Health Damage Assessment about Construction Noise of Tunnel Adopting Drilling and Blasting Method

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Abstract. A lot of noise pollution will be produced in the process of tunnel construction, which will seriously damage the workers' health. In order to reveal the health damage characteristics caused by tunnel construction noise and improve workers' occupational health level, this paper established an assessment system of health damage caused by tunnel construction adopting Drilling and Blasting Method, including standardization of noise exposure, characterization of health risk and quantification of health damage. During the 5-year tunnel construction, the total DALY of all workers is 4.256 a, and the total damage of drilling is the largest (DALY=1.743 a), followed by shotcrete (DALY=0.646 a), while the pouring lining (PL) is zero due to the slight noise exposure. In addition, except for pouring lining (PL), the per capita damage of shotcrete is the largest (DALY=0.131 a), personal protection needs to be strengthened, and the assembling reinforcement (AR) is the smallest (DALY=0.032 a). This study applied the occupational noise exposure assessment to tunnel engineering for the first time, providing a reference for workers to protect against noise pollution.

1. Introduction

In recent years, noise pollution has been plaguing people's production and life, and even affecting people's health[1-2]. According to the research, 42.11% of the 1838 workers exposed to noise suffered from different degrees of health damage[3]. In the construction process, the noise caused by material cutting, metal impact, mechanical operation and so on is harmful to human health[4]. However, unlike architectural engineering, tunnel construction often leads to more significant noise pollution due to the confined space and long-term operation of machinery[5-7].

Noise pollution is a kind of occupational exposure. In order to clarify the damage of noise pollution to human health, it is necessary to conduct a health damage assessment about construction noise. In terms of assessment methods, the most widely used one is the Guidelines for Exposure Assessment created by the US Environmental Protection Agency[8], which is mainly divided into four parts: hazard identification, dose-response assessment, exposure assessment, and risk characterization. Researchers from the World Health Organization (WHO) have proposed an assessment framework for occupational noise exposure based on the Guidelines for Exposure Assessment[9].

Although the assessment system about occupational noise is mature, it is mainly used in factories and architectural engineering project[10], and less is used in tunnel engineering. In order to explore the health damage characteristics caused by tunnel construction noise, this paper built a health damage...
assessment model combining with the existing researches. This model consists of the health risk 
amendment and health damage quantification.

2. Materials and methods

2.1. Sampling protocol

2.1.1. Sampling site. The Guigala Tunnel is an important control project in the Lhasa-Zedang 
expressway, which is located in Tibet, China. Its length is 12,850m. And the average elevation of the 
tunnel is 4,200m. The main tunnel adopts a three-centered circular section, and the section area of the 
single tunnel is 65.65 m² (no invert arch, no superelevation) and 81.42 m² (including invert arch). Most 
of the surrounding rock is IV grade. The main tunnel and inclined shaft are constructed by Drilling and 
Blasting Method.

2.1.2. Sampling methods and data collection. Generally, tunnel construction involves a number 
of different procedures with different machinery and construction methods, so the noise level is different. 
The workers of each procedure are generally in the same zone, and the noise sources of the same 
procedure are homogeneous, so the noise exposure of the workers of different procedure was tested 
separately. In this paper, the tested procedures mainly include drilling, slag-out, shotcrete, laying 
waterproof board (LWB), assembling reinforcement (AR) and pouring lining (PL). In addition, the 
blasting was not included in the test because of the short noise duration and the workers’ safe evacuation.

The noise testing system in this paper was composed of PAA6 dual-channel audio tester and 
AWA6223 acoustic calibrator, which meet the requirements of the Emission Standard of Environment 
Noise for the Boundary of Construction Site[11] and Electroacoustic-Sound Calibrators[12]. In order 
to prevent the interference of airflow on the tunneling face, the microphone was covered with a 
windscreen during the test. The microphone sensor was placed at 1.5 m above ground. And there are 
three test points in the same procedure, and each point was tested for 10 min.

2.2. Health risk assessment system
In this paper, the occupational noise exposure of tunnel construction workers was quantitively assessed 
by using the health damage assessment model in the field of public environmental health. The model 
mainly involves the following three parts: standardization of noise exposure, characterization of health 
damage and quantification of health damage.

2.2.1. Standardization of noise exposure. The noise exposure level in this paper shall be calculated 
according to the Technical Guidelines for Noise Impact Assessment[13], and the calculation is carried 
out according to the Eq. (1).

\[
L_{A,eq,m} = 10 \log \left[ \frac{1}{T_m} \sum_{n=1}^{N_m} t_n 10^{0.1L_{A,n}} \right]
\]  

(1)

Where \(L_{A,eq,m}\) is the A-weighted equivalent continuous sound pressure level for procedure \(m\) 
(dB(A)), and \(L_{A,n}\) is the noise pressure level of testing point \(n\) in procedure \(m\), (dB(A)). \(T_m\) is the total 
testing time of procedure \(m\), (h), and \(t_n\) represents the testing time of point \(n\) in procedure \(m\), (h).

According to the occupational health risk assessment system, the exposure level of construction 
workers in the harmful environment should be taken as the 8-hour daily average exposure dose. 
According to relevant specifications[14], the equivalent daily average exposure noise can be obtained 
according to the Eq. (2).

\[
L_{EX,8h,m} = L_{A,eq,m} + 10 \log \left( \frac{T_{m,e}}{T_0} \right)
\]  

(2)
Where \( L_{\text{EX},h,m} \) is the 8-hour daily average noise exposure of procedure \( m \), (dB(A)). \( T_{m,e} \) is the daily effective working hours of procedure \( m \), which are shown in Table1. And \( T_0 \) is the reference value of working hours, which is 8 h.

### Table 1. Daily effective working hours of each procedure.

| Procedure | Drilling | Slag-out | Shotcrete | LWB | AR | PL |
|-----------|----------|----------|-----------|-----|----|----|
| Effective working hours (h) | 8.5 | 7.0 | 8.5 | 8.5 | 9.0 | 8.0 |

2.2.2. Health risk characterization. A large number of studies have shown that the health damage caused by noise is mainly reflected in hearing loss, which is irreversible\[9,10,15\]. Therefore, the damage in this paper mainly focuses on hearing loss. According to relevant researches\[9,16\], Eq.(3) can be used to characterize the health risk value caused by noise pollution.

\[
ER = (RR - 1) \times EpR
\]

Where \( ER \) is the estimated excess risks, which are shown in Table 4. \( RR \) is the relative risk due to occupational noise, which is shown in Table 2. And the \( EpR \) is the expected risk due to occupational noise, which is shown in Table 3.

### Table 2. Relative risk (RR) based on age group and level of exposure.

| Level       | 15-29 | 30-44 | 45-59 | 60-69 | 70-79 | >80 |
|-------------|-------|-------|-------|-------|-------|-----|
| <85 dB(A)   | 1.00  | 1.00  | 1.00  | 1.00  | 1.00  | 1.00|
| 85-90 dB(A) | 1.96  | 2.44  | 1.91  | 1.66  | 1.12  | 1.00|
| >90 dB(A)   | 7.96  | 5.62  | 3.83  | 2.82  | 1.62  | 1.00|

### Table 3. Expected risk (EpR) based on the age group.

| Age        | 15-29 | 30-44 | 45-59 | 60-69 | 70-79 | >80 |
|------------|-------|-------|-------|-------|-------|-----|
| Prevalence (%) | 1.25 | 2.84  | 5.74  | 9.35  | 16.55 | 25.35|

### Table 4. Estimated excess risks (ER) based on age group and level of noise exposure (%).

| Level       | 15-29 | 30-44 | 45-59 | 60-69 | 70-79 | >80 |
|-------------|-------|-------|-------|-------|-------|-----|
| <85 dB(A)   | 0     | 0     | 0     | 0     | 0     | 0   |
| 85-90 dB(A) | 1.2   | 3.52  | 5.22  | 6.17  | 1.99  | 0   |
| >90 dB(A)   | 8.7   | 13.12 | 16.24 | 17.02 | 10.26 | 0   |

2.2.3. Health damage quantification. The years of health loss and premature death life loss caused by noise can be quantified by effect analysis and damage analysis. The quantitative results are called disability-adjusted life years (DALY), which can be determined according to Eq. (4).

\[
DALY_m = \sum_i \left( N_{m,i} \times ER_{m,i} \times DW \times D_m \right)
\]

Where the \( N_{m,i} \) represents the number of workers in the age group \( i \) of process \( m \), which are shown in Table 5, and \( ER_{m,i} \) is the additional damage value of noise exposure of workers in age group \( i \) of procedure \( m \). And the \( DW \) is the disability weight, which is 0.192 according to relevant research\[17\]. \( D_m \) represents the total construction duration of procedure \( m \), which equal to 5a.
Table 5. Age distribution of workers in each procedure.

| Procedure | 15-29 | 30-44 | 45-59 | Total |
|-----------|-------|-------|-------|-------|
| Drilling  | 4     | 5     | 5     | 14    |
| Slag-out  | 1     | 5     | 0     | 6     |
| Shotcrete | 0     | 5     | 1     | 6     |
| LWB       | 0     | 2     | 6     | 8     |
| AR        | 5     | 10    | 5     | 20    |
| PL        | 1     | 4     | 5     | 10    |

3. Results and discussion

3.1. Analysis of sampling results

Through the on-site test, the results of noise exposure of Guigala tunnel construction workers under different procedures are shown in Table 6.

Table 6. Noise exposure of each procedure.

| Procedure | Test location                          | Noise source            | LA,1   | LA,2   | LA,3   | Mean value ±SD | L, Aeq | LEX,8h |
|-----------|---------------------------------------|-------------------------|--------|--------|--------|----------------|--------|--------|
| Drilling  | 5m behind the drilling machine         | Rock drills             | 108.9  | 109.4  | 109.1  | 109.1±0.25     | 109.1  | 101.9  |
| Slag-out  | 3m beside the loader                   | Loaders                 | 89.8   | 91.1   | 90.6   | 90.5±0.66      | 90.5   | 83.3   |
| Shotcrete | Under shotcrete cantilever             | Pump truck and impact of concrete | 99.8   | 100    | 101.1  | 100.3±0.70     | 100.3  | 93.1   |
| LWB       | Within the operation area              | Nail gun                | 87.8   | 87.7   | 87.1   | 87.5±0.38      | 87.5   | 80.3   |
| AR        | Within the operation area              | Iron pounding           | 86.3   | 86.7   | 85.9   | 86.3±0.40      | 86.3   | 79.0   |
| PL        | Under the trolley                      | Pump truck and impact of concrete | 82.5   | 82.3   | 83.1   | 82.6±0.42      | 82.6   | 75.4   |

From Table 6, it was found that the noise exposure of drilling, slag-out, and shotcrete exceeded the limitation (90 dB (A)) of the specification[18], mainly due to the operation of large-scale machinery and the closure of environment. Among all procedures, the workers of drilling suffered from the highest noise exposure (109.1 dB (A)) because of the fact that 14 rock drills operated simultaneously in this procedure. Although the noise sources of shotcrete and PL were the same (Table 6), the noise exposure of PL was far less than that of shotcrete, which was 82.6 dB (A) and 100.3 dB (A), separately. Because the shotcrete was the rapid impact between concrete and the rock wall under the action of the high-pressure sprayer, while PL was the slower flow of concrete into the lining formwork through pumping. It was worth mentioning that although large construction machinery was not involved in the operation of LWB, the intensive use of nail guns would make greater noise (87.5 dB (A)).

3.2. Health damage analysis

Substitute the parameters into the Eq. (1) - (4) to get the damage value of noise pollution to the workers’ health during the tunnel construction, as shown in Fig.1. As can be seen from Fig.1 that the 5-year tunnel construction will cause serious noise pollution to all workers, with total health damage to 4.256a, of which the workers belonging to drilling will suffer from the most serious total health damage...
(DALY=1.743a), followed by shotcrete. However, the noise level in the PL is very slight (82.6 dB (A)), which is not enough to cause a serious impact on the human[9], so its health damage value is 0.

Especially, in terms of per capita damage, only the damage of shotcrete and AR were inconsistent with the total damage (Fig.1). The main reason is that although the noise exposure of shotcrete is second only to drilling (Table 6), the value of per capita damage is greater than drilling owing to the minimum number of workers(6). Similarly, since the AR is the high labor-intensive procedure[19], it often requires a number of workers, resulting in a minimum per capita health damage except for PL.

3.3. Noise reduction measures
In order to reduce the noise-induced health damage, some measures must be taken. But the advanced low-noise construction machinery technology is not mature, with high cost. Therefore, the most appropriate method is reducing it on its propagation path, that is, some techniques such as sound absorption, sound insulation, noise elimination, and vibration isolation are used to control the noise intensity of the workplace within the relevant standards. In addition, workers should strengthen their self-protection, such as wearing noise-reducing earplugs.

4. Conclusion
Combined with the health damage assessment model in the field of public environmental health, this paper established the health damage assessment system of noise pollution in tunnel construction for the first time, which obtained the specific quantitative value of health damage in each procedure, and also provided a reference for workers' self-protection in the noise environment. The main conclusions of this paper are as follows:

1) In tunnel construction, due to the closure of the construction environment and the operation of large-scale machinery, the construction workers suffer from serious noise pollution, resulting in huge health damage (DALY=4.256 a). And there are obvious differences in health damage among various procedures, in the influence of effective working time, number of the worker.

2) In terms of the total health damage, the procedure with the most serious damage is drilling (DALY=1.743a), which is 2.7 times of the shotcrete. In addition, the workers of pouring lining suffer from little health damage.

3) From the perspective of per capita health damage, the worker of shotcrete suffers from the maximum (0.131a) due to a small number of workers, and they should strengthen the self-protection. On the contrary, the damage in assembling reinforcement is the lightest (DALY=0.032a) except for pouring lining.

Figure 1. Comparison of health damage in each procedure.
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