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NUREG/CR-6190
VOL. II

Protection Against Malevolent Use of Vehicles at Nuclear Power Plants

Vehicle Barrier System Selection Guidance

Manuscript Completed: February 1994
Date Published: February 1994

Prepared by
U.S. Army Corps of Engineers, Omaha District
Protective Design-Mandatory Center of Expertise
215 North 17th Street
Omaha, NE 68102-4978

Prepared for
U.S. Nuclear Regulatory Commission
Washington, DC 20555
NRC FIN A0400

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ABSTRACT

This manual provides a simplified procedure for selecting land vehicle barriers that will stop the design basis vehicle threat adopted by the U.S. Nuclear Regulatory Commission. Proper selection and construction of vehicle barriers should prevent intrusion of the design basis vehicle. In addition, vital safety related equipment should survive a design basis vehicle bomb attack when vehicle barriers are properly selected, sited, and constructed. This manual addresses passive vehicle barriers, active vehicle barriers, and site design features that can be used to reduce vehicle impact velocity.

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SECTION 1 - INTRODUCTION

1.1 Purpose

This manual provides a simplified procedure that may be used to select vehicle barriers to prevent intrusion by the design basis vehicle threat adopted by the U.S. Nuclear Regulatory Commission. The procedure presented can be used to determine the adequacy of existing vehicle barriers or it can be used for the planning of new vehicle barriers. The user of this manual should either have a background in civil engineering or should consult a civil engineer when using the manual.

1.2 Scope

This manual presents guidance based on an existing database of vehicle barriers. The procedure presented is an accepted way of demonstrating conformance; however, it is not exclusive. Other procedures based on sound scientific and engineering principles are also acceptable. Barriers not in the database are not disallowed and means of demonstrating conformance for these barriers is discussed.

1.3 Organization

The procedure for controlling vehicle intrusion is organized into the sections listed below.

Section	Topic
2	Vehicle Barrier Systems
3	Design Basis Threat
4	Passive Vehicle Barriers
5	Active Vehicle Barrier Ratings
6	Velocity Reduction Measures
7	Other Vehicle Barriers
8	Documentation
9	Conclusions

SECTION 2 - VEHICLE BARRIER SYSTEMS (VBS)

2.1 Purpose

This section gives the user a basic knowledge of the components of a VBS and the methods by which these components are rated for intrusion resistance.

2.2 System Objective

The purpose of a VBS is to prevent intrusion of vehicles into an area. Additionally, VBS are sited to provide sufficient standoff distance from vital area barriers to minimize damage that could be caused by a vehicle bomb. Refer to Volume I of this NUREG for further information on standoff distance. The area encompassed by the VBS is called an exclusive standoff zone. Only vehicles that have been searched should be allowed into the exclusive standoff zone. The system must be capable of resisting vehicle impact, maintaining at least the required minimum safe standoff distance to vital area barriers, and providing continuous protection in all areas where approach by land vehicle is possible.

2.3 Description

A VBS consists of two components--passive vehicle barriers and active vehicle barriers. Passive vehicle barriers are placed along the perimeter of the exclusive standoff zone except at points through which vehicle access is allowed. These barriers have no moving parts and are in a continuous "ready" position. Active vehicle barriers are used at points in the perimeter of an exclusive standoff zone through which vehicle access is allowed. These barriers are maintained in an active position and must be deactivated by authorized personnel to permit authorized vehicle access. At points that require infrequent vehicle access, removable passive barriers are sometimes used. Where active barriers are used, care must be taken to provide a consistent level of protection where the passive and active barriers interface. The VBS must not be vulnerable to unauthorized entry when an active vehicle barrier is allowing an authorized vehicle access. Both types of barriers are described in subsequent sections.

2.4 Barrier Crash Ratings

Vehicle barriers are rated based on two measures of performance--kinetic energy resisted and penetration allowed.

2.4.1 Kinetic Energy Ratings

The kinetic energy resistance measure of performance rates the capacity of a barrier to stop a vehicle of a particular gross weight at a given velocity. This capacity is measured in kinetic energy according to equation 2-1.

$$KE = 0.03344 \times W \times V^2 \qquad \text{(Eq. 2-1)}$$

KE = kinetic energy (foot-pounds)
W = vehicle weight (pounds)
V = vehicle velocity (miles per hour)

The barrier rating is typically determined through crash testing of full-scale barriers but may also be determined through detailed structural analysis.

2.4.2 Penetration Rating

Some barriers, depending on their construction, allow a vehicle to penetrate some distance before forcing the vehicle to a complete stop. When selecting the standoff distance, the amount of penetration needs to be considered in locating the VBS. Standoff distance--the distance from the stopped vehicle, not the VBS--to the protected facility is required for protection from vehicle bombs. Before siting a new VBS, refer to Volume I of this NUREG for information on determining effective standoff distance and for determining the minimum safe standoff distance that is required to provide the desired level of protection to vital areas.

SECTION 3 - DESIGN BASIS THREAT

3.1 Purpose

This section defines the design threat that a vehicle barrier system (VBS) must resist.

3.2 Definition

The design threat that a VBS has to stop is a specified gross vehicle weight, including weight of material transported, and impact velocity. These two parameters allow calculation of the kinetic energy that VBS must resist.

3.3 Design Basis Threat

The design basis vehicle threat can be found in the Addendum to Regulatory Guide 5.68. That document defines the vehicle weight, maximum payload, and maximum attainable velocity. Also defined in that document is the kinetic energy associated with the combined vehicle weight and payload and maximum attainable velocity, KE_{max}. This KE_{max} is the maximum kinetic energy that any VBS need resist. All of this information has been determined by the Nuclear Regulatory Commission to be Safeguards Information, and it should be handled accordingly.

3.4 Protective Measures Implementation

If site conditions do not provide for velocity reduction, the maximum attainable velocity should be used in calculating the VBS requirements. If it can be demonstrated that site conditions prevent vehicles from attaining the maximum velocity at a point or points along the exclusive standoff zone perimeter, a lesser velocity can be used in calculating the VBS requirements for that point or points. Examples of site conditions that can reduce vehicle velocity are curved approach roads, inclines, ditches, berms, etc. Section 6 contains information on velocity reduction. The kinetic energy associated with the lesser velocity is calculated using equation 2-1. No vehicle barriers are needed in areas of the exclusive standoff zone perimeter that are unapproachable by land vehicle due to site conditions. Examples of site conditions that would prevent approach by land vehicles are bodies of water and terrain. The velocity that is used to determine VBS requirements and the associated kinetic energy have been determined by the Nuclear Regulatory Commission to be Safeguards information, and it should be handled accordingly.

SECTION 4 - PASSIVE VEHICLE BARRIERS

4.1 Purpose

This section provides information from an existing database of passive vehicle barriers. Passive vehicle barrier ratings as well as construction details are contained in this section. If passive vehicle barriers other than those cited are used, or proposed for use, refer to section 7.

4.2 Passive Vehicle Barriers

Information on concrete planters, Jersey barriers, bollards, and cable reinforced fences is presented below. The information on these types of passive vehicle barrier systems includes typical construction details, kinetic energy ratings, and penetration allowed. Proper installation, along with foundation designs consistent with local site conditions, of barriers with kinetic energy ratings equal to or greater than KE_{max} require no additional site features related to passive vehicle barriers to reduce velocity. However, additional site features for velocity reduction may be required related to active vehicle barriers. The use of passive vehicle barriers with kinetic energy rating less than KE_{max} requires the user to provide positive means for velocity reduction as discussed in section 6.

4.2.1 Basis of Ratings

The basis of the barrier ratings presented, both kinetic energy and penetration, are analytical modeling using the computer program BIRM (Barrier Impact Response Model) and other methods. Information on BIRM is contained in U.S. Army Corps of Engineers Protective Design - Mandatory Center of Expertise Technical Report PDC-TR 90-2, *BIRM -- A Vehicle Barrier Response Model Using BARRIER VII*. The penetration that is reported represents maximum barrier deflection. These values do not consider vehicle vaulting or components of the vehicle that may disengage and be propelled beyond the barrier as is normally reported in full-scale crash testing.

4.2.2 Foundations

Foundation designs consistent with local site conditions, along with proper installation, are required for barriers to perform properly. Ratings for different soil conditions are provided for planters, Jersey barriers, and bollards. Sandy loam, saturated clay, and stiff clay are described in geotechnical engineering and soil mechanics manuals. Base material is a double crushed, well-graded aggregate mixed with a binder material. Base material is commonly used in highway and building foundation construction and is a suitable material for subgrade preparation. Soil type is not a major parameter for cable reinforced fence.

4.2.3 Concrete Planters

Table 4.1 contains kinetic energy ratings and penetration ratings for concrete planters in various foundation conditions. Figure 4.1 contains typical construction details of concrete planters. To be considered anchored, the planter must be embedded 1 foot, 6 inches into the foundation, as illustrated in figure 4.1. For a concrete foundation, the planter must be embedded 18 inches, with the top 6 inches of the foundation being concrete. Planters not meeting this embedment criteria should be considered unanchored.

4.2.4 Jersey Barriers

Table 4.2 contains kinetic energy ratings and penetration ratings for Jersey barriers in various foundation conditions. Figure 4.2 contains typical construction details of Jersey barriers. To be considered anchored, the barriers must be secured to the foundation every 3 feet, 3 inches along the barrier, alternating from side to side, with 1-inch diameter by 3-foot-long steel pins. Jersey barriers not meeting this criteria should be considered unanchored.

4.2.5 Bollards

Table 4.3 contains kinetic energy ratings and penetration ratings for bollards in various foundation conditions. Figure 4.3 contains typical construction details of bollards.

4.2.6 Cable Reinforced Fences

Table 4.4 contains kinetic energy ratings and penetration ratings for fence reinforced with two 3/4-inch diameter extra improved plow steel cables with various deadman spacings. Figures 4.4 through 4.7 contain typical construction details of cable reinforced fences.

Table 4.1 Concrete planter ratings

Foundation	Kinetic Energy Rating (ft-lb x 1000)	Penetration Allowed (ft)
Concrete	$\geq KE_{max}$	1
Base Material	$\geq KE_{max}$	2
Stiff Clay	$\geq KE_{max}$	1
Saturated Clay	$\geq KE_{max}$	1
Sandy Loam	$\geq KE_{max}$	1
Unanchored on Concrete	94	1

Table 4.2 Jersey barrier ratings

Foundation	Kinetic Energy Rating (ft-lb x 1000)	Penetration Allowed (ft)
Concrete	$\geq KE_{max}$	1
Base Material	$\geq KE_{max}$	1
Stiff Clay	$\geq KE_{max}$	2
Saturated Clay	210	1
Sandy Loam	286	1
Unanchored on Concrete	24	1

Table 4.3 Bollard ratings

Foundation	Kinetic Energy Rating (ft-lb x 1000)	Penetration Allowed (ft)
2 Feet on Center		
Concrete	$\geq KE_{max}$	1
Base Material	$\geq KE_{max}$	1
Stiff Clay	$\geq KE_{max}$	1
Saturated Clay	$\geq KE_{max}$	1
Sandy Loam	$\geq KE_{max}$	1
3 Feet on Center		
Concrete	$\geq KE_{max}$	1
Base Material	$\geq KE_{max}$	1
Stiff Clay	$\geq KE_{max}$	1
Saturated Clay	287	1
Sandy Loam	210	1
4 Feet on Center		
Concrete	$\geq KE_{max}$	2
Base Material	474	3
Stiff Clay	210	1
Saturated Clay	210	1
Sandy Loam	210	1

Table 4.4 Cabled fence ratings

Deadmen Spacing (ft)	Kinetic Energy Rating (ft-lb x 1000)	Penetration Allowed (ft)
200		
	211	28
	146	24
	94	19
	53	14
	23	9
	6	5
100		
	94	18
	53	13
	23	9
	6	4
50		
	53	9
	23	6
	6	3

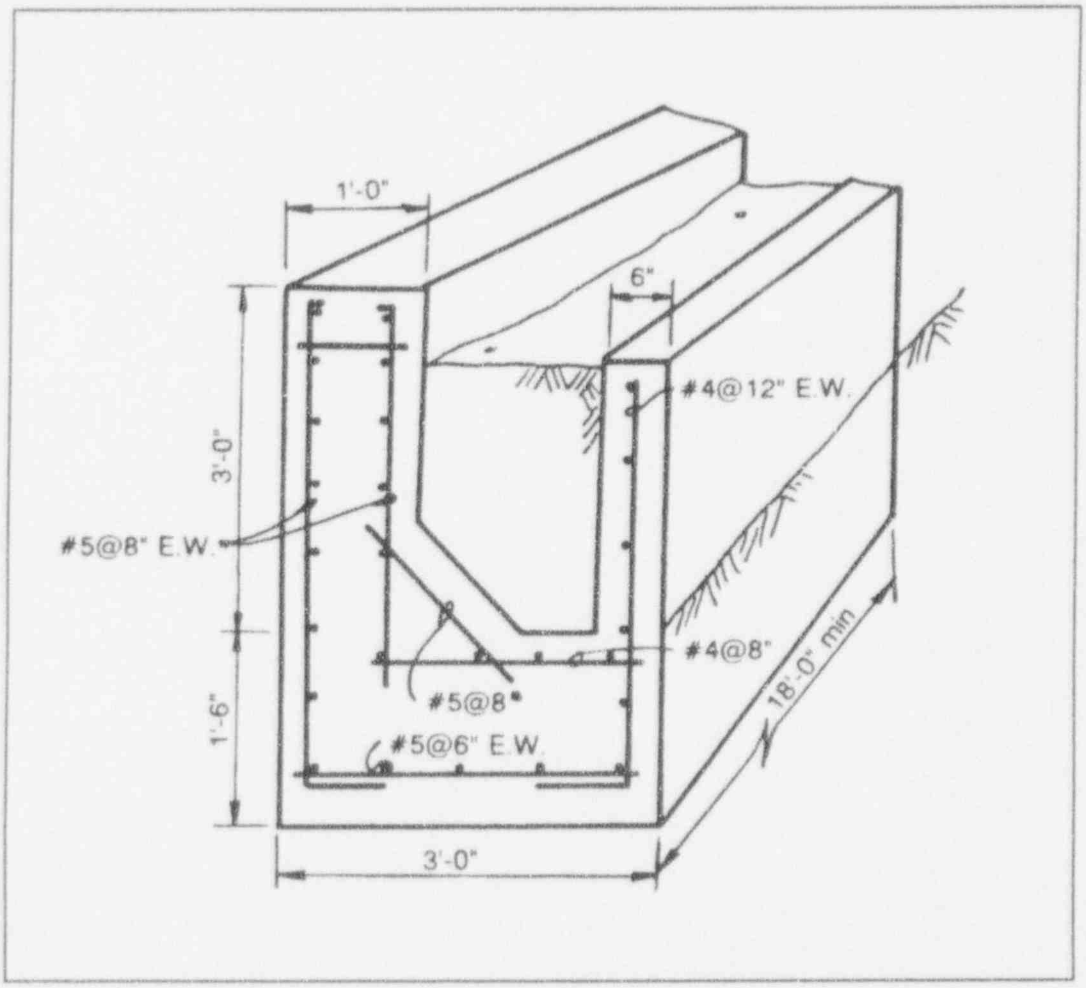

Figure 4.1 Minimum construction requirements for concrete planters

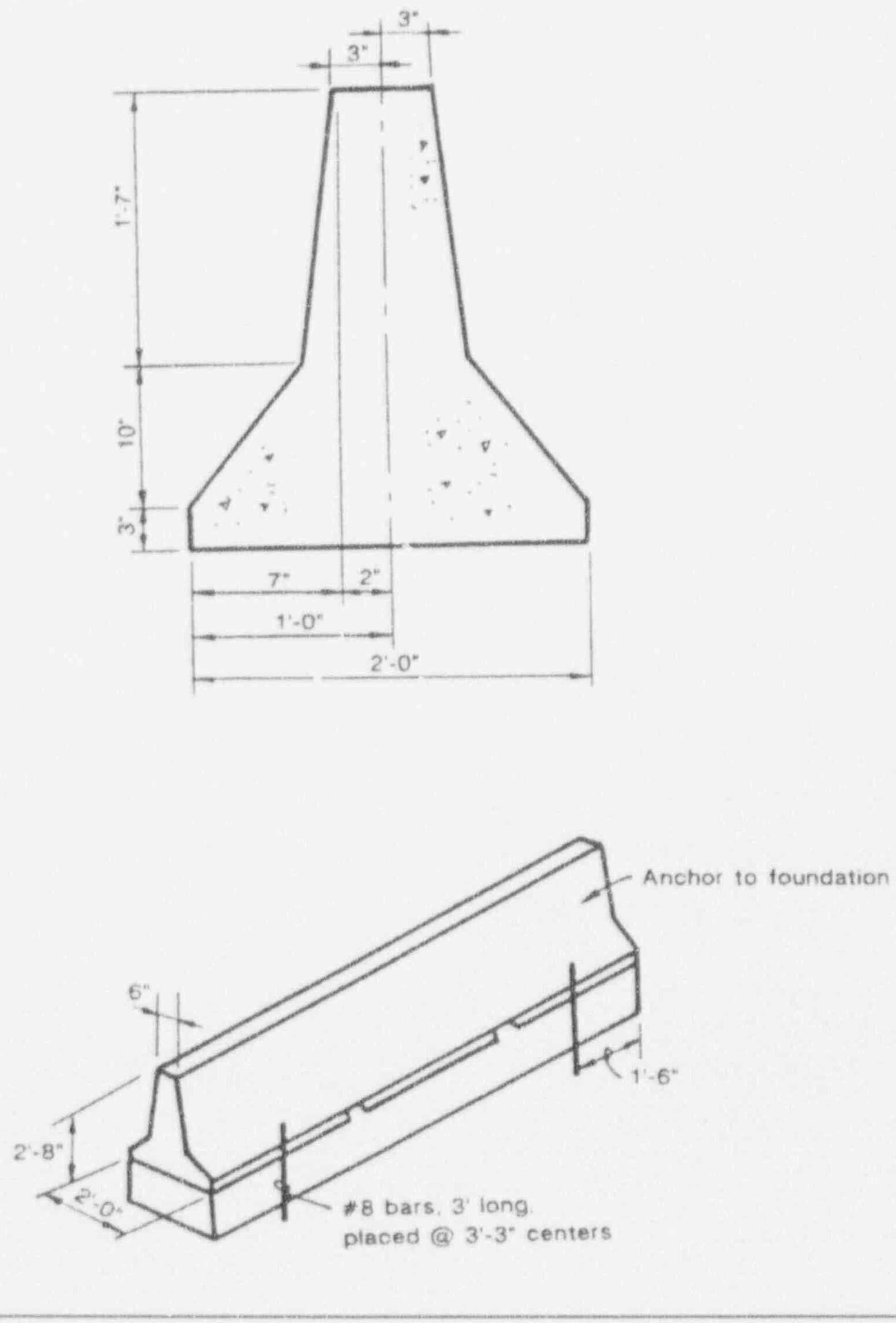

Figure 4.2 Minimum construction requirements for Jersey barriers

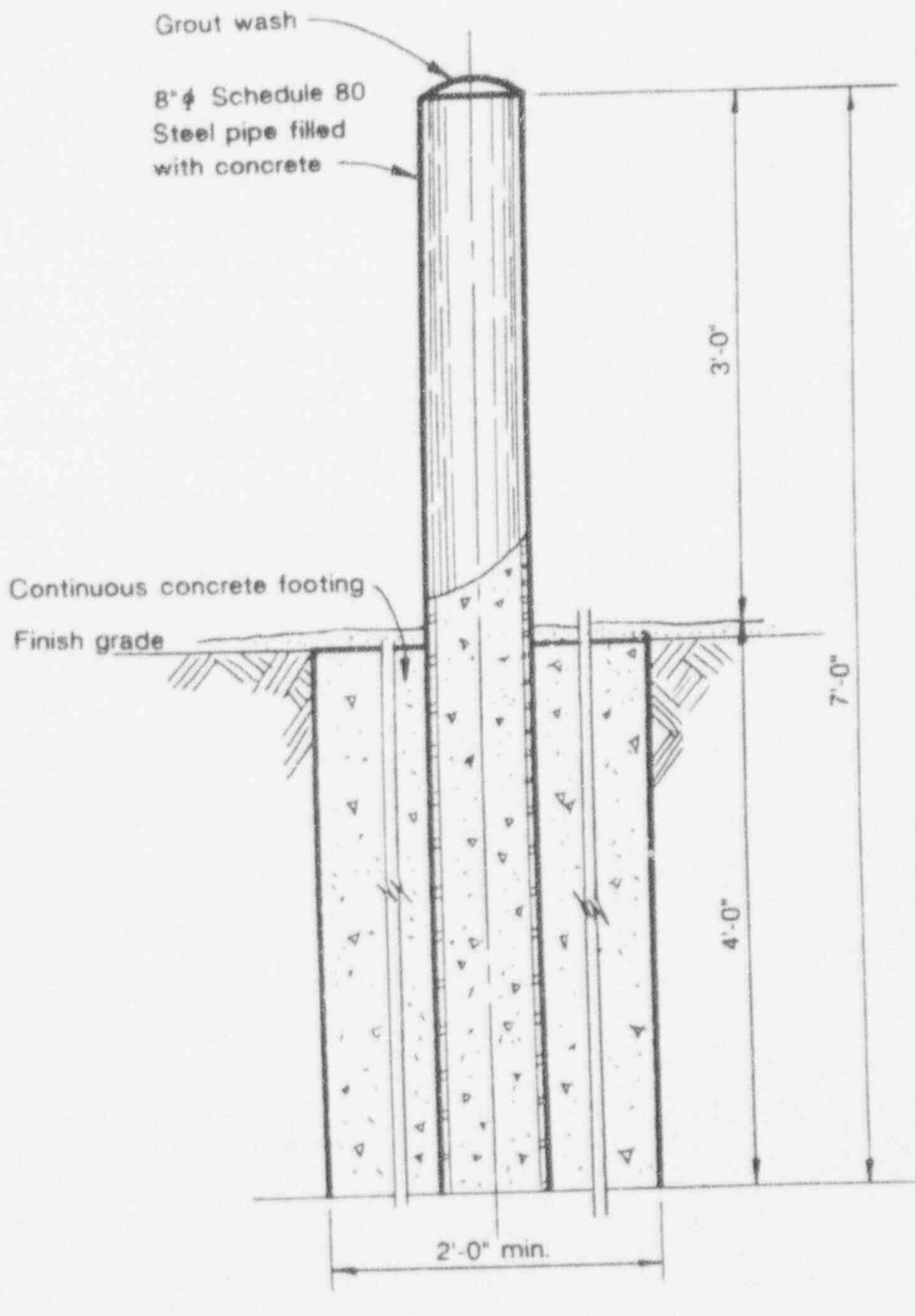

Figure 4.3 Minimum construction requirements for bollards

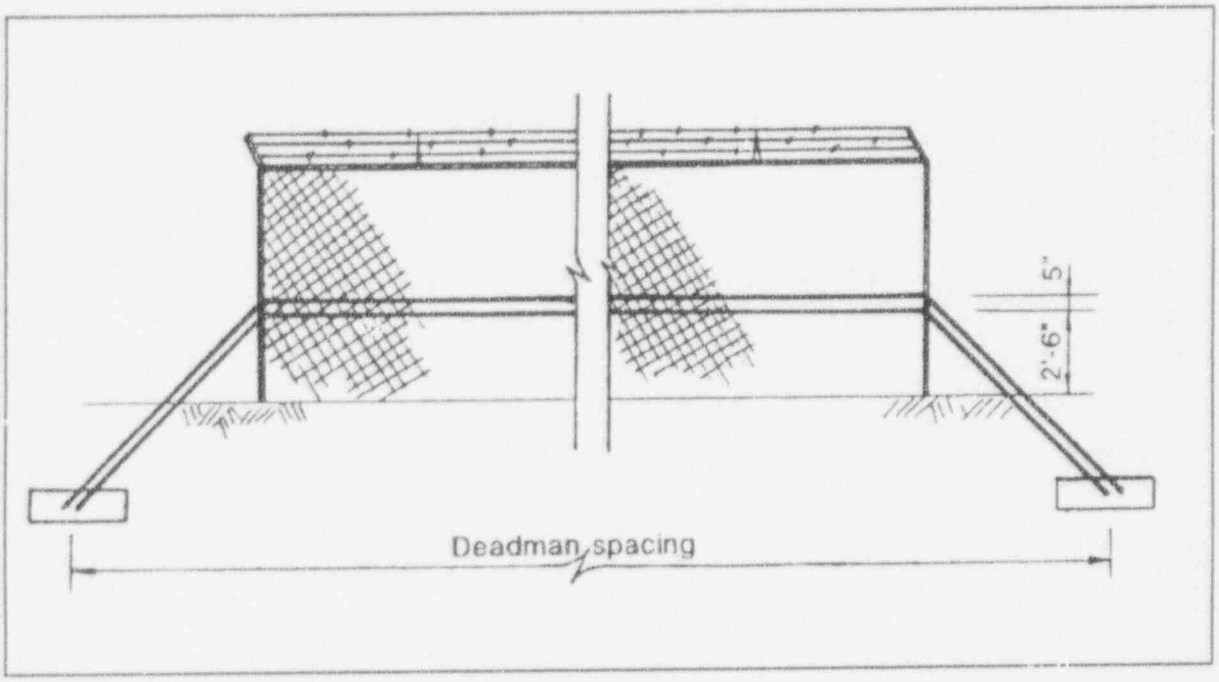

Figure 4.4 Chain-link fence with two 3/4-inch diameter cables

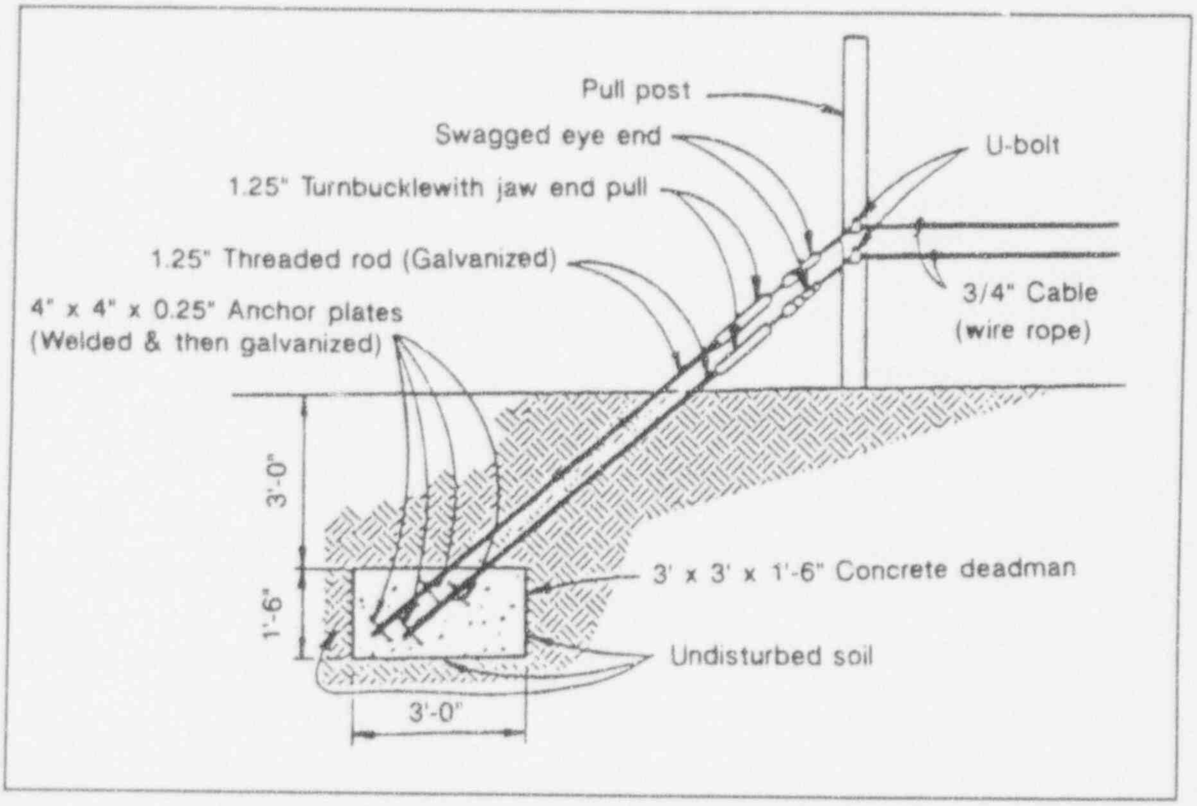

Figure 4.5 Deadman detail

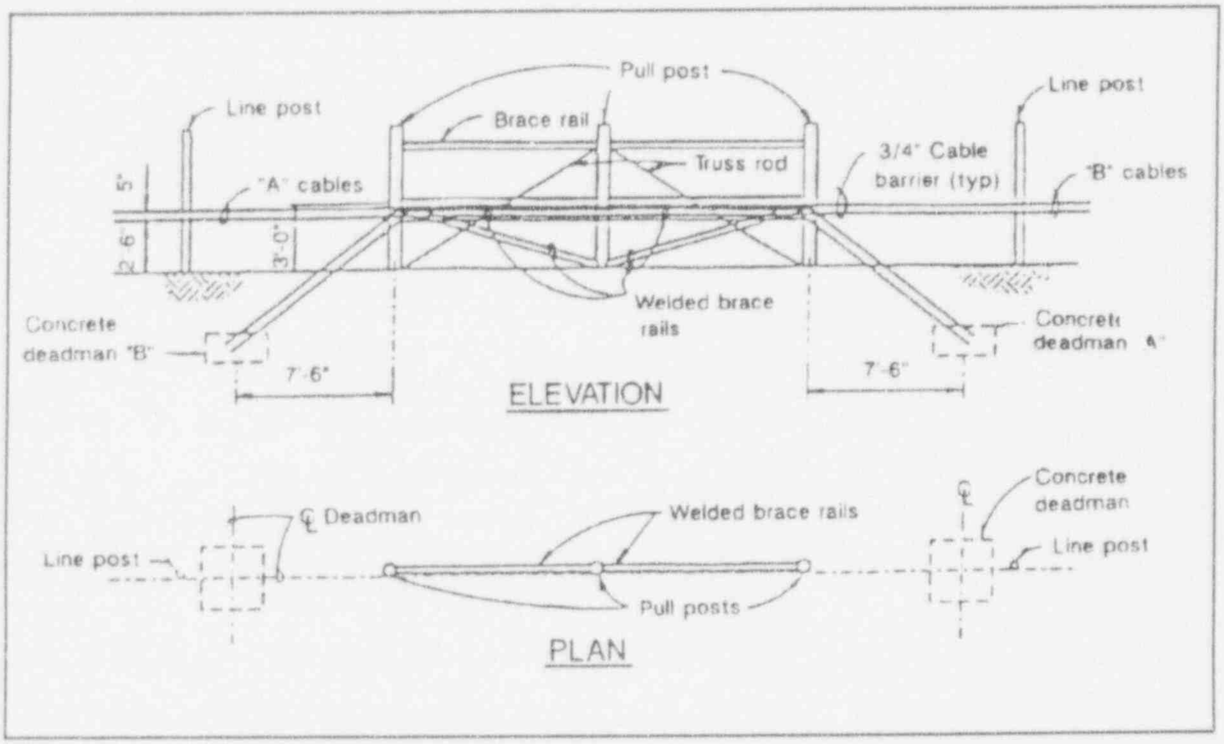

Figure 4.6 Intersect of two cable runs detail

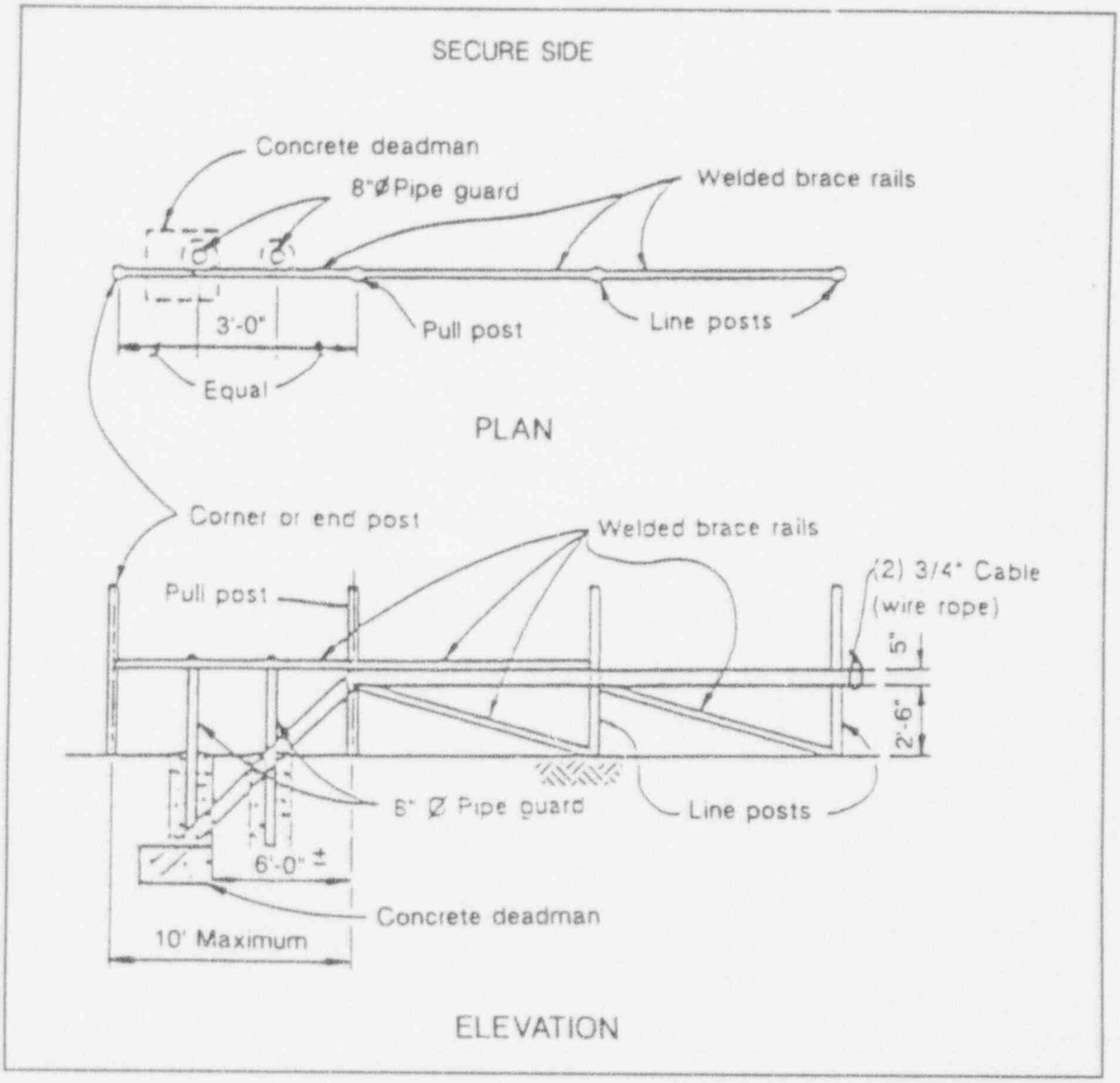

Figure 4.7 Corner or end post detail

SECTION 5 - ACTIVE VEHICLE BARRIER RATINGS

5.1 Purpose

This section provides information from an existing database on the crash ratings of active vehicle barriers. If active vehicle barriers other than those cited are used, or proposed for use, refer to section 7.

5.2 Active Vehicle Barriers

Table 5.1 provides a list of active vehicle barriers that have established ratings based on crash testing and analytic modeling. Proper installation, along with foundation designs consistent with local site conditions, of barriers with kinetic energy ratings equal to or greater than KE_{max} require no additional site features related to active vehicle barriers for velocity reduction. However, additional site features for velocity reduction may be required related to passive vehicle barriers. The use of active vehicle barriers with kinetic energy rating less than KE_{max} requires the user to provide means for velocity reduction as discussed in section 6.

Table 5.1 Results of active vehicle barrier tests

Barrier	Kinetic Energy (ft-lb x 1000)	Penetration[1] Allowed (ft)
Dragnet Vehicle[2] Arresting Barrier (VAB)	86.1	10.2
Dragnet VAB[2]	517.7	19.4
Dragnet VAB[2]	124.8	13.8
Dragnet VAB[2]	440.7	23.5
Dragnet VAB[2]	394.3	26.3
Dragnet VAB[2]	498.7	>30.0
Dragnet VAB[2]	296.0	51.6
Dragnet VAB[2]	$\geq KE_{max}$	93.5
Delta TT207 30 in. high 208 in. long (Drum type)	541.7	29.0
Delta TT207 30 in. high 108 in. long (Drum type)	501.6	27.0
Delta TT207S 38 in. high 108 in. long (Drum type)	$\geq KE_{max}$	0.75
Delta TT207FM 36 in. high 144 in. long (Plate type)	$\geq KE_{max}$	0
Delta TT212 (crash beam)	97.6	0
Delta TT210 (Bollard)	519.8 535.0	12.2 0
Delta TT224 24 in. high 17 in. wide (Drum type)	168.7	82.0

Table 5.1 Results of active vehicle barrier tests (continued)

Barrier	Kinetic Energy (ft-lb x 1000)	Penetration[1] Allowed (ft)
Delta TT280 Crash gate	$\geq KE_{max}$	5.5
Delta TT282 Crash gate	$\geq KE_{max}$	0
Delta SGC 1000 Swing gate (Not crash tested)	200.8[3]	
Delta TT281 38 in. high Crash blocker	$\geq KE_{max}$	5.5
Delta SC3000 Industrial Cantilever Gate (Not crash tested)	361.7[3]	
Nasatka MSB III 31 in. high (Plate type)	$\geq KE_{max}$	0
Nasatka MSB V 34 in. high (Drum type)	$\geq KE_{max}$	10.0
Nasatka MSB VII 24 in. high (Plate type)	535.0	0
Nasatka MSB XI 18 in. high (Plate type)	120.4	8.0
True Portapungi (Portable or fixed)	$\geq KE_{max}$	40.0
True Magnum (Drum type)	$\geq KE_{max}$	0
True Magnum Narrow Blade	$\geq KE_{max}$	2.0

Table 5.1 Results of active vehicle barrier tests (continued)

Barrier	Kinetic Energy (ft-lb x 1000)	Penetration[1] Allowed (ft)
True Stinger (Plate type)	$\geq KE_{max}$	2.0
True Magnum Defender Bollards	421.5	10.5
True Magnum SEMA-4 Vehicle Crash Beam	75.2	2.0
Barrier Concepts Inc. VSB-F10 (Portable or fixed)	$\geq KE_{max}$	0
B&B Electromatic Crash Beam (R-25 Manual)	106.7	4.0
Embassy Crash Gate EGS-1	$\geq KE_{max}$	0

(1) Values presented represent maximum observed penetration of vehicle or vehicle components.

(2) Not tested per Department of State (DOS) or Department of Defense (DOD) standards and the tests were not observed by a government agency. The barrier system is Federal Highway Administration (FHA) approved for use on federal-aid highway projects.

(3) Kinetic energy is based on analytical modelling.

SECTION 6 - VELOCITY REDUCTION MEASURES

6.1 Purpose

This section provides procedures for causing impact velocity reduction. Barriers with lesser kinetic energy ratings can be used if the impact velocity can be reduced from the maximum attainable velocity. The maximum attainable velocity should be used if it cannot be demonstrated that site conditions will provide velocity reduction.

6.2 Determining Reduced Vehicle Velocity

The information below can be used to determine the velocity that vehicles can attain as they approach vehicle barriers. This information addresses maximum velocity on paved curves and on straight paved roads and is conservative for off-road approaches.

6.2.1 Velocity on Curves

Figure 6.1 can be used to determine the maximum attainable vehicle velocity on curves. This figure assumes a flat paved roadway with a coefficient of friction of 0.6. This is a representative coefficient for most dry roads and should provide conservative results across a wide range of surface conditions. Determine the maximum velocity based on the radius of curve to the middle of the road. At velocities greater than those shown in figure 6.1 for the various radii, the vehicle will begin to skid.

6.2.2 Velocity on Straight Roads

Figure 6.2 can be used to determine the maximum velocity of vehicles on straight roads. This figure shows vehicle velocity from a dead start on a dry road and includes data for flat roads and three different uphill grades. Figure 6.2 should provide conservative results for other road surface conditions. Do not use figure 6.2 for downhill grades. Where possible, avoid downhill grades toward the VBS. Using the data appropriate for the grade of the road, determine the maximum velocity based on the distance between the point at which the vehicle starts from a dead stop and the vehicle barrier. If the vehicle has an initial velocity before it begins its run at the barrier, refer to figure 6.2 at the initial velocity and read the distance corresponding to that velocity. Move to the right from that corresponding distance by the distance to the barrier and read the velocity associated with that new distance.

6.2.3 Traffic Obstacles

Traffic obstacles such as those shown in figure 6.3 can be used to slow vehicles approaching a vehicle barrier on existing roads without curves or on roads with curves of insufficient radius to slow traffic. Traffic obstacles include oil drums, planters, Jersey barriers, and various concrete or steel objects. These obstacles will not stop a vehicle on impact, but they will slow it down or cause the driver to drive around them, which will also slow the vehicle. Use the obstacles to create "S" curves in the road as illustrated in figure 6.4. Use figure 6-5 to determine the required spacing in a straight section of two-lane road using barriers or groups of barriers with an effective width of 10 feet. Use wider barriers for lane widths greater than 12 feet. Figure 6.5 can conservatively be used for establishing obstacles in off-road approaches as well.

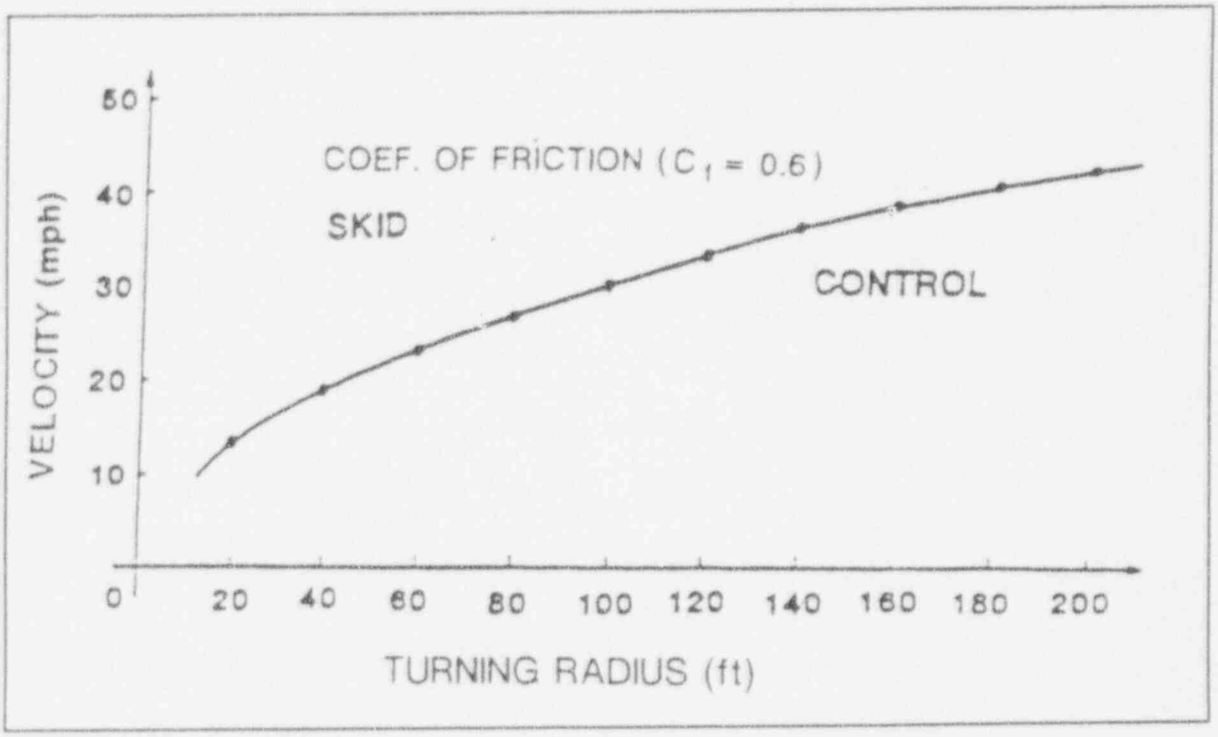

Figure 6.1 Maximum vehicle velocity on curves

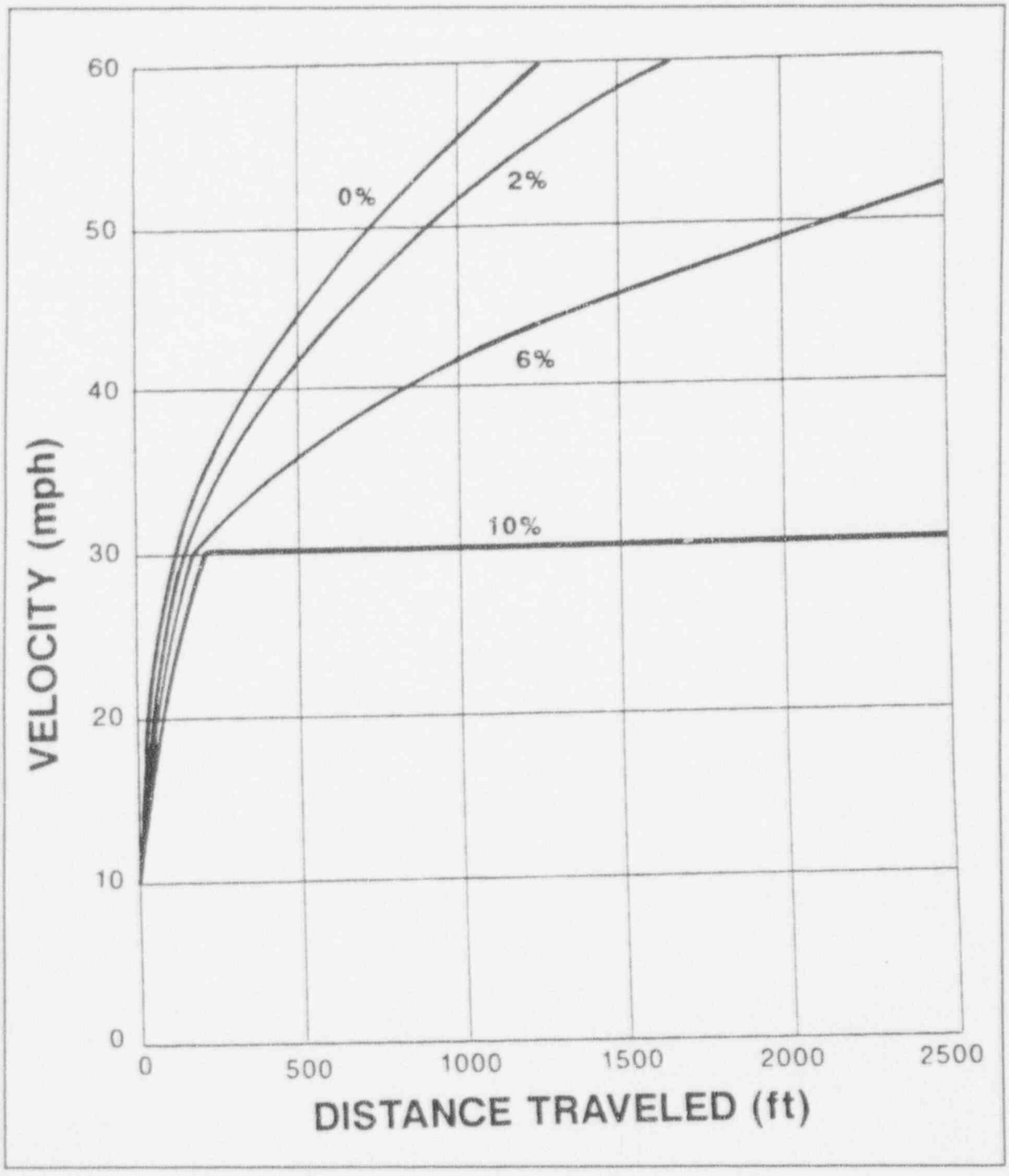

Figure 6.2 Vehicle velocity from dead start

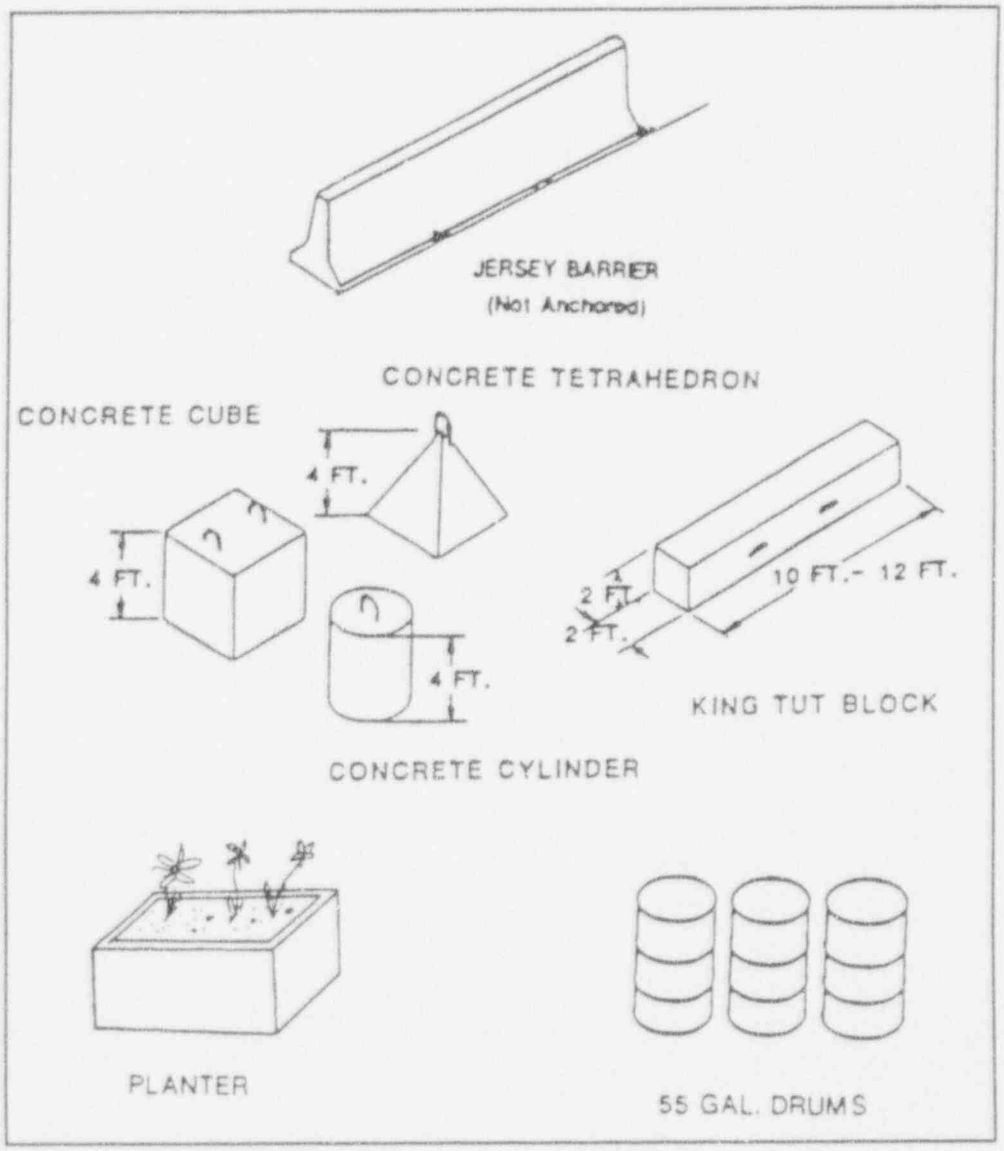

Figure 6.3 Perimeter barriers used as traffic obstacles

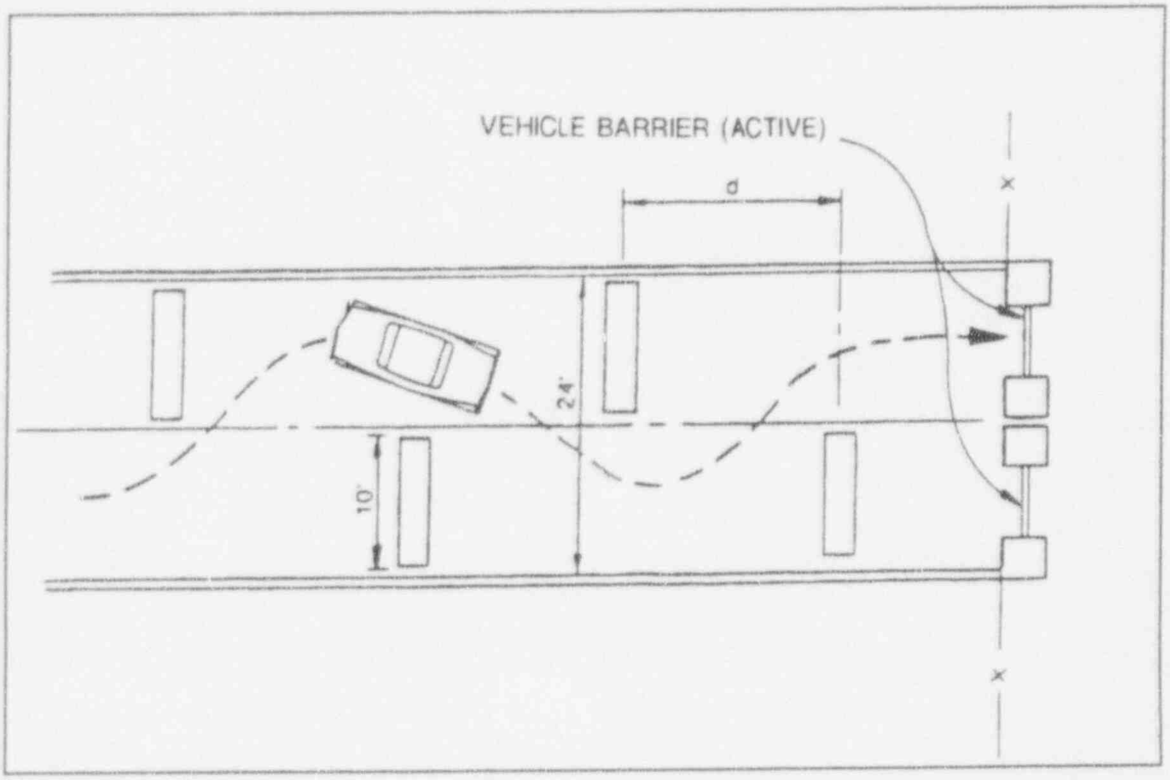

Figure 6.4 Application of traffic obstacles

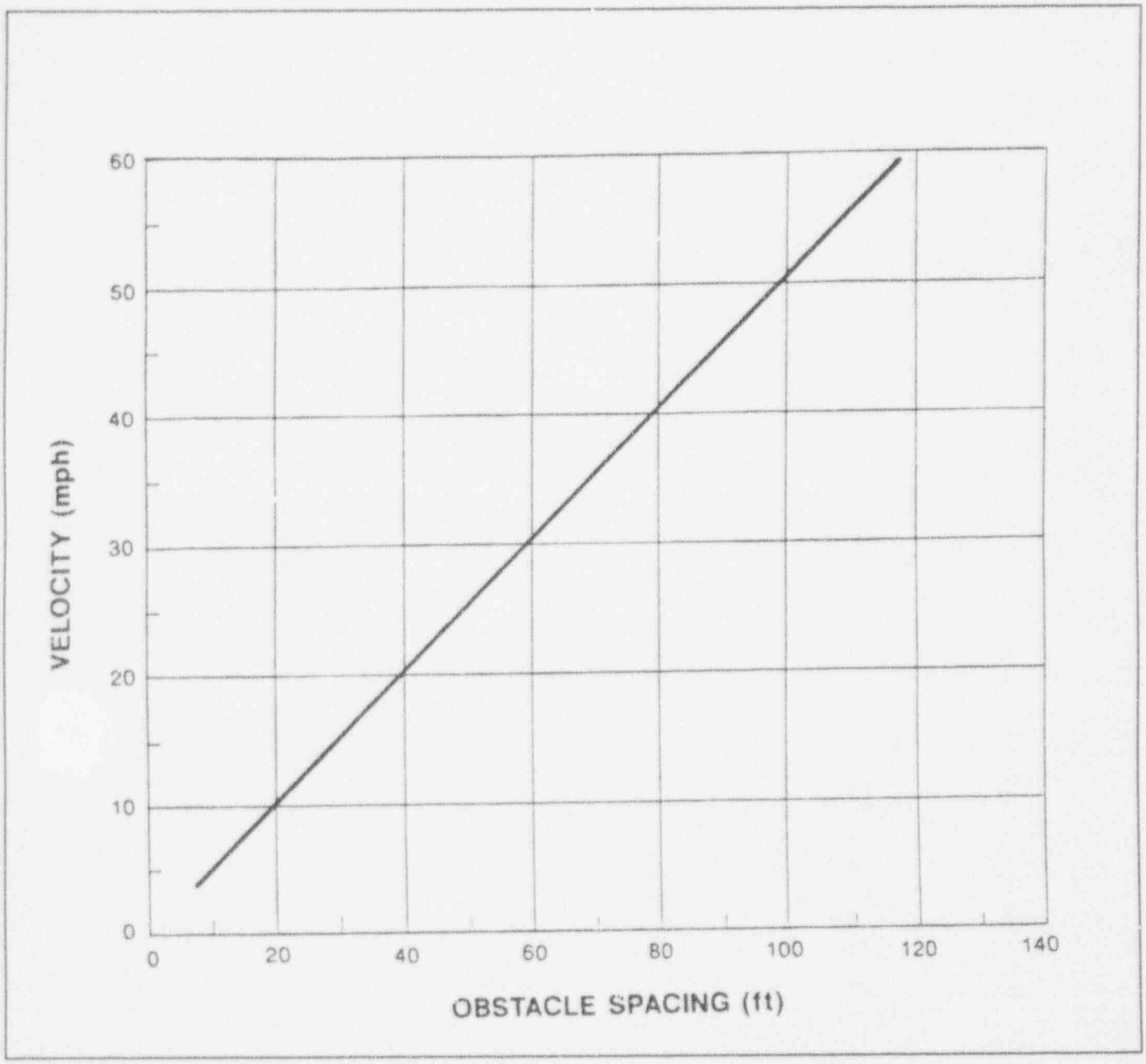

Figure 6.5 Obstacle spacing vs. vehicle velocity

6.2.4 Examples

6.2.4.1 Curves

There is a maximum speed at which a vehicle can negotiate a curve. Using the graph in figure 6.6, the traction coefficient, the initial speed, and the measurements for the radius of curvature, the maximum speed for each curve can be determined. For example, figure 6.6 shows that if the radius of the curve is 160 feet, the maximum speed at which the curve can be negotiated is 38.5 mph. Since we have assumed no acceleration on curves, the resultant speed is the speed at which the vehicle can negotiate the curve.

6.2.4.2 Straight Paths From a Dead Start

To find the maximum velocity of a vehicle at the end of a straight path starting at a dead start, follow the example presented in figure 6.7. In this example, the road will be straight, level (0% grade), and the distance that the vehicle travels will be 500 feet. The following steps demonstrate the procedure to use.

(a) Find 500 feet on the horizontal axis and label this point S.

(b) Draw a vertical line up from point S until it intersects the 0% grade curve.

(c) Draw a horizontal line from the intersection point to the vertical axis.

(d) Read the maximum velocity V_S from the vertical axis, 45 mph.

6.2.4.3 Straight Paths With an Initial Velocity

To find the maximum velocity at the end of a straight path when the vehicle has an initial velocity, follow the example presented in figure 6.8. In this example, the roadway will be level (0% gradient), the initial speed will be 40 mph and the distance traveled, S, will be 700 feet The following steps explain the procedure to be used.

(a) Label the initial speed V_T = 40 mph on the vertical axis of the graph.

(b) Draw a horizontal line from V_T = 40 to the point where that line intersects the 0% gradient curve.

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

(d) Read the acceleration distance at this point from the horizontal axis, 380 feet.

(e) Label the point T = 380 feet.

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

$$S + T = 700 + 380 = 1{,}080 \text{ feet}$$

(g) Find the distance $S + T$ (1,080 feet) on the horizontal axis and label this point Z.

(h) Draw a vertical line up from point Z to the 0% gradient curve.

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

(j) Read the speed V_Z from the vertical axis, 56 mph.

6.2.4.4 Traffic Obstacles

The use of traffic obstacles is very effective in slowing vehicles on existing roads of insufficient radius. The placed obstacles include any mass that will slow down a vehicle or cause a driver to drive around them. Figure 6.9 presents an example based on a desired vehicle speed to determine traffic obstacle spacing. From the graph, a vehicle speed of 25 mph is chosen and

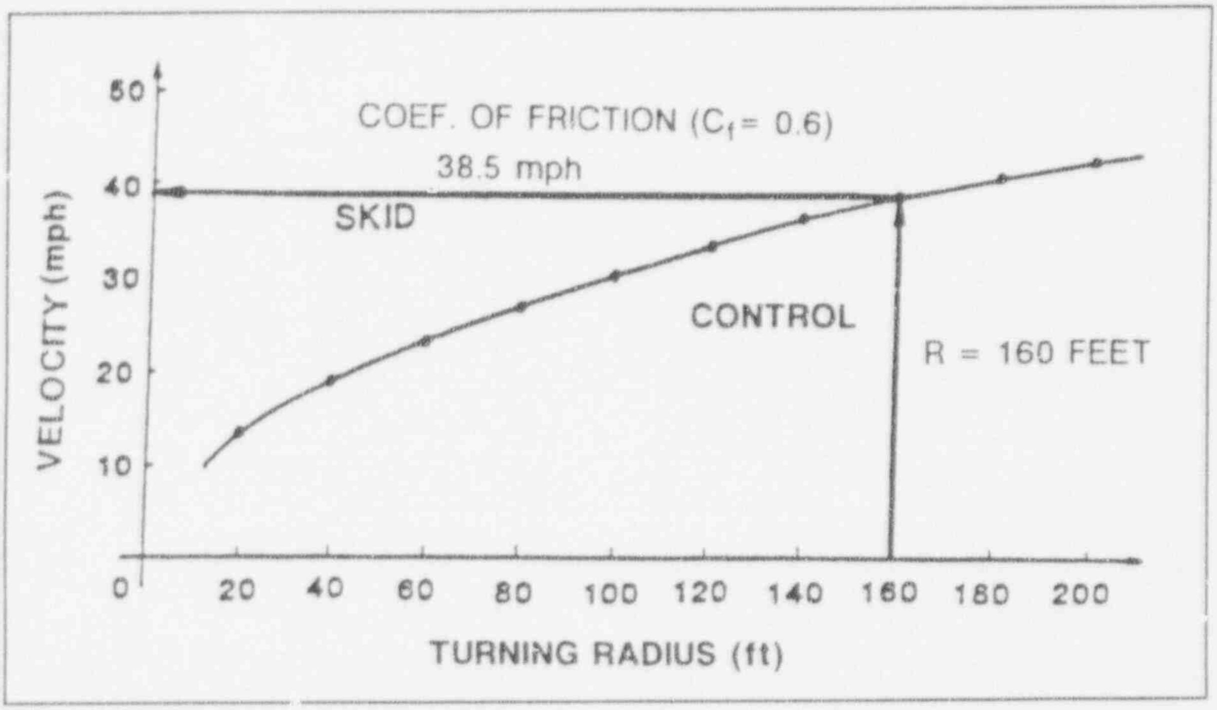

Figure 6.6 Example - Maximum vehicle velocity on curves

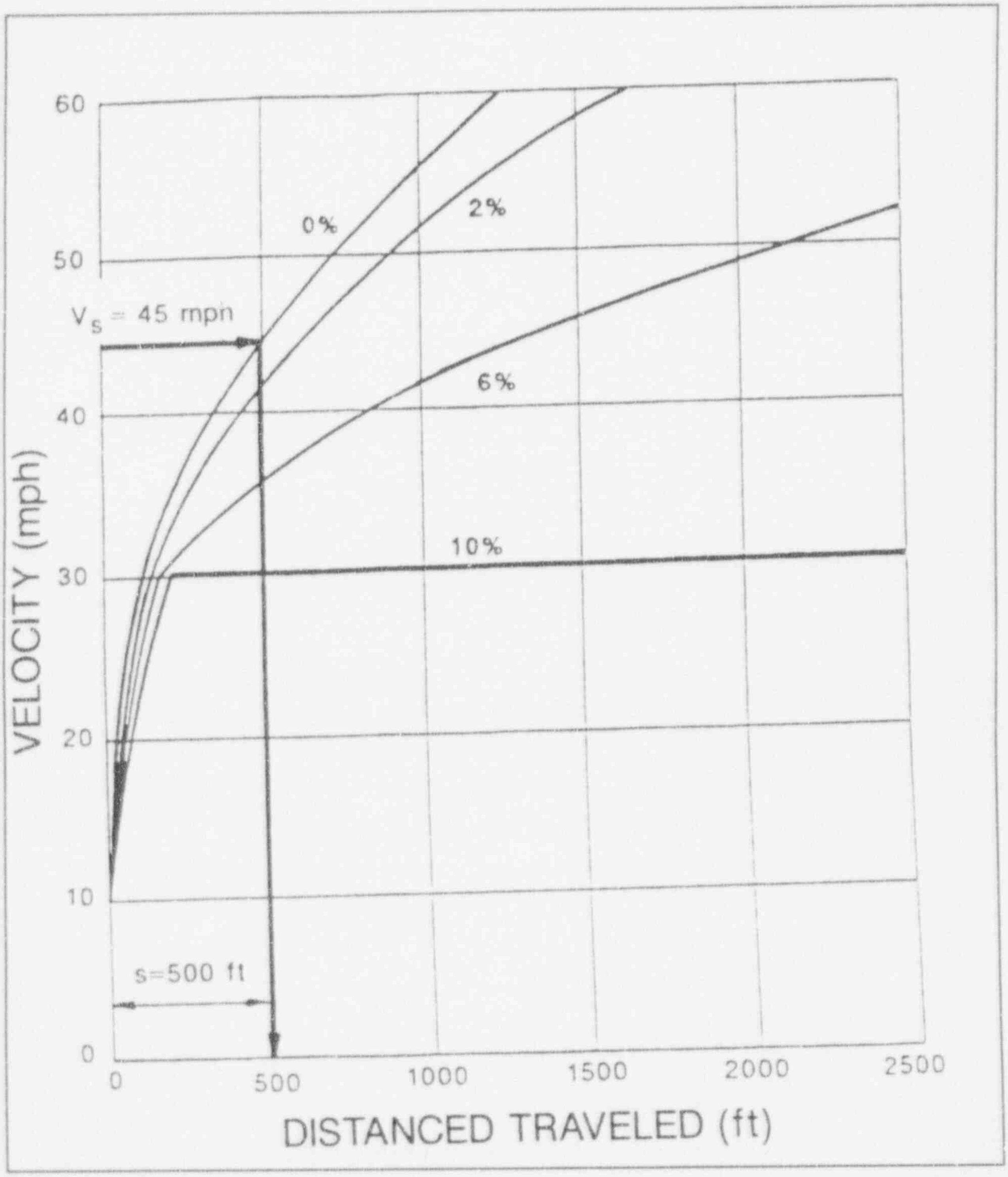

Figure 6.7 Example - Vehicle velocity from dead start

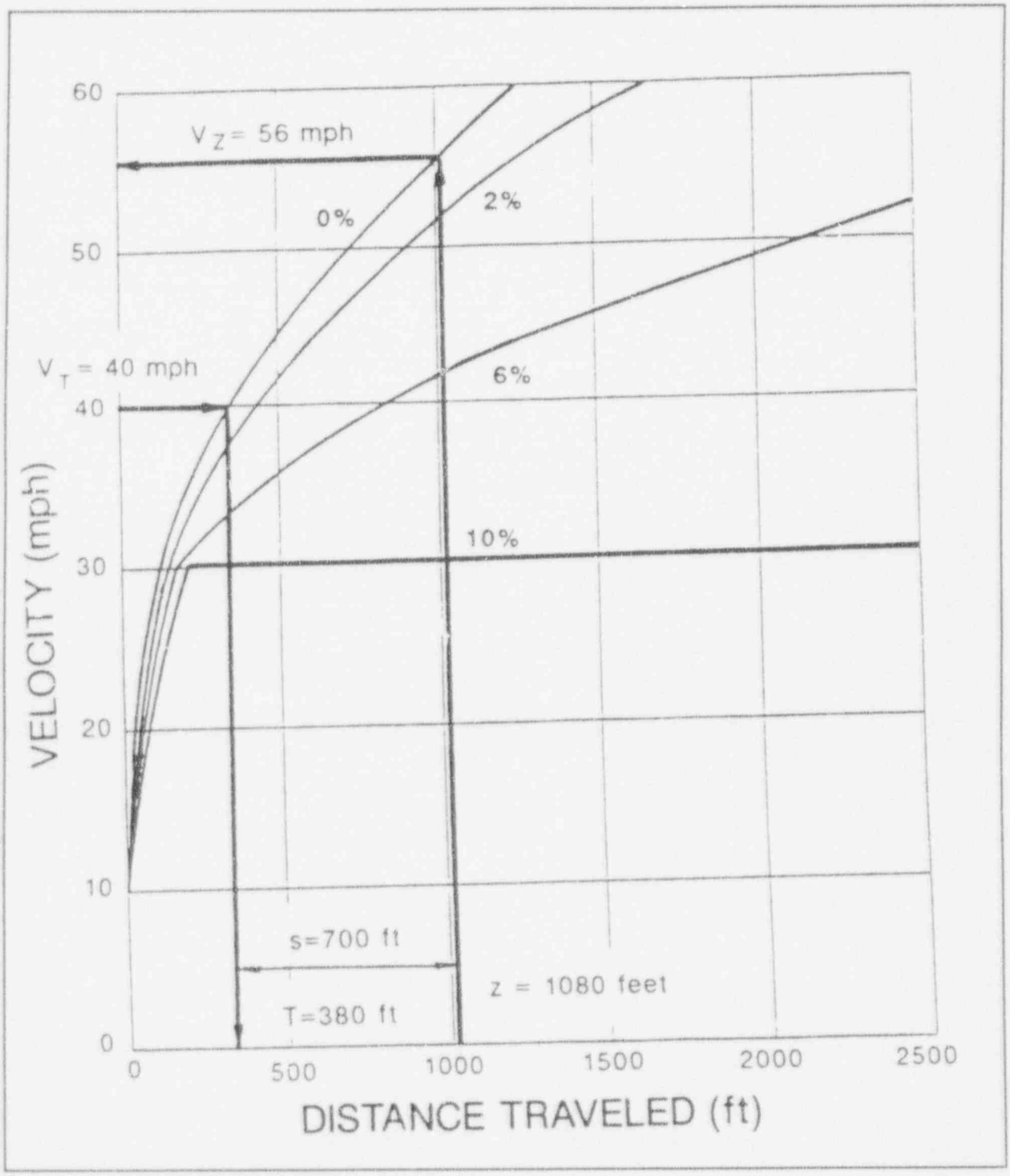

Figure 6.8 Example - Vehicle velocity with initial velocity

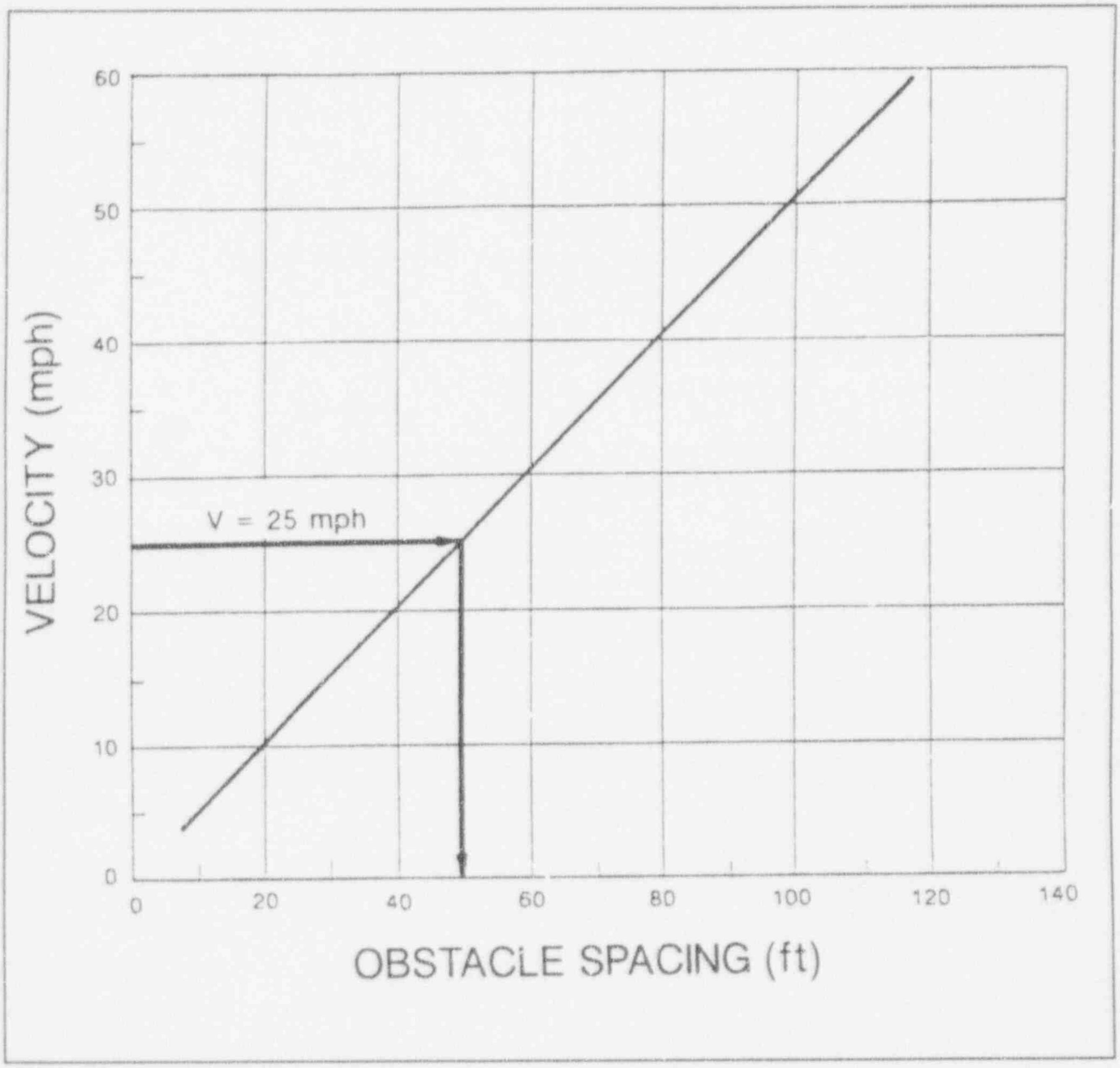

Figure 6.9 Example - Obstacle spacing vs. vehicle velocity

a parallel line to the horizontal axis is drawn to the point where that line intersects the diagonal line. At this point, draw a vertical line down from this intersection point to the horizontal axis. For this example, the obstacle spacing required equals 49 feet as read on the horizontal axis.

6.3 Determining Kinetic Energy

The design kinetic energy is calculated by using equation 2-1 with the design basis velocity and the combined vehicle and explosives weights listed in the Addendum to Regulatory Guide 5006.

6.4 Barrier Selection

After calculating the kinetic energy, the tables in sections 4 and 5 can be used to select a barrier. Enter the appropriate table and select a barrier that has an equal or higher rating than the kinetic energy calculated in section 6.3.

SECTION 7 - OTHER VEHICLE BARRIERS

If other vehicle barriers are used, their crash ratings must be established. This can be accomplished by a qualified testing organization performing full-scale crash testing by approved procedure or by a dynamic nonlinear analysis performed by qualified personnel.

SECTION 8 - DOCUMENTATION

Documentation guidelines are contained in Regulatory Guide 5.68.