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A Study of Shotgun Pellet Ricochet

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ABSTRACT: A study of shotgun pellet ricochet was conducted with a 12-gauge shotgun with a 457-mm (18-in.) cylinder bore barrel and 00 buckshot, both commonly used by law enforcement agencies. Concrete patio block and concrete road surface were used as intermediate target surfaces because of the common occurrence of these or similar materials in the environment. The shotgun was fired at close range so that a more accurate measurement of the angle of incidence, angle of ricochet, and pattern of shotgun pellet distribution could be obtained than is possible at greater distances. Because of the limited range of impact forces that the intermediate target materials could withstand and still retain their structural integrity, the angles of incidence used during this study were small (below 30°). A series of five shots at the nominal angles of incidence of 5°, 10°, 15°, 20°, and 25° were fired at each surface. Illustration board, a readily penetrable material, was used as a final target to record the shot pattern of the ricocheted shotgun pellets. The actual values of the angles of incidence, as well as the angles of ricochet, were calculated trigonometrically for each round fired. The centers of mass and the dispersals of the shotgun pellet patterns were also calculated.

KEYWORDS: criminalistics, ballistics, shotguns

Forensic scientists are occasionally called upon to reconstruct the circumstances of shooting incidents. It may be necessary to estimate the range from which a shot was fired or to determine the path of the projectile. A considerable amount of research has been devoted to methods for establishing the range from which small arms such as pistols, rifles, or shotguns were discharged at a target, typically a human being [*1*]. Similarly, a number of methods for establishing the pathways of single projectiles have also been developed [*1*]. Projectile ricochets introduce complications into the interpretation of shooting incidents [*1*]. Jauhari [*2,3*] has studied the behavior of several common small-caliber bullets when they ricochet off metal surfaces, while Haag [*4*] has explored the effect of incident velocity on the ricochet behavior of spherical metal projectiles striking metal plates. Haag also examined the ricochet behavior of several common pistol and rifle rounds.

Although a limited number of studies have been devoted to the problem of the ricochet of single projectiles, virtually no published research has considered the ricochet behavior of shotgun pellets, despite the fact that shotguns are frequently used in shooting incidents.

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Firearm instructors at the Federal Bureau of Investigation Academy at Quantico, Virginia [5] have reported test firings demonstrating ricochet phenomena for various weapons, including a 12-gauge shotgun firing 00 buckshot. Intermediate targets included turf, asphalt, and concrete surfaces. These tests were informal and were intended primarily as a guide for instructing police officers in offensive and defensive tactics. No attempt was made to measure angles of incidence, angles of ricochet, or the dispersal of the shotgun pellets after ricochet.

A thorough investigation of shotgun pellet ricochet should address a variety of parameters that may affect the angle of ricochet and the dispersal of the shot pattern. These variables include the angle of incidence, the range, the nature of the intermediate target surface, the gauge of the shotgun, its choke, and the number and size of the pellets in the load. We have not attempted to determine the effect of each of these variables on dispersal patterns but have limited our experiments to varying the angle of incidence and the nature of the intermediate target with a single type of weapon using one kind of ammunition. In this way, we have been able to develop a protocol for the investigation of the effects of ricochet on shotgun pellet patterns and have identified the significant problems involved in attempting to estimate the angle of incidence from the pellet dispersal or from the angle of ricochet.

Experimental Procedure

The following equipment was used in this experiment:

(a) a 12-gauge Remington Model 870 shotgun with a 457-mm (18-in.) cylinder-bored barrel;

(b) Remington 12-gauge, 70-mm (2¾-in.) 00 buckshot shotgun cartridges; nominal pellet diameter, 8 mm (0.33 in.); nine pellets per round;

(c) smooth white illustration board measuring 760 by 1015 by 1.6 mm (30 by 40 by 1⁄16 in.);

(d) red concrete patio blocks measuring 457 by 457 by 51 mm (18 by 18 by 2 in.);

(e) slabs of smooth concrete road surface; and

(f) an adjustable support structure constructed of 9.5-mm (⅜-in.) rectangular steel tube (see Fig. 1).

The 12-gauge shotgun with a 457-mm (18-in.) cylinder bore barrel and the 00 buckshot were selected for use in this experiment because they are used by many law enforcement agen-

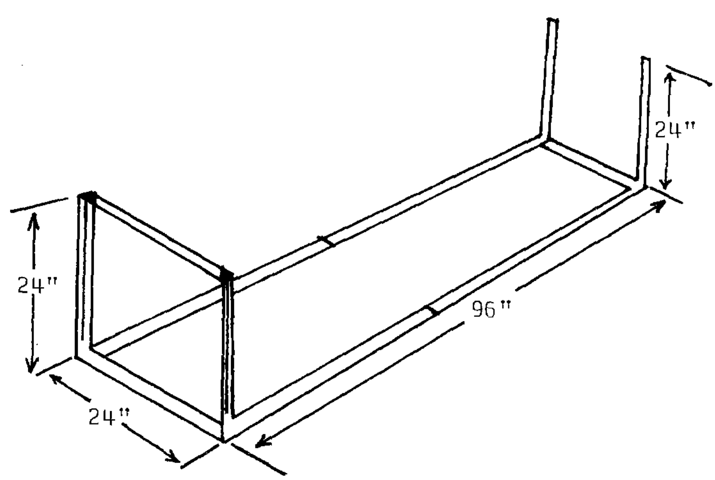

FIG. 1—*Adjustable support structure. (1 in. = 25.4 mm.)*

cies. The shotgun cartridges contained a granulated polyethylene filler material to cushion and protect the shot pellets, reduce shot deformation, and improve the pattern. This filler material did not appear to significantly affect the results of the experiment. The concrete patio blocks and slabs of concrete road surface were used as the intermediate target surfaces because of their common occurrence in the environment. There was no observable surface pattern in any of the intermediate target surfaces used. Illustration board was used as the final target because it retains its overall integrity while permitting the shotgun pellets to penetrate it completely.

The tubular steel support structure provided a stable platform on which to rest the barrel of the shotgun and to mount the final target. The structure was designed so that its overall length was adjustable to a maximum of 2.4 m (8 ft) by using sliding final target mounts, which could be secured by locking screws at the desired position. The height of the horizontal support bar on which the barrel of the shotgun rested was adjustable from 51 mm (2 in.) to 0.6 m (2 ft). This structure was an adaption of a design by Haag [*4*].

Five rounds for each approximate angle of incidence of 5, 10, 15, 20, and 25° were fired at each intermediate target surface. 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 intermediate target pellet impact area ranged from 0.7 to 0.9 m (2½ to 3 ft). The horizontal distance from the approximate center of the intermediate target pellet impact area to the final target surface ranged from 1.4 to 1.5 m (4½ to 5 ft).

Prior to the firings, the steel support structure and the intermediate target surface were leveled. The approximate angle of incidence was determined before the firing by measuring the angle formed between the shotgun barrel and the plane of the surface of the intermediate target. Monofilament fishing line was stretched parallel to the axis of the shotgun barrel to a point on the intermediate target surface, and the angle made by the fishing line and the leveled surface of the intermediate target was measured with a protractor. The desired angle of incidence was obtained by adjusting the height of the shotgun barrel, the location of the target point on the intermediate target surface, or both. When the desired angle of incidence was obtained, the horizontal support bar was locked at the proper height. The position of the shotgun barrel on the horizontal support bar and the target point on the intermediate target surface were then marked. A round was fired.

After the firing, the shotgun barrel was repositioned by using the marks on the horizontal bar and the impact point on the intermediate target surface. The height of the shotgun barrel remained as it was before the firing since the horizontal support bar on which it rested had been secured. The vertical distance from the center of the shotgun barrel to a plane level with the intermediate target surface was measured and recorded. This measurement was simplified by establishing a plane below the muzzle of the shotgun level with the intermediate target surface. A carefully leveled patio block or slab of concrete was found to be satisfactory. The horizontal distance from the muzzle of the shotgun barrel to the center of the pellet impact area (approximate center of mass of the striking pellets) on the intermediate target surface was measured and recorded. These horizontal and vertical measurements were used to calculate trigonometrically the actual angle of incidence. The horizontal distance from the center of the pellet impact area on the intermediate target surface to the point on the final target (the illustration board) along the line of fire and parallel to the plane of the intermediate surface was also measured. This measurement, along with the height of the center of mass of the pellet holes on the terminal target as measured from the plane of the intermediate target surface, was used to calculate trigonometrically the angle of ricochet.

To locate the center of mass of the pellet holes, a grid overlay (engineering Mylar® with 25-mm [1-in.] grids subdivided into 2.5-mm [1/10-in.] grids) was placed over the final target with the x axis along the bottom of the intermediate target surface and the y axis parallel to the vertical edges of the terminal target. The locations of the pellet holes were then recorded.

These data were used to calculate the center of mass and the dispersal of the pellet pattern. The center of mass (*com*), or first moment [*6*], of each pattern was calculated from the following formulas:

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

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

The dispersal of the pattern was determined by calculating the second moments of each pattern [*6*]:

$$S_x = \sqrt{\sum_{i=1}^{9} (x_i - x_{com})^2/9}$$

$$S_y = \sqrt{\sum_{i=1}^{9} (y_i - y_{com})^2/9}$$

This treatment is similar to that used by Mattoo and Nabar [*7*] for determining range of fire from the dispersal of buckshot. In those cases where the pellets fragmented, the approximate centers of the largest fragment holes were used in calculating the center of mass and pellet dispersal. Pellet holes were distinguished from holes made by wads or fragments of intermediate target by shape and by the presence of lead residue. Test shots were fired at each angle of incidence with extended final targets to verify that all pellets and pellet fragments were accounted for and to check the stability of the support structure and the final target.

Results and Discussion

Concrete Road Surface

The slabs of concrete road surface used in these experiments displayed great resiliency. Even at high angles of incidence the intermediate target surface did not crater or otherwise disintegrate. The shotgun pellets left a thin layer of lead alloy residue on the target surface. As the angle of incidence increased, the pellets were increasingly flattened, as indicated by the slitlike perforations in the final target.

The experimental data for the shots fired at the concrete road surface are given in Table 1. General trends may be noted immediately. The angle of ricochet increases with increasing angle of incidence but always remains substantially smaller than the angle of incidence (Fig. 2). Furthermore, the dispersal of the pellets in the x (horizontal) direction increases with increasing angle of incidence, while the dispersal of the pellets in the y (vertical) direction increases only slightly (Fig. 3). For any particular nominal angle of incidence there is considerable variation among the angles of ricochet and the horizontal and vertical dispersals S_x and S_y for each shot in the series. It should be borne in mind that only nine pellets were fired in each shot; therefore, random variations in the pellet trajectories after ricochet produced by irregularities in the surface or by random collisions between pellets may result in substantial differences between the pellet patterns of successive shots fired at the same angle of incidence.

Jauhari [*8*] has developed a mathematical treatment for the ricochet of single projectiles that may be applied to shotgun pellets. Figure 4 shows a spherical projectile at the instant of impact with the intermediate target, where V_i and V_r are the velocities of incidence and

TABLE 1—*Angles of incidence, angles of ricochet, and dispersals obtained using concrete road slabs.*

Angle of Incidence, °	Angle of Ricochet, °	Horizontal Dispersal S_x, in.[a]	Vertical Dispersal S_y, in.[a]	β/α
6	1	1	1	0.1661
6	2	2	0	0.3322
6	1	2	1	0.1661
6	2	1	1	0.3322
6	1	1	0	0.1661
9	1	2	0	0.1102
9	2	1	1	0.2205
9	2	2	0	0.2205
9	1	2	1	0.1102
9	2	1	0	0.2205
14	1	2	0	0.0700
14	2	2	0	0.1401
15	2	3	0	0.1401
15	3	3	1	0.1956
15	2	3	0	0.1303
19	4	4	1	0.2031
19	3	4	1	0.1522
19	3	3	1	0.1522
19	3	4	1	0.1522
19	3	3	1	0.1522
26	5	5	1	0.1794
26	6	5	2	0.2155
26	6	6	1	0.2155
25	5	5	2	0.1876
26	6	5	2	0.2155

[a]1 in. = 25.4 mm.

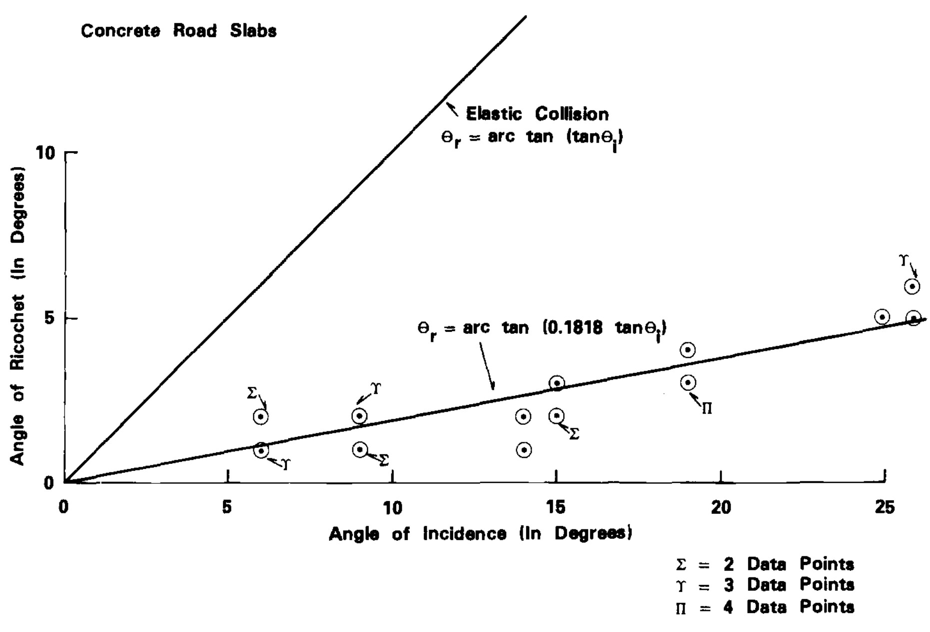

FIG. 2—*Angle of ricochet as a function of angle of incidence for the concrete road surface.*

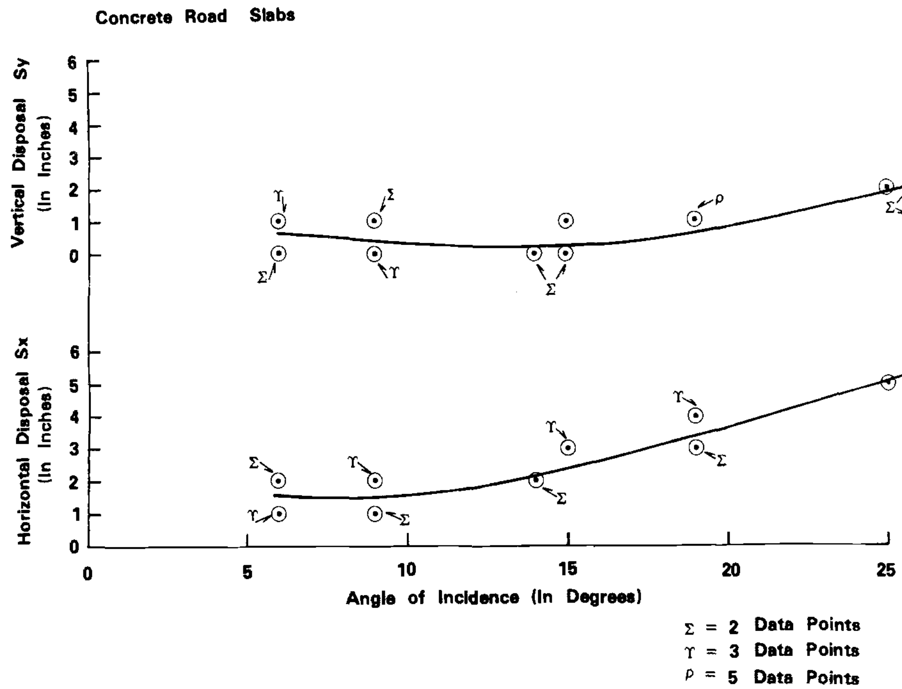

FIG. 3—*Horizontal and vertical dispersals* S_x *and* S_y *as functions of angle of incidence for the concrete road surface. Solid lines are the best smooth curves through each set of data points.*

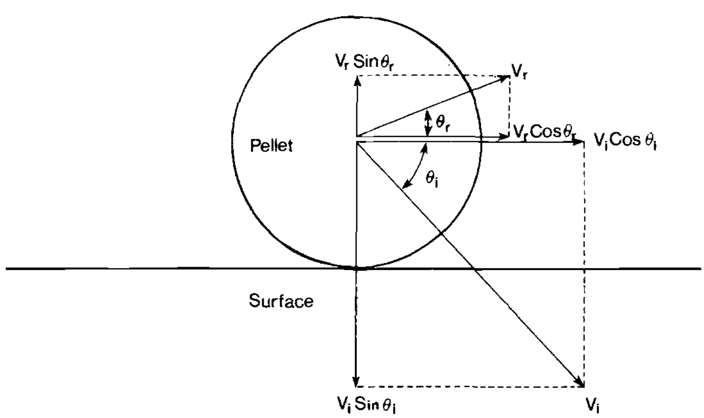

FIG. 4—*Shotgun pellet at instant of impact with intermediate target.*

ricochet, respectively, and θ_i and θ_r are the angles of incidence and ricochet, respectively. Let α be the ratio of the horizontal components of the projectile velocities after and before impact, namely,

$$\alpha = (V_r \cos \theta_r)/(V_i \cos \theta_i) \qquad (1)$$

Similarly, let β be the ratio of the vertical components of the projectile velocities after and before impact, namely,

$$\beta = (V_r \sin \theta_r)/(V_i \sin \theta_i) \tag{2}$$

Dividing Eq 2 by Eq 1 yields

$$\beta/\alpha = \tan \theta_r / \tan \theta_i \tag{3}$$

Jauhari [*8*] has derived equations for the determination of α and β separately from a knowledge of θ_i, θ_r, and the dimensions of the crater produced in the surface by the impact of the projectile.

Although Jauhari's mathematical treatment was derived for single projectiles, it is also applicable to the behavior of a collection of projectiles if the motion considered is that of the center of mass of the shot string. Interactions between pellets in the shot mass may then be regarded as internal interactions of a system of particles; as such, these interactions cannot influence the total linear momentum of the shot mass and have no effect on the motion of the center of mass of the shot mass [*9*].

Equation 3 may be rewritten as follows:

$$\theta_r = \arctan[(\beta/\alpha)\tan \theta_i] \tag{4}$$

With $\beta/\alpha = 0.1818$, Eq 4 fits the values of θ_r in Table 1 with a χ^2 value of 5. The probability of obtaining such a fit purely by chance is less than 1%. For the ratio β/α to be constant, (a) α and β must increase together, (b) α and β must both remain constant, or (c) α and β must decrease together. Case (c) is the only physically reasonable situation. If α and β both decrease with increasing angle of incidence, then the shot string loses velocity to the same degree in both the horizontal and vertical directions upon impact with the intermediate target. Because the pellets are spread out along the direction of flight, each of the pellets in turn will decelerate on impact with the concrete surface.

Breitenecker and Senior [*10*] have demonstrated that when the leading pellets in the shot string decelerate while passing through an intermediate target, the pellets in the rear of the shot string overtake the lead pellets and collide with them, producing a scattering of the shot string. This phenomenon has been called the "billiard ball effect" in analogy to the scattering of a cluster of billiard balls by the cue ball. A similar situation occurs when the leading pellets in the shot string collide with an intermediate target surface; the leading pellets are slowed by the impact and are overtaken by trailing pellets in the shot string, and collisions between the pellets of the shot string cause the string to scatter. However, the presence of the intermediate target surface reduces the pellet dispersal in the vertical direction; pellets that acquire an additional downward velocity component through collision with other pellets are deflected upward by ricochet from the intermediate target surface. The horizontal velocity components acquired through collisions are not similarly affected; thus, the ricocheting pellets will spread more in the horizontal direction than in the vertical direction. Because the total loss in velocity on impact increases with increasing angle of incidence, the spread produced by the billiard ball effect increases with increasing angle of incidence.

Concrete Patio Block

The concrete patio block proved to be less resilient than the slabs of concrete road surface. As the angle of incidence increased, the impact of the shotgun pellets produced deep and extensive cratering and cracked the patio block outside the immediate impact area. Shots were attempted at a nominal angle of 30°; however, the impact of the pellets shattered the intermediate target material. There were numerous small perforations in the final targets produced by concrete fragments acting as secondary projectile. As in the case of the concrete road surfaces, high angles of incidence resulted in considerable flattening of the shotgun pellets.

The same general trends in angle of ricochet and in pellet dispersals as functions of angle of incidence found for the concrete road surfaces were also observed for the patio blocks (Table 2). The angle of ricochet increases with increasing angle of incidence while remaining substantially smaller than the angle of incidence (Fig. 5). The dispersals S_x and S_y both increase with increasing angle of incidence, with S_x being substantially greater than S_y at higher angles of incidence (Fig. 6).

The angle of ricochet in the case of patio blocks obeys a different functional relationship with the angle of incidence than was the case with the concrete road surface. As indicated in Table 2, β/α increases with increasing angle of incidence. This implies that in contrast to the phenomena observed with the concrete road surface α decreases faster than β with increasing angle of incidence or, equivalently, the horizontal component of the velocity of ricochet decreases faster with increasing angle of incidence than does the vertical component. Presumably this is related to the increased cratering at the higher angle of incidence. The trailing pellets in the shot string may experience a ramp or "ski jump" effect in which some of their horizontal velocity component is converted to vertical velocity. On the other hand, pellets encountering craters produced by the leading pellets in the shot string may dissipate more of their horizontal velocity through friction. In this latter circumstance, we would predict that the vertical and horizontal dispersals of the pellet patterns would be greater when patio block is used than when concrete road surface is used as an intermediate target surface. While the vertical spread is in fact greater at the higher angles of incidence, the same is not true for the horizontal dispersals. This indicates that simple loss of horizontal velocity does not explain the increase of β/α with increasing angle of incidence.

TABLE 2—*Angles of incidence, angles of ricochet, and dispersals obtained with concrete patio blocks.*

Angle of Incidence, °	Angle of Ricochet, °	Horizontal Dispersal S_x, in.[a]	Vertical Dispersal S_y, in.[a]	β/α
8	1	1	1	0.1242
9	1	2	1	0.1102
9	1	2	1	0.1102
9	1	1	0	0.1102
9	1	1	1	0.1102
17	3	2	2	0.1714
16	3	2	2	0.1828
16	2	3	2	0.1218
16	3	2	1	0.1828
17	2	2	1	0.1142
16	4	2	1	0.2439
17	4	2	1	0.2287
17	3	2	1	0.1714
17	6	2	2	0.3438
17	4	1	2	0.2287
22	10	4	2	0.4364
22	10	3	2	0.4364
23	11	5	2	0.4579
22	10	5	2	0.4364
23	6	4	3	0.2476
26	16	6	3	0.5879
25	15	6	4	0.5746
26	14	5	3	0.5112
26	11	5	2	0.3985
25	15	6	3	0.5746

[a]1 in. = 25.4 mm.

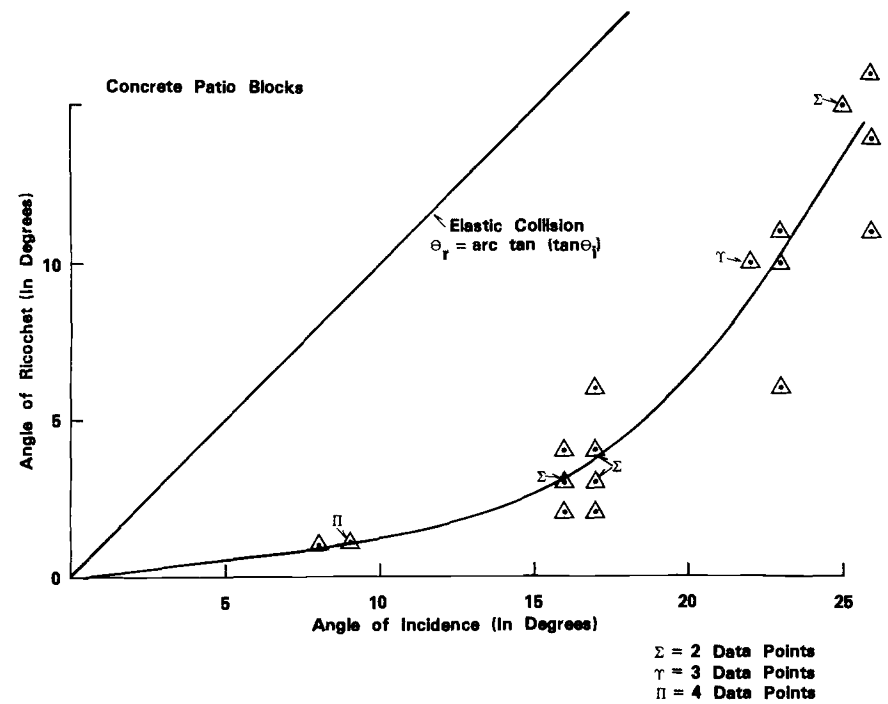

FIG. 5—*Angle of ricochet as a function of angle of incidence for the concrete patio blocks. Lower solid line is the best smooth curve through the set of data points.*

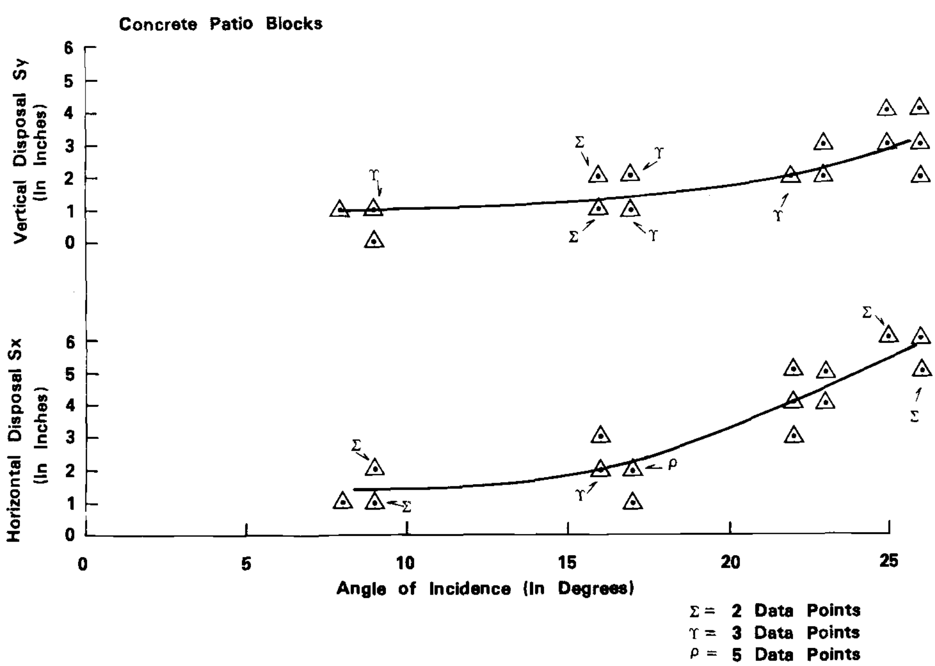

FIG. 6—*Horizontal and vertical dispersals* S_x *and* S_y *as functions of angle of incidence for the concrete patio block. Solid lines are the best smooth curves through each set of data points.*

Reconstruction of Incidents

In reconstructing the circumstances of a shooting incident certain known parameters are used to derive other unknown parameters. For example, the observed dispersal of powder tattooing on clothing or skin may be used along with experimental dispersal patterns produced by the suspect firearm at various ranges to estimate the range from which the suspect firearm was fired in the shooting incident in question. In the case of a shooting incident involving shotgun ricochet, there are a variety of parameters to consider, including the angles of incidence, the angle of ricochet, the horizontal dispersal, the vertical dispersal, the distance from the weapon to the intermediate target, and the distance from the intermediate target to the final target. Because only the interrelationships among angle of incidence, angle of ricochet, and the horizontal and vertical dispersals were explored in this project, discussion will be limited to the problem of estimating one of these parameters when the others are known.

It seems reasonable to assume that the pellet pattern in the final target will be known, as will the positions of the final and intermediate targets. Consequently, θ_r, S_x, and S_y will be known, and θ_i will be the quantity to be estimated. The degree of scatter observed in S_x and S_y versus θ_i for both target surfaces makes estimates of θ_i using S_x or S_y rather imprecise. Because of the overlap of the values of S_x and S_y for both target surfaces, θ_i can only be estimated with a precision of $\pm 10°$. When θ_r is available, θ_i may be estimated with a precision of $\pm 5°$ for both intermediate target surfaces. In some cases this precision may be sufficient to confirm or refute the statements of witnesses concerning the circumstances of a shooting incident.

Conclusion

The results of this study indicate systematic trends in angle of ricochet and pellet pattern dispersal as functions of increasing angle of incidence. In all instances, the angle of ricochet was markedly less than the angle of incidence. The angle of ricochet increased monotonically with increasing angle of incidence. Both vertical and horizontal dispersal increased with increasing angle of incidence, with the horizontal dispersal of the pellets covering a greater distance than the vertical dispersal. There was significant deformation or fragmentation of the shotgun pellets and significant energy loss at the higher angles of incidence. The trends were seen when both intermediate target surfaces were used. The concrete road surface, the harder of the two intermediate target surfaces, displayed lower angles of ricochet, greater horizontal versus vertical spread of the shotgun pellets, and more deformation or fragmentation of the shotgun pellets relative to angle of incidence than the softer concrete patio block.

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