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A Study of Shotgun Ricochet from Steel Surfaces

REFERENCE: Hartline, P. C., Abraham, G., and Rowe, W. F., "**A Study of Shotgun Ricochet from Steel Surfaces,**" *Journal of Forensic Sciences,* JFSCA, Vol. 27, No. 3, July 1982, pp. 506-512.

ABSTRACT: A study was conducted with a 12-gauge shotgun having a 508-mm (20-in.) cylinder-bored barrel firing 00 buckshot. This type of weapon and shot are commonly used by law enforcement agencies. Sheets and plates of steel were used as intermediate targets. A series of shots was fired at close range at angles of incidence below 35°. Illustration board, a readily penetrable material, was used as a final target to record the shot pattern of the ricocheted shotgun pellets. The angles of incidence and of ricochet were determined trigonometrically for each round fired. The horizontal and the vertical dispersals of each shotgun pellet were also calculated. The results obtained are compared with those reported by McConnell et al for intermediate targets of concrete road surface material and concrete patio block.

KEYWORDS: criminalistics, ballistics, shotguns, trajectory, ricochet, buckshot

In a recent study of shotgun pellet ricochet patterns, McConnell et al [*1*] investigated the problems associated with estimating the angle of incidence from the dispersals of the shotgun pellet patterns or the angle of ricochet. The present study is intended as a continuation of that investigation. With a few exceptions, the current tests were performed in the same manner as in the previous study. The main difference was the nature of the material selected as an intermediate target. In the earlier study, concrete road surface material and concrete patio block were used because these or similar materials are readily found in the environment. For the same reason, two types of steel similar to materials found as components of vehicles, heavy machinery, office furnishings, storage tanks, and the like were used in the present study as intermediate targets.

Various factors that may influence the ricochet of shotgun pellets are geometry of the surface of the target, range of fire, barrel length and choke of gun, and type of ammunition. For simplicity, it was decided, however, that this study be restricted to only two factors: thickness of the intermediate target and angle of incidence. To permit comparison with the

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense. Received for publication 30 Oct. 1981; accepted for publication 14 Dec. 1981.

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work of McConnell et al [1], the experimental conditions of that study were duplicated as closely as possible.

Experimental Procedure

The following were used in this experiment:

(a) a Winchester Model 1200 12-gauge shotgun with a 508-mm (20-in.) cylinder-bored barrel;

(b) Western Super X 12-gauge 70-mm (2 ¾-in.) 00 buckshot shotgun cartridges; nominal pellet diameter, 8 mm (0.33 in.); nine pellets per round;

(c) pieces of smooth white illustration board measuring 760 by 1015 by 1.6 mm (30 by 60 by 1/16 in.);

(d) steel plates measuring 457 by 610 by 9.5 mm (18 by ⅜ in.)

(e) panels of sheet steel measuring 508 by 508 by 0.74 mm (20 by 20 by 0.029 in.); and

(f) an adjustable support structure constructed of 9.5-mm (⅜-in.) rectangular steel tubing, modified from a design by Haag [2]. This was the same structure used by McConnell et al [1].

McConnell et al [1] used a 12-gauge shotgun with a 457-mm (18-in.) cylinder-bored barrel firing 00 buckshot shotgun cartridges. Similar items were used in this study in an effort to duplicate the experimental procedures of the earlier study. The shotgun cartridges contained a granulated polyethylene filler material designed primarily to cushion and protect the shot pellets, reduce shot deformation, and improve the overall shot pattern.

For firing, intermediate targets (steel plates and panels of sheet steel) were placed in the center of the support structure and the final target (illustration board) was held upright. The horizontal distance from the muzzle of the shotgun to the final target was approximately 2.2 m (7½ ft). The distance from the muzzle of the shotgun to the approximate center of the pellet impact area of the intermediate target ranged from 0.9 to 1.1 m (3 to 3½ ft). The horizontal distance from the approximate center of the pellet impact area of the intermediate target to the surface of the final target ranged from 1.2 to 1.3 m (3 ft, 10 in. to 4 ft, 4 in.). The approximate angle of incidence was determined prior to firing in the same manner as reported by McConnell et al [1]. Five rounds were fired at the surface of the intermediate target for each angle of incidence: approximately 5°, 10°, 15°, 20°, 25°, and 30°.

After each shot the actual angles of incidence and ricochet were determined by the methods of McConnell et al [1]. An overlay of engineering Mylar® ruled in a 25-mm (1-in.) grid with 2.5-mm (1/10-in.) divisions was used to measure the locations of the points of impact of the pellets on the final target. The center of mass and the horizontal and vertical dispersals of the pellet pattern were then calculated from these data. The center of mass (*com*), or first moment [3], of each pattern was calculated from the following formulas:

$$x_{com} = \sum_{i=1}^{9} x_i/9$$

$$y_{com} = \sum_{i=1}^{9} y_i/9$$

where x and y represent horizontal and vertical distances, respectively, from the center of the board. The angle of ricochet was calculated trigonometrically from y_{com} and the horizontal distance from the intermediate target to the final target. The horizontal and vertical dispersals, S_x and S_y, of the pattern were determined by calculation of the second moments of each pattern [3]:

$$S_x = \left[\sum_{i=1}^{9} (x_i - x_{com})^2/9 \right]^{1/2}$$

$$S_y = \left[\sum_{i=1}^{9} (y_i - y_{com})^2/9 \right]^{1/2}$$

Pellet holes were distinguished from those made by wads by size, shape, and the presence of lead residue. In those cases where the pellets fragmented, the approximate centers of the largest fragment holes were used in the center of mass and pellet dispersal calculations. In the case of one shot fired at an angle of incidence of approximately 30°, the pellets were too badly fragmented to permit meaningful calculations of the angle of ricochet or of S_x and S_y.

Results and Discussion

At the lowest angle of incidence (5°), the panels of sheet steel were penetrated by the shotgun pellets; therefore, no further shots at this target material were attempted. The surfaces of the 9.5-mm (3/8-in.) thick steel plates were not cratered or damaged in any way by the impact of the fired pellets, but a thin layer of lead residue was deposited by the pellets on the target surface. As the angle of incidence increased, fragmentation of the pellets occurred. Similar results were obtained by McConnell et al [1] with concrete road surface material and concrete patio blocks as intermediate targets. In this study, however, secondary projectiles, such as those observed with the concrete patio block, were not generated, probably because the intermediate targets were not cratered.

Table 1 contains the experimental results for the shots fired at the 9.5-mm (3/8-in.) thick steel plates. The angle of ricochet did not uniformly increase with the angle of incidence (Fig. 1). This is most likely an artifact produced by the difficulty in determining small angles of ricochet. The horizontal dispersal of the pellets increased monotonically as the angle of incidence increased, but the vertical dispersal showed only a slight increase as the angle of incidence increased (Fig. 2). These results are similar to those obtained by McConnell et al [1].

Jauhari [4] has proposed that the ricochet of single projectiles be described by the equation

$$\tan \theta_r / \tan \theta_i = \beta / \alpha$$

where θ_i = the angle of incidence, θ_r = the angle of ricochet, and α and β are the ratios of the horizontal to the vertical component of velocity before and after ricochet, respectively. McConnell et al [1] showed that the behavior of shotgun pellets ricocheting from concrete road surface material could be adequately described by the above equation when β/α is a constant. The method of least squares applied to the data in Table 1 yielded a β/α value of 0.018. Such a value results in a χ^2 value of 20, which signifies that there is a less than 20% chance that such a fit could be obtained purely by chance.

A surprisingly large number of shots produced holes in the final target below the level of the intermediate target. This phenomenon may be due to what is described by Breitenecker and Senior [5] as the billiard ball effect. Collisions between pellets after ricochet from the intermediate target may cause some pellets to strike below the level of the intermediate target. A more plausible explanation is that the intermediate target tilted toward the final target when struck by the shotgun pellets. (The intermediate targets were not rigidly anchored to the ground.)

Figures 3 and 4 compare the results obtained in the present work with those of McConnell et al [1]. For ease of illustration, only the trend lines have been shown. The most readily discernible trend is the decrease in the angle of ricochet at a particular angle of incidence as the intermediate target material becomes harder, that is, from readily cratered concrete

TABLE 1—*Angle of incidence, angle of ricochet, and dispersal for 9.5-mm (3/8-in.) steel plate.*

Angle of Incidence, °	Angle of Ricochet, °	Horizontal Dispersal S_x, in.[a]	Vertical Dispersal S_y, in.[a]	β/α
8	0	1	0	0
7	0	1	0	0
7	0	1	0	0
7	0	1	0	0
7	0	1	0	0
11	0	2	1	0
11	0	2	0	0
11	0	2	1	0
10	1	1	0	0.0990
10	0	2	0	0
16	1	3	1	0.0609
16	1	2	1	0.0609
16	1	3	1	0.0609
16	0	1	0	0
15	1	2	0	0.0651
21	0	3	1	0
21	1	2	0	0.0455
21	0	3	1	0
21	0	2	1	0
20	0	2	1	0
23	0	3	1	0
23	0	4	1	0
23	0	2	1	0
23	0	3	1	0
23	0	3	1	0
32	1	4	2	0.0279
32	1	5	1	0.0279
33	1	5	1	0.0269
33	2	6	3	0.0538

[a] 1 in. = 25.4 mm.

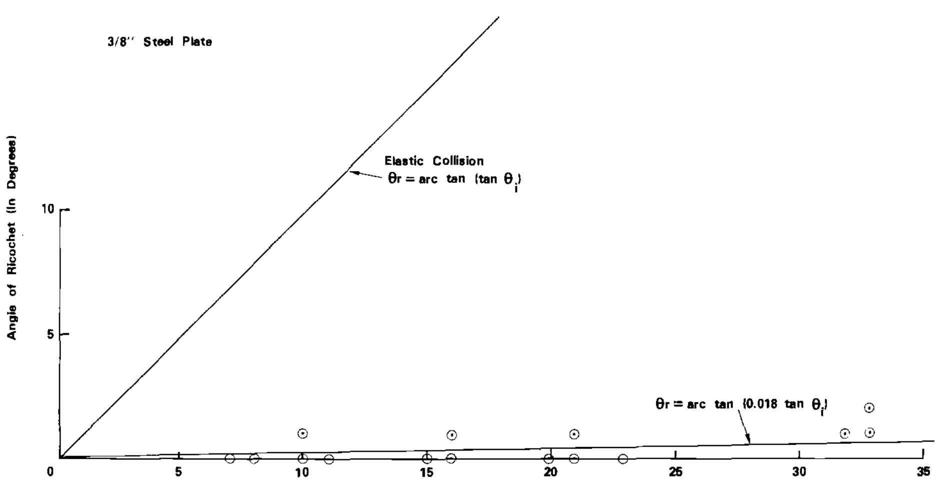

FIG. 1—*Angle of ricochet as a function of angle of incidence for 9.5-mm (3/8-in.) steel plate.*

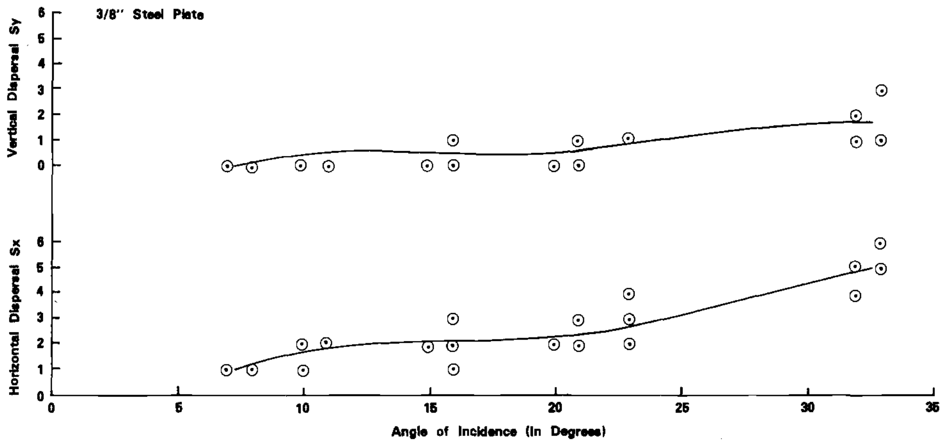

FIG. 2—*Horizontal and vertical dispersals,* S_x *and* S_y*, as function of angle of incidence for 9.5-mm (3/8-in.) steel plate. Solid lines are the best smooth curves through each set of data points.*

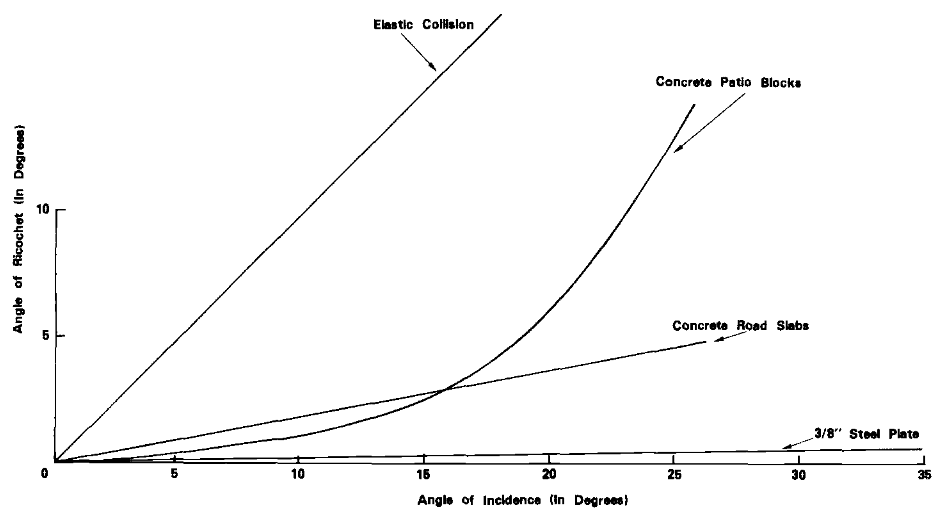

FIG. 3—*Angle of ricochet as a function of angle of incidence for three intermediate target surfaces. Only trend lines are shown.*

patio block to steel plate. As expected, the collisions of the shotgun pellets with the intermediate target become increasingly inelastic (that is, energy-dissipating) as harder intermediate materials are used.

As was found by McConnell et al [*1*], the horizontal and vertical dispersals, S_x and S_y, respectively, both increased with increasing angle of incidence, with the horizontal dispersal generally being greater than the vertical dispersal. However, the dispersals increased more slowly in the case of the steel plates than in the case of the concrete patio blocks or road slabs. The reverse would be expected if the billiard ball effect described by Breitenecker and Senior [*5*] is operating. As the initial pellets in the shot string strike the intermediate target they are decelerated. Since the impact with the steel plates will be more inelastic and more

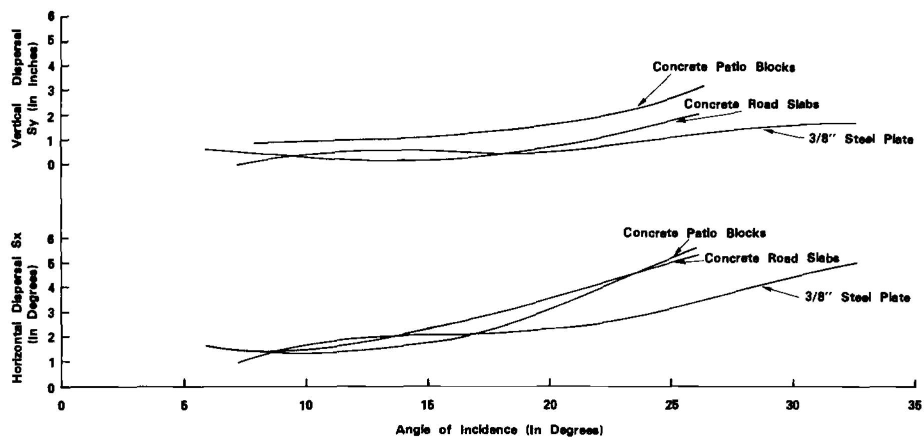

FIG. 4—*Horizontal and vertical dispersals,* S_x *and* S_y*, as functions of angle of incidence for three intermediate target surfaces. Only trend lines are shown.*

kinetic energy will be dissipated in the distortion or fragmentation of the pellets than in impacts with concrete materials, the trailing pellets in the shot string will then more readily overtake and scatter the leading pellets in a ricochet from steel plates. As Fig. 4 clearly demonstrates, however, for comparable angles the dispersals of the pellets ricocheting from the steel plate are less than those observed for the other two surfaces. Either the billiard ball effect does not function as described or there is an additional phenomenon that acts to diminish the horizontal spread of the pellets. Friction is one such possible phenomenon: rolling or sliding friction may decrease the horizontal velocity components given each pellet by interpellet collisions.

In reconstructing shooting incidents where a ricochet has occurred, estimating the angle of incidence is often important. As may be seen from Table 1 and Fig. 1, when the intermediate target material is steel plate the angle of ricochet provides little guidance in estimating the angle of incidence. On the other hand, the horizontal dispersal shows greater change with the angle of incidence than does the angle of ricochet. Nevertheless, the overlap of S_x values is too great to permit meaningful estimates of the angle of incidence. In contrast, McConnell et al [*1*] found that in favorable circumstances the angle of incidence could be estimated to within 5° by using either the angle of ricochet or the horizontal and vertical dispersals.

Conclusions

The results of this study indicate that the ricochet of shotgun pellets from 9.5-mm (3/8-in.) thick steel plate is less elastic than the ricochet of shotgun pellets from either concrete road surface material or concrete patio block. The mathematical model of Jauhari [*4*] was found to represent adequately the angle of ricochet as a function of angle of incidence.

The horizontal and vertical dispersals of the shotgun pellet patterns were found to increase with increasing angle of incidence, with the horizontal dispersal always being greater than the vertical dispersal. These findings are similar to the results obtained by McConnell et al [*1*] for concrete road surface material and concrete patio block. In contrast, the horizontal and vertical dispersals increased more slowly with angle of incidence for 9.5-mm (3/8-in.) thick steel plate than for the other intermediate targets. This may have been due to the dissipation of kinetic energy by frictional forces.

Acknowledgment

The authors wish to thank W. D. Foster, Ph.D., of the Armed Forces Institute of Pathology, for his assistance with statistical computations.

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