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Acoustic aspects in the construction and upgrading of military firing ranges - Part 1

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ABSTRACT

Military firing ranges are indispensable facilities to train armed forces in handling and use of small arms. In the past, such ranges were outdoor installations. Due to noise problems around some of these shooting ranges they will be replaced more and more by indoor shooting facilities, which increases the noise impact on the personnel. First, the design of shooting ranges must consider the internal and external firing safety. However, acoustics comes next. There are two different but equally important objectives. The facilities should be built in such a way that (1) the noise impact on the hearing of personnel and (2) the noise impact on the neighbourhood is as low as possible. The design of shooting ranges should already take these aspects into account during the planning phase. This article focusses on the topic of acoustic safety (1) and is divided into two parts.
Part I: The first part describes the procedure acoustic safety and demonstrates how requirements for surfaces in planned facilities are determined from computer-aided calculations using ray tracing in combination with the AHAAH model.

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INTRODUCTION

Firing ranges (site firing ranges, indoor firing ranges) are an indispensable part of the training facilities on which the Bundeswehr trains its armed forces in the handling and use of small arms and prepares them for operations. When constructing or adapting these facilities to new training and exercise scenarios, military requirements are naturally the first priority. The design is then carried out with regard to internal and external firing safety. The facility must take structural measures to ensure that firing on the ranges is safe for personnel and that there is no danger to the neighborhood. In the updating of the Bundeswehr's construction guidelines, according to which the facilities are built, acoustics now also play an increasingly important role with two different but equally important objectives. The facilities should be built in such a way that (1) the noise impact on the hearing of personnel and (2) the noise impact on the neighborhood is as low as possible. The systems should already take these two aspects into account during the planning phase. This approach ensures that the systems are economical, safe and environmentally compatible.

1. STATE OF AFFAIRS

Until recently, the Bundeswehr based the construction of indoor shooting ranges (Raumschießanlagen - RSA) on the civilian shooting range guideline (Zivile Schießstandrichtlinie [1]). Within this guideline, the following specifications are noted with regard to the hearing exposure of an RSA:

- The reverberation time should be less than 0,5 s between 125 Hz and 4 kHz
- The average sound absorption coefficient should not fall below $\alpha_S > 0{,}5$

So if a facility meets these specifications, there are obviously no restrictions on shooting operations. Ultimately, this means that according to [1], the same number of shots can be fired in a RSA with a sufficiently short reverberation time as on an open shooting range without higher hearing exposures for the personnel.

It can be shown that the risk of hearing damages in rooms decreases with increasing room volume while the surface quality remains the same. A large room is therefore less problematic for hearing exposure during shooting than a small one. This is due to the fact that the risk to human hearing is not determined solely by the direct sound of an impulse source, but also depends on subsequent pulses [2]. If these are caused by reflections, the risk is reduced if the subsequent pulses occur with the lowest amplitude possible. This is more likely in large rooms than in small ones.

1.1. Reverberation Time and the Risk of Hearing Damage

The reverberation times of two different sized rooms with otherwise identical surfaces are compared below. For the calculation according to Eyring's formula, an absorption coefficient $\alpha_S = 0{,}5$, a relative humidity of 50 %, a room temperature of 20 °C and the frequency 1 kHz were assumed for all surfaces. The result is shown in table 1.

Table 1: Reverberation times of two rooms.

Room	Length	Width	Height	Reverberation Time
R1	100 m	50 m	10 m	1,08 s
R2	10 m	5 m	3 m	0,30 s

It can be clearly seen that the large room does not meet the civilian shooting range directive, while the small room exceeds the requirements. If the rooms in table 1 were shooting ranges the large one could not be used according to [1].

1.2. Requirements

The simple calculation example in the previous section showed that the reverberation time is not a suitable parameter for assessing the risk to hearing due to structural conditions during shooting. Furthermore, it must be added at this point that the energetic consideration of the acoustic processes in a shooting room or on a shooting range is not sufficient to properly determine the exposure of the hearing. Shots are highly transient signals that hit absorbers at discrete, constantly reproducing angles of incidence. This means that the consideration of a surface in the diffuse field is not appropriate for gunshot noise. Accordingly, absorption coefficient measurements in reverberation chambers are unsuitable for adequately describing the behavior of an absorber in relation to impulse noise. Methods are therefore required that allow to derive the sound pressure time curve at the ear of the personnel during shooting. This is the only way to make appropriate predictions regarding the increased hearing exposure caused by structural conditions in shooting rooms or on open shooting ranges.

1.3. Solution Approach

Since 2022, the appendix *Anwendung Baulicher Lärmschutz für Schießanlagen der Bundeswehr der Baufachlichen Richtlinie (BFR) [3] (Application of structural noise protection for Bundeswehr firing ranges of the Bundeswehr Construction Guideline)* is available, which was initiated by IUD I 5 of the German Ministry of Defense. The appendix is currently divided into the parts *Akustische Sicherheit (Acoustic Safety)* and *Immissionsschutz (Immission Control)*. The content of the *Acoustic Safety* will be presented in the remainder of this article.

2. ACOUSTIC SAFETY (AKUSTISCHE SICHERHEIT)

The BFR chapter *Acoustic Safety* describes the procedure for classifying a shooting range[4] with regard to its additional hearing exposure due to the structural conditions. The facility under investigation is compared with a reference facility. The decisive factor here is that hearing exposure data for various weapon, ammunition and hearing protection combinations is available for open facilities with only a very small number of reflective surfaces (reference facility). However, this data cannot be transferred directly to indoor firing ranges or open ranges with a higher degree of protection. A conversion factor is required.

2.1. Quality Number (Qualitätszahl) Q_S

The so-called quality number Q_S represents the factor that is required to calculate permissible shotnumbers in a facility with increased number of reflections. It indicates the percentage by which the maximum shotnumber can be increased or must be reduced in order to ensure the same hearing exposure as on a reference firing range:

$$Q_S = \frac{N_S}{N_A}. \tag{1}$$

where N_A is the maximum number of shots on a reference shooting range and N_S is the maximum number of shots determined at a relevant shooter position on the shooting range under investigation. An open shooting range with inclined sidewalls serves as the reference shooting range. The quality score can be determined both by prediction and by measurement. The required number of shots N_S and N_A are calculated from predicted or measured sound pressure time histories using the AHAAH model [4].

[4] This applies to shooting ranges as well as shooting rooms

Load Classes (Belastungsklassen)

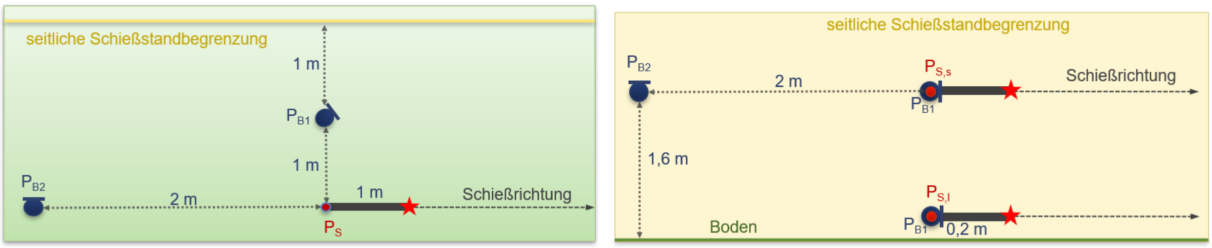
The quality number Q_S is classified according to table 2. The table can be used for each load class A to F, the relative number of shots compared to the reference system can be taken from the table.

Table 2: Classification of the load classes.

Class	Quality Number	Relative number of shots to the reference situation
A	$0{,}9 \leq Q_S$	90 %
B	$0{,}7 \leq Q_S < 0{,}9$	70 %
C	$0{,}5 \leq Q_S < 0{,}7$	50 %
D	$0{,}3 \leq Q_S < 0{,}5$	30 %
E	$0{,}1 \leq Q_S < 0{,}3$	10 %
F	$0 \leq Q_S < 0{,}1$	0 %

2.2. Determination of the Quality Number

The hearing exposure of the training personnel is decisive for assessing the acoustic safety of a system. According to figure 1, the sound pressure time curves are determined at the assessment positions P_{B1} and P_{B2}. The first is assumed to be one meter and the latter two meters away from the shooter position P_S. The muzzle - depicted as a red star in Figure 1 - is 1 m in front of the shooter position P_S. The muzzle for a standing shooter position has a height of 1,6 m and for a lying shooter position it has a height of 0,2 m. This also affects the height of assessment position P_{B1} but not P_{B2}. Crouched shooters are not taken into account.



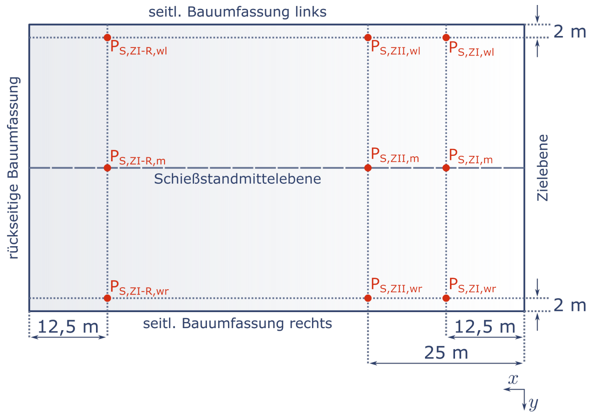
(a) Top view (b) Side view

(seitliche Schießstandbegrenzung = Lateral shooting range boundary; Schießrichtung = Firing direction; Boden = Floor)

Figure 1: Assessment positions [3].

Relevant Shooter Positions

To determine the quality number after measurement, relevant shooting positions P_S are specified (Maßgeblichen Schützenpositionen). P_S is successively moved to the relevant shooter positions according to Figure 2 (red dots) within the facility under investigation and the sound pressure time histories at the assessment positions are then determined. In justified cases - for example by utilizing symmetries - shooter positions can be combined.



Translations

rückseitige Bauumfassung	=	*Rear building enclosure*
seitl. Bauumfassung links	=	*Lateral building enclosure left*
Schießstandmittenebene	=	*Shooting stand centre level*
seitl. Bauumfassung rechts	=	*Lateral building enclosure right*
Zielebene	=	*Target level*

Figure 2: Relevant shooter positions [3].

Determination by Forecast - Personnel Load Map

The determination of a so-called personnel load map is recommended for a computer-aided forecast of the quality number. This can be used to identify critical and non-critical areas within a facility, enabling differentiated assessments and recommendations for subsequent operation. The personal load map (Personalbelastungskarte - PBK) is a grid map with a grid size of one by one meter, as shown in Figure 5a. The representative value of the quality number must be specified for each grid cell. As it is usually not sufficient to determine the value of the quality number in the center of the cell, it is necessary to sample the quality number within the cell. For this purpose, the shooter position P_S and the associated assessment positions P_{B1} and P_{B2} are moved on a fine-resolution sub-grid within a CAD model of the system and a separate sound field simulation is carried out for each position. From the quality figures determined in this way, the lowest value is to be specified as representative for the entire cell.

2.3. Reflective Properties

As already explained at the beginning, the proper consideration of reflections within a facility is an essential prerequisite for the entire procedure presented here. Since absorption coefficient measurements from reverberation chambers provide inadequate key figures for surface materials if they are to be used to reduce shooting noise, a standardized method was selected that meets the special requirements. DIN EN 1793-5:2018-12 [5] was used which is known from the field of road construction. Additional, purpose-oriented simplifications were defined that allow smaller samples. In addition, near-field holography methods are permitted [6]. Nevertheless, the principle applies that measurements according to DIN EN 1793-5 are decisive if both methods were used.

Reflection Classes

After determining the angle- and frequency-dependent reflection properties, the wall and ceiling systems are assigned to the so-called reflection classes according to Figure 3 (Reflexionsklassen). The reflection coefficient shown there corresponds to the value of the measured reflection coefficient. For every third octave between 500 Hz and 4 kHz, it is necessary to fall below the horizontal curves in Figure 3 in order to satisfy a reflection class. For example, to meet reflection class RK6, a wall system in the frequency range 1 kHz to 4 kHz would have to have a reflection coefficient of at least 0,5. Below 1 kHz, the requirements drop slightly, as this frequency range is less critical in terms of hearing hazard.

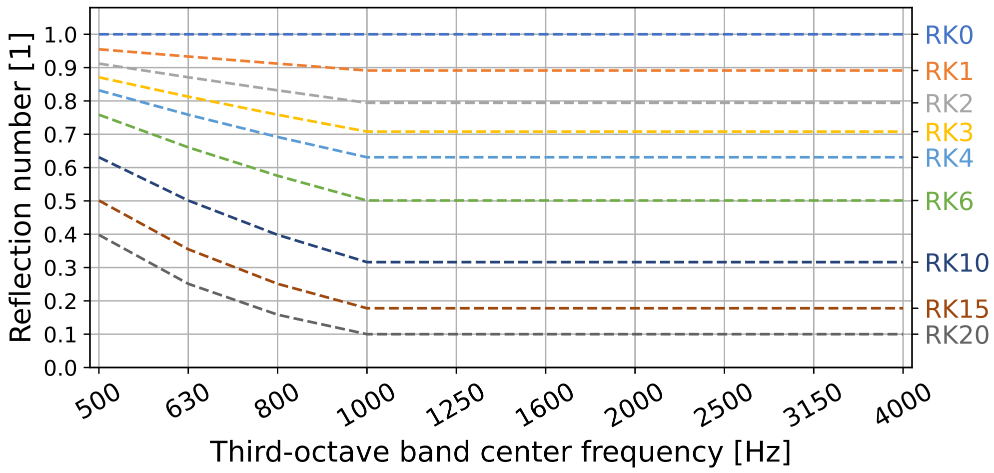


Figure 3: Third-octave specific reflection numbers of the reflection classes.

Impact on the Forecast

The use of reflection classes has great advantages, especially within the planning process. The operator of the system makes certain demands on the capacity utilization, from which the required quality figures result. The computer-aided forecast calculations are then used to determine the minimum reflection classes that the various surfaces of a shooting range must have in order to meet the requirements. It is quite common to combine very acoustically effective systems with reflection classes RK10 or higher with less acoustically effective ones. Specific details on the required acoustic quality of the systems to be installed can therefore be provided at the time of the tender.

3. APPLICATION EXAMPLE

A brief practical example is used to compare the *Acoustic Safety* and *Civilian Shooting Range Directive* methods. The geometries and surface characteristics of two existing facilities are shown in Table 3 and the measured reverberation times in Figure 4.

Table 3: Basic properties of two shooting rooms.

Size / Surface	Large shooting room	Small shooting Rrom	RK
Length	34 m	30 m	-
Width	12 m	6 m	-
Height	3 m	3 m	-
Volume	1224 m^3	540 m^3	-
Floor	Rubber / Linoleum		RK1
Side walls & Ceiling	Expanded glass plate		RK3
Back wall	Ventilation system		RK4
Projectile trap	Dust protection curtain	Slat bullet trap	RK0

According to the specifications of the civilian shooting range directive, the large room would not meet the requirements due to excessive reverberation times. Shooting operations would ultimately not be possible here. The small shooting room fulfills the required reverberation times - except for 2 kHz - and would probably be classified as suitable. The same number of shots would be possible here as outdoors. This result does not seem appropriate.

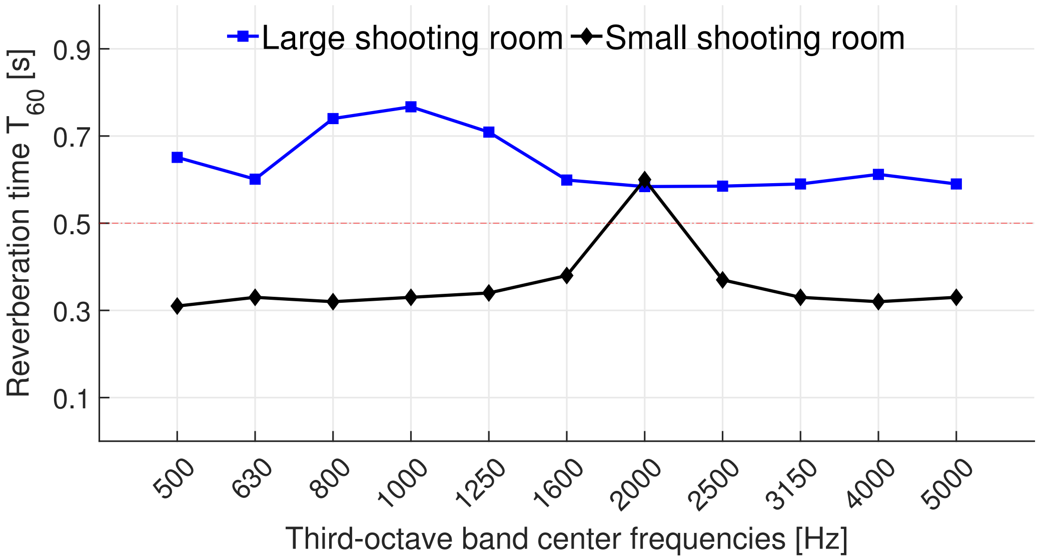
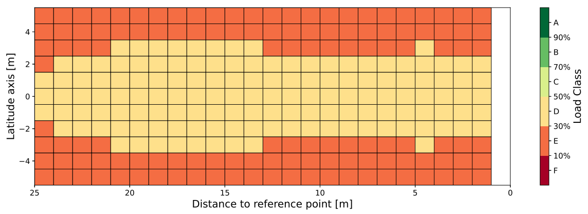
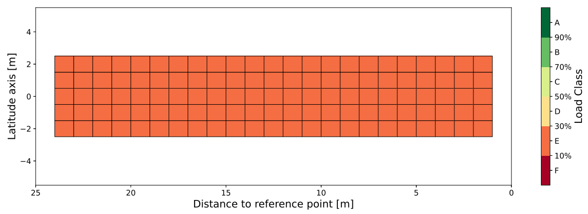


Figure 4: Measured reverberation times.

Based on the reflection classes noted in Table 3, prediction calculations were carried out using the *Acoustic Safety* method for both shooting ranges. An open shooting range with a gravel floor served as a reference. The latter complies with reflection class RK6. The resulting personnel exposure maps can be seen in the figures 5a and 5b. It is clear that these maps can be used to differentiate, depending on the location, how many safe shot numbers are possible in the two halls compared to the reference. It can also be seen that there is less hearing exposure in the larger shooting room than in the smaller one. This information can be taken into account when planning occupancy. As a result, efficient and safe operation is possible in both rooms.



(a) Large shooting room.



(b) Small shooting room.

Figure 5: Personnel load maps for the two shooting rooms.

The *Acoustic Safety* provides the basis for the proper planning, assessment and optimization of shooting ranges with regard to their acoustic safety. The method has already been successfully applied and validated several times.

4. ACKNOWLEDGEMENTS

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