속도로 신설 공사 건설 현장 근로자들의 소음 노출을 저감할 수 있는 방법들을 제시하며 특히 현장에서 적용할 수 있는 새로운 체계적인 방법인 "소음 주의 구역"을 제안한다.

고속도로 건설 현장에서 소음원이 되는 장비, 기계, 도구와 근로자들의 소음 노출 특성을 알아 보았으며, 개인 청력 보호구, 공학적제어수단 (engineering controls), 관리적제어수단 (administrative controls)을 어떻게 적용할 것인가를 제시하였다.

개인청력 보호구만으로는 소음 노출을 효율적으로 저감시킬 수 없음을 보였으며, 공학적제어수단은 기술적 및 경제적 문제로, 관리적제어수단은 공사 기간 단축과 같은 실제적인 이유로 해서 시행 되기가 어렵다.

따라서 이 연구에서는 실제적으로 적용할 수 있는 체계적인 방법으로서 "소음주의구역 (Noise Perimeter Zones)"을 새롭게 제안하였다. 이 "소음주의구역"은 높은 수준의 소음원이 존재하는 고속도로 건설 공사 현장에 지정된다. 이 구역안에서는 근로자들의 출입이 통제되며 또한 개인청력 보호구, 공학적제어수단, 관리적 제어수단과 같은 적절한 제어수단이 사용되어야 한다.

주 제 어 : 건설 현장 소음, 소음제어수단, 청력보호구, 소음주의구역

Ⅰ. INTRODUCTION

Noise is one of the major health hazards in construction sites. Many studies reported high level of exposures to noise among construction workers (Blute et al., 1999; Greenspan et al., 1995; Kerr

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et al., 2002; Legris & Poulin,1998; Neitzel et al., 1999; Seixas et al., 2001; Sinclair & Hafidson, 1995). The U.S. Environmental Protection Agency (EPA) and the National Institute for Occupational Safety and Health (NIOSH) estimated that the number of U.S. construction workers who were exposed to high levels (above 85 dBA) of occupational noise is 513,000 and 421,000, respectively (National Institute for Occupational Safety and Health, 1998; U.S. Environmental Protection Agency, 1981). One study reported that high percentages (44–65%) of construction workers - operating engineers, carpenters, and plumber/pipe fitters groups - perceived hearing losses (Lusk et al, 1998).

Occupational Safety and Health Administration (OSHA) and NIOSH have recognized the problems of high level of noise exposures in construction. Hearing loss is currently one of the National Occupational Research Agenda (NORA) priority research areas and some of their hearing loss projects focus on construction workers. In August 2002, OSHA published the advance notice of proposed rulemaking to revise the construction noise standards to include a hearing conservation component for the construction industry, similar to that for general industry. This hearing conservation component would be a key factor for increasing efforts to protect construction workers from high level of noise exposures.

The objectives of this study are 1) to overview the characteristics of noise exposures in highway construction, 2) to recommend necessary control means for reducing noise exposure levels of highway construction workers, 3) to evaluate the limitations of those control means, and 4) to suggest a new practical method to reduce exposures to noise in highway construction.

Ⅱ. NOISE SOURCES AND EXPOSURE CHARACTERISTICS IN HIGHWAY CONSTRUCTION

A variety of construction equipment and hand tools are used in highway construction sites. This includes power cranes, excavators, loaders, tractors, dozers, scrapers, compaction equipment, graders, rock excavation equipment, concrete equipment, and paving equipment. Many of these machines need high power and they are equipped with diesel engines, which are one of the major noise sources in highway construction. Other sources include the vibration of other parts by construction equipment and the impaction or friction of construction equipment on hard materials such as rocks and concrete.

The sources of noise can be categorized into several groups. First, an engine or other equipment makes noise by transmitting its sound energy directly to the environment. Second, construction equipment causes other parts to vibrate and thus creates secondary noise. Third, impact of construction equipment on materials or friction between the equipment and materials generates noise.

Some characteristics of noise exposures in highway construction are quite different from the exposures in other work environments. Noise sources are widespread and multiple, and construction workers are often exposed very closely to these noise sources. Short-term peak exposures are one of the major concerns and a lot of impact/impulsive noise exist in the construction sites, which makes it very difficult to evaluate exposure levels in a conventional way such as 8-hour time weighted averages. Measurements of noise levels using noise dosimetry or task-based measurements may not capture all the necessary information for assessing the possible hearing loss due to construction noise. Also, resources and technology for this assessment are very limited in most of the construction industry.

Exposure levels from in construction sites often exceeded the permissible Exposure limit of 90 dBA (Blute et al., 1999; Greenspan et al., 1995). And the workers often work in enclosed or partially enclosed spaces or in the environments that many tools and machines run simultaneously, which makes the problems worse and more complicated. Difficulty in hearing or hearing loss due to high noise level may make other safety hazards more dangerous. Vibration and chemical hazards usually exist along with the noise, which may cause synergic adverse effects on workers' health.

Ⅲ. NOISE CONTROL MEANS IN HIGHWAY CONSTRUCTION

Noise control in highway construction is not an easy matter. Ideally, it should consist of engineering controls, administrative, and hearing protectors, with most emphasis in that order. In addition, it includes good purchasing policy of selecting construction equipment that generates less noise. Engineering controls are the primary means of reducing noise exposures and administrative controls are essential to achieve effective hearing loss prevention (NIOSH, 1978; NIOSH, 1996). Hearing protection devices can be used in addition to engineering and administrative controls for the workers in the environments with high level of noise. However, the use of hearing protectors should be the last resort to protect workers from high levels of noise, engineering and administrative controls being the priority. Unfortunately, hearing protectors are the only available noise control means in many of the highway construction sites.

A. Hearing Protectors

The Noise Reduction Rating (NRR) is a single-number rating method that indicates how much overall noise level is reduced using a hearing protector. This is tested in laboratories and should be derated under real conditions. NIOSH collected NRR data of hearing protectors sold in the United States and showed that the hearing protection level in the real world is less effective than laboratory data under ideal conditions (NIOSH, 1994). Therefore, OSHA instructed its compliance officers to derate the NRR by 50% (OSHA, 1983) and the NIOSH criteria (NIOSH, 1998) suggest that labeled NRRs be derated as following:

- Earmuffs: Subtract 25% from the manufacturer's labeled NRR.
- Formable earplugs: Subtract 50% from the manufacturer's labeled NRR.
- All other earplugs: Subtract 70% from the manufacturer's labeled NRR.

When the noise exposure level in dBA is known, the effective noise level (ENL) for A-weighted measurements can be calculated using the following equation:

$$ENL = dBA - (\text{derated } NRR - 7) \quad (1)$$

And the required manufacturer’ NRR to get target effective levels at a given noise exposure level can be calculated using the NIOSH criteria and the equation for ENL.

Noise in highway construction includes continuous, intermittent and impact/impulsive sounds. Certain impact/impulsive noise from some equipment/process in highway construction has more sound energy at high frequencies. Noise from diesel engines has broadband characteristics with higher sound energy in the low frequency range. Hearing protectors are usually relatively effective in reducing noise with high frequencies but not in controlling noise with low frequencies. Generally, earmuffs and earplugs reduce high frequency sound well. Earmuffs reduce mid frequency noise more effectively and earplugs reduce low frequencies better. So, earplugs are a better selection than earmuffs for reduction of diesel engine noise. However, earmuffs are generally more effective than earplugs as shown above. Therefore, hearing protectors should be selected based on available information on noise exposure level as well as noise spectral characteristics.

Table 1 – Table 3 shows the required NRR values for earmuffs, formable earplugs and other earplugs, respectively considering the NIOSH criteria. For example, if a worker who is exposed to a noise exposure at 95 dBA wants to wear an earmuff in order to reduce the exposure level to 85 dBA, the worker should use one with NRR of 23dB. These tables illustrates that formable earplugs are effective only for relatively low levels of noise exposures and other plugs are practically not effective at all to protect most workers in the real world. NIOSH recommends double hearing protection (earplugs and earmuffs) when workers are exposed to high level (100 dBA) of noise. However, it should be noted that double protection adds only 5 to 10 dB of attenuation to single protection (Nixon & Berger, 1991).

Hearing protectors, especially earplugs, are widely used because they are easy to implement. This does not necessary mean that they are effective means to reduce high level of noise exposures. Actually, as shown above, not many hearing protectors provide sufficient protection from high-level noise in real world. Therefore, they should be used only as supplemental means to engineering and/or administrative controls.

Blute et al. (1999) reported that generally, construction workers often did not wear hearing protection, even though the majority of the workers were concerned about their hearing loss and believed that a hearing protector would reduce their long-term hearing loss. Reasons for not wearing hearing protectors include discomfort, the inability to hear the sounds related to the equipment, difficulty in communicating with coworkers, fears of not being able to hear warning alarms, and the belief that workers have no control over an inevitable process that culminates in hearing loss (Berger, 1980; Helmkamp, 1986; Lusk et. al., 1993).

B. Engineering Controls

Engineering controls reduce sound level at the source and are effective ways to reduce noise exposure. The following means are among the available engineering controls that can be applied in high construction (Baker, 1993; Bell & Bell, 1994; Husick, 1999; NIOSH, 1978; NIOSH, 1996).

- Installing high-quality mufflers/silencers on engine-powered

Table 1. Required manufacturer's NRR (dB) for earmuffs to achieve target effective levels at given noise exposure levels

Exposure Level (dBA)	Required Manufacturer's NRR (dB) for Earmuffs		
	Target Effective Level (dBA)		
	80	85	90
85	16	—	—
90	23	16	—
95	29	23	16
100	36	29	23
105	43	36	29
110	49	43	36

Table 2. Required manufacturer's NRR (dB) for formable earplugs to achieve target effective levels at given noise exposure levels

Exposure Level (dBA)	Required Manufacturer's NRR (dB) for Earmuffs		
	Target Effective Level (dBA)		
	80	85	90
85	24	—	—
90	34	24	—
95	44	34	24
100	54	44	34
105	64	54	44
110	74	64	54

Table 3. Required manufacturer's NRR (dB) for other earplugs to achieve target effective levels at given noise exposure levels

Exposure Level (dBA)	Required Manufacturer's NRR (dB) for Earmuffs		
	Target Effective Level (dBA)		
	80	85	90
85	40	—	—
90	57	40	—
95	73	57	40
100	90	73	57
105	107	90	73
110	123	107	90

equipment.

- Erecting acoustical enclosures and barriers around equipment.
- Installing sound absorbing materials and vibration isolation system for hand tools and materials.
- Replacing worn, loose, or unbalanced machine parts to cut down on noise generated by vibration.
- Keeping machine parts well lubricated to cut down on noise created by friction.

These engineering control means should be evaluated based on their effectiveness and technical feasibility in applying them to the specific conditions of highway construction sites. Neitzel et al. (1999) reported a significant reduction of noise level for heavy equipment operators when using a noise transmission barrier. However, the application of engineering controls is not feasible in many of highway construction sites due to technical and/or economical reasons. Highway construction usually has an intensive schedule and sometimes noise control is not one of the priorities of the project. There are often many other safety issues that are regarded as more important to keep workers safe. Also, the environment in the construction area changes daily, which makes it difficult to install engineering controls for noise reduction. We observed the construction workers in the highway construction in Boston, Massachusetts, U.S.A in 1999 and found hearing protectors were the only means that were used to protect workers from exposure to high levels of noise.

C. Administrative Controls

Administrative controls are changes in work schedule or operations in order to reduce worker noise exposures (NIOSH, 1998). They should be considered in construction plans. However, not many construction companies use them because their priorities are not on the hearing protection of construction workers. A simple, practical approach on how to apply the administrative controls should be suggested to the construction industry in order to overcome the reluctance of implementing those controls. And the "Noise Perimeter Zones", which is developed in this study, will serve as a systematic method to reduce the noise exposure levels in highway construction industry.

Ⅳ. NOISE PERIMETER ZONES

A "Noise Perimeter Zone" is the zone in highway construction where a high level of noise sources exists. Calculating a Noise Perimeter Zone consists of the following steps:

1. Measure the sound pressure level at a distance from a point noise source.
2. Measure the distance between the noise source and measurement point.
3. Convert the measured sound pressure to the estimated sound power of the noise source using Table 4 or the following equation:

$$L_W = L_P - DI + 20\log_{10} r + 11 \quad \cdots\cdots (2)$$

where

L_W = sound power level of the point source (re 10^{-12} W) in dB

L_P = sound pressure level in dB

DI = directivity index for semispherical radiation = $10\log_{10}2$

r = distance from source (meter)

4. Calculate a Noise Perimeter Zone distance using Table 5 or the following equation:

$$\text{Noise Perimeter Zone distance} = 10^{\frac{(L_W - L_P + DI - 11)}{20}} \quad \cdots\cdots (3)$$

5. Estimate the maximum exposure time within the Noise Perimeter Zone using Table 6 or the following equation:

$$\text{Maximum exposure time} = \left(\frac{8\text{hours}}{2^{(\text{Exposure level,dBA} - \text{Target level,dBA})/5\text{dBA}}}\right) \quad \cdots\cdots (4)$$

The assumptions for the above calculations are as follows:

1. There is only one major noise source in the area.
2. The noise source is considered is as a point source.
3. A 5 dB exchange rate is used.

Strictly speaking, use of this approach will be limited to cases where there is only a single point source in an area. However, even though there is more than a single noise source in the area, the calculations can be performed for the dominant noise source.

Example: A construction worker is working at 3 meters away from a generator and the sound pressured is measured at 92 dBA at the worker's position. From Table 4, the estimated sound power level for the generator is 110 dBA. If a target noise exposure level is 85 dBA, the distance for the Noise Perimeter Zone is 4.7 meters from Table 5. This distance is the perimeter of the Noise Perimeter Zone and only necessary workers should work inside this zone. The maximum work hours for the worker inside the Noise Perimeter Zone at 3 meters away from the noise source is calculated, using the equation (4), at 3 hours if none of control means are used. The

Table 4. Calculated sound power level (PWL, dB) of a point source using a measured sound pressure level (dB) and a measured distance (meter) from the source

Measured Sound Pressure Level (dB)	Calculated Sound Power Level (dB)									
	Measured Distance from Source (meter)									
	1	2	3	4	5	6	7	8	9	10
70	78	84	88	90	92	94	95	96	97	98
72	80	86	90	92	94	96	97	98	99	100
73	82	88	92	94	96	98	99	100	101	104
76	84	90	94	96	98	100	101	104	103	104
78	86	92	96	98	100	104	103	104	105	106
80	88	94	98	100	104	104	105	106	107	108
82	90	96	100	104	104	106	107	108	109	110
84	92	98	104	104	106	108	109	110	111	112
86	94	100	104	106	108	110	111	112	113	114
88	96	102	106	108	110	112	113	114	115	116
90	98	104	108	110	112	114	115	116	117	118
92	100	106	110	112	114	116	117	118	119	120
94	102	108	112	114	116	118	119	120	121	122
96	104	110	114	116	118	120	121	122	123	124
98	106	112	116	118	120	122	123	124	125	126
100	108	114	118	120	122	124	125	126	127	128

Table 5. Calculated Noise Perimeter Zone distance (meter) using the sound power level (dB) of a point source and a target sound pressure level (dB)

Sound Power Level of Point Source (dB)	Calculated Distance (meter)				
	Target Sound Pressure Level (dB)				
	80	85	90	95	100
90	1.2	0.7	–	–	–
92	1.5	0.8	0.5	–	–
94	1.8	1.1	0.6	–	–
96	2.2	1.3	0.8	0.4	–
98	2.7	1.6	0.9	0.6	–
100	3.2	2.0	1.2	0.7	–
102	3.9	2.4	1.4	0.9	0.5
104	4.7	2.9	1.8	1.1	0.6
106	5.5	3.5	2.2	1.4	0.8
108	6.5	4.1	2.6	1.8	1.0
110	7.6	4.7	3.2	2.2	1.3
112	8.9	5.3	3.8	2.8	1.6
114	6.3	5.9	4.4	3.6	2.0
116	5.9	6.3	5.0	4.5	2.5
118	31.7	17.8	10.0	5.6	3.2
120	39.9	22.4	12.6	7.1	4.0

worker should wear a hearing protector to work more than 3 hours inside the Noise Perimeter Zone or the work schedule should be adjusted so that the work time does not exceed the limit.

Access to the Noise Perimeter Zone will be controlled and only designated workers who need to come in for their work should stay inside the zone. This method will keep unnecessary workers out of high-level noise zone. The workers inside the zone should have proper control means including administrative controls such as adjusting worker schedules, adjustment of operating procedures, and relocating workers. The control means may also include other engineering controls and personal protectors.

Suter (2002) suggested that keeping noisy operations away from construction workers who are not involved in the process is one of the least expensive and most rewarding noise control practices. "Noise Perimeter Zones" is suggested as a practical approach to reduce the noise exposure levels in highway construction industry. Successful implementation of this approach will require the cooperation of both construction workers and the management. Elimination of generating high level noise sources (by purchasing and using construction equipment that generate low levels of noise) should be a better long-term solution for noise control in highway construction.

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Table 6. Noise exposure duration (hours) not to be exceeded at a given exposure level with a 5 dB exchange rate

Exposure Level (dBA)	Target Sound Pressure Level (dBA)		
	80	85	90
85	4	8	16
90	2	4	8
95	1	2	4
100	.5	1	2
105	.25	.5	1
110	.125	.25	0.5

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