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## PROPAGATION OF GUNFIRE NOISES FROM OPEN AIR, PARTIALLY ENCLOSED FIRING RANGES INTO A SURROUNDING COMMUNITY

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### INTRODUCTION

Acoustical model studies and acoustical field measurement studies were used to assess the acoustical impact of gunfire noises from open air, partially enclosed firing ranges on a residential community. While acoustical field measurements provided valuable information for the assessment of existing conditions and the prediction of the effects of some proposed changes, an acoustical scale model provided a greater level of confidence in the accuracy and predictive value of the field measured data as well as a means to study the effects of proposed changes under controlled conditions that would have been difficult, if not impossible, to assess in the field.

This study is concerned with reducing the sound levels 1) inside the ranges to minimize the loudness of sounds to which instructors and trainees are exposed and 2) at distances remote from the range for community noise control purposes. Partially enclosed structures such as these provide unique challenges from a noise control engineering standpoint. While enclosing the structure would serve to reduce the level of noise to which neighboring communities may be exposed, it would subsequently increase the sound levels inside the space. Likewise, an outdoor firing range would reduce the noise exposure levels for the gunmen and instructors, but increase the sound levels at neighboring communities. Acoustical scale modeling used in conjunction with several field measurement studies of the firing range provides a means by which many options and proposed solutions can be quickly tested.

The methods, results, and conclusions in this report are based on a feasibility study performed for a law enforcement agency and designed to assess the acoustical impact of the construction of four indoor firing ranges on a residential community. Two existing ranges serve as a model for the new ranges. Preliminary site plans have the front or side of the new ranges facing the community at a distance of 500 ft (156.3 m), twice as close as the existing ranges.

### EXISTING RANGES

The firing ranges under investigation are partially enclosed structures with the clerestory openings in the saw-tooth roof serving as the intake openings for ventilation air (see Figure 1). Fans suspended in several of the clerestory openings draw ventilation air downstream to the bullet trap for lead abatement purposes. The ranges are approximately 160 ft (50 m) wide and 200 ft (62.5 m) long. The lowest part of the ceiling panels are 10 ft (3.1 m) high. The panels are angled upwards to a height of 22 ft (6.9 m).

The interior surfaces of the ranges consist of a concrete floor, slotted acoustical concrete block walls, and PVC coated, glass fiber panels on suspended steel plates. The lower portion of several rows of glass fiber panels have deteriorated from bullet fragments ricocheting off of portable targets leading to a suggestion to remove the absorbent panels.

The three parameters targeted in the feasibility study and investigated through the use of field measurement and acoustical model studies were the:

1. *directionality effect of the range* - the increase or decrease in sound levels at points remote from the range resulting from the change in orientation of the building;
2. *absorbent ceiling panel effect* - the difference in sound levels, both inside and outside the range, attributable to the placement of absorbent materials on the ceiling; and
3. *barrier effect* - the increase or decrease in sound levels in the community resulting from the addition of a sound absorbent barrier on the upper walls of the sides of the range creating a horizontal roof line flush with the peaks of the clerestory.

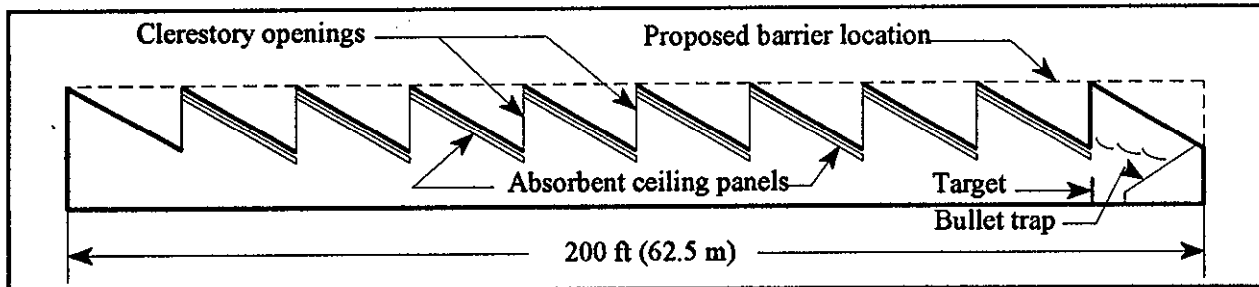


Figure 1. Diagrammatic section of typical firing range (not to scale).

## METHOD

Acoustical field measurements and acoustical model studies provided the data used to evaluate the acoustical qualities of the firing ranges and to test the effects of several noise control techniques. Acoustical field measurements were taken in the existing firing ranges using either guns firing in the range or pink noise amplified through a loudspeaker as the source. Data from the field measurements was used to predict the directionality effect and absorbent ceiling panel effect. Acoustical model studies of the existing firing ranges were conducted to provide a better understanding of the manner in which the sound propagates within the model and out through the clerestory openings; to isolate the variables from the field measurement studies; and to quantify the effects of adding an acoustical barrier to the upper portion of the side wall (in the open triangular portions).

**Field Measurement Studies Using Guns As The Source.** Acoustical field measurements of gunshots from the existing firing ranges were taken over the course of two days. Overall A-weighted, C-weighted, and flat-weighted measurements were made using an Ivie model PC-40 real time analyzer with an Ivie model IE2P preamplifier and an Ivie model 1134 RP pressure and random response air condenser  $\frac{1}{2}$  in. (13 mm) diameter microphone. This instrument meets ANSI specifications for a Type I sound level meter. The analyzer was calibrated with a Brüel and Kjaer Type 4228 pistonphone before and after each measurement session. Peak accumulated, peak average, and fast average values were recorded for most gunshots. The types of guns fired included various rifles, shotguns, and pistols. Measurement locations were selected on each side of the firing ranges at a distance of 500 ft (156.3 m), the distance to the nearest residential community.

**Field Measurement Studies Using Pink Noise As The Source.** A loudspeaker test was conducted to provide a consistent sound source for some of the earlier tests and to measure the reverberation time of the firing range for use in the estimation of noise reduction attributable to the absorbent ceiling panels. Data from an earlier field measurement study designed to test the distance from the range at which the sound measured at ground level is free of the barrier effects of the range walls, termed the acoustical shadow effect, varied greatly. The nature of the training within the range at the time of the measurements was such that different quantities and types of firearms were being discharged. This made the repeatability of the experiment at different locations very difficult.

For the acoustical shadow experiment, a JBL MR802 loudspeaker was located in the center, rear of the room. Pink noise produced by an Ivie IE-20B noise generator was amplified by a Crown CT200 amplifier and played through the loudspeaker at over 90 dBA at 6 ft (1.9 m). A-weighted, fast averaged measurements were taken at 30 ft (9.4 m) inside the range, and 100 ft (31.3 m), 250 ft (78.1 m), and 500 ft (156.3 m) to the front and

side of the range using the PC-40 real time analyzer.

Several steps were taken to derive the noise reduction attributable to the addition of absorbent ceiling panels. The first step was to measure the reverberation time in the existing room. The loudspeaker was placed in the center, rear of the room. Pink noise was amplified and played through the loudspeaker at over 100 dBA. The pink noise signal was stopped by a relay in the PC-40 and the time it took for the sound to decay in each octave band was recorded. This procedure was repeated nine times, with the microphone mounted 5'-6" (1.7 m) above the finish floor in 9 different locations around the room. The reverberation time was used to help determine the sound absorption (in sabins) attributable to the room surfaces at each octave band from 125 Hz to 4000 Hz. Using Equation 1:

$$RT = 0.05 V/a \quad (1)$$

where RT = reverberation time (s)  
 V = room volume (ft<sup>3</sup>)  
 a = total square feet of room absorption (sabins)

in conjunction with published data of the absorption coefficients of the room materials and the surface area of each material in the range, the total sabins in the room for both conditions (with and without absorbent ceiling panels) were estimated for each octave band. The noise reduction (NR) attributable to the glass fiber ceiling panels at each octave band was estimated from Equation 2 and from using the Hopkins-Stryer equation.

$$NR = 10 \log a_2/a_1 \quad (2)$$

where NR = room noise reduction (dB)  
 a<sub>2</sub> = total room absorption with absorbent ceiling panels (sabins)  
 a<sub>1</sub> = total room absorption without absorbent ceiling panels (sabins).

**Acoustical Model Studies.** The model was constructed at 1:24 scale of 5/8 in. (16 mm) particle board and 1 in. (25 mm) thick glass fiber duct board (see Figure 2). The dimensions of the model were 6'-9" (2.1 m) W x 7'-4" (2.3 m) L x 11" (0.3 m) H. The materials were chosen due to the close approximation of their absorption coefficients in the scaled frequency range of interest to the absorption coefficients of the materials used in the real room.

The sound source in the scale model is a high voltage spark which produces an impulse of high intensity and short duration similar to a real gunshot. In the real room, the approximate frequencies of interest lie between 100 Hz and 2 kHz, based on the typical spectrum of guns used in the ranges (Chiang et al., 1993). Scaled in the model, these frequencies become 2.4 kHz and 48 kHz. A low-pass filter with a cutoff frequency of 48 kHz and a high-pass filter with a cutoff frequency of 2.4 kHz were combined to filter out frequencies outside of the 2.4-48 kHz range. A 1/4 in. (6.5 mm) diameter random incidence microphone (Larson-Davis model 2520) with a preamplifier (Brüel and Kjaer model 2633) receives the impulse from the spark source. The impulse is amplified (if necessary), filtered, converted to decibels, and displayed on a digital oscilloscope for analysis (Siebein, 1986; Eplee, 1989). The difference in decibels between two impulses was determined by subtracting their integrated energy level values in decibels.

The spark source was located in the model at what would be the equivalent of the 7 yard firing line and the 50 yard firing line in the real room. Source locations were chosen at opposite ends of the range to determine the effects of source location on the sound levels in each of three directions from the model. The microphone was located in three receiver positions (front, side, and rear) at an equivalent distance [500 ft (156.3 m) at 1:24 scale], designated as Dir. 1, Dir. 2, and Dir. 3, respectively, on the diagrammatic drawings to follow.

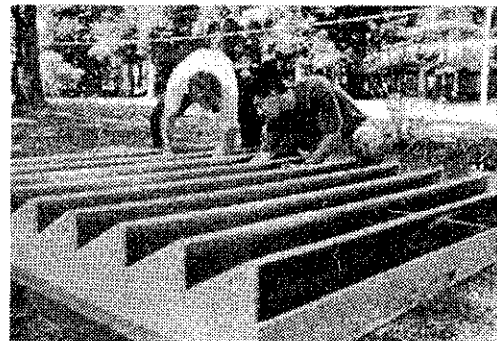


Figure 2. 1:24 scale model used for model studies

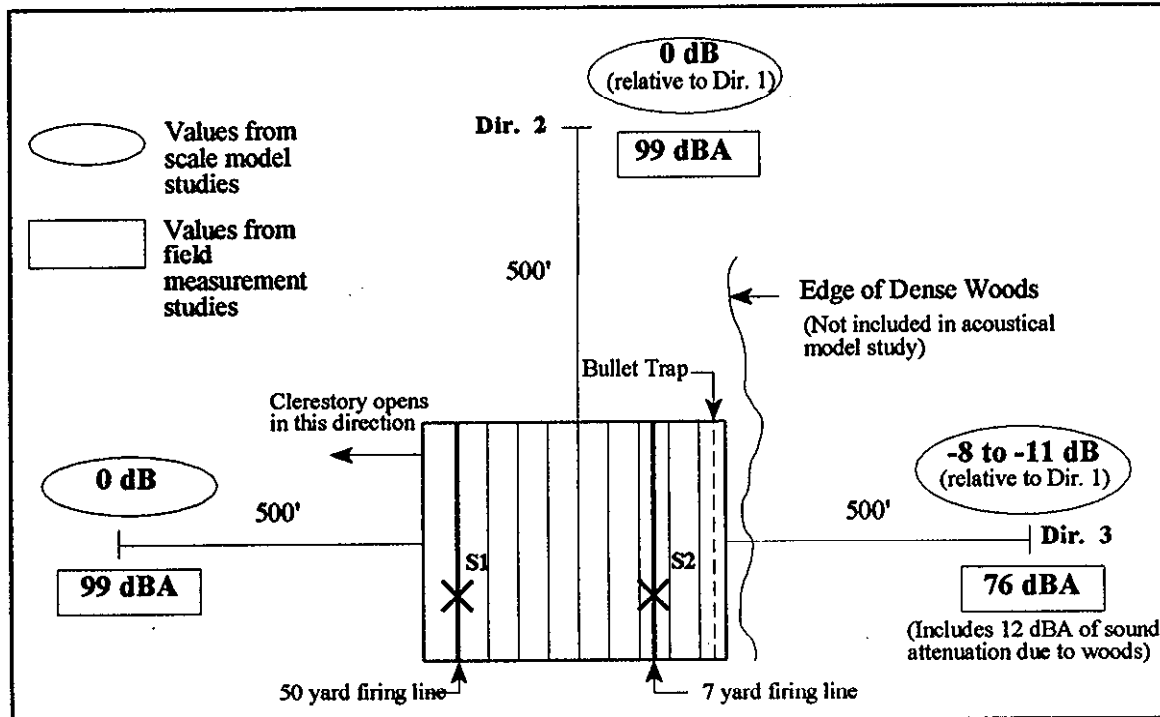


Figure 3. Diagrammatic drawing of field measurement and acoustical model studies of directionality effect (not to scale).

## RESULTS

**Directionality effect.** The effect of building orientation on the amount of sound propagated into the community was originally determined through field measurement studies and later confirmed and expanded upon by acoustical model studies. Results of both studies are shown in Figure 3. Several factors, not present in the earlier studies, contributed to the repeatability of the sound source in the field measurement study.

1. M-16 rifles were the only guns being fired during the course of the study.
2. The rifles were fired by the same number of trainees from the same location (50 yard firing line).
3. The amount of rounds fired in each session remained constant.
4. A person located at a window in the firing range notified the person taking the measurements when the guns were about to be fired using personal communication equipment. This process reduced a large portion of the guesswork that went into the earlier measurements.

The accumulated peak A-weighted sound pressure levels (SPLs) measured at 500 ft (156.3 m) to the front and side of the range were equal at 99 dBA. The SPL measured at 500 ft (156.3 m) to the rear was 76 dBA. The difference of 23 dBA includes two components: the directionality effect of the range and the effect of the 500 ft (156.3 m) of woods between the rear of the range and the measurement location. Using Miller's (1981) values for the attenuation of medium to dense woods, it was estimated that 12 dBA of sound attenuation was attributable to the woods. This resulted in a directionality effect of 11 dBA. That is, the SPL at a given point 500 ft (156.3 m) or greater from the front of the range can be reduced by approximately 11 dBA by rotating the building 180°.

In the acoustical model study, the difference between the sound level at locations Dir. 1 and Dir. 3, and Dir. 2 and Dir. 3 is in the range of 8-11 dB. Specifically, when the source was located at S1 (50 yard firing line), the difference was 11 dB. This is the same value estimated for the directionality effect from the field measurement study at the same source location. When the source was located at S2 (7 yard firing line) the difference was 8 dB, suggesting that the relative source position can influence the directionality effect up to 3 dB.



and rear of the range) at a distance of 500 ft (156.3 m).

1. Due to the directionality of the clerestory openings (opening to the front), sound levels at 500 ft (156.3 m) to the rear of the firing range will be 8-11 dB lower than those at the front, assuming a common source.
2. Sound levels to the front and side of the building will be approximately equal at distances of 250 ft (78.1 m) and greater. This is a result of the geometric spreading of the sound as it leaves the clerestory openings.
3. Absorbent material located on the ceiling of the ranges will reduce the sound levels within the range by 4-5 dB. Sound levels at locations 500 ft (156.3 m) to the front, side, and rear of the ranges will be reduced by 3-9 dB. The variability depends on the source and receiver locations.
4. The addition of a sound absorbent barrier to the upper portion of the side wall of the firing ranges, flush with the peaks of the clerestory and closing in the triangular openings, will reduce the sound levels 500 ft (156.3 m) to the side of the range by 5 dB. It will also increase the sound level 500 ft (156.3 m) to the front of the building by 0-2 dB and 500 ft (156.3 m) to the rear of the building by 2-3 dB.

Beyond simply providing the possible noise reduction attributed to several complex design alternatives involved in the study of the ranges, the acoustical model studies have provided other, more subtle information that is difficult, if not impossible, to deduce from field measurements.

1. The variability in sound levels from different source locations within the ranges can now be more accurately quantified. The study of the directionality effect shows a 3 dB difference in the sound level measured at 500 ft (156.3 m) to the rear of the range when the source locations were changed. The combination of source location S1 and receiver location Dir. 3 resulted in the greatest difference (11 dB) in sound levels measured between location Dir. 1 and Dir. 3. These results show, and the reflectograms confirm, that sound propagates primarily out of the two or three clerestory openings closest to the source, with less intense sound reflections arriving later and adding little to the overall energy of the impulse.
2. There were variations found in many of the field measurements not included in this report or in any specific study. The results of the acoustical model study show that the variability is not only attributable to the different firearms in use, but also attributable to the location of the source. This is an important finding because it demonstrates the need to have absorbent material on some portion of each of the ceiling sections to avoid the possibility of sound escaping from portions of the room without being partially absorbed as the firing line is moved throughout the range.

In summary, the use of several methods to analyze sound propagation from the range and noise control options has provided the design team with; a better understanding of the manner in which sound propagates within the room and out through the clerestory openings into the surrounding areas; greater confidence in the field measured data; and the ability to focus on specific aspects of sound propagation that would not be possible, or cost effective, in the real room.

## REFERENCES

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