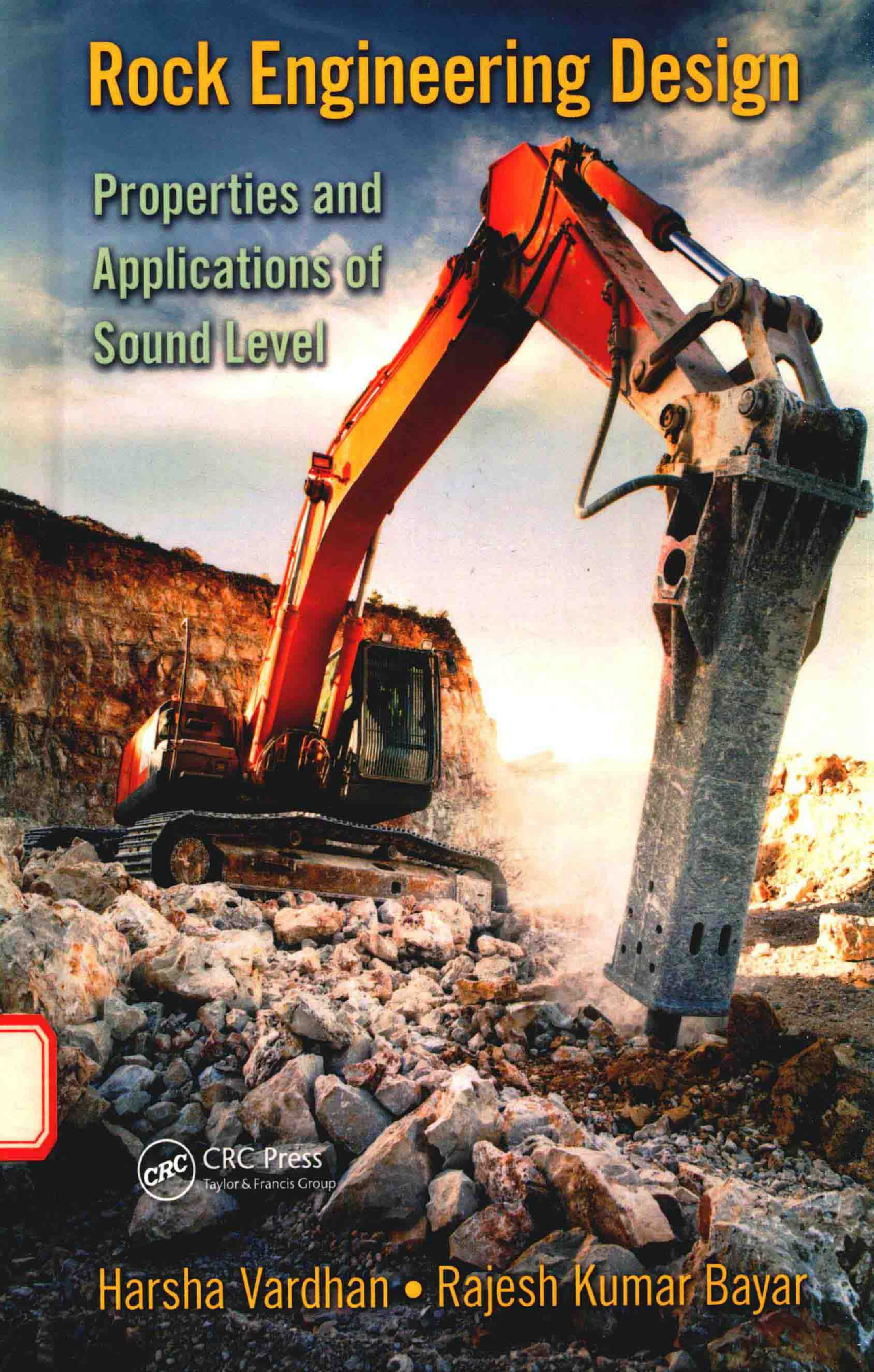
Rock Engineering Design

Properties and Applications of Sound Level



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Harsha Vardhan • Rajesh Kumar Bayar

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Preface

Engineering design of rocks is a complex process, requiring knowledge of their various physico-mechanical properties. There are established standard techniques for determining rock properties, which have been used around the world for quite some time.

The application of sound level in determining the fault and its diagnosis in the mechanical industries is very well known to scientists and engineers. However, its application in rock engineering design is not very common. Only a few studies can be traced pertaining to the application of sound level in rock engineering design. It is our intention to present to engineering students, scientists, and engineers the basic concepts and principle on which sound level can be used in solving rock engineering design problems in the clearest and simplest form possible. A major objective of this book is to help students to develop interest in using sound level as a tool in rock design applications.

This book has been developed out of many years of research experience gained by the authors. There are numerous books on the subject of rock mechanics and design. However, to our knowledge, a book specifically in the area of rock engineering design using sound levels is not available on the market today. This was the main intention in bringing out this book. The theory presented is as simple as possible to make the subject interesting to readers. The book is equally useful for readers with backgrounds in both mining and civil engineering disciplines.

Regarding its organization, the book consists of 10 chapters, well arranged in a coherent manner. All the chapters are presented in a logical order, starting with Chapter 1, which provides a general introduction to noise, its effects, and standards. Chapter 2 discusses the application of noise monitoring for mining equipments, whereas Chapter 4 discusses the application of acoustic emission techniques in geotechnical fields. The equipments for drilling, measurement of sound, and physico-mechanical properties of rocks are discussed in Chapter 5. The process involved in the measurement of rock properties and sound level is discussed in Chapter 6. The statistical values of the rock properties and sound level produced during drilling of different rocks are summarized in tables and figures in this chapter. Chapter 7 explains developed regression models, whereas procedure and the results of developed artificial neural network models are presented in Chapter 8. A case study carried out during this work is discussed in Chapter 9. Finally, a summary and suggestions for further work in this direction are given in Chapter 10.

This book focuses on the indirect method with emphasis on the development of numerical models in rock engineering design using sound levels.

This does not mean that the direct methods are not important. In practice, a project should always include some types of laboratory or in situ tests, and the indirect methods can only be used to supplement the direct methods.

We are grateful to various authors and publishers who permitted to reproduce their illustrations. We are equally grateful to the reviewer of the manuscript of this book who made extremely valuable suggestions and has thus contributed in enhancing the standard of the book. Further, we gratefully acknowledge the support and the cooperation of the staff of Taylor and Francis who were responsive to our wishes and helped to create the present layout of the books. We shall feel amply rewarded if the book proves helpful in the development of genuine research studies.

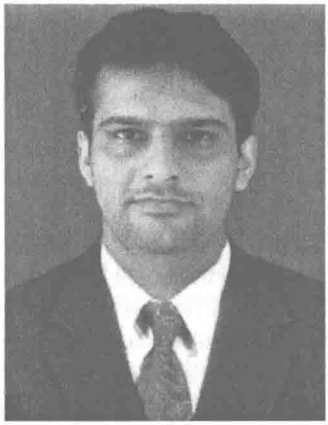
Harsha Vardhan and Rajesh Kumar Bayar

The Authors

Dr. Harsha Vardhan completed his B. Tech in mining engineering from the National Institute of Technology Karnataka at Surathkal and a Ph.D. from the Indian School of Mines, Dhanbad. Before joining the faculty at NITK Surathkal, he worked with Mysore Minerals Ltd. (a Government of Karnataka undertaking) for around 2 years. At present he is working as Associate Professor, Department of Mining Engineering, National Institute of Technology Karnataka at Surathkal and Mangalore. He is a fellow of Disaster Advances, and life member of the Institution of Engineers, India, and a member of Institution of Public Health Engineers, India; Mining, Geological and Metallurgical Institute of India; Acoustical Society of India; Mining Engineers Association of India; and Indian Society for Technical Education. Over a period of time, he has developed expertise in the area of mine environment, underground ventilation, and noise control of mining equipment. He has developed special interest in the application of acoustics in rock mechanics.

Dr. Vardhan is actively involved in research and consultancy, and he has to his credit more than 86 research papers in international and national journals and conferences. He is on the editorial board and reviewer of several professional journals in the area of his expertise. He has received the Award for Best Research Publication from the Government of Karnataka; Engineering Gold Medal and D. N. Thakur Award from the Mining, Geological and Metallurgical Institute of India; and Certificate of Merit from the Institution of Engineers, India. He was also honored with the Career Award for Young Teachers from the All-India Council for Technical Education, New Delhi, and Young Scientist Award from the Ministry of Science and Technology, Government of India.

His work has taken him on various assignments to the United States, France, Thailand, Belgium, and Indonesia. He is also involved in providing technical assistance to various government and statutory bodies, which has drawn national attention.



Dr. Rajesh Kumar Bayar completed his Bachelor of Engineering degree in mechanical engineering from Mysore University, his Master of Technology in advanced manufacturing engineering, and a Ph.D. from the National Institute of Technology Karnataka at Surathkal. Before joining the Technical Institute of Ministry of Manpower, Sultanate of Oman, he worked with the N.M.A.M Institute of Technology, Nitte, for around 10 years. At present he is working on the faculty of the Department of Engineering, Mechanical Section, Higher College of Technology, Muscat, Sultanate of Oman. He is a life member of the Indian Society for Technical Education. Over a period of time, Dr. Bayar has developed expertise in the area of CAD/CAM, finite element analysis, artificial neural network, and rock mechanics. He is actively involved in research and consultancy.

Contents

1

About Noise in General

1.1 Genesis of Noise, Its Propagation, and Unit

Sound is generated due to surface vibrations or due to turbulence of an air stream, which sets up rapid pressure variation in the surrounding air. A sound wave is a longitudinal vibration of a conducting medium such as air or water. Sound waves can be represented as sinusoidal patterns with given amplitudes and frequencies. The intensity of sound, which is related to its loudness, is represented by the amplitude of the sound wave. Sound waves require a medium to travel. The medium must have mass and elasticity, and this is the reason why sound does not travel through vacuum. When sound is produced, a transfer of energy from the source to the surrounding molecules takes place. The velocity of propagation of disturbance in a medium depends on its density and elasticity and is given by the equation

$$C = K\,(E/\rho)^{1/2}$$

where E = Modulus of elasticity of the medium, N/m^2
  ρ = Density of the medium, kg/m^3
  K = Constant

For air under normal conditions, the velocity of propagation of sound is approximately 344 m/s.

The rate at which this disturbance occurs is expressed in cycles per second or hertz (Hz), which is the international unit of frequency. A higher-pitched sound is one that is higher in frequency. The normal human ear is sensitive to frequencies between about 20 Hz and 20 kHz.

For the purpose of accommodating the large range of sensitivity of the human ear, where the greatest intensity that can be tolerated at the threshold of pain is 10^{13} times that corresponding to the threshold limit of hearing (20 μPa), a logarithmic scale is used, and the unit of measurement is the bel (B). It is defined as

$$1\ \text{Bel} = \log_{10}\,(P/P_r)^2$$

where P = measured root mean square (rms) pressure, Pa
  P_r = reference root mean square (rms) pressure, Pa

The lower limit of the threshold of hearing (20 μPa) is taken as the reference pressure (P_r). The entire auditory range is covered in 13 steps, 10^0 to 10^{13}. One bel signifies a 10-fold increase in intensity, two bels signify a 100-fold increase in intensity, and three Bels signify a 1000-fold increase in intensity, etc. For practical use, bels are too big, and therefore the scale is divided into tenths, the units being known as *decibels*. It is defined as

$$1 \text{ Decibel (dB)} = 10 \log_{10} (P/P_r)^2$$

This scale is appropriate to human hearing system, as the human ear also responds in a logarithmic way.

Before measuring the sound level, it is processed through a *weighting network* to simulate the human auditory system. Various research groups have worked on weighting networks and termed them as A-weighting, B-weighting, C-weighting, and flat-weighting. Nowadays, the A-weighting network is commonly used by regulatory bodies. If the measured sound pressure level is X dB using an A-weighting network, then it is expressed as "The A-weighted sound level is X dB" or simply X dB(A).

1.2 Common Terminology

Exchange rate: Defined as "the change in sound level corresponding to a doubling or halving of the duration of a sound level while a constant percentage of criterion exposure is maintained."

Average sound level: The logarithmic average of the sound during measurement duration (specific time period), using the chosen exchange rate factor. Exposure to this sound level over the period would result in the same noise dose as the actual (unsteady) sound levels.

Noise dose: The percentage of time a person is exposed to noise that is potentially damaging to hearing. Zero represents no exposure and 100 or more represents complete exposure. It is calculated by dividing the actual time of exposure by the allowed time of exposure. The allowed time of exposure is determined by the criterion duration and by the sound level (the higher the level, the shorter the allowed time). The sound levels must be measured with A-frequency weighting and slow exponential time weighting.

Energy equivalent sound level (L_{eq}): The equivalent steady sound level that, in a stated period of time, would deliver the same amount of sound energy as the fluctuating or time varying sound during the same period. It can be calculated using the equation:

$$L_{eq} = 10 \log \Sigma f + 90$$

Where,

f = Fractional exposure factor = 0.125 t antilog [0.1 (L – 90)]

t = Time interval in hours

L = A-weighted steady sound level in dB for time interval "t"

Threshold sound level: The A-weighted sound level below which, the sound produces little or no noise dose accumulation and may be disregarded. It is used for hearing damage risk assessment.

1.3 Impact of Noise

Worldwide, increasingly stringent regulations coming into force are limiting the exposure of workers to industrial noise. As a result, industrial noise is gaining importance not only to employers but also to state and central government officials, trade unions, occupational hygienists, physicians, and insuring companies.

A number of machines and operations in mines produce high sound levels, which may have a significant effect on worker/operator health. Apart from health issues for personnel, noise is also known to cause significant economic loss to an organization. Daniel et al. (1998) reported that, in the state of Washington alone, the annual disability settlements for hearing-related problems approached nearly 22.8 million dollars.

The ill effects of noise can broadly be categorized under three headings: interference with speech communication, auditory, and nonauditory effects.

1.3.1 Interference with Speech Communication

Interference with speech communication is one of the most serious consequences of noise. ReVelle and ReVelle (1974) estimated some 30 to 40 million Americans feel speech interference after being exposed to certain sound levels.

The A-weighted sound level from 50 to 60 dB is known to affect normal conversation. If this level goes beyond 75 dB, then speech interference occurs (Pandey, 1978a; Pal and Saxena, 1999). Speech can be perceived most effectively, particularly as distinct from noise, when all frequencies from 300 to 6000 Hz are adequately presented to the listener (Stanley, 1969). But in a real situation it may be difficult as there is considerable variation in sound energy over the entire audible range of frequencies (Harris, 1979). This is particularly true for mining equipment with which considerable variations in sound levels are observed over the audible frequency range (Margaret, 1969).

A survey carried out in India regarding noise pollution due to open-pit coal mining activity indicated that around 47.3% mine workers and 48.9% officers feel speech interference during working hours (Dubey and Nath, 2000).

1.3.2 Auditory Effects

Auditory effects are the effects of noise on hearing systems. Wright (1964) indicated the first noted report on the effects of noise by Ramazzini in 1700, in *De Morbis Artificium Diatriba* that workers who hammer copper gradually became deaf. Labenz et al. (1967) measured the hearing of 66 operators of earth moving equipments. The results indicate considerable hearing loss among operators of all age groups as compared to those not exposed to it. Williams and Ross (1968) found that the effects of noise on hearing vary with the spectrum and intensity of the noise, the duration of exposure, the interval between exposures, the susceptibility of the individual, the presence or absence of other ear complaints, and whether the noise is intermittent or continuous.

Noise is known to cause both temporary and permanent threshold shifts. Powell (1956) indicated that any loss of hearing due to noise, which persists even after a period of 6 months, must be regarded as permanent. Glorig (1958) and Pandey (1978b) found that the loss of hearing sensitivity that results from exposure to continuous broadband noise, is first characterized by a decrease in sensitivity in the frequencies around 4000 Hz.

All people are not equally sensitive to noise (Walker, 1963). Aljoe et al. (1985) found that at the age of 60, over 70% of the miners had a hearing loss greater than 25 dB, and about 28% had a hearing loss greater than 40 dB.

The range of frequencies that can be heard by human beings is somewhat variable. Young people with normal hearing may hear all tones from 20 Hz to 20 kHz. All frequencies are not heard equally well at very low sound pressure levels (Davis, 1947). However, at a high sound pressure level, for example, 100 dB, all tones may be heard equally well. Most individuals develop an increase in hearing levels as a result of aging (Glorig, 1958). It is usually very difficult to distinguish increased hearing levels resulting from nonnoise factors, that is, disease or injury, and from those caused by exposure to noise. However, sufficient evidence exists to indicate that exposure over a period of years to noise whose sound pressure level exceeds 85 dB may cause both temporary and permanent elevations of threshold hearing levels (Rudmore, 1958). There is also evidence to indicate that a small number of individuals are highly susceptible to noise (Archibald, 1964; Barker and Gill, 1972; Gerald, 1975; Khuntia and Mishra, 1994; Singh et al., 1997).

1.3.3 Nonauditory Effects

Nonauditory effects are the effects of noise other than hearing loss. It has been reported by several researchers that exposure to high sound levels lead to increased heartbeat, indigestion, tension, anxiety, anger, and emotional imbalances (Franken, 1974; Miller, 1974; Broner, 1978; Krichagin, 1978; Peter and Bochum, 1978; Roychowdhury and Dhar, 1982; Das and Deshbhratar, 1982; Park and Park, 1983; Mitra, 1987; Job, 1988; Tiwari, 1992; Tripathy and Patnaik, 1994; Mukhopadhyay and Dey, 1999).

Hetu et al. (1988) reported anxiety, stress, isolation in groups, and negative self-image due to hearing loss. A similar study on industrial workers by Hetu et al. (1994) indicated "fear of social isolation" as the main reason of not reporting noise-induced hearing loss.

Leigh and Miller (1998) found that hearing loss accounted for more lost days than any other occupational illness. Singh et al. (1999) described a model showing the connections between noise reactions and health effects. Suter (2002) described a study conducted by Hallberg who interviewed wives whose husbands suffered noise induced hearing loss. A summary of the wives response indicated that the husbands' hearing loss was often the cause of misunderstandings and irritation within the family.

Noise not only affects workers' health but also reduces productivity (Neely, 1967; Hockey, 1972; Pujara, 1998; Bhatia, 2002). According to Niebel and Freivalds (1999), intermittent broadband noise can lead to decrease in productivity and increase in employee fatigue due to annoyance and distraction.

1.4 Statutory Provisions Pertaining to Noise Exposure in India and Other Countries

Assessment of the degree of noise harmful to a workplace is done by comparing the values measured at workplaces to the permissible threshold limit values (TLV) adopted by different countries.

National standards adopted by different countries lay down maximum permissible sound levels, depending on the kind of work being done and the length of exposure, with due consideration to two basic criteria, viz. (a) the threshold at which effects become noticeable (short-term action) and (b) protection of the health and working capacity of the workers, assuming lengthy systematic exposures. There are further two more criteria as well: (c) the optimum condition for output and quality of work and (d) a reasonable degree of comfort for the worker.

1.4.1 Noise Standard in India

In India, for general industries, ISO (International Standard Organization) code of practice is followed in terms of noise. ISO recommends a limit of 90 dB for the 8-hour average A-weighted sound level and halving the duration for every 3 dB increase in sound level (3 dB exchange rate) on the basis of equal energy criteria as given in Table 1.1.

To regulate and control noise pollution for mining occupations in India, the Directorate General of Mines Safety (DGMS) in its circular No. DGMS Cir.Tech./18 of 1975 and DGMS Cir.Tech./5 of 1990 suggests a warning limit of 85 dB and a danger limit of 90 dB for the 8-hour average A-weighted

TABLE 1.1

ISO Noise Standard

A-weighted sound level (dB)	87	90	93	96	99	102	105	108	111	114
Exposure time (hours)	16	8	4	2	1	1/2	1/4	2/15	1/15	1/30

TABLE 1.2

ACGIH Noise Standard

A-weighted sound level (dB)	80	85	90	95	100	105	110	115[a]
Exposure time (hours/day)	16	8	4	2	1	1/2	1/4	1/8

Note: Exposure to pulse or impact noise, should not exceed 140 dB (peak acoustic pressure).

[a] Exposure to continuous or intermittent A-weighted sound level louder than 115 dB is not permitted.

sound level. DGMS also recommends A-weighted sound level of 115 dB at and above which the unprotected ear may run a risk of hearing impairment and therefore appropriate ear protective devices should be used, and 140 dB where no worker should enter even with ear protection.

1.4.2 Noise Standard in United States of America

In 1972, the National Institute for Occupational Safety and Health (NIOSH) had set the occupational exposure limit to noise as:

The present limit for the 8-hour average A-weighted sound level is 90 dB, but 85 dB is urged and must henceforth be observed by all new plants. It also states that no worker should be exposed to A-weighted sound level in excess of 115 dB at any time.

The American Conference of Governmental Industrial Hygienists (ACGIH) proposed the limit for continuous or intermittent noise which is given in Table 1.2.

Occupational Safety and Health Administration (OSHA) has given maximum permissible exposure levels under Federal Code of Regulations 1972, which is given in Table 1.3.

When daily exposure to noise is made up of two or more periods of exposure to sound of different intensities, the sums of the following fractions

$$C_1/T_1 + C_2/T_2 + \dots C_n/T_n \text{ should not be more than unity}$$

where

C_i = time of exposure for particular sound levels

T_i = permissible exposure time at that sound levels

TABLE 1.3
OSHA Noise Standard

A-weighted sound level (dB)	90	92	95	97	100	102	105	110	115
Exposure time (hours/day)	8	6	4	3	2	1½	1	1/2	1/4 or less

TABLE 1.4
Noise Standards in Argentina

A-weighted sound level (dB)	91–95	96–100	101–105	106–110	111–115
Exposure time allowed (hours/day)	6	4	2	1	1/2

1.4.3 United Kingdom

In April 1972, the Department of Employment and Productivity issued a code of practice for reduction of exposure to noise and laid down the limits of exposure. For an 8-hour average A-weighted sound level, the limit is 90 dB when the noise is relatively constant.

1.4.4 Australia

The maximum permissible A-weighted sound level envisaged (1973) by law is 90 dB at present and 85 dB in 5 years time for continuous exposures (40 hours a week). It also states that no worker may be exposed to A-weighted sound level in excess of 115 dB at any time.

1.4.5 Argentina

The regulations pertaining to noise exposure in Argentina is given in Table 1.4.

1.4.6 France

In 1971, the Technical Committee in the Ministry of Public Health adopted the following limits: a warning limit of 85 dB for the 8-hour average A-weighted sound level and 90 dB as a limit above which a danger is present and there is a real risk of occupational deafness.

1.4.7 Canada

The Labor Code Regulations for noise control in January 1973 states that no employer should allow an employee to work in a place where A-weighted sound level reaches 90 dB or more. The employer should have reasonable grounds