ay 1989

U.S. Depart ent of Transportation
Research a Special Programs Administration
Transporta n Systems Center
Cambridge, MA 02142

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PREFACE

A major concern associated with the security of U.S. Department of State embassies and missions outside the continental United States is to protect facilities and compounds from vehicular intrusions. The first line of protection for a facility or compound is a barrier around the perimeter. This document, sponsored by the Department of State, Bureau of Diplomatic Security, Physical Standards Division, presents a methodology by which the appropriate data can be collected and analyzed to make an informed decision about the perimeter barrier needed. It is intended to ensure the selection of barriers which provide the penetration protection recommended by the Department of State.

Developed under the direction of Patrick Fitzgerald (Chief, Standards and Development), Douglas H. Georgian (Engineering Project Manager), and Gerald E. Meyers (Structural Engineer), the Perimeter Barrier Selection Guide was prepared by William T. Hathaway and Patricia K. Hammar of the Transportation Systems Center. The authors would like to express their appreciation to Douglas Georgian for his detailed guidance and valuable insights into the needs of Department of State field personnel.

METRIC / ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x - 32) (5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES: 0 1 2 3 4 5 6 7 8 9 10

CENTIMETERS: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 | 25.40

QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10 286.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (CONT.)

LIST OF TABLES

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This document provides a methodology to determine the magnitude of the threat from attack vehicles to the perimeter of a facility. The threat is determined by the penetration tolerance and the maximum speed attainable. After the threat is defined this document assists in choosing an appropriate barrier.

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1. INTRODUCTION

Perimeter barriers are structures designed to protect an embassy by preventing an attacking vehicle from penetrating the embassy compound. Many types of protective barriers have been developed. The goal of this guide is to help you select the type or types of protective perimeter barriers that provide the amount of penetration protection recommended by the U.S. Department of State (DOS).

This document provides a methodology by which the appropriate data can be collected and analyzed to make an informed decision about the barrier needed. To accomplish this, the magnitude of the threat to which the barrier will be exposed needs to be established. The magnitude of the threat will be determined by the speed of the attack vehicle and the amount of penetration, if any, that can be tolerated. Recognizing that different portions of the perimeter may be exposed to different magnitudes of threat, we need to divide the barrier into sections which will be subjected to the same magnitude of threat. Two factors constitute the threat: penetration (measured by the L level) and speed (measured by the K level). The L level defines how far the vehicle penetrates the barrier, and the K level defines the speeds that the barrier is able to withstand. These two factors will be used to determine the type of barrier which should be selected.

The L level, a measure of the penetration allowed by a barrier, deemed acceptable in the barrier selection process is determined by how far the barrier is from the building(s) that it is protecting. For example, if the barrier allows 5 feet of penetration but the buildings are 105 feet away, it may provide sufficient protection. The method for determining the minimum L level for each section of barrier is presented in Section 2.

The K level corresponds to the maximum vehicle impact speed for which a particular barrier segment must be designed. The K level data presented in this guide represent the impact severity to which a barrier has been tested without failure. For the barrier selection process presented here, there are three K levels. To determine which barrier is required, you must determine the maximum possible speed at which the attack vehicle could strike a particular portion of barrier. The method for determining this maximum speed is presented in Section 3.

As Sections 2 and 3 describe how to choose barriers, Section 4 describes the various types of fixed (passive) and active barriers, including their corresponding L and K levels of protection, from which to choose

1.1 REQUIRED TOOLS

The procedure for determining both the K and L levels begins with the preparation of a sketch. Therefore, the first step of the selection process involves assembling the tools needed to make these sketches. These tools are listed in Table 1-1. It will save time if you assemble all of your tools before beginning. While alternative tools are listed, taking the time to assembie as many of the recommended tools from Table 1-1 as possible will increase the accuracy of your results.

TABLE 1-1. RECOMMENDED TOOLS

Procedure	Recommended Tool	Adequate Tool
Measure distance	Measuring wheel calibrated in tenths of feet able to record up to 1,000 feet without resetting	100-foot tape measure
Measure gradient	Clinometer calibrated in percent gradient	Traffic template (in back of book)
Sketch compound boundaries	Clipboard and graph paper (graph paper included)	Graph paper
Perform computations	Calculator with trigonometric functions	Calculator used with table of sine and cosine functions in appendix

Note: Before performing these procedures, see if scaled sketches of both the compound and the perimeter of the compound are available.

2. L LEVEL REQUIREMENTS

The various L levels of penetration protection are listed in Table 2-1.

TABLE 2-1. L LEVELS

DOS L Level	Maximum Attack Vehicle Penetration
L1	20 to 50 Feet
L2	3 to 20 Feet
L3	0 to 3 Feet

To determine the L level required, the first step is to establish how far the vehicle may be allowed to penetrate the barrier. To determine this, we need to know the distance between the barrier and the closest building(s).

2.1. SKETCH THE COMPOUND INTERIOR

The compound interior is the decisive factor in identifying L level requirements. If there is a map drawn to scale available, such as the one shown in Figure 2-1, you can save a significant amount of time. However, do not rely solely on the accuracy of the map and its scale. You need to check the map scale by measuring the actual distance between a building and a barrier (a building and a barrier located near each other are most convenient). To do this, measure perpendicularly from the barrier to the corner of the building, and then compare this measurement to the scaled distance between the same building and barrier measured the same way on the map.

To assist in determining whether the map is drawn to scale, make a computation similar to the one presented in the following equation. First, look for the scale on the bottom of the map; in Figure 2-1, the scale is 1 inch = 200 feet. If the distance that you measured between the building and the barrier is 120 feet, the corresponding distance on the map should be 0.6 inches (as shown in the following equation).

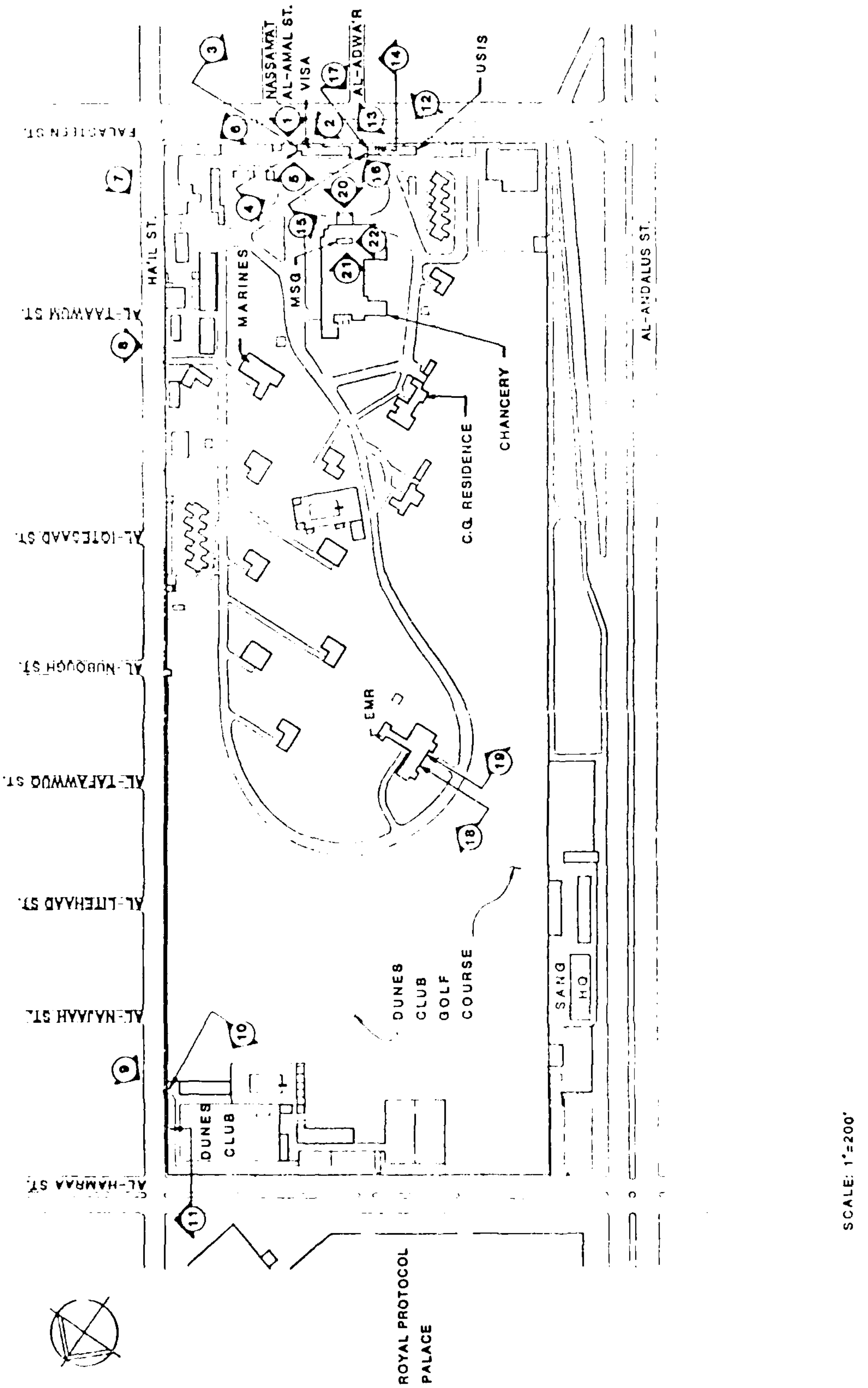


FIGURE 2-1. SCALED MAP OF COMPOUND INTERIOR

$$measured\ distance\ in\ feet \ \mathbf{X}\ \frac{inch\ measurement\ in\ scale}{foot\ measurement\ in\ scale} = x\ inches$$

$$120\ feet\ \mathbf{X}\ \frac{1\ inch}{200 feet} = .6\ inches$$

In the event that you need to compute the actual distance in feet from the scaled distance in inches on the map, the equation is

$$measured\ distance\ in\ inches\ \mathbf{X}\ \frac{foot\ measurement\ in\ scale}{inch\ measurement\ in\ scale} - distance\ in\ feet$$

If the distance measured on the map is .6 inches and you need to find the corresponding distance in feet, using the same scale, the previous equation would be completed as follows:

$$.6\ inches\ \mathbf{X}\ \frac{200\ feet}{1\ inch} = 120\ feet$$

If the map is calibrated in metric units, the same equations may be used, substituting centimeters for inches in both the scale and the measured distance in the equation and meters for feet in both places. Do not mix feet or inches with metric measurements. Another way of working with a map in metric units is to convert all of the metric measurements into feet and inches. This is done as follows:

1 centimeter	= .39 inches	1 inch	= 2.54 centimeters
1 meter	= 3.28 feet	1 foot	= .305 meters

$$distance\ in\ meters\ \mathbf{X}\ \frac{3.28\ feet}{1\ meter} = distance\ in\ meters\ \mathbf{X}\ 3.28\ ft/m$$

$$= distance\ in\ feet$$

$$distance\ in\ centimeters\ \mathbf{X}\ \frac{.39\ inches}{1\ cm} = distance\ in\ inches$$

If you need to convert from U.S. to metric measurements, use the following equations:

$$\textit{distance in feet} \ \mathbf{X} \ \frac{.305 \ \textit{meter}}{1 \ \textit{feet}} = \textit{distance in meters}$$

$$\textit{distance in inches} \ \mathbf{X} \ \frac{2.54 \ \textit{cm}}{1 \ \textit{inch}} = \textit{distance in centimeters}$$

If there is no scale on the map or if the scale on the map is not accurate (for example, if 1 inch on the map displayed in Figure 2-1 did not equal 200 feet, a measurement of 120 feet in the field would not correspond to 0.6 inch on the map), you will need to develop your own scale. To establish a scale, repeat the aforementioned measurement; that is, measure the distance between a building and a barrier, and measure this distance on the map. Then set up the following scale:

$$\textit{measured distance in feet} = \textit{measured distance in inches}$$

To simplify your scaling factor, divide both sides by the number of inches measured:

$$90 \ \textit{feet} = .4 \ \textit{inches}$$

$$\frac{90 \ \textit{feet}}{.4} = \frac{.4 \ \textit{inches}}{.4}$$

$$225 \ \textit{feet} = 1 \ \textit{inch}$$

Then measure two other building and barrier locations in the compound and on the map, and establish a scale for each location. If all these scales are equivalent, use this scale and the map to compute the rest of the distances. If they are not the same, follow the directions below.

If no suitable map is available, you will need to sketch the compound. The sketch should include the perimeter barrier (or its proposed location) and all buildings within the barrier to be protected. You will need to measure and record the following:

1. the length of each section of compound boundary and the angle between sections using the traffic template and the instructions in the back of the guide;

2. the angle of the turns and the radius of the bends in the barrier; and

3. the distance between each corner of the compound buildings and the nearest two compound boundaries. (Note that this distance should be projected at a 90-degree angle from the compound boundary.)

Record these measurements on the rough sketch of the compound (Figure 2-2). These measurements will be used to establish the allowable L level.

2.2 LABEL APPROPRIATE L LEVELS

DOS standards require that an attack vehicle be stopped no less than 100 feet from the exterior of each building. Therefore a barrier which allows penetration equal to the distance between the barrier and the closest building minus 100 feet is acceptable. (For example, if the barrier is 125 feet from the closest building, 25 feet of penetration could theoretically be allowed.)

Take either the scaled map or the sketch which you completed, and analyze it for distances. First, identify all barrier sections which are more than 150 feet from any interior building, and label all such sections L1 (Figure 2-3), which is the minimum L level required. Next, find all compound boundary sections which are more than 120 feet and less than 150 feet from any interior building. Label all these sections L2. As shown in Figure 2-4, all other compound boundary sections are within 120 feet of a building and should be labeled L3. If the exact distance for any portion of the boundary cannot be determined from the sketch or map (thereby making it unclear which category is appropriate), you must go into the compound and measure the area.

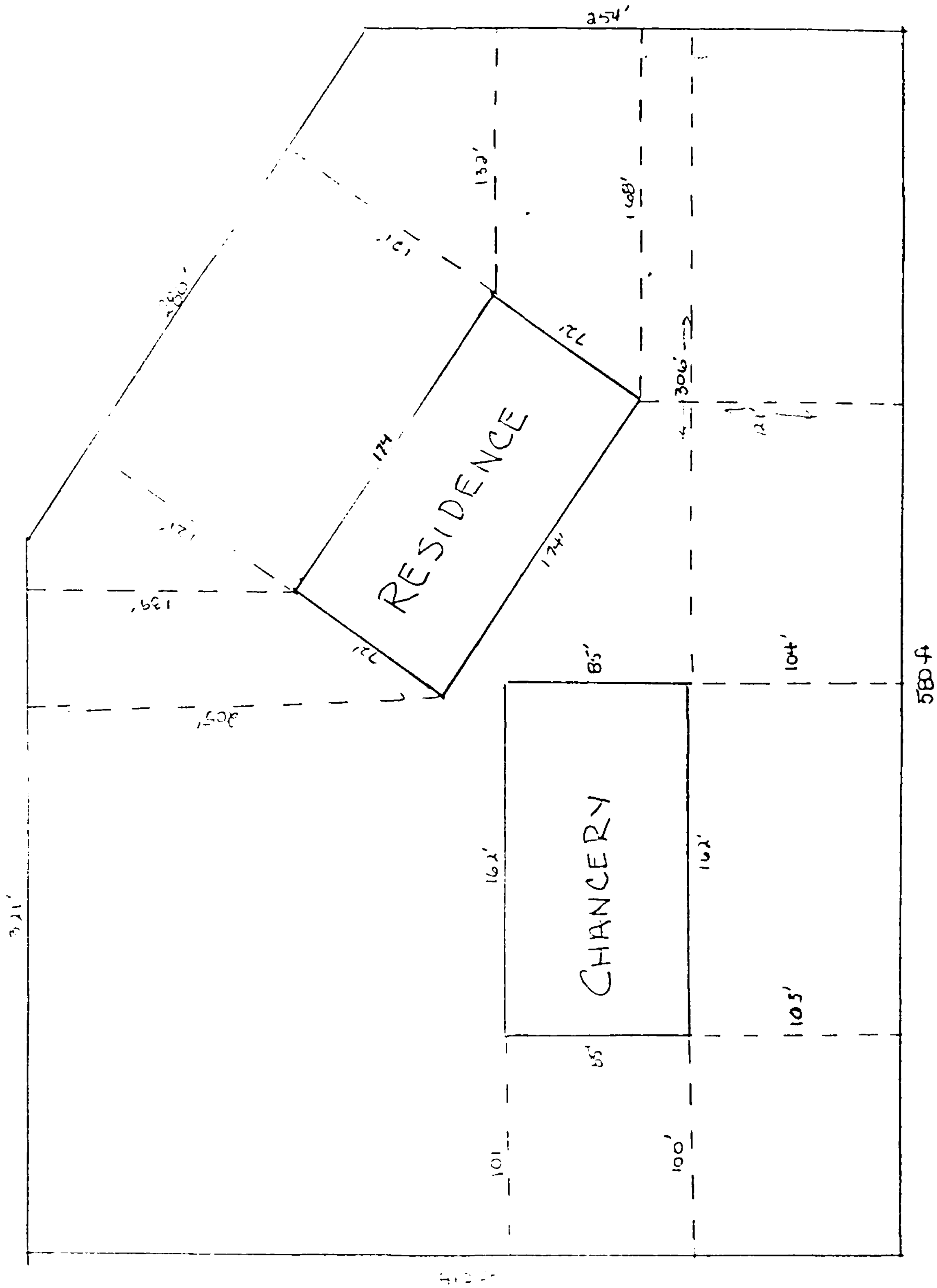


FIGURE 2-2. EXAMPLE OF A ROUGH SKETCH OF A COMPOUND WITH DISTANCES TO BUILDINGS MARKED

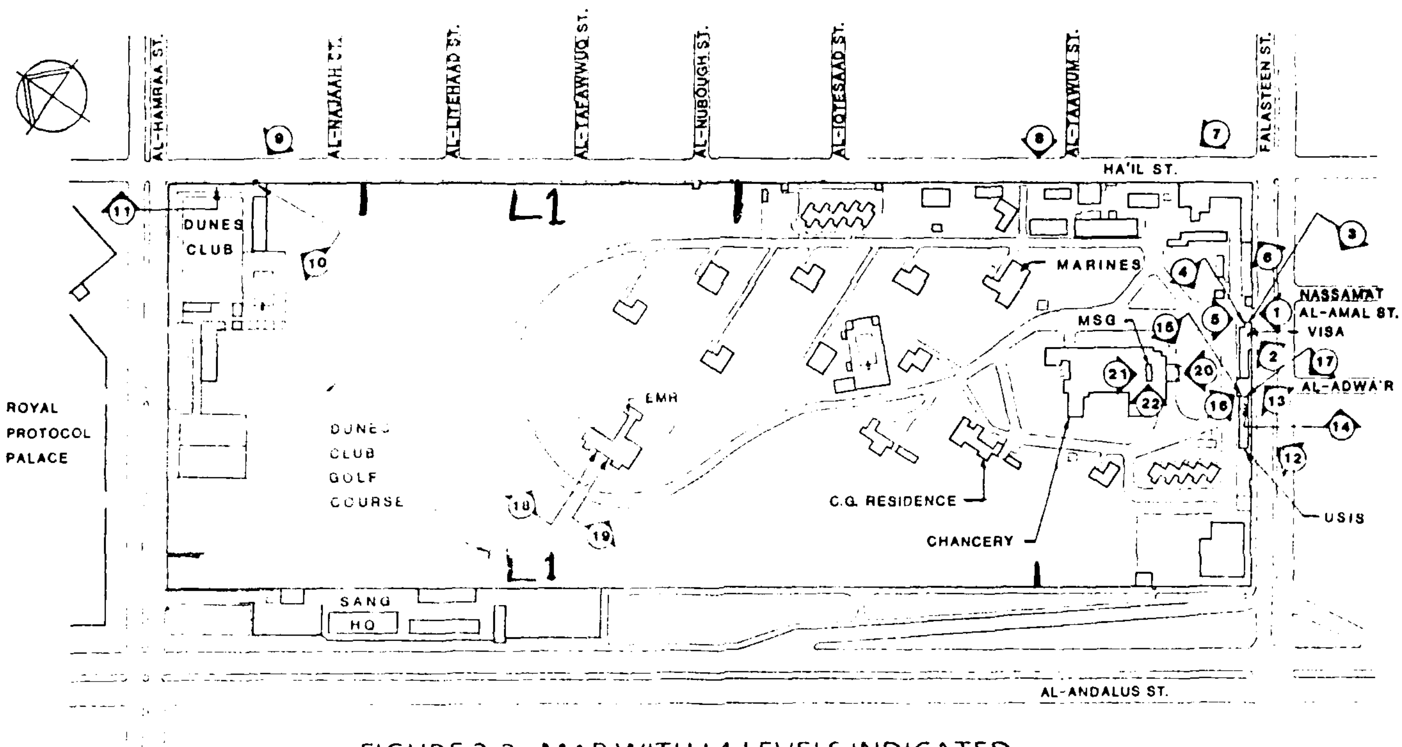


FIGURE 2-3. MAP WITH L1 LEVELS INDICATED

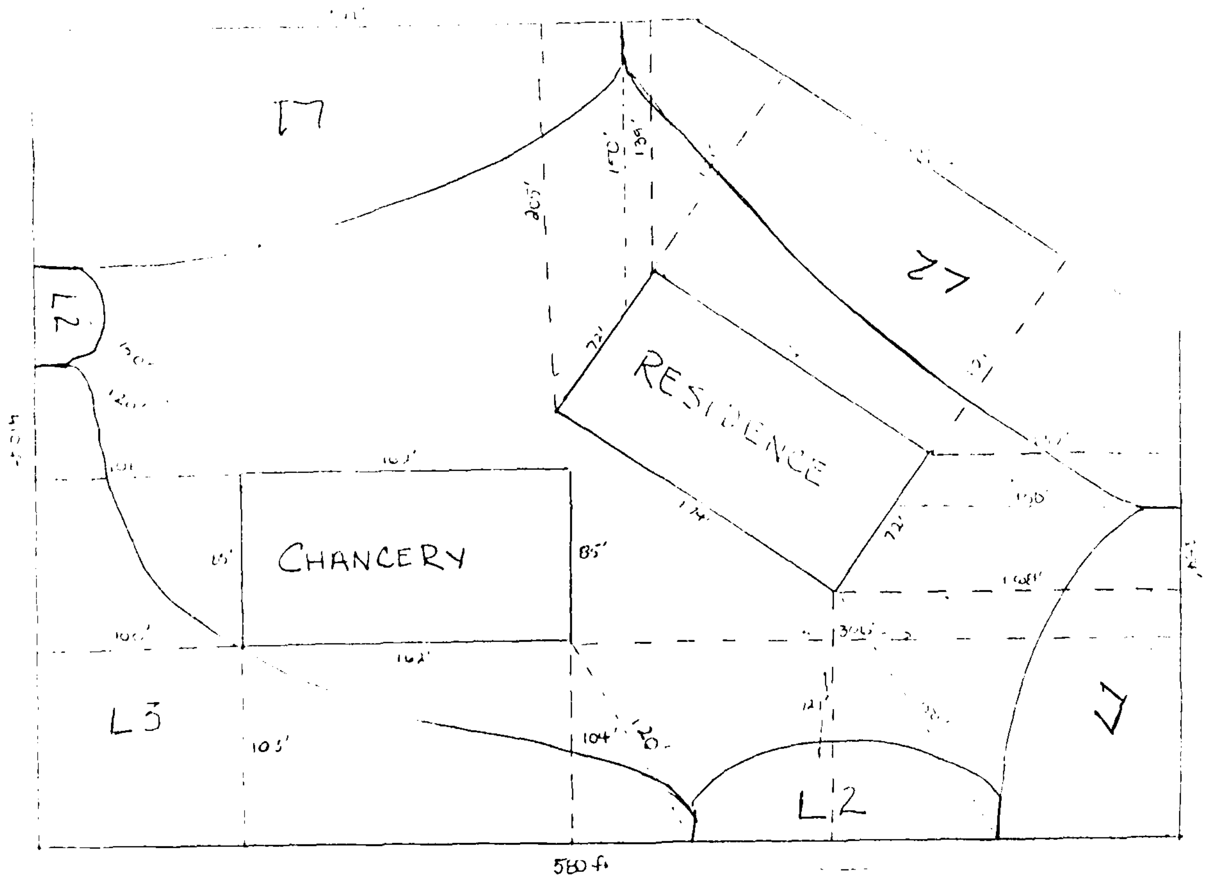


FIGURE 2-4. SKETCH WITH L1, L2, AND L3 LEVELS INDICATED

3. K LEVEL REQUIREMENTS

To identify the required K level (see Table 3-1), we must again divide the barrier into areas with the same level of threat. Different sections of the embassy perimeter will be oriented in such a manner that they will be exposed to different impact speeds. To identify the maximum K level required for a specific segment of the compound boundary, the most severe impact condition (a combination of vehicle speed and impact angle) must be determined.

TABLE 3-1. K LEVELS

DOS Level	Attack Vehicle Speed (Mph)
	Nominal Speed
K4	30
K8	40
K12	50

The maximum impact speed of an attack vehicle is a function of the topography of the area surrounding the compound boundary. It depends on the distance available for vehicle acceleration, the radius of the turns the vehicle must make to reach the barrier, the path surface, and the gradient. As shown in Figure 3-1, the individual segments of the barrier can be struck from a variety of paths. In this example, the compound is shielded by closely spaced buildings on two sides of the exterior of the perimeter barrier. The two remaining sides (north and east) are vulnerable to an attack vehicle. Two streets, each a potential attack path, lead directly to the compound boundary. It is apparent that certain segments of the compound boundary can be attacked from more than one street. In addition, each street contains an infinite number of impact locations. For example, the north boundary could be struck by an attack vehicle moving along street 1 in either direction or street 2 heading south.

While moving along these streets, the attack vehicle can strike the compound boundary at any location along the perimeter. As a result, a vast number of potential impact conditions (combinations of vehicle speed and impact angle) occur at any point along the compound boundary. K threats, as defined by DOS, correspond to the speed of a perpendicular attack (from a 90-degree angle between

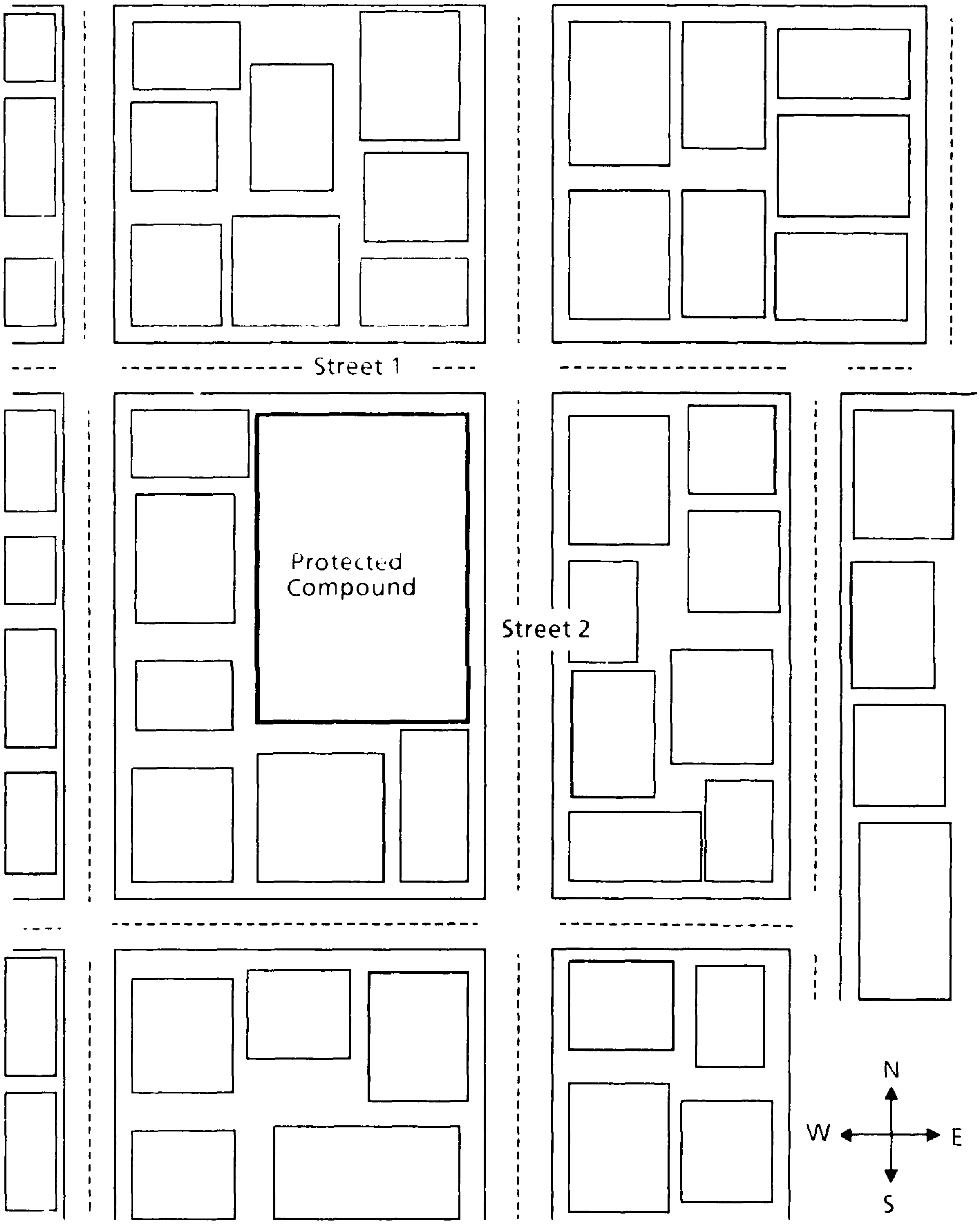


FIGURE 3-1. POSSIBLE ATTACK PATH CONFIGURATIONS

the vehicle and the barrier). Therefore, to compute the effective loading on the barrier, we will consider only the component of the speed perpendicular to the barrier. This effective loading is a function of both the vehicle impact speed and angle at which the vehicle strikes the compound boundary. The goal of this section is to find the impact conditions that lead to the greatest perpendicular speed for each section of the barrier.

3.1 SKETCH THE PERIMETER OF THE COMPOUND

As the initial step in establishing the maximum vehicle impact speed and associated impact angle, you must sketch the area surrounding the compound. This sketch will be used to identify potential attack vehicle paths, thereby establishing the K threats. Although the sketch will later be completed in more detail, where needed, it will save time later on to be accurate now.

This sketch will include the edge of the compound perimeter and the area within 1,200 feet of the perimeter. Use the map or sketch of the compound boundary discussed in Section 2.1 to correctly draw the compound in this sketch. (You may change the scale of this drawing, but try to keep the proportions of the boundary the same.)

To assist in drawing the sketch, walk around the compound perimeter so that you can identify all the items as you draw them. This will help you place the items proportionally on the rough sketch. Because the area to be included may be large, you may want to draw separate sketches showing the 1,200-foot area immediately in front of each boundary. You should also label all buildings as you draw them. This will help you to orient the sketch correctly. The checklist in Table A-1 lists some of the items you should consider when sketching.

3.2 ADD MEASUREMENTS AND ATTACK PATH CHARACTERISTICS

As you look at the sketch you have just completed, you should be able to identify various paths that may be taken to reach the barrier. These paths need to be analyzed to establish the potential attack paths. To properly analyze a path, you will need to perform the following procedures:

(1) Measure the distance between the compound boundary and a constraint boundary (anything that cannot be driven over, such as walls, buildings, waterways deeper than 3 feet, etc.).

(2) Measure the width of paths (streets, alleys, sidewalks, lawns, parks, etc.) parallel or perpendicular to the compound boundary. (Note that the width should be measured as the entire surface along which an attack vehicle can travel. For example, if there are sidewalks on either side of the street, the width of the street should include the width of the sidewalks.) If the width of the path is less than 5 feet, the path will not allow passage of a vehicle and may be disregarded.

(3) Examine the surface composition of each attack path. Is it asphalt, brick, concrete, gravel, or soil?

(4) Calculate the gradient, in degrees, of each potential attack path using the clinometer, if available, as recommended, or the traffic template and instructions in the back of this guide. Record the gradient on the sketches, "G = X°". Be sure to record the direction of the gradient: " + " if the compound is uphill, "-" if the compound is downhill. (See the instructions for making these measurements on the traffic template or clinometer.) If the gradient is uphill at greater than 60 degrees, the path is not negotiable.

(5) Measure each straight path. Figure 3-2 shows a number of straight paths. In this figure, a straight path would be measured from circle to circle (i.e., "a" to "b", "c" to "d", etc.). To allow for more than one attack path to use each straight section, the straight paths need to be measured in terms of unbroken sections (i.e., those segments not interrupted by intersections or curves). If there is more than one way to reach the beginning of a straight section, it is important to find the maximum speed at which the vehicle can enter that section. Since this method assumes acceleration on only straight sections of path, where curves are present, it will be necessary to measure straight paths from the middle of the curve or intersection that initiates the straight section of attack path to the middle of the curve or intersection which ends the straight section. Since these straight paths will overlap our measurements for curves, any acceleration which is possible during the curves will be included in the calculation of the acceleration on the straight paths.

For intersections, the center of the intersection will be an appropriate end point for the preceding straight section and any turns that could be made in order to reach

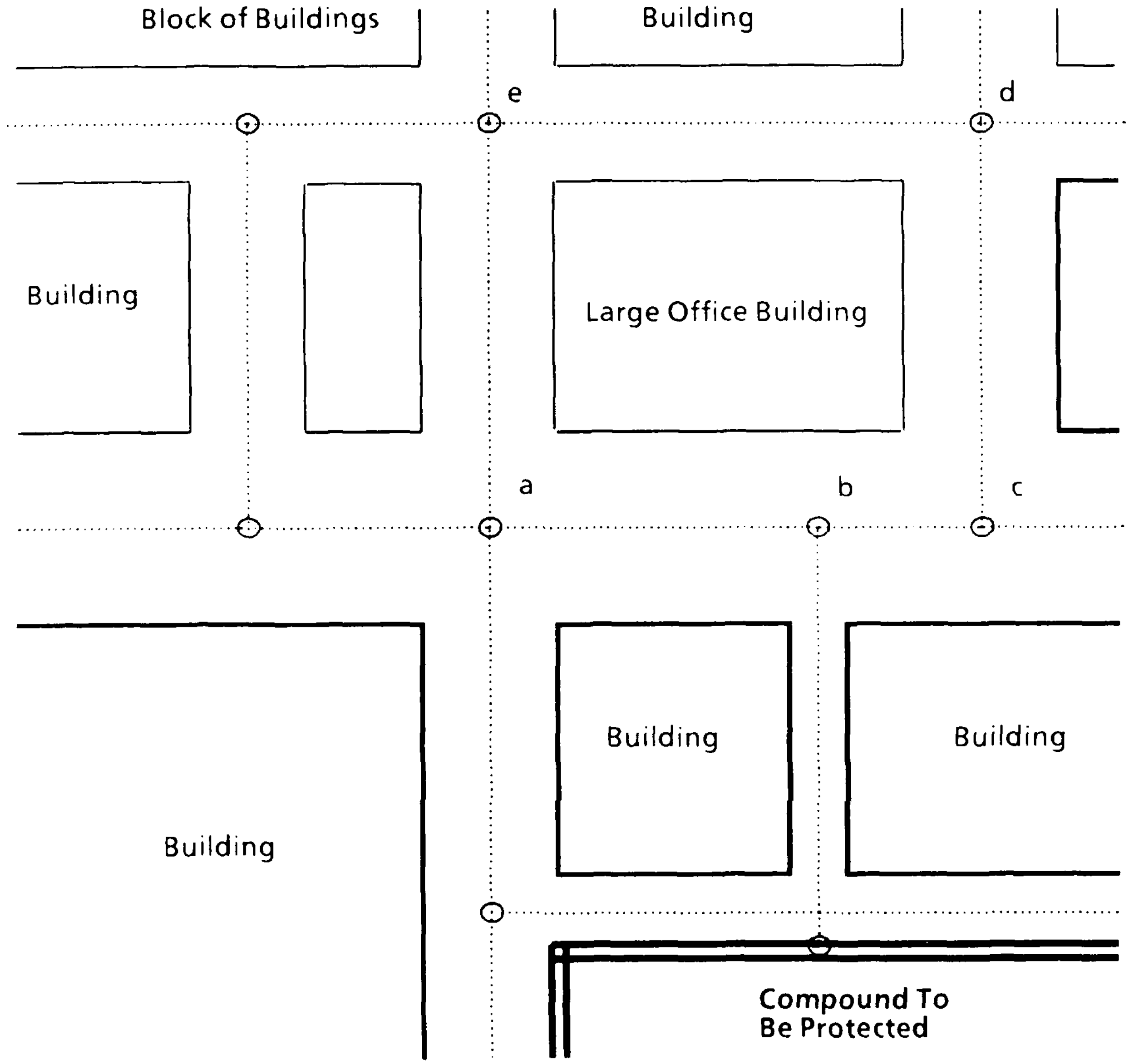


FIGURE 3-2. MEASURING STRAIGHT PATHS

the new straight section. Straight sections between curves on a curved road will be measured as shown in Figure 3-3. The "B" and "C" points in each triangle represent the two end points of the curve, and the "A" points are the center points of the curves. Measure from the center of the first curve to the center of the second curve. Any straight sections leading directly to the barrier will be measured the full distance to the barrier (as shown in Figure 3-2).

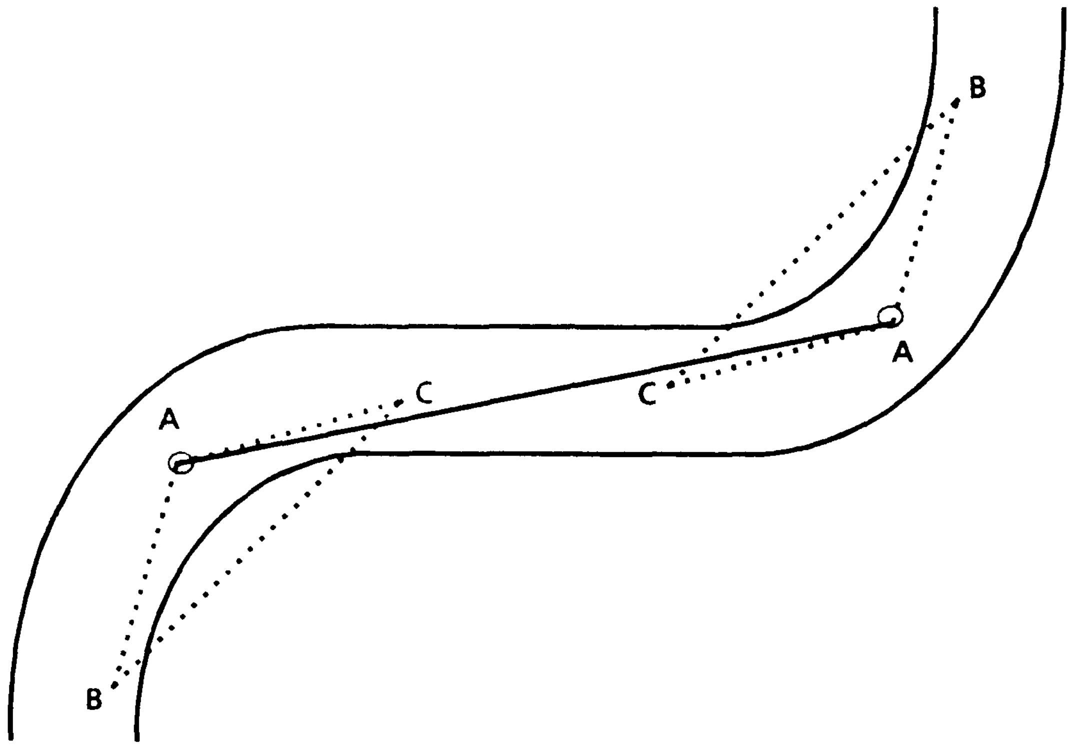


FIGURE 3-3. MEASURING STRAIGHT PATHS BETWEEN CURVES

(6) Measure the Curvature Characteristics. Find the points along the road edge where the curve begins and ends (on either side of these points the vehicle is going straight), and measure the distance between them. As shown in Figure 3-4, this distance is the chord (C). At the midpoint of the chord, measure the distance between the chord and the road edge, which is the middle ordinate (M). If you are unsure of the exact points where the curve begins and ends or if you cannot measure the distance because of an obstacle, take multiple measurements of the same curve using 100-foot or 50-foot chord lengths.

If the curve is too small to be passable by a vehicle without backing up, consider this portion of the path closed off.

Record all measurements on the sketch.

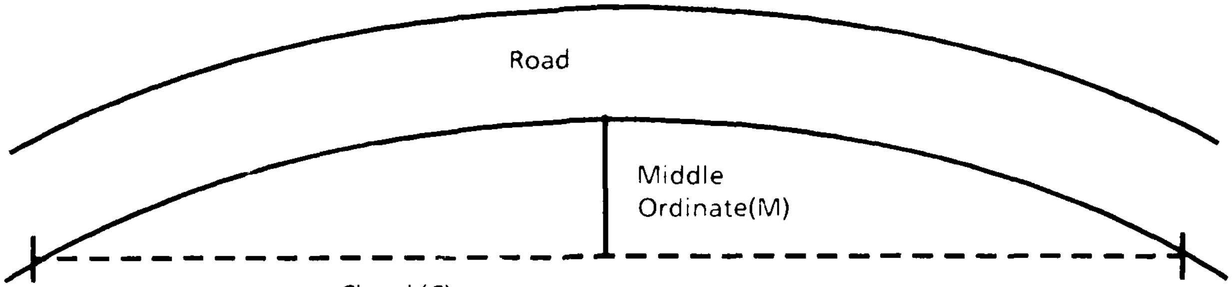


FIGURE 3-4. MEASURING CURVES

3.3 FIND RADIUS OF CURVATURE

Next, using the chord/middle ordinate method, find the radius (R) of each of the curves that you measured. That is, insert the distances you measured for the chord (C) and the middle ordinate (M) into the following formula:

$$R = \frac{C^2}{8M} + \frac{M}{2}$$

Where:

R = *The radius of curvature in feet*

C = *The length of the chord in feet*

M = *The length of the middle ordinate in feet*

If C = 100 feet and M = 6 feet:

$$R = \frac{100^2}{8 X 6} + \frac{6}{2}$$

$$R = \frac{100 X 100}{48} + 3$$

$$R = \frac{10,000}{48} + 3$$

$$R = 208.3 + 3 = 211.3 \textit{ feet}$$

If you took multiple measurements, use the the average radius calculated from those measurements as the radius of curvature. If the radius of the curve is more than 186 feet on a paved surface or 334 feet on an unpaved surface, the vehicle can negotiate the curve at 50 mph, and the curve can therefore be considered a straight path.

3.4 DETERMINE TIRE TRACTION COEFFICIENT

A factor which influences the speed at which an attack vehicle can travel is the tire traction coefficient along the various portions of the path. Therefore, recording the tire traction coefficient of each portion of the path is important in selecting a protective barrier. Use Table 3-2 to determine the tire traction coefficient for each portion of path. Write "f = " followed by the tire traction coefficient on the sketch of the compound exterior.

TABLE 3-2. TIRE TRACTION COEFFICIENT AS A FUNCTION OF SURFACE COMPOSITION

Surface Composition	Tire Traction Coefficient (f)
Paved (asphalt, tar, brick, or concrete)	0.9
Unpaved (gravel or soil)	0.5

Note: For portions of the path with varying surface compositions, print the largest of the tire traction coefficients for the paths on the sketch.

3.5 CALCULATE MAXIMUM IMPACT SPEED OF ATTACK VEHICLE

The speed of the attack vehicle depends on the distance available for acceleration on straight paths and the radius of the curves. When deciding whether an attack vehicle could use a path, consider the width of the path and the radius of turns on the path. If you are unsure of the width or radius of potential attack paths, measure them. Note: Paths can be on any surface that can be driven over, including streets, lawns, parks, sidewalks, and beaches.

For each section of the barrier, identify the possible attack paths. The maximum speed against which you must protect is the speed which can be attained by an attack vehicle following any of these paths. The maximum speed for which barriers are tested is 50 mph, which is a K12 threat level. For each section of the perimeter, you must determine whether a vehicle can, while traveling over an attack path, achieve a speed of at least 50 mph. If the vehicle can achieve a 50-mph impact speed or greater, the corresponding section of the perimeter requires a 50-mph barrier (K12). Since 50 mph (K12) is the maximum protection level, if a path permitting a 50-mph impact speed is found, no other paths for that section of barrier need be analyzed.

To determine the attack vehicle speed for each section of barrier, you must use the rough sketch of the perimeter and your knowledge of the area surrounding the compound. With these, <u>you should identify for each section of the perimeter the longest, straightest, and most level path that an attack vehicle could take to reach each section of the compound boundary</u>.

A straight path, as identified in Section 3-2, is the area over which the vehicle may accelerate. To compute velocity over a distance, you need to know (1) the velocity at the beginning of the straight section, (2) the distance, and (3) the gradient. We will assume that a vehicle enters the area 1,200 feet away from the compound at 30 mph. The initial velocity for any straight path which does not begin 1,200 feet from the barrier will need to be calculated. This initial velocity will be equal to the maximum ending velocity of the paths which lead to this point. The path which leads to this point will be a combination of straight sections and curved sections. The straight sections, as shown in Figure 3-3, are measured from the center of the curves. The curves are measured from the beginning of the curve to the end of the curve, and only the largest radius of curvature (i.e., the curve allowing the fastest speed) which can be negotiated between the constraints need be measured. The measurement for the curve does not need to start along the straight path. It can be offset from the straight path, as shown in Figure 3-5. Thus some portions of the roadway contain both a curved and a straight section. The curve "E-E", in Figure 3-5, uses the widest area available and overlaps a portion of both the straight sections "D-B" and "B-C".

Three straight paths, "A-B", "B-C", and "B-D", are shown with solid lines. The curve

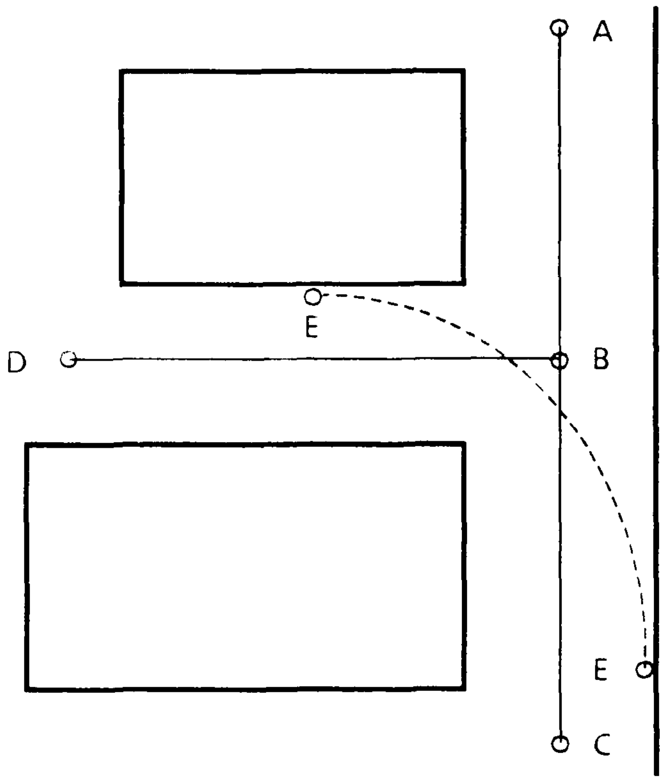


FIGURE 3-5. COMBINATION OF STRAIGHT AND CURVED PATHS

"E-E" is shown with a dotted line. There are two paths the vehicle can take to reach point "C" in our example: "A-B to B-C" and "D-B to B-C".

Path "A-B to B-C" includes two straight sections of path. To calculate the speed at point "C" using this path, you need to know the speed at point "A", the gradient in each straight path, the road surface of each straight path, the distance between "A" and "B", and the distance between "B" and "C". (These measurements should have been recorded on your sketch in Section 3-2.) The speed at point "A" is used first (along with the gradient and the coefficient of traction) to calculate the speed at which the vehicle can reach point "B"; this speed is then used as an initial speed (along with the gradient and the coefficient of traction) to calculate the speed at which the vehicle can reach point "C". Section 3.5.1 explains how to compute the speed which can be obtained over these straight paths.

Path "D-B to B-C", on the other hand, requires a turn, "E-E". Although the curve "E-E" shown in Figure 3-5 goes past point "B", it is necessary to make the curve before entering straight section "B-C". To calculate the speed at point "C" using this path, you need to know the speed at point "D", the gradient in each section, the road surface of each straight path, the radius of the curve "E-E", the distance between "D" and "B", and the distance between "B" and "C". (These measurements should have also been recorded on your sketch in Section 3-2.) The speed at point "D" is used first (along with the gradient and the coefficient of traction) to calculate the speed at which the vehicle can reach point "B". An additional check needs to be done, however, to see if the curve can be negotiated at this speed. The radius of curve "E-E" is used (along with the coefficient of traction) to compute the maximum speed at which the vehicle can negotiate the curve. These two speeds (the speed which can be reached along the straight path "D-B" and the maximum speed at which the vehicle can negotiate the curve) are compared. The lesser of these two numbers is used as the initial speed of the vehicle (along with the gradient and the coefficient of traction) to calculate the speed at which the vehicle can reach point "C". Section 3.5.1 explains how to compute the speed over straight paths, and Section 3.5.2 explains how to compute the maximum speed at which a vehicle can negotiate a curve.

3.5.1 Straight Paths

The vehicle enters the straight path at an initial speed "V_T". For a straight path, the gradient (G) of the hill will slow or quicken the vehicle accordingly. To adjust for the gradient, take the distance measured (S), and multiply it by the cosine of "G", as shown in the following equation. (See Table A-2 for a list of sines and cosines.) Use this adjusted "S" to find the speed:

$$S_E = S_M \times (1 + COSINE\ G)$$

Where:

S_E = *Equivalent distance with zero gradient*

S_M = *Measured distance*

G = *Gradient*

In this equation, cosine "G" will be negative if the vehicle is going uphill and positive if the vehicle is going downhill.

Figure 3-6 shows the speed versus distance for a medium-duty, fully loaded truck (a Ford F600), which is the attack vehicle that we will consider, at maximum acceleration and 0 gradient. Figure 3-6 is a graph of data obtained from the Ford Motor Company.

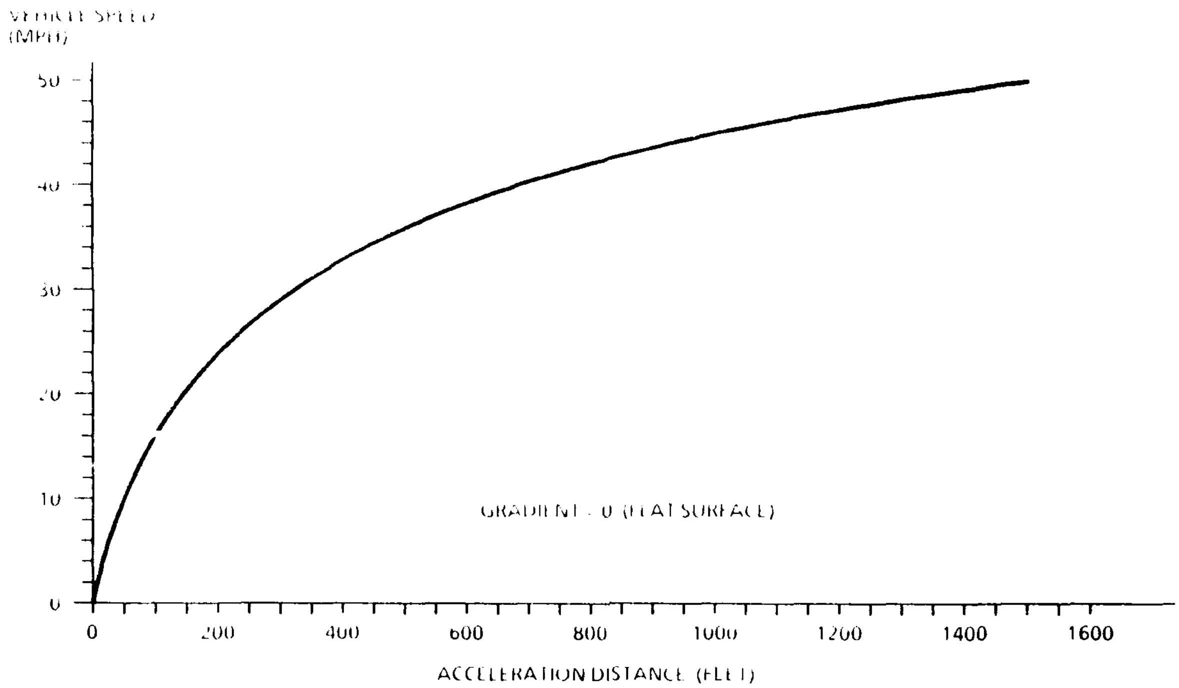


FIGURE 3-6. VEHICLE SPEED AS A FUNCTION OF ACCELERATION DISTANCE

To find the maximum speed at the end of any straight path, follow the example presented in Figure 3-7. In this example, the initial speed will be 32 mph and the distance (S) will be 700 feet. The following steps explain the procedure to be used:

(a) Label the speed V_T = 32 mph on the vertical axis of the graph.

(b) Draw a line parallel to the horizontal axis from V_T = 32 to the point where that line intersects the curve.

(c) Draw a vertical line (parallel to the speed axis) down from this intersection point to the horizontal axis.

(d) Read the acceleration distance at this point from the horizontal axis (370 feet in this example).

(e) Label the point T = 370 feet.

(f) Add the distance S (in feet) to the value of T:

$$S + T = 700 + 370 = 1,070 \text{ feet}$$

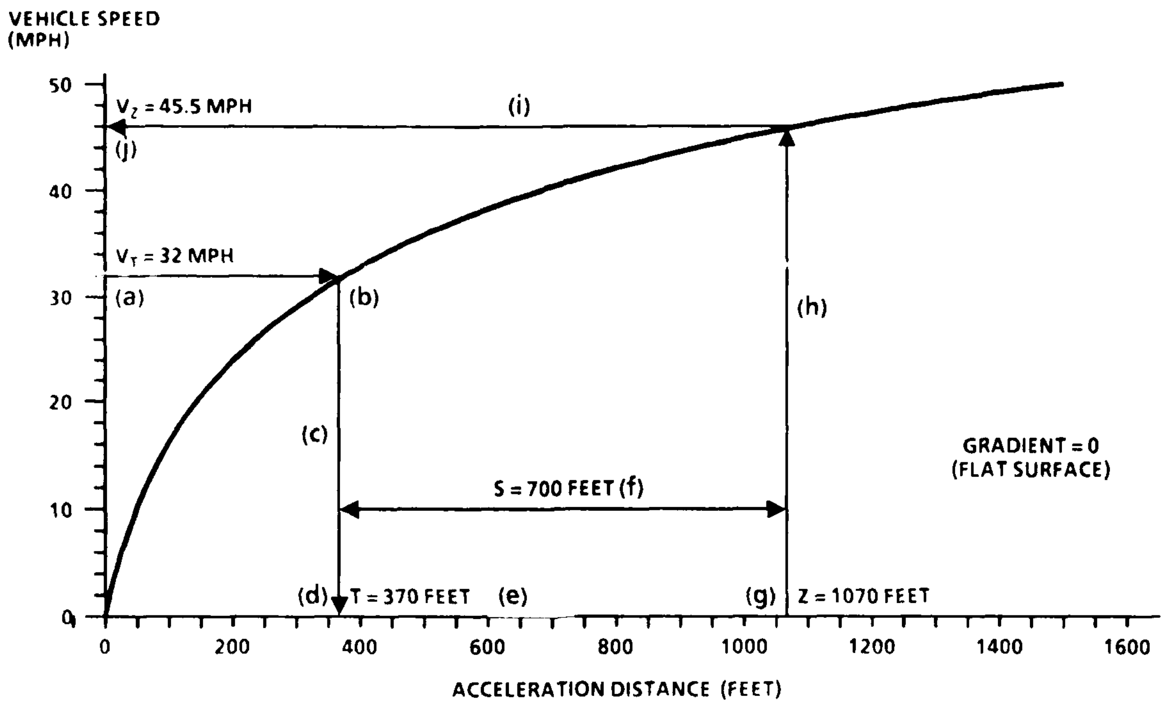


FIGURE 3-7. EXAMPLE OF COMPUTING ACCELERATION FROM AN INITIAL SPEED

(g) Find the distance S + T (1070 feet) on the horizontal axis and label this point Z.

(h) Draw a vertical line (parallel to the speed axis) up from point Z to the curve.

(i) Draw a horizontal line (parallel to the distance axis) from the point of intersection to the speed axis.

(j) Read the speed V_Z from the vertical axis (V_Z = 45.5 mph in this example).

(k) Round V_Z up to the next highest whole number (46 mph).

Write the speed "V_Z" along the distance over which it is attained.

Note: The gradient is assumed to be zero (level ground). Had the gradient been 10, it would have been necessary to establish an equivalent distance "S" prior to using Figure 3-7.

3.5.2 Curves

There is a maximum speed at which a vehicle can negotiate a curve. Using the graph in Figure 3-8, the traction coefficient, the initial speed, and your measurements for the radius of curvature, the maximum speed for each curve can be determined. For example, you can see in Figure 3-9 that if "f = .5" (unpaved) and the radius of the

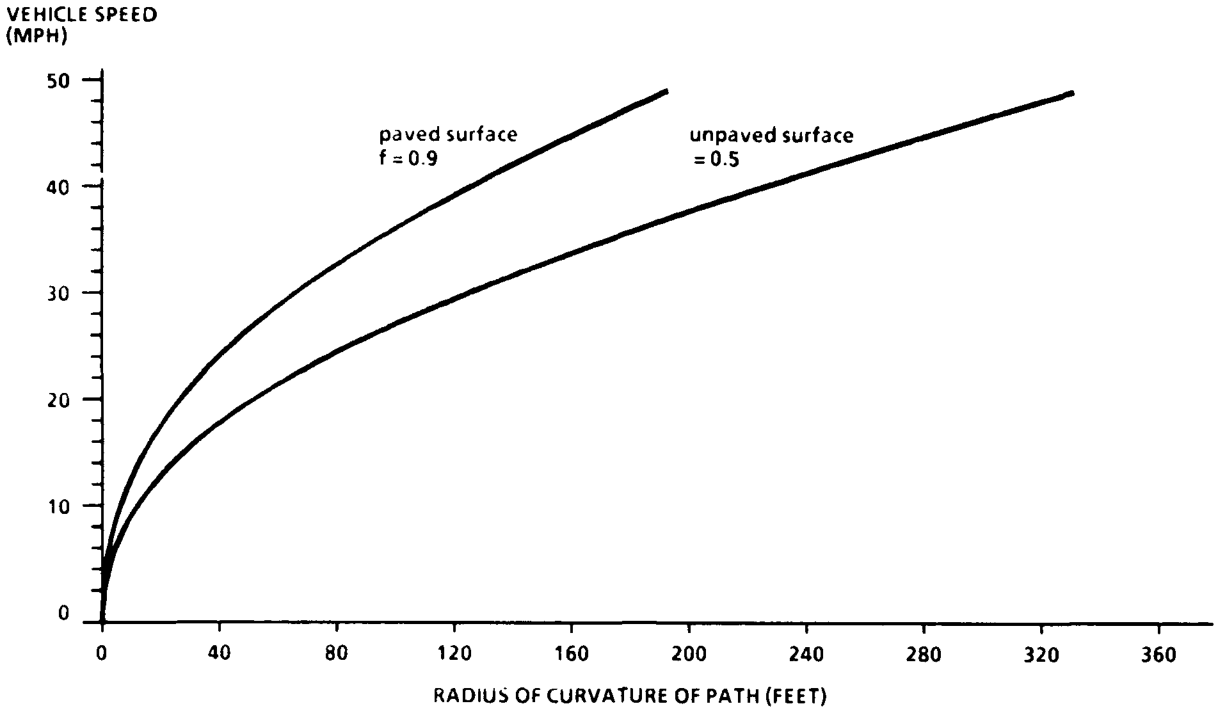


FIGURE 3-8. MAXIMUM VEHICLE SPEED AS A FUNCTION OF RADIUS OF CURVATURE

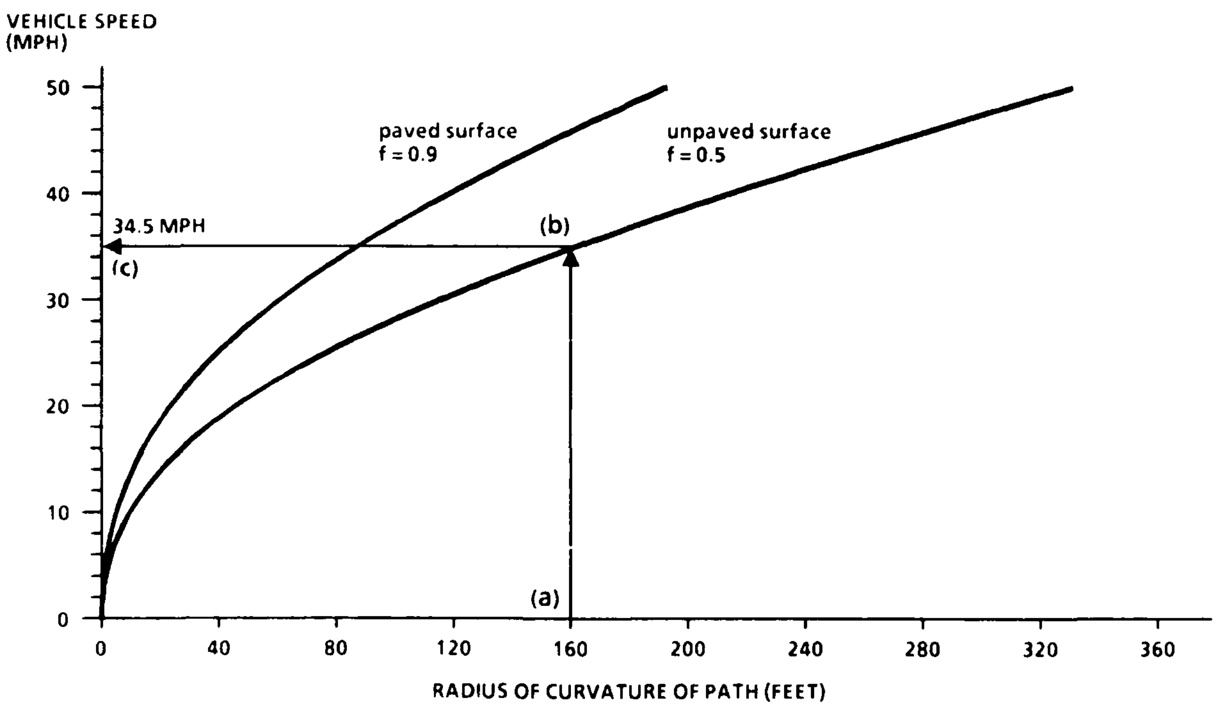


FIGURE 3-9. EXAMPLE OF COMPUTING SPEED AROUND CURVES

curve is 160 feet, the maximum speed at which the curve can be negotiated is 34.5 mph. There are two curves on the graph in Figure 3-8, one for "f = .5" and the other for "f = .9" (paved); use the curve of the correct traction coefficient of the path being measured. In Figure 3-5, a vehicle entering curve "E-E" will begin with the speed resulting from the straight path "D-B". Since we have assumed no acceleration on curves, the curve cannot lead to a speed greater than that attained on the path "D-B", and the vehicle cannot travel from "D" to "B" to "C" without making the curve "E-E". Therefore, the ending speed from the straight path "D-B" followed by the curve "E-E" is the lower of either the speed at which the vehicle enters the curve or the speed at which the vehicle can negotiate the curve. Write this speed at the curve on your sketch. Consider this as a possible initial speed for the straight path "B–C".

3.5.2.1 Curved Impact - Any path where the vehicle must turn in order to strike the barrier is considered a curved impact. An example of such a path is given in Figure 3-10. The angle of impact affects the amount of the velocity imparted head-on to the barrier. The perpendicular component of the velocity determines the seriousness of the impact. The offset distance is the distance in which the vehicle can negotiate the turn. In Figure 3-10, the offset "D_Z" is the distance from the constraint boundary to

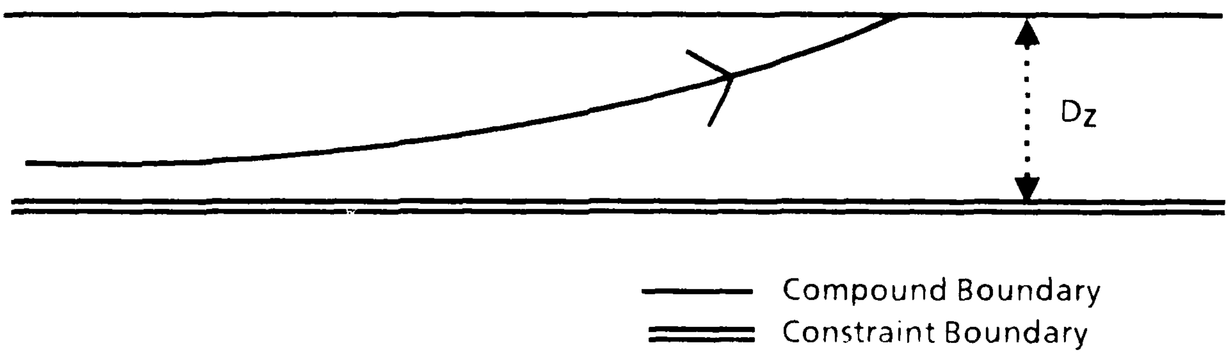


FIGURE 3-10. EXAMPLE OF A CURVED ATTACK PATH

the barrier. Figures 3-11 and 3-12 show the impact angle versus speed for a given offset (D_Z) for f = .5 and f = .9, respectively. To use these graphs you need to know "f", "D_Z", and the speed "v" of the vehicle entering this portion of path. Use the graph with the appropriate "f" value. Find "v" along the horizontal (speed) axis. Draw a vertical line to the curve for the appropriate "D_Z". Draw a horizontal line from this point to the vertical (impact angle) axis. Read the angle at this point. Use this angle to perform the following calculation, which gives you the perpendicular speed (Vp):

$$Vp = v \sin\theta$$

Use this perpendicular speed to establish K level requirements. For the

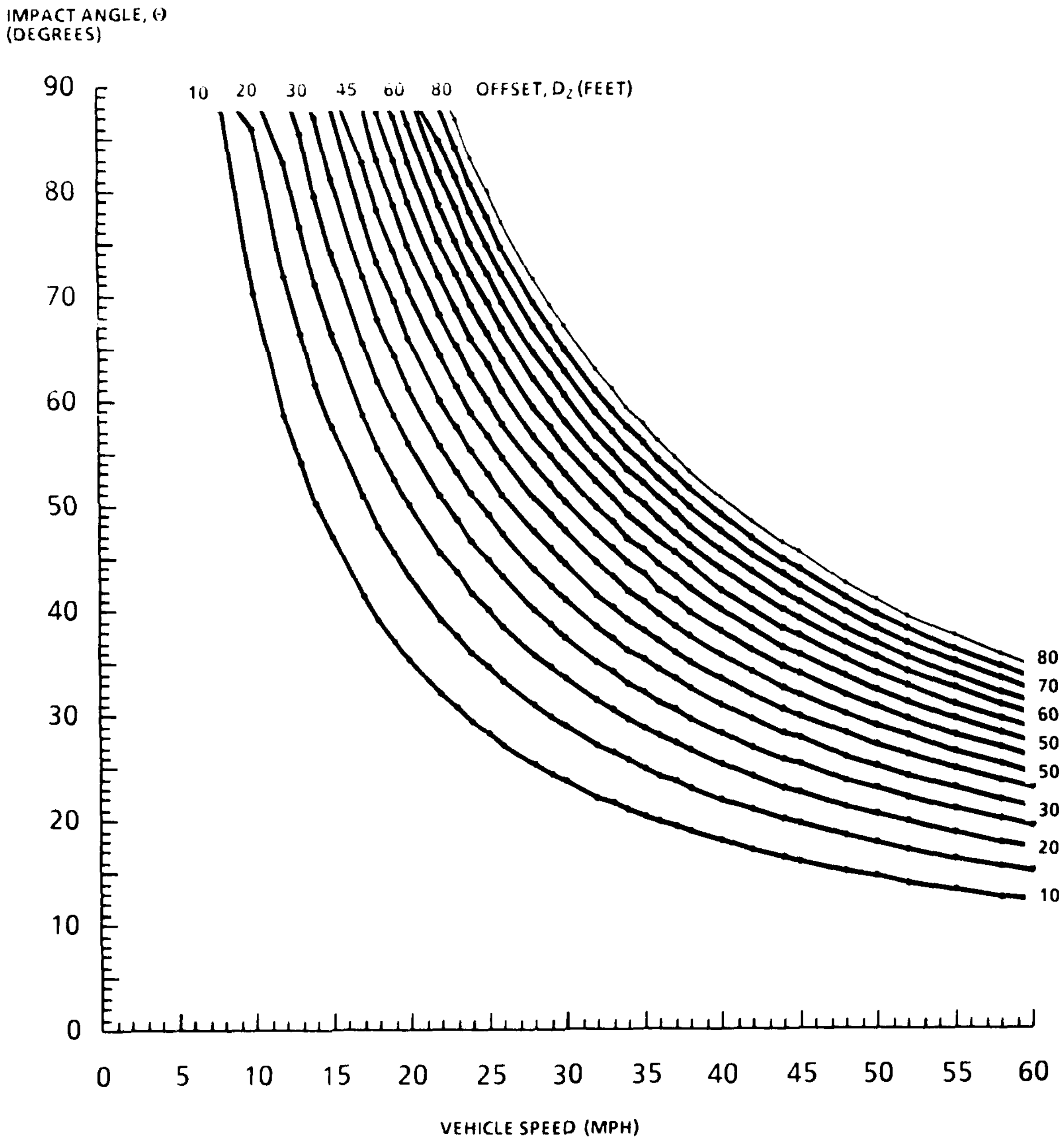


FIGURE 3-11. IMPACT ANGLE WITH RESPECT TO VEHICLE SPEED (f = .5)

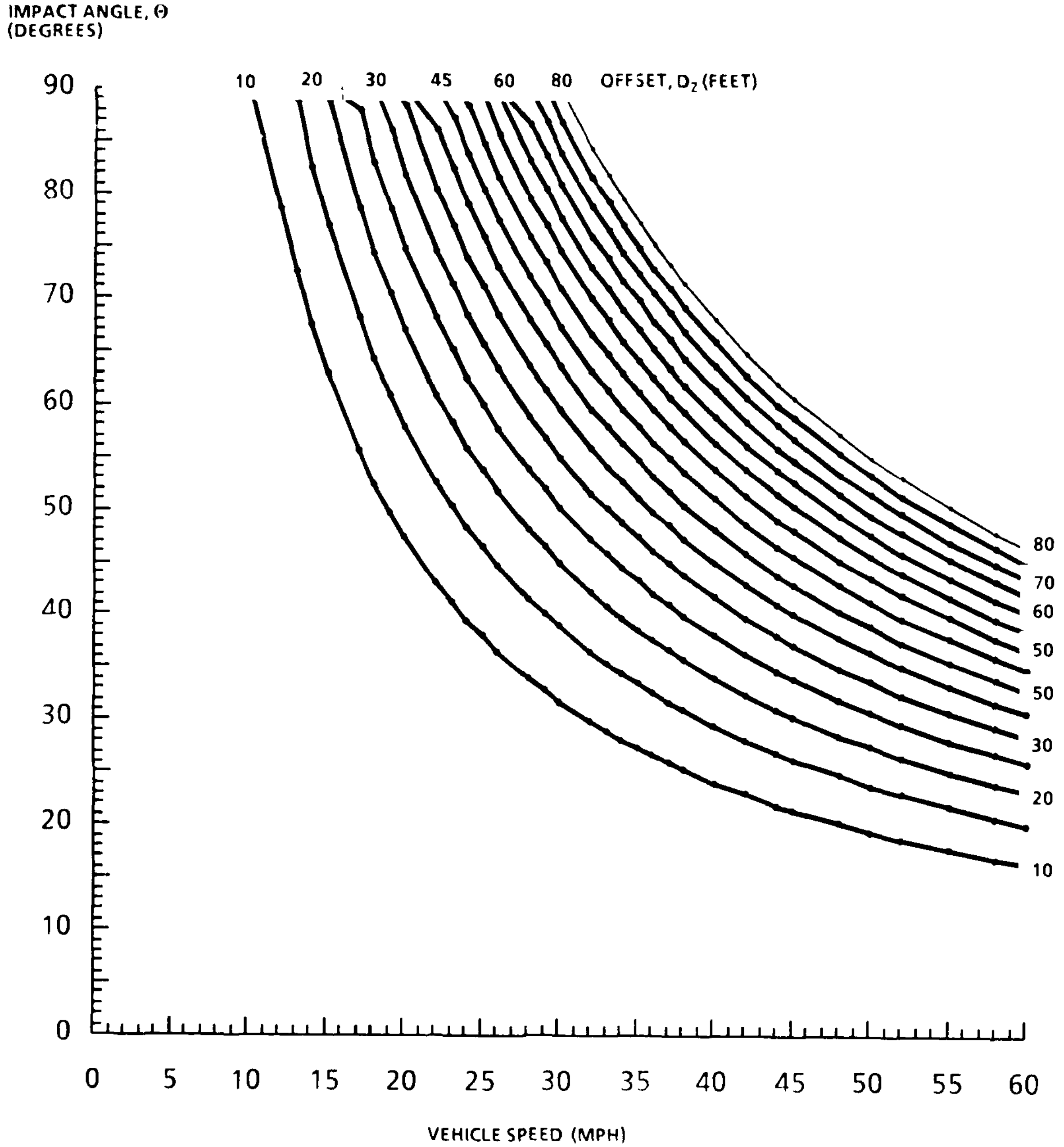


FIGURE 3-12. IMPACT ANGLE WITH RESPECT TO VEHICLE SPEED (f = .9)

in Figure 3-10, this speed will be applicable to each section of barrier with the same initial values for "v", "f", and "D_Z".

Figure 3-13 is another example of a curved impact. For this example let path 1 intersect the barrier at a speed equal to the straight path to point "A". This speed is

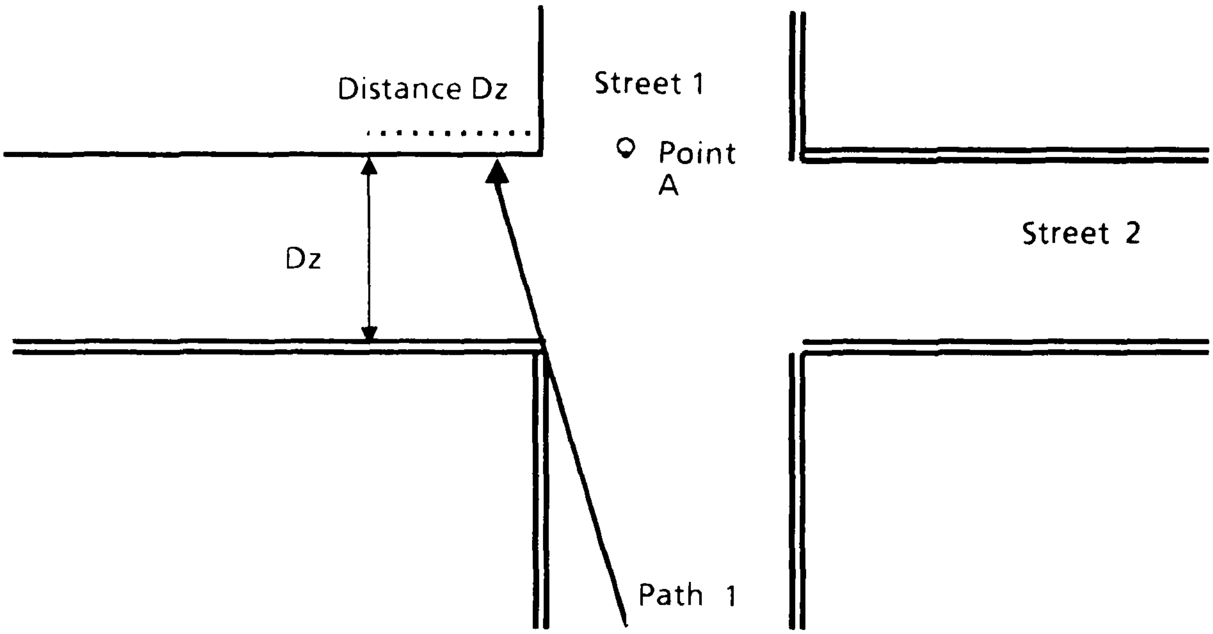


FIGURE 3-13. ANOTHER EXAMPLE OF A CURVED IMPACT

applicable to the section of barrier the same distance as "D_Z"from the end of the barrier (shown with a dotted line in Figure 3-13). The barrier section further from the constrained corner than "D_Z" is subject to a curved impact from street 2 similar to the one shown in Figure 3-10. Remember each section of barrier must be examined for the longest, straightest, and most level path. Each possible curved impact must be analyzed for the most direct and fastest possibility.

4. BARRIER DESCRIPTIONS

DOS specifications define three levels of attack-vehicle penetration (L levels), presented in Table 2-1. According to these specifications, acceptable performance of the protective barrier requires that

1. the attack vehicle is stopped in one of the three penetration distances presented in Table 2-1;

2. the attack vehicle is disabled after the initial penetration; and

3. the protective barrier is intact and in place after the impact.

Penetration distance is a function of barrier design and vehicle speed; the greater the speed of the attack vehicle, the deeper the penetration. DOS specifications define three levels of attack-vehicle speed (K levels), presented in Table 3–1.

Now that we know the L level and K level needed for each barrier segment, we can figure out the most economical way to provide protection. The following pages describe the barriers which have been tested. Included in the description are the L and K levels which this barrier will meet. After you find the barriers that match your requirements, you can consider secondary barrier selection factors such as cost, aesthetics, etc.

Barriers are selected for the minimum penetration distance (highest L value) and for the maximum vehicle speed (highest K value) given the topography and physical constraints of the area surrounding the compound.

There are two types of protective barriers: fixed (passive) barriers and active barriers. Both types are permanent installations; that is, they are usually an extension of or are anchored to a foundation (for example, reinforced concrete) in the ground. Fixed barriers are designed to remain in their original deployed configuration, and cannot be lowered or opened to permit vehicle or pedestrian passage. Such barriers are employed to enclose virtually the entire accessible perimeter of a compound.

Active barriers (gates) are integrated into gaps left in the fixed barrier to permit vehicle and pedestrian access to the compound. Active barriers can assume two operational configurations. First, in their normal deployed position, they constitute an above-ground barrier identical in function to their adjacent passive counterparts. Second, these security devices can be lowered or rotated on a vertical axis to permit passage to and from the compound.

4.1 FIXED (PASSIVE) BARRIERS

DOS standards require that an attack vehicle is stopped before it comes within 100 feet of a building inside the compound boundaries. Use Table 4-1 to identify the types of fixed barriers which do not allow the attack vehicle to come within 100 feet of a compound building at the maximum attack-vehicle speed for each section of the perimeter. Descriptions of the different types of fixed barriers follow.

TABLE 4-1. FIXED BARRIER TYPE AS A FUNCTION OF PENETRATION AND SPEED

Barrier	Description	L Level	K Level (max speed)
DS-3	Concrete-filled steel bollards	L3	K12 (50 mph)
DS-6	Reinforced concrete inverted T	L3	K8 (40 mph)
DS-7	Reinforced concrete inverted T	L3	K4 (30 mph)
DS-9	Reinforced concrete planter	L3	K12 (50 mph)
DS-10	Concrete-filled steel bollards in groups of 3	L2	K12 (50 mph)

Reinforced Concrete Inverted T (DS-6 and DS-7)

An inverted T barrier is a wall resting on a footing. The entire footing and part of the wall are embedded in the existing soil or in a crushed stone mix.

Figure 4-1 presents two above-ground views of barrier DS-6, and Figure 4-2 shows a drawing of its representative cross section. The same information for barrier DS-7 is presented in Figures 4-3 and 4-4, respectively.

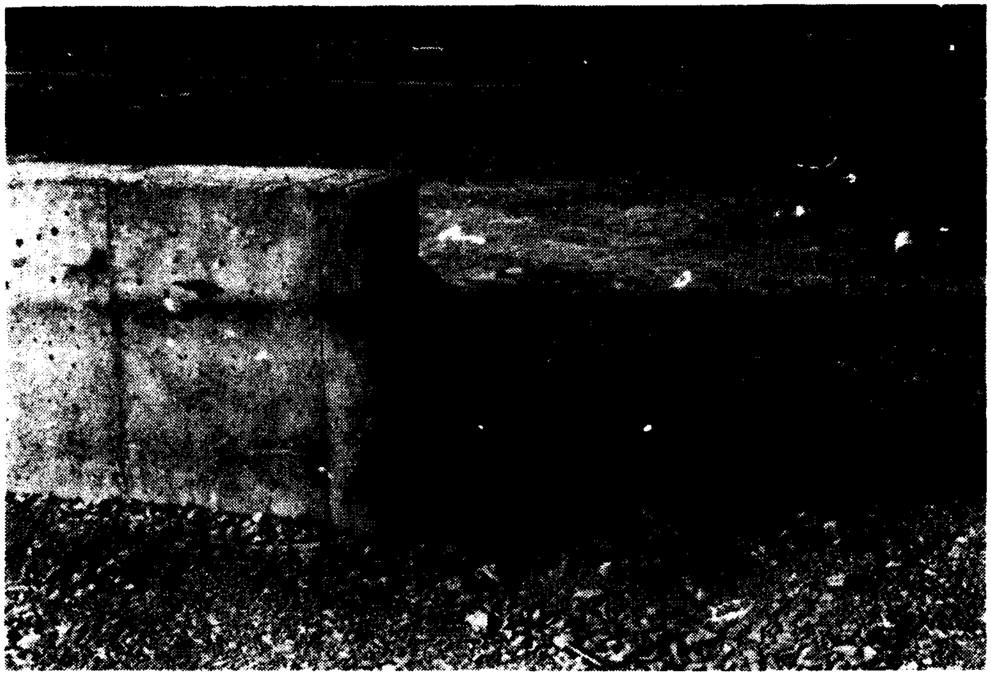


FIGURE 4-1. ABOVE-GROUND VIEWS OF DS-6

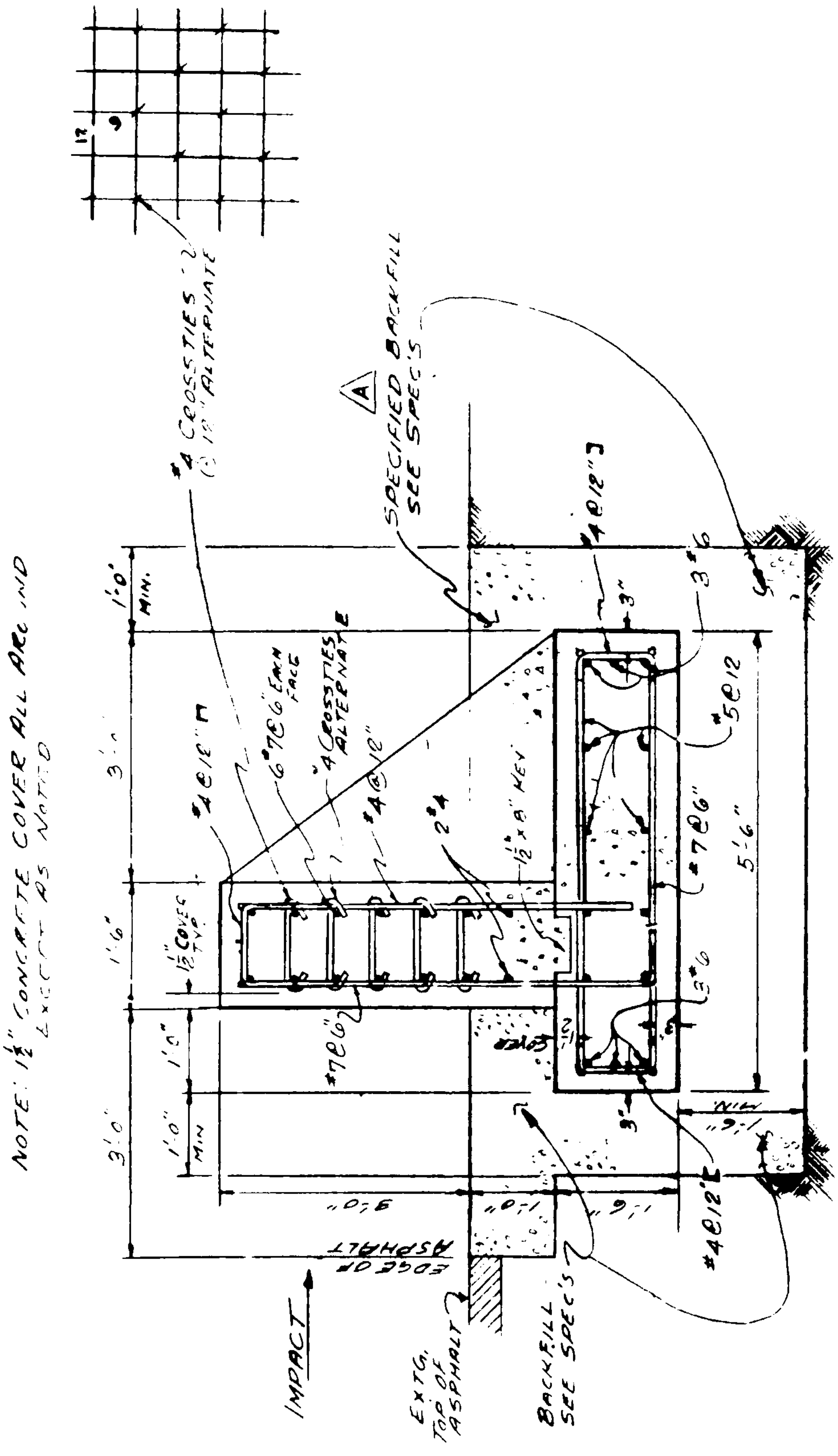


FIGURE 4-2. CROSS SECTION OF DS-6

FIGURE 4-3. ABOVE-GROUND VIEWS OF DS-7

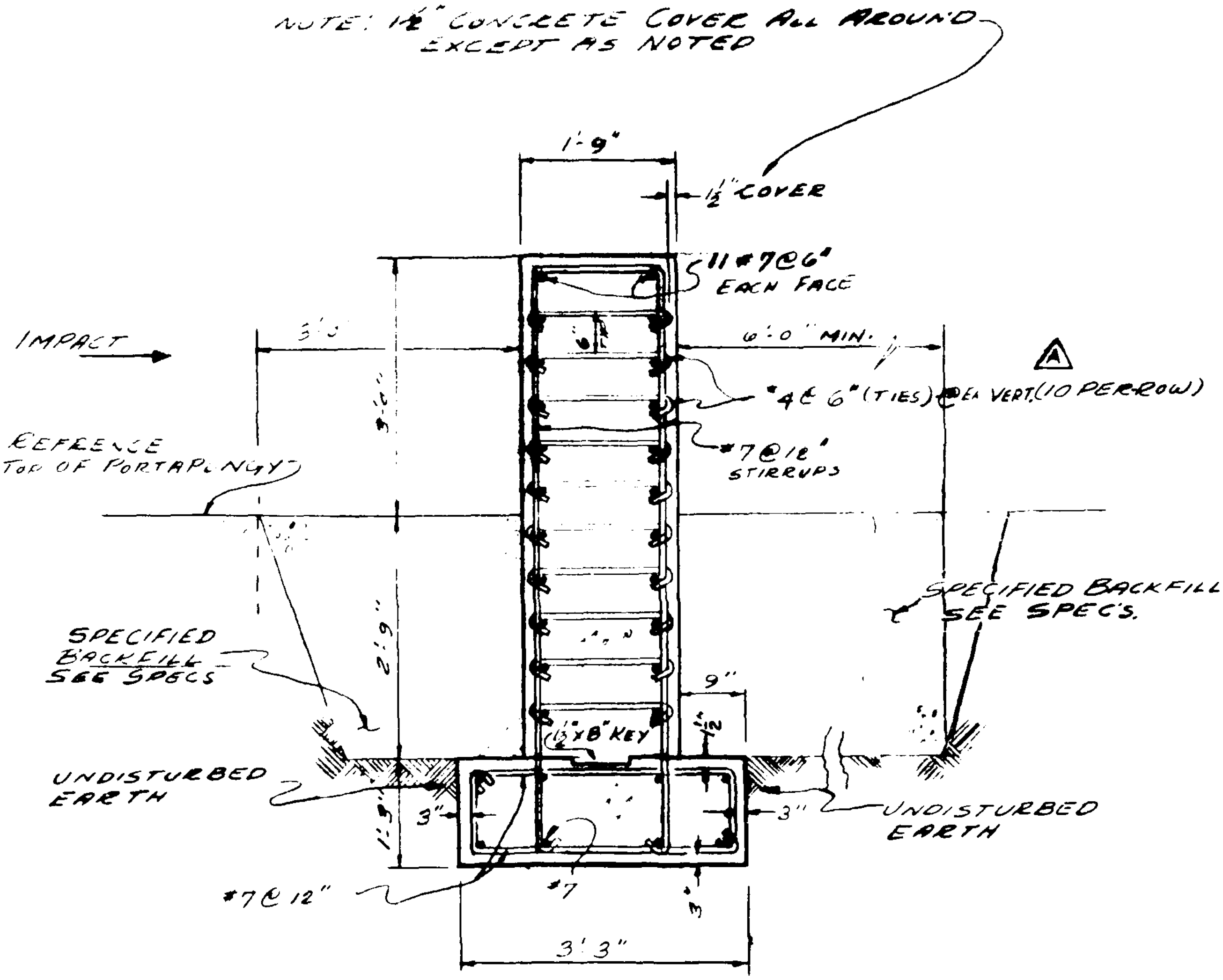


FIGURE 4-4. CROSS SECTION OF DS-7

Reinforced Concrete Planter (DS-9)

Planter barriers are 3-foot-thick reinforced concrete walls resting on a footing. Part of the wall and the entire footing are embedded in the existing soil or in a crushed stone mix. The walls contain regularly spaced cavities that are filled with soil. Flowers or shrubs are planted in the soil to enhance the barrier's appearance.

Above-ground views of barrier DS-9 are presented in Figure 4-5. A representative cross section of the barrier is shown in Figure 4-6.

Concrete-Filled Steel Bollards (DS-3 and DS-10)

Bollard barriers consist of strong concrete-filled steel pipes embedded in a reinforced concrete footing. The footing is embedded in the existing soil or in a crushed stone mix.

Figure 4-7 presents above-ground views of barrier DS-3. Its representative cross section is depicted in Figure 4-8. Similar information for barrier DS-10 is presented in Figures 4-9 and 4-10, respectively. DS-10 is designed for pedestrian access and should be used in small sections in conjunction with other barriers. Figure 4-11 is an example of how DS-10 could be used.

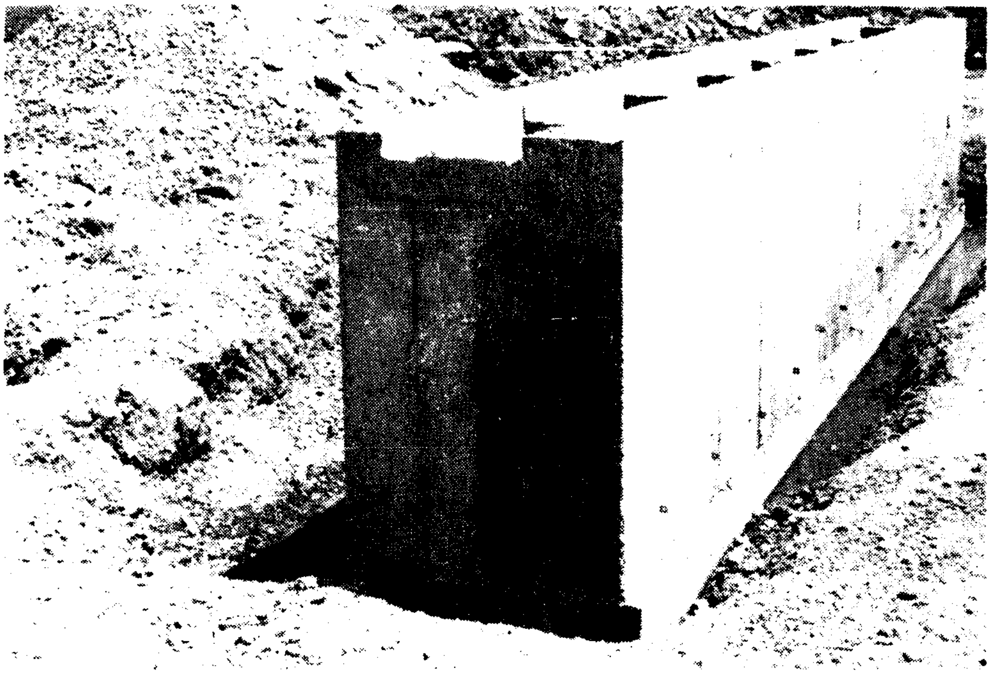


FIGURE 4-5. ABOVE-GROUND VIEWS OF DS-9

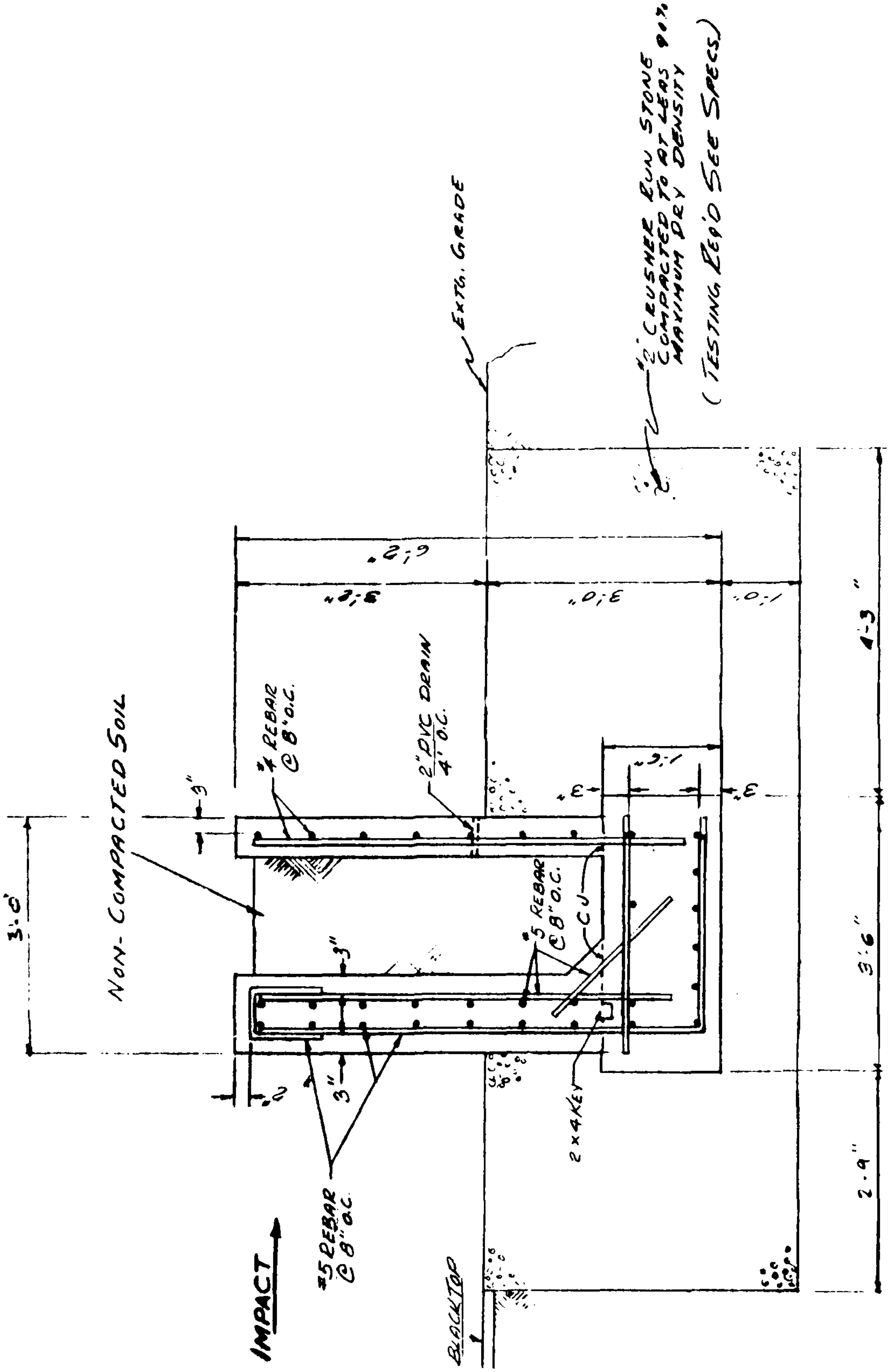


FIGURE 4-6. CROSS SECTION OF DS-9

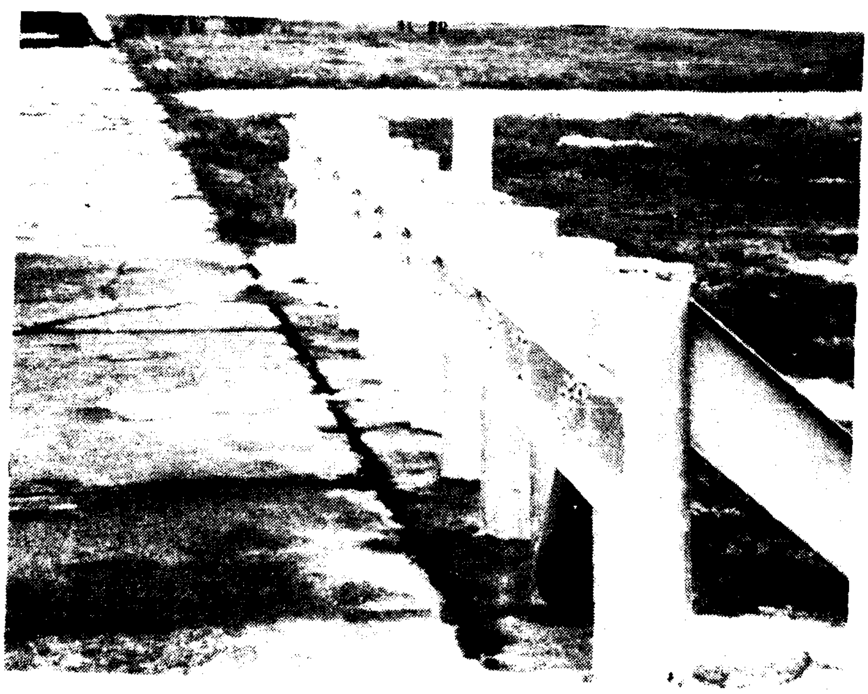


FIGURE 4-7. ABOVE-GROUND VIEWS OF DS-3

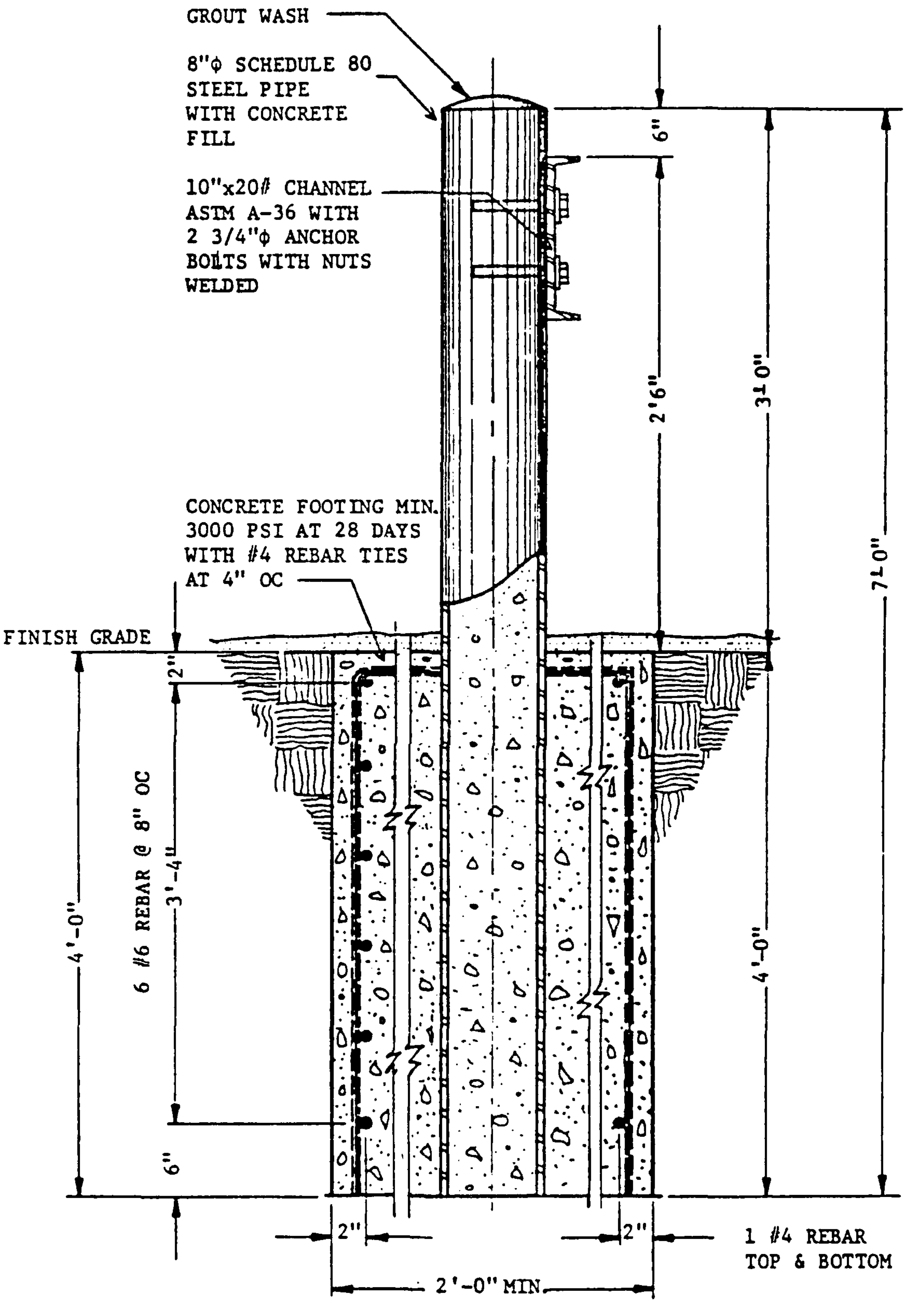


FIGURE 4-8. CROSS SECTION OF DS-3

FIGURE 4-9. ABOVE-GROUND VIEWS OF DS-10

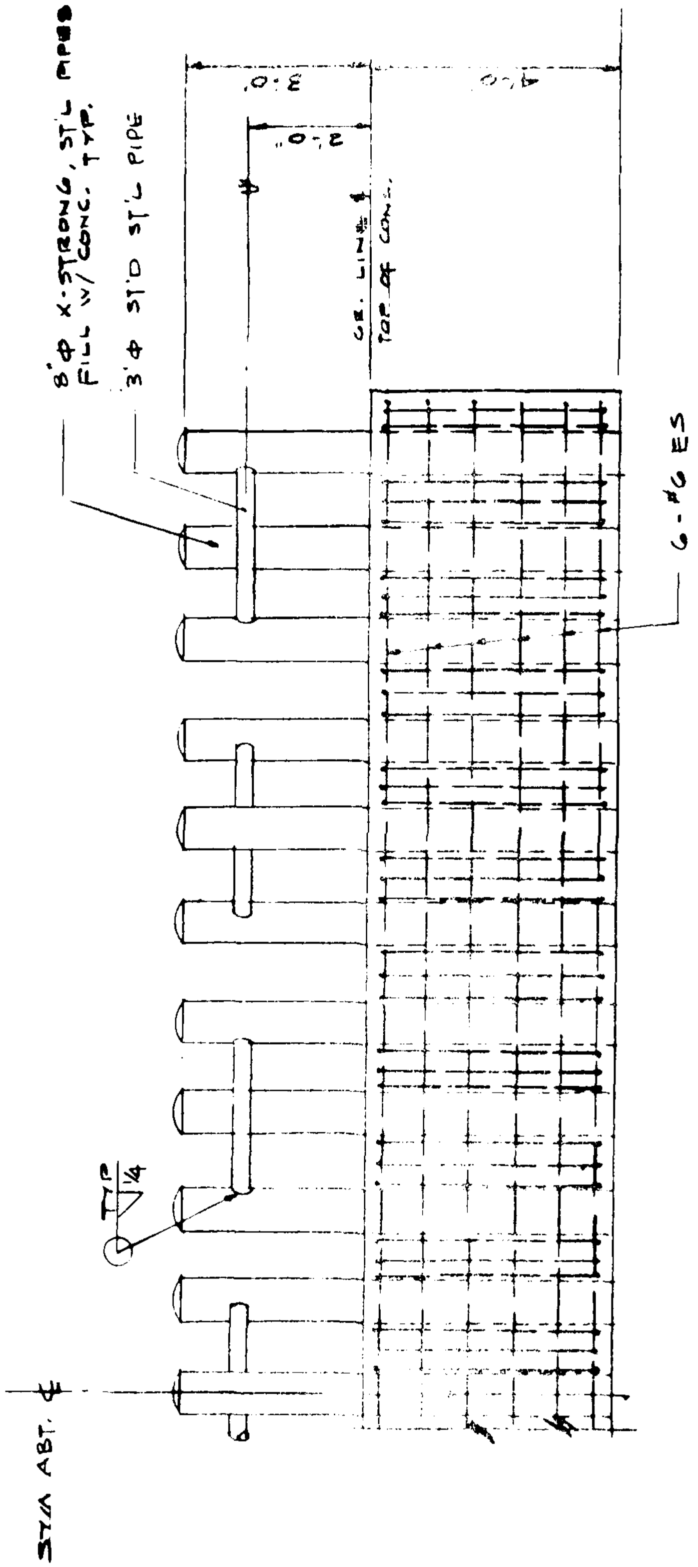


FIGURE 4-10. CROSS SECTION OF DS-10

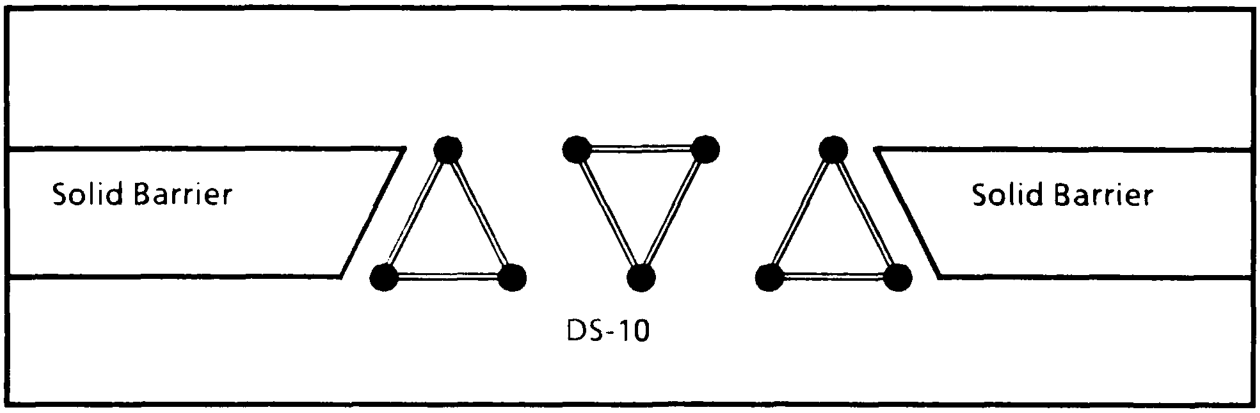


FIGURE 4-11. DS-10 CONFIGURATION ALLOWING PEDESTRIAN ACCESS

4.2 ACTIVE BARRIERS

Use Table 4-2 to identify the types of active barriers which meet the penetration protection level selected and the maximum attack-vehicle speed for each entrance into the compound. Thirteen active barriers have been certified. A description of each follows.

TABLE 4-2. ACTIVE BARRIER RATINGS

Manufacturer	Model	Rating
Barrier Concepts, Inc.	VSB 80187-P10 VSB 80187-F10	K12/L1 K12/L3
Catalpa Gate Company, Inc.	EGS-1	K12/L3
Delta Scientific Corporation	TT207s TT210 TT280	K12/L3 K4/L2 K12/L2 and K8/L3
Meridian Engineering	Model 0915	K12/L2
Nasatka Barrier, Inc.	NMSBII NMSBIV	K12/L3 K12//L3
Terio International, Inc.	TI/Terio	K12/L3
Western Industries, Inc.	Magnum Portapungi De-Fender	K12/L3 K8/L1 K4/L2

Vehicle Surface Barrier (VSB) 80187 (P-10 and F-10)

The VSB has both a portable surface-mounted model (P-10) and a fixed model (F–10). They are manufactured by Barrier Concepts, Inc. (See Figure 4-12 for photograph.)

EGS-1 Gate

The EGS-1, manufactured by Catalpa Gate Company, Inc., is a vertical gate set in a reinforced concrete foundation. (See Figure 4-13 for photograph.) The above-ground dimensions are 12 feet wiae by 57.5 inches high by 17 feet long. The foundation excavation is 6 feet deep by 20 feet wide by 17 feet long.

TT207s Hydraulic Wedge Barricade

The TT207s, manufactured by Delta Scientific Corporation, is a wedge-shaped gate set in a reinforced concrete foundation. (See Figure 4-14 for photograph.) The above-ground dimensions are 38 inches high by 64.5 inches long with an optional width of 72 to 144 inches. The foundation excavation is 52.5 inches deep by 97.5 inches long with an optional width of 114.25 to 186.25 inches.

TT210 Hydraulic Bollards

The TT210, also manufactured by Delta Scientific Corporation, is a set of three retractable steel bollards encased in a reinforced concrete foundation. (See Figure 4-15 for photograph.) The above-ground dimensions are 30 inches high by 10.75 inches in diameter. The foundation excavation is 60 inches deep by 30 inches in diameter.

TT280 Linear Crash Gate

The TT280, also manufactured by Delta Scientific Corporation, is a vertical gate set in a reinforced concrete foundation. (See Figure 4-16 for photograph.) The above-ground portion is a swing gate. The foundation excavation is 54 inches deep by 48 inches wide by 96 inches long.

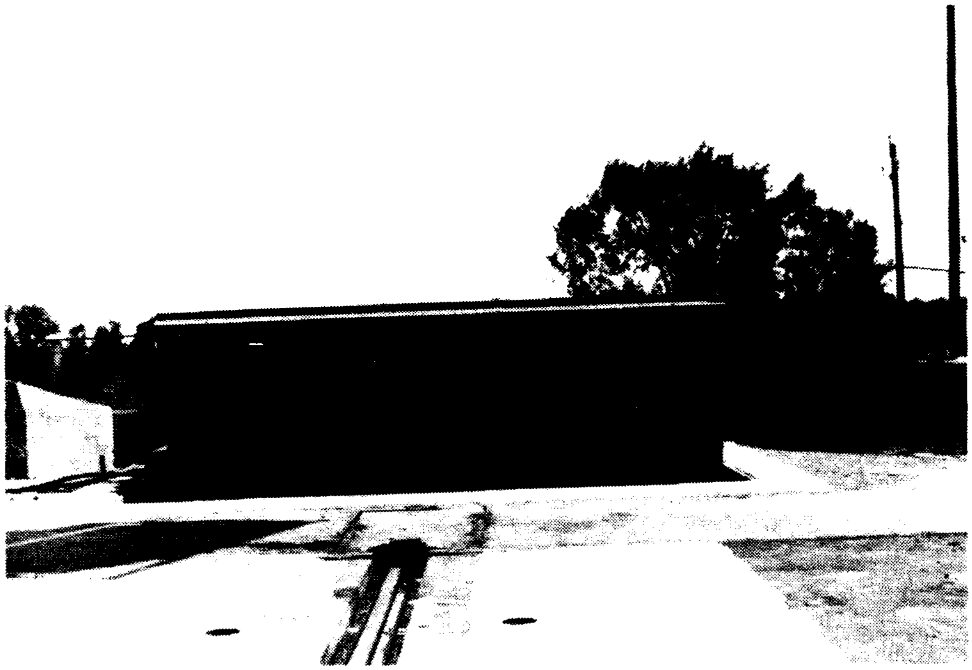


FIGURE 4-12. VEHICLE SURFACE BARRIER (VSB) 80187

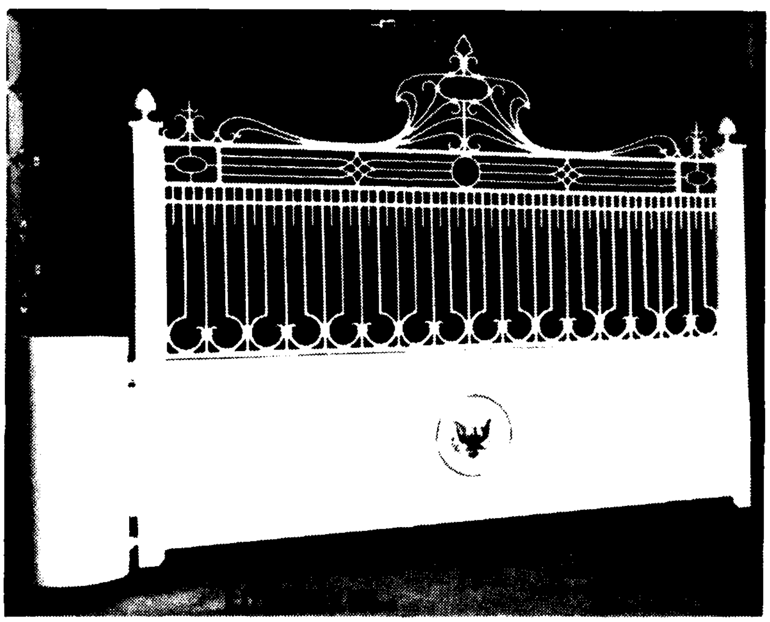


FIGURE 4-13. EGS-1 GATE

FIGURE 4-14. TT207s HYDRAULIC WEDGE BARRICADE

FIGURE 4-15. TT210 HYDRAULIC BOLLARDS

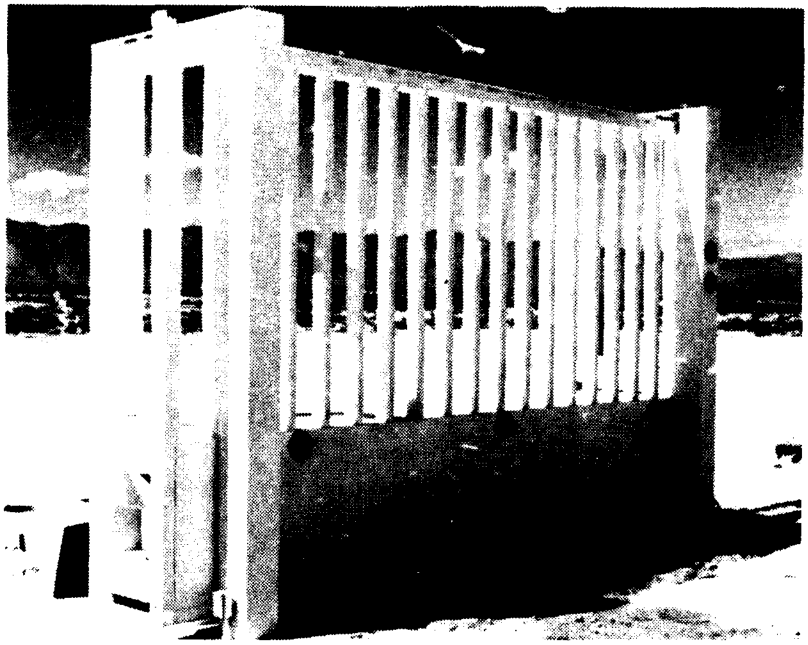


FIGURE 4-16. TT280 LINEAR CRASH GATE

Model 0915 Security Gate

The Model 0915, manufactured by Meridian Engineering, is a wedge-shaped gate set in a reinforced concrete foundation. (See Figure 4-17 for photograph.) The above-ground dimensions are 38 inches high by 88 inches long by 106 inches wide. The foundation excavation (which includes a section of backfill) is 50 inches deep by 122 inches wide by 144 inches long.

NMSB II Maximum Security Barrier

The NMSB II, manufactured by Nasatka Barrier, Inc., is a wedge-shaped gate set in a reinforced concrete foundation. (See Figure 4-18 for photograph.) The above-ground dimensions are 31 inches high by 168 inches wide (10 feet of road width) by 144 inches long. The foundation excavation is 1 foot deep by 14 feet long by 12 feet wide with a 30-inch leg along the front edge.

NMSB IV Maximum Security Barrier

The NMSB IV, also manufactured by Nasatka Barrier, Inc., is a wedge-shaped gate set in a reinforced concrete foundation. The NMSB IV looks very similar to the NMSB II.

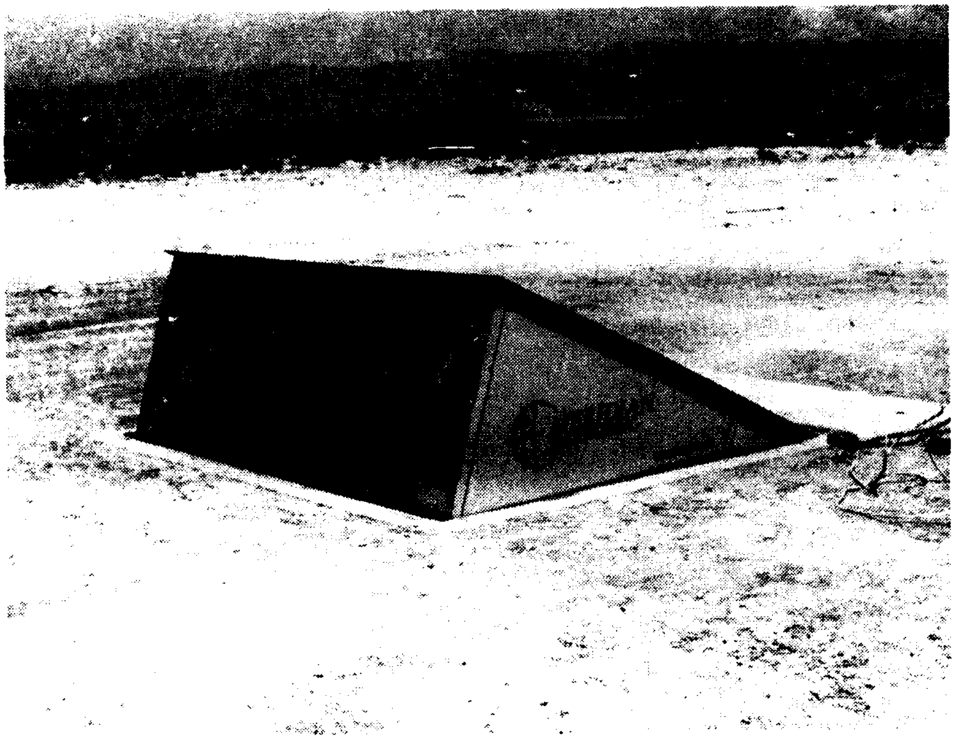


FIGURE 4-17. MODEL 0915 SECURITY GATE

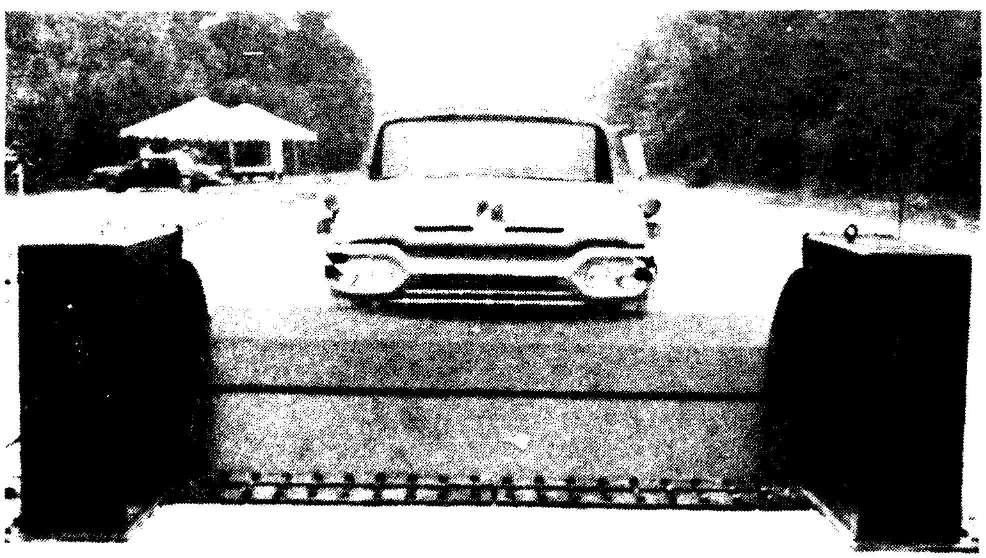


FIGURE 4-18. NMSB II MAXIMUM SECURITY BARRIER

TI/Terio Vehicle Restraining System

The TI/Terio Vehicle Restraining System, manufactured by Terio International, Inc., is a vertical gate consisting of a wire rope net secured to a steel I-beam frame, which is set in a reinforced concrete foundation. (See Figure 4-19 for photograph.) Fully extended, the barrier is over 6 feet high and 10 to 12 feet wide.

Magnum Heavy Duty Vehicle Arrest System

The Magnum, manufactured by Western Industries, Inc., is a wedge-shaped gate set in a reinforced concrete foundation. (See Figure 4-20 for photograph.) The above-ground dimensions are 32 inches high by 52 inches long with an optional width of 71 to 155 inches. The foundation excavation is 5 feet deep by 14 feet long by 14 feet wide.

Portapungi Vehicle Barrier

The Portapungi, also manufactured by Western Industries, Inc., is a shallow mount barrier. See Figure 4-21 for photograph.

De-Fender Series Retractable Vehicle Bollard Barricades

The De-Fender, also manufactured by Western Industries, Inc., is a retractable bollard barricade. See Figure 4-22 for photograph.

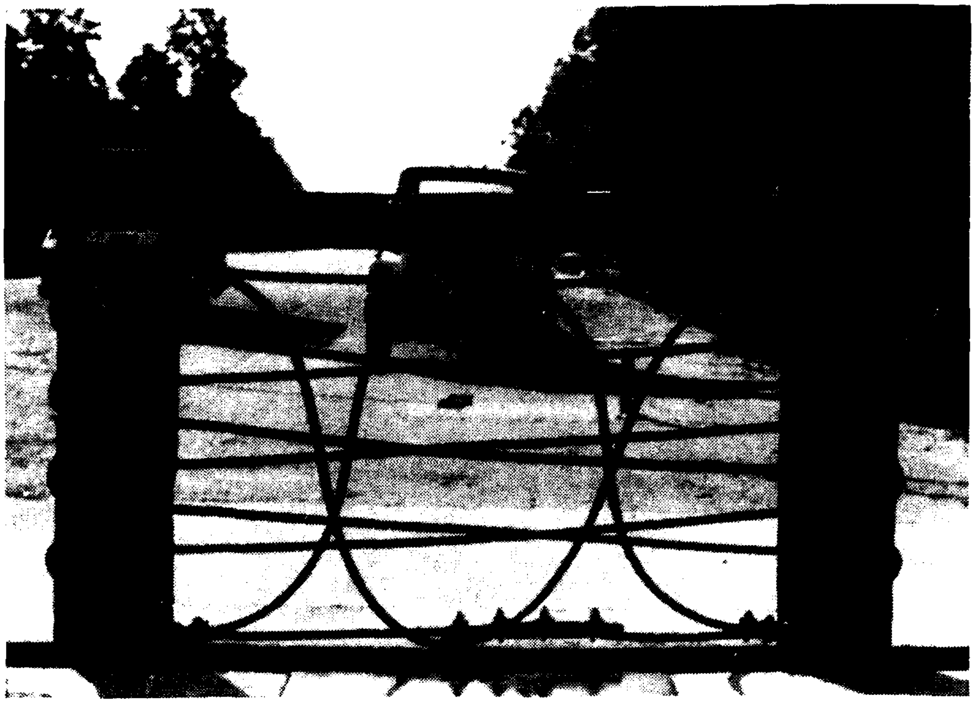


FIGURE 4-19. TI/TERIO VEHICLE RESTRAINING SYSTEM

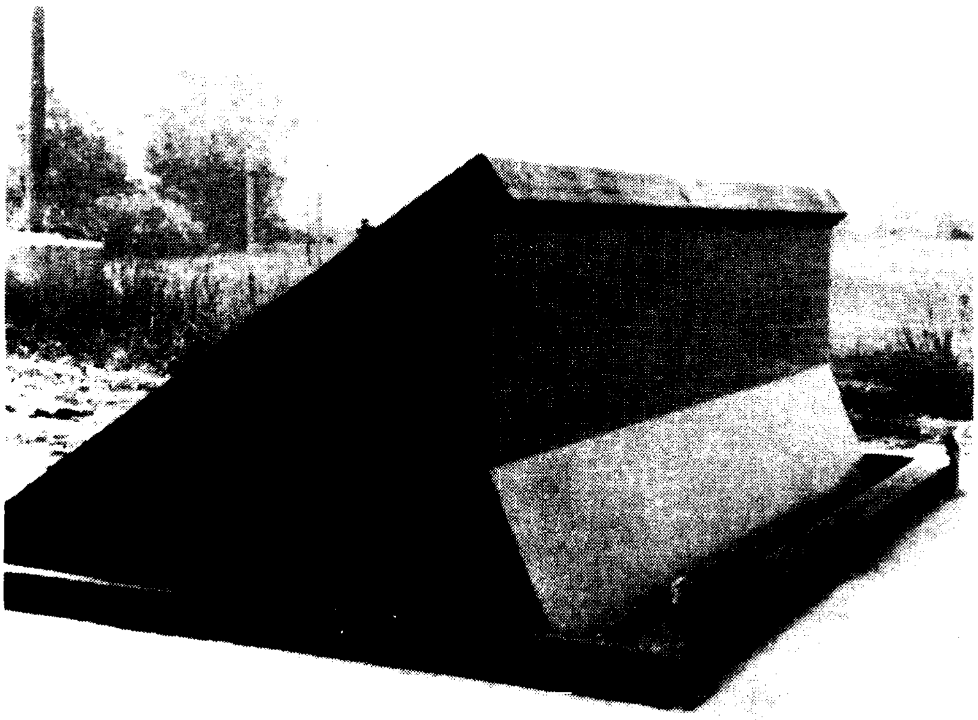


FIGURE 4-20. MAGNUM HEAVY DUTY VEHICLE ARREST SYSTEM

FIGURE 4-21. PORTAPUNGI VEHICLE BARRIER

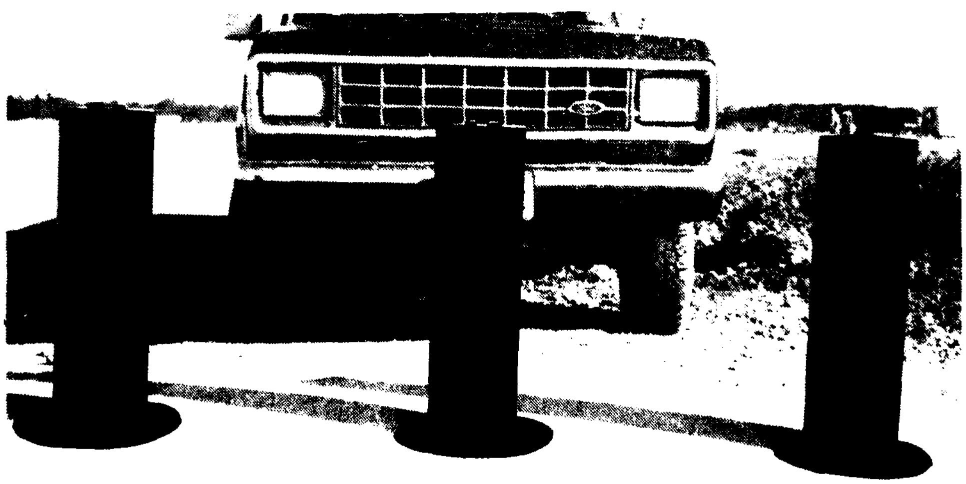


FIGURE 4-22. DE-FENDER SERIES RETRACTABLE VEHICLE BOLLARD BARRICADES

GLOSSARY

Active barrier	Penetration-resistant gate which can be lowered or rotated to permit vehicles or pedestrians to pass into or out of the compound.
Bollard	Steel pipe filled with concrete used in fixed barrier construction.
DOS	Department of State.
Fixed (Passive) barrier	Barrier designed to remain in its original deployed configuration, i.e., it cannot be lowered or opened to permit vehicle or pedestrian passage.
K level	Department of State term to categorize attack vehicle speed to assess severity of impact. K4 includes speeds from 28.0 to 37.9 mph; K8, 38.0 to 46.9 mph; and K12, 47.0 to 56.9 mph.
L level	Department of State term to categorize the distance that an attack vehicle penetrates a compound. L1 includes distances from 20 to 50 feet; L2, 3 to 20 feet; and L3, 0 to 3 feet.
Measuring wheel	An instrument to measure long distances.
mph	Miles per hour.
Nominal speed	An approximated speed representing a small range of actual vehicle speeds.
On center	Measured from the center of an object.
Protective barrier	Permanent structure located along the perimeter of a compound designed to ward off high-speed ramming attacks by heavy, explosive-laden vehicles.

APPENDIX

TABLE A-1. CHECKLIST OF PERIMETER MAPPING CONSIDERATIONS

Items To Be Considered	Considered
Buildings Outside the compound but within 1200 feet of the compound boundaries	
Sidewalks and driveways leading to the compound	
Streets Outside the compound boundaries but within 1,200 feet of the compound boundaries	
Waterways (creeks, rivers, irrigation ditches, canals, oceans, lakes, seas) Outside the compound boundaries but within 1,200 feet of the compound boundaries and at least 3 feet deep at their lowest (low tide or when drained)	
Ditches Outside the compound boundaries but within 1,200 feet of the compound boundaries and at least 3 feet deep at their lowest, and at least 10 feet wide	
Monuments (statues, fountains, grave stones, works of art) Outside the compound boundaries but within 1,200 feet of the compound boundaries and at least 3 feet high and 3 feet in circumference	
Mountains Outside the compound boundaries but within 1,200 feet of the compound boundaries and unpassable by 4-wheel drive vehicles	

TABLE A-2. SINES AND COSINES

Angle	Sine	Cosine	
0	0.00	1.00	90
1	.018	1.00	89
2	.035	.999	88
3	.052	.999	87
4	.070	.998	86
5	.087	.996	85
6	.105	.995	84
7	.122	.993	83
8	.139	.990	82
9	.156	.988	81
10	.174	.985	80
11	.191	.982	79
12	.208	.978	78
13	.225	.974	77
14	.242	.970	76
15	.259	.966	75
16	.276	.961	74
17	.292	.956	73
18	.309	.951	72
19	.326	.946	71
20	.342	.940	70
21	.358	.934	69
22	.375	.927	68
23	.391	.921	67
24	.407	.914	66
25	.423	.906	65
26	.438	.899	64
27	.454	.891	63
28	.470	.883	62
29	.485	.875	61
30	.500	.866	60
31	.515	.857	59
32	.530	.848	58
33	.545	.839	57
34	.559	.829	56
35	.574	.819	55
36	.588	.809	54
37	.602	.799	53
38	.616	.788	52
39	.629	.777	51
40	.643	.766	50
41	.656	.755	49
42	.669	.743	48
43	.682	.731	47
44	.695	.719	46
45	.707	.707	45
	Cosine	Sine	Angle

EQUATIONS AND WORK SPACE

Equation to compute distance in inches on scaled map from actual distance:

$$\textit{measured distance in feet} \times \frac{\textit{inch measurement in scale}}{\textit{foot measurement in scale}} = \textit{x inches}$$

Equation to compute actual distance from distance in inches from map:

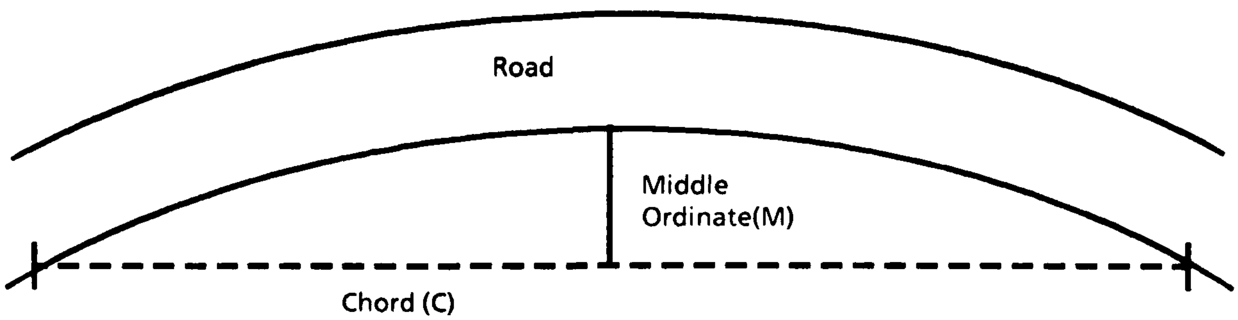
$$\textit{measured distance in inches} \times \frac{\textit{foot measurement in scale}}{\textit{inch measurement in scale}} = \textit{distance in feet}$$

Setting up a scale:

$$\textit{measured distance in feet} = \textit{measured distance in inches}$$

EQUATIONS AND WORK SPACE

Equation to compute radius of curvature:



$$R = \frac{C^2}{8M} + \frac{M}{2}$$

where R is the radius of the curve in feet
C is the length of the chord in feet
M is the length of the middle ordinate in feet

EQUATIONS AND WORK SPACE

Equation to find adjusted distance due to gradient:

$$S_{EQUIVALENT\ S\ WITH\ 0\ GRADIENT} = S_{MEASURED\ DISTANCE} \text{ x } COSINE\ G$$