



DAMS SECTOR

Active and Passive Vehicle Barriers Guide

September 2020

Contents

Introduction	1
Scope	1
Site-Specific Plans	1
Site Security Plan	1
Vehicular Access Control Plan	1
Passive Vehicle Barriers	4
Fixed Barriers.....	4
Re-deployable Systems	4
Active Vehicle Barriers	5
Commonly Used Active Vehicle Barriers.....	5
Intended Use Considerations	5
Safety Considerations.....	6
Maintenance Considerations.....	6
Barrier Selection and Specification	7
Site Characteristics and Operational Constraints	7
Attack Scenarios and Standoff Distances	7
Vehicle Crash Test Standards	8
System Selection	9
Appendix A: Open Source Technical Resources	10
Appendix B: Calculating Vehicle Kinetic Energy and Determining Maximum Vehicle Velocity	11
Appendix C: Notional Site of Areas Requiring Barriers	15

Introduction

The Dams Sector Active and Passive Vehicle Barriers Guide is intended to assist dam owners and operators with understanding various types of active and passive vehicle barriers and how to incorporate those barriers into facility security plans. The guide also provides a cursory level of technical information regarding barriers and includes references to assist owners and operators in properly designing protective schemes and selecting vehicle barriers and their appurtenant safety and security systems.

This guide is an update to the version originally published in 2010. The need for the guide was identified by the Dams Sector Security Education Workgroup, which is composed of members from the Dams Sector Coordinating Council (SCC) and the Dams Sector Government Coordinating Council (GCC). The SCC and the GCC constitute an effective partnership mechanism for public-private collaboration with the Cybersecurity and Infrastructure Security Agency (CISA) as the Sector-Specific Agency for the Dams Sector.

Scope

This guide focuses on attack scenarios in which an aggressor uses a moving vehicle-borne improvised explosive device (VBIED) to penetrate a controlled perimeter and immediately detonates the explosives at or near a target. For this type of threat, a comprehensive vehicle access control plan is critical for the site. This guide addresses the types of barriers that could be considered in an access control plan for moving VBIEDs.

This guide does not address waterside barriers; however, owners and operators should consider waterside access when conducting a comprehensive review of overall site security needs. The *Dams Sector Waterside Barriers Guide (2017)*, available through the Homeland Security Information Network – Critical Infrastructure (HSIN-CI) Dams Portal, provides additional information on this topic.

Site-Specific Plans

Site Security Plan

Most dam projects should develop and execute a site-specific security plan. Among other information, this plan identifies the threats the site is likely to encounter and the measures taken to counteract them, based on threat and vulnerability assessments and commensurate with the facility's operational needs and financial resources. The need for vehicle access control to protect against the possible use of VBIEDs may be necessary and, if required, should be addressed in the site security plan.

For information on developing a site-specific security plan, see the *Dams Sector Protective Measures Handbook, A Guide for Owners and Operators (2017)*, available through the HSIN-CI Dams Portal.

Vehicular Access Control Plan

The threat and vulnerability assessments that form the basis for the site security plan and vehicular access control plan should contain or outline a description of the threat vehicle types, sizes, and weights that need to be protected against. The overall access control plan, if applicable and needed, should address vehicular and personnel access to the site and check or validate credentials and vehicle contents. A general access control plan may also include an access control point with signage, fencing, gates, barriers (active and/or passive), and structures such as a guard post screening area or visitor control center.

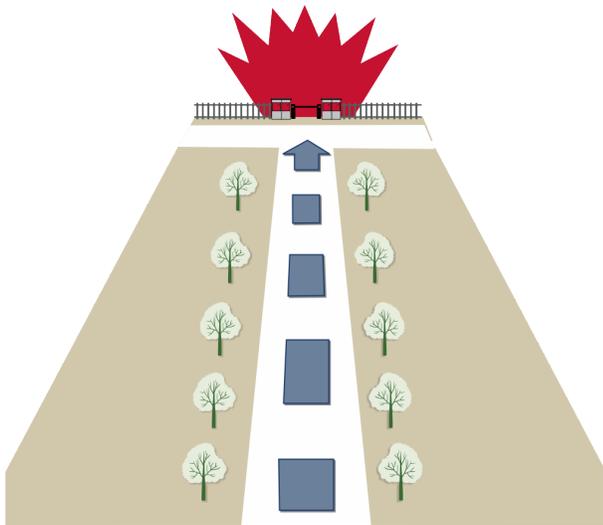
Development of the vehicle access control plan depends on several factors:

- **Acceptable standoff distance:** This determination depends on the likely magnitude (type and size) of the explosive and the asset's susceptibility to compromise and/or damage from it.

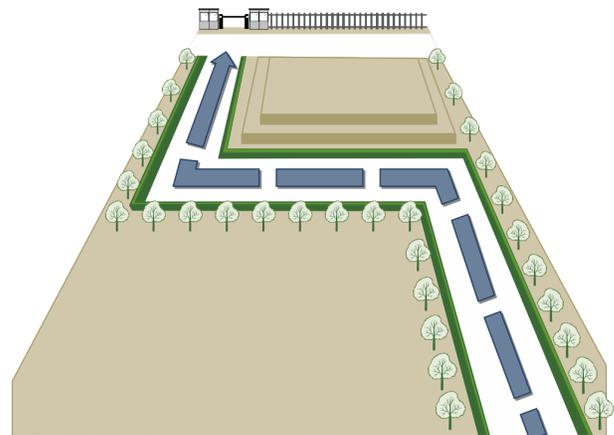
- **Type of vehicle used:** Passenger cars can carry far less explosives than semi-trailers; other types of delivery trucks would fall somewhere between these extremes.
- **Analysis:** An analysis determines the speed of the vehicle when it strikes a barrier.

It is typically less costly to design barriers for a slow-moving sedan than a fast-moving flatbed truck. It may be possible to limit vehicle speeds by configuring speed management features inside and outside the perimeter or by placing various traffic control devices (e.g., Jersey barriers) in the corridor to force vehicles to maneuver slowly. Geometric design considerations can be effectively used to limit the approach speed of hostile vehicles, thus reducing the effectiveness of a potential attack (Figure 1). Horizontal deflections, such as chicanes or traffic circles, will force the approaching vehicle to reduce speed or potentially lose control.

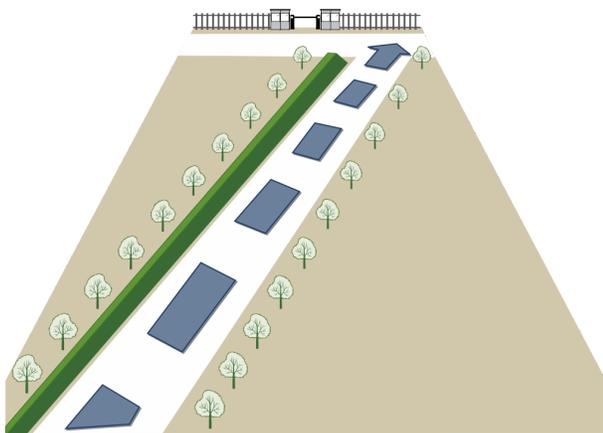
Figure 1: Traffic Calming



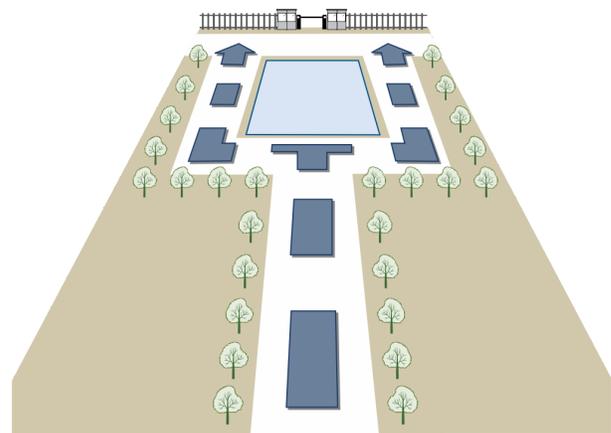
A direct route toward an asset allows a hostile vehicle to build up speed on approach.



Chicanes and offset approaches to an asset reduce hostile vehicle approach speed.



Moving a road or an asset to create an indirect approach will lead a hostile vehicle away from the asset.



Removing vehicle access from the front of an asset removes the potential for using a vehicle as a weapon and establishes a standoff distance from parked hostile vehicles.

Source: Derived from Center for the Protection of National Infrastructure (CPNI) *Integrated Security, A Public Realm Design Guide for Hostile Vehicle Migration, 2nd Edition*

Based on the fact that kinetic energy is proportional to the square of velocity, these types of measures can reduce the level of performance required for the vehicle barrier by reducing the maximum speed that a vehicle could potentially reach before impacting the barrier. Additional considerations must be given to the class of vehicles that could be affected by geometric design considerations. A design that prevents or slows heavy trucks may not affect cars, while a solution designed to slow cars may prevent heavy maintenance vehicles or first responders (e.g., fire trucks) from entering the area.

The key criteria for effective mitigation design are the threat vehicle's mass (weight) and its speed, which define the corresponding kinetic energy of the moving vehicle. Appendix B provides examples of maximum vehicle velocity and vehicle kinetic energy calculations based on parameters such as vehicle acceleration, approach slope, approach distance, approach width, and other factors.

The access control plan should take into account the surrounding terrain and the critical components that need protection. Areas not accessible by vehicle (i.e., traversable versus non-traversable terrain) do not require barriers. Rough terrain can reduce vehicle speeds and allow for the use of less costly barriers. The access control plan should contain features that guard against the possibility of vehicles running off road and ramming next to an asset entrance.

The notional site in Appendix C shows areas that require barriers and demonstrates the importance of a continuous ring of active and passive vehicle barriers around the area to be protected. Figure 2 illustrates the use of active and passive barriers to restrict access.

There are sophisticated barrier systems designed to prevent or limit the penetration of a moving vehicle attempting to gain access to an asset. Multiple rating systems and crash testing standards have been developed to characterize the performance of barrier systems. A given "rating" generally conveys the particular stopping power of a barrier in relation to the speed and weight of an oncoming vehicle (which can be translated into the corresponding kinetic energy) and the allowable penetration distance. A rated system has been subjected to crash testing according to an industry standard and has achieved the corresponding rating. Rated barriers are generally more costly and should be used only where a risk assessment has identified a set of higher threats and/or consequences that would justify the added expense. Where consequences are significant, and the location remote, it may be prudent to install a barrier with a rating higher than called for by the analysis because the heavier, more robust barrier may provide greater resistance to tamper and defeat at a modest increase in cost.

Figure 2: Use of Active and Passive Barriers



Source: U.S. Department of State

Passive Vehicle Barriers

Where protection is necessary against VBIEDs, a site or asset controlled perimeter could be established in part or in whole with a passive vehicle barrier system. Passive barriers have no moving parts; their effectiveness relies on their ability to absorb energy and transmit it to their foundations. Designs, movable or permanent, vary widely.

Fixed Barriers

While **fences** can be used as barriers, normal fences are not effective in stopping moving vehicles. Chain-link fences can be supplemented with high-strength cables, mounted within the fence and securely anchored, as shown in Figure 3. This approach is similar to the double, triple, or quadruple cable systems often used in the medians and shoulders of some highways to prevent cross-over accidents.

Concrete walls, if properly designed and constructed, can perform well as a barrier. Key elements in the effectiveness of such walls are their height, thickness, reinforcement, and foundation depth.

Re-deployable Systems

Movable concrete obstructions can be used as effective passive barriers. Typical applications include large planters, Jersey barriers, and boulders. Non-anchored or unlashed concrete barriers, such as Jersey or Texas barriers, work well for establishing standoff distances for a stationary VBIED, but are typically not adequate for stopping or mitigating a ramming attack. However, they are very effective in establishing speed zones, causing drivers to slow down prior to reaching the target zone or entry gate.

Bollards are a common type of passive barrier used where continuous walls are not acceptable. They can also more easily blend in with architectural and landscaping features where aesthetics may be important. Bollards can be constructed individually or in a continuous, reinforced concrete footing. However, typical bollards are capable of stopping automobiles traveling at modest speeds, only. For higher speeds or larger vehicles where vehicular penetration is of concern, it may be necessary to use special designs, such as larger bollards, closer bollard spacing, steel beams connecting the bollards, and/or stronger footings in addition to the selection of different, more effective passive barriers.

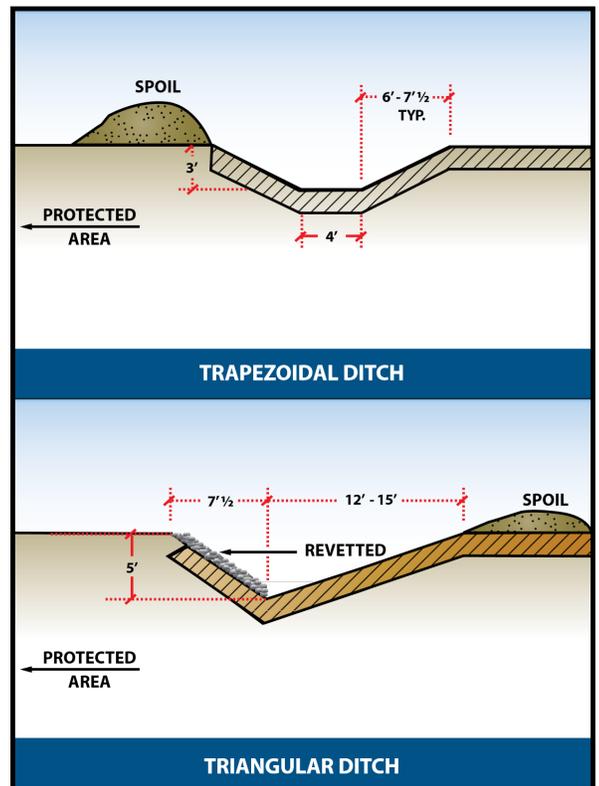
Terrain can be used as an effective vehicle barrier, as illustrated in Figure 4. For example, it is difficult for certain types of vehicles to pass or traverse ditches with sufficient width, depth, and overly steep slopes. Similarly, berms can be effective if properly configured. Landscaping (e.g., trees, shrubs) can be used to supplement the effectiveness of ditches and berms.

Figure 3: Anchored Fence



Source: U.S. Army Corps of Engineers

Figure 4: Terrain as a Passive Barrier



Source: Unified Facilities Criteria 4-022-2

Active Vehicle Barriers

Vehicle access control points or entry control points where credentials and/or vehicle contents are checked may require installation of an active vehicle barrier (AVB). Active barriers have the capability of operating continuously to support facility protection and controlled ingress and egress. As with passive vehicle barriers, active barrier design varies widely. However, special consideration related to intended use, safety, and maintenance should be made for active barriers, due to the need for continuous operation to support their intended use.

Commonly Used Active Vehicle Barriers

Gates, when used for vehicle control, are often referred to as an operable portion of fencing. While the gate typically matches the adjacent fixed fencing aesthetically, it is mounted on wheels or hinges to enable open and closure. This may be accomplished manually or with a gate operator to accommodate remote operation. These types of barriers typically complete the outer controlled pedestrian access perimeter. However, most fence-type gates are not designed to stop a moving vehicle that attempts unauthorized entry.

Traffic arm barriers are common features at many paid parking facilities and toll booths. However, these devices have no stopping power. Some versions are designed and able to resist a moving vehicle impact by using a much stronger or reinforced arm that is anchored into massive supports on both sides of the roadway.

Retractable bollards are frequently used in areas where operation is infrequent. As such, they normally remain in an up position.

A wedge barrier gets its name from the distinctive wedge shape, when viewed from the side. Another common name for this barrier is plate barrier because, when activated, the barrier consists of a steel plate angled upward toward the approaching vehicle. When not activated, the plate is flush with the roadway, enabling motorists to pass. These barriers can be very effective in resisting high-speed impacts. They can also be designed to deploy very quickly (e.g., within one second) during an emergency fast operate activation.

Barrier-net systems include energy absorbers and are attached to vertical steel end supports that are anchored in concrete. Some net systems can span more than 200 feet and have the capability to stop a 15,000-pound vehicle at impact speeds of over 50 mph. Barrier-net systems can be installed and placed in a series to provide extensive perimeter coverage.

Intended Use Considerations

Selecting the appropriate type of active vehicle barrier depends on several factors related to staffing capabilities, assessed threats, and the location and intended use of the barrier. Reviewing and answering the following questions can help owners and operators select the most appropriate barrier for site and access requirements:

- If the entry is unstaffed all or part of the time, will the barrier need to be used in conjunction with a pedestrian gate?
- When the entry is unstaffed, will the barrier resist/prevent unauthorized operation or tampering?
- When the entry is unstaffed, what can be done to provide supervision or monitoring of the barrier (e.g., tamper and/or intrusion sensors, video monitoring)?
- When the entry is staffed, will the barrier normally be open or closed? If the barrier is normally open, is there a need for a back-up barrier that can be closed quickly if a vehicle attempts to force its way past the entry control point?
- What is the design speed and weight of the vehicle that must be stopped?
- How quickly must the barrier open or close?

Active Barriers in Action

The U.S. Army Corps of Engineers developed relocatable active vehicle barriers that can be utilized in various locations. The Aggressor Vehicle Entry Readiness Technology (AVERT) can be deployed by two personnel without tools or equipment in less than 20 minutes. The AVERT system can easily open and close to restrict or grant access to approaching vehicles. The Field Expedient Non-Lethal Vehicle Arresting Barrier (FENVAB) is a larger system that requires more time and effort to deploy.

- What environmental conditions may affect operation of the barrier?
- Is it permissible to place the barrier foundations in the engineered fill of an embankment dam?
- What are the maintenance requirements of the barrier?
- What impact will the proposed barrier have on motorist safety?
- What impact will the operation of an active barrier have on public and guard-staff safety?
- Are aesthetics important at this location?
- For a remote location, what is the expected law enforcement response time?

Further discussion of these factors is available in Unified Facilities Criteria (UFC) 4-022-02 and 4-022-03 (see Appendix A: Open Source Technical Resources, references 1 and 2).

Safety Considerations

While all AVBs can create a temporary obstruction across a roadway, this approach has the potential to cause safety problems. Unintended AVB activation can cause injury or death to motorists. Accordingly, appropriate speed limits need to be enforced and implementation of safety features such as warning signs, additional signals, and detection loops in the access corridor are essential for any AVB installation. Safety is of particular concern where rapid deployment is possible, such as with wedge barriers. For additional information on safety issues, see Appendix A: Open Source Technical Resources, reference 3.

Maintenance Considerations

Active barriers must be capable of operating continuously. Their materials, hydraulics, hinges, movable parts, and electrical connections must be capable of operating in the site's specific environmental conditions. In addition to being operational in freezing rain, high heat, and heavy wind, snow, rain, or dust, the systems must have reasonable installation and maintenance costs. Part of the active barrier selection process is remaining aware of manufacturer requirements for installation, operations, maintenance schedules, and procedures to ensure maximum system reliability.

More detailed selection and procurement recommendations are available in the U.S. Department of Defense guide specification for active vehicle barriers, Unified Facilities Guide Specifications (UFGS) 34 71 13.19 (see Appendix A: Open Source Technical Resources, reference 5). Note that the recommendations included in this guide and referenced technical resources are intended to be applicable under all situations. Organizations should tailor the recommendations to the specific types of barriers required, site design constraints, and environmental factors.

Barrier Selection and Specification

Site Characteristics and Operational Constraints

Performing a site assessment is an important initial step to provide information about site characteristics and operational constraints that ensures the selected barrier system will fit into the existing or planned site, without penalty in performance or cost. A site assessment is a complete analysis of site physical characteristics, including roads, buildings, vehicle parking areas, topography, and pedestrian and traffic flow. Results of the site assessment identify opportunities, requirements, and constraints that impact site design.

To enable the consideration and selection of an appropriate barrier system, the site assessment process should include a wide range of subject matter experts, traffic engineering studies, and a site survey. The **traffic engineering studies** should determine expected traffic type (including pedestrian), peak volume, duration of peak volume, traffic patterns, and parking. A **site survey** should include preparation of a detailed and scaled map of the protected facility and surrounding topography to include elevation lines, major dimensions, and descriptions of the following components:

- Structures, roads, terrain, landscaping, (current and planned) security features, exits and entrances, and locations of critical infrastructure
- Geotechnical survey
- Underground utilities and electrical diagrams
- Environmental constraints (e.g., drainage, temperature, pollution) and ground conditions (e.g., grade and surface type)
- Property perimeter

When developing **maps**, include any features outside the perimeter that could possibly be used to reduce vehicle speed, prevent access to the perimeter barrier, shield structures from damage in the event of an explosion, or affect an aggressor's progress in any other way. Planned changes to surrounding roads or facilities should also be considered and clearly indicated on maps as planned features.

Throughout the site assessment process, identify and take into consideration **operational constraints** such as vehicle explosion standoff distance requirements, site drainage flows, runoff collection points, vehicle entry queue space, and distance from turnoff roadways to site perimeter entry control points.

Attack Scenarios and Standoff Distances

The magnitude of blast loading depends on the amount of energy released by the detonation and the distance from the blast source. For a given type and size of explosive threat, the magnitude of the blast loading rapidly decays with distance. Therefore, standoff distance—defined as the distance between the blast source and the location of the asset that requires protection—plays an important role in determining the potential extent of blast damage and the type of protection measures that may be required.

The most important concept when selecting active or passive vehicle barriers for mitigation of VBIED attacks is increasing standoff by maximizing the distance between the asset that requires protection and the final position of the hostile vehicle (after maximum penetration of the barrier). One approach to determining appropriate standoff distances is to develop an attack scenario.

The sample attack scenario considered in this document is a hostile vehicle carrying a VBIED penetrating a perimeter and detonating at or near a target. Selection of the type of barrier and its location requires careful consideration, as standoff distance from the detonation greatly influences the resulting blast effects. Critical assets should be evaluated and prioritized by consequence of damage or failure of each. This practice will help the designer focus on high impact areas and provide weighted value for balancing protection with budget constraints.

The analysis begins by determining the maximum credible size of the potential hostile vehicle. For example, larger vehicles can carry a larger payload of explosives. Once a category of hostile vehicle is established, the charge weight of explosives can be determined. The Gross Vehicle Weight Rating (GVWR) and curb weight can be easily found online for a given vehicle (Appendix B provides some general reference values). The payload capacity is the difference between the two. Once the hostile vehicle is selected and explosive charge weight is determined, asset damage estimates can be determined with varying standoff distances.

Vehicle Crash Test Standards

For high-risk situations, stopping power—limiting penetration of a threat hostile vehicle—can be the primary requirement identified through the site assessment. Therefore, it is imperative to rely on consistent rating and testing approaches to characterize the performance of barrier systems when impacted by a moving vehicle.

The U.S. Department of State (DoS) developed a rating system and test standard in 1985 to support the protection of embassies and consular buildings overseas. The standard (SD-STD-02.01) considered a single type of vehicle (medium-duty truck) weighing 15,000 pounds and three different impact velocities (30, 40, and 50 mph). Each velocity corresponds to a different level of kinetic energy (451, 802, and 1250 ft-kips), which is represented by a “K” level: K4, K8, or K12. The original standard also considered three different penetration distances: L1, L2, and L3, corresponding to 1 meter (3.3 feet), 6 meters (19.7 feet), and 15 meters (49.2 feet), respectively.

The standard was updated in 2003 by eliminating the multiple penetration levels and limiting penetration distance to no more than 3.3 feet in all cases. This was done in part to account for space constraints associated with embassies and consular buildings, which typically did not offer large open spaces between the perimeter and the protected location. The revised standard (SD-STD-02.01, Revision A) also included additional specifications for the vehicle to be used in the crash test as well as specifications for the consistent measurement of the corresponding penetration distance. Under the revised standard, a K4 rating indicated that a medium-duty truck weighing 15,000 pounds and traveling at 30 mph would achieve a penetration not exceeding 1 meter (3.3 feet). For reference purposes, Appendix B shows examples of kinetic energy calculations and the corresponding “K” rating that would be notionally required for the corresponding value of kinetic energy.

Table 1: ASTM International Impact Condition Designations

Vehicle / Curb Weight (lbs)	Minimum Test Velocity (mph)	Condition Designation
Small Passenger Car (SC) 2,420 lbs	30 mph	SC30
	40 mph	SC40
	50 mph	SC50
	60 mph	SC60
Full-size Sedan (FS) 4,630 lbs	30 mph	FS30
	40 mph	FS40
	50 mph	FS50
	60 mph	FS60
Pickup Truck (PU) 5,000 lbs	30 mph	PU30
	40 mph	PU40
	50 mph	PU50
	60 mph	PU60
Standard Test Truck (M) 15,000 lbs	30 mph	M30
	40 mph	M40
	50 mph	M50
Class 7 Cabover (C7) 15,873 lbs	30 mph	C730
	40 mph	C740
	50 mph	C750
Heavy Goods Vehicle (H) 65,000 lbs	30 mph	H30
	40 mph	H40
	50 mph	H50

Table 2: ASTM International Penetration Ratings¹

Designation	Dynamic Penetration Rating
P1	<1 meter (3.3 feet)
P2	1.01 to 7 meters (3.31 to 23.0 feet)
P3	7.01 to 30 meters (23.1 to 98.4 feet)
P4	30 meters (98 feet) or greater

For its sites, the DoS will only consider barriers with an ASTM F2656/F2656M – 20 rating of M30 P1, M40 P1, and M50 P1

In 2007, ASTM International developed a new standard (ASTM F2656-7) that added design flexibility by reintroducing the different penetration distances, incorporating additional vehicle categories, and including different impact velocities for some of the vehicle categories. This standard has been subsequently updated in the latest version (ASTM F2656/F2656M–20) with refined testing and measurement specification.

ASTM F2656/F2656M–20 “Standard Test Method for Vehicle Crash Testing of Vehicle Security Barriers” considers the vehicle categories, impact velocities, and penetration ratings summarized in Tables 1 and 2. The standard provides the basis for certifying barriers against different types of vehicles (small passenger car, full-size sedan, pickup truck, standard test truck, class 7 cabover truck, and heavy goods vehicle) and various vehicle speeds (30, 40, 50, and 60 mph). For example, an M30 P1 rating means a medium-duty truck weighing 15,000 pounds and traveling at 30 mph would achieve a penetration not exceeding 1 meter (3.3 feet). Note that this performance is equivalent to the K4 rating in the previous DoS standard. Similarly, the performance represented by M40 P1 and M50 P1 ratings would be equivalent to the K8 and K12 ratings, respectively, in the previous DoS standard.

More detailed data can be found in the ASTM International F2656/F2656M–20 Standard. See Appendix A: Open Source Technical Resources, reference 9.

System Selection

As discussed above, Appendix B provides examples of maximum vehicle velocity and vehicle kinetic energy calculations based on vehicle parameters and access road characteristics. In addition, the selection of the barrier must consider the acceptable levels of penetration that maintain minimum standoff distance between the final position of the vehicle and the asset requiring protection. Beyond the specific performance requirements for the barrier system, it is important to consider factors unique to the facility such as its location, if the system will be unstaffed or unsupervised, and law enforcement response time. The factors may allow significant opportunity and time for an attacker to defeat, tamper with, dismantle, destroy, or circumvent a vehicle barrier system. To address these unique risks and vulnerabilities, mitigation methods such as monitoring, assessment, robustness, and redundancy should be considered when choosing the requirements and specifications for the barrier system.

Appendix A: Open Source Technical Resources

The following technical resources are referenced throughout this document and may be used to learn more protective design, including barriers.

1. U.S. Department of Defense (August 9, 2010). UFC 4-022-02 Selection and Application of Vehicle Barriers, with Change 1. Retrieved from <https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-4-022-02>.
2. U.S. Department of Defense (October 1, 2013). Unified UFC 4-022-03, Security Fences and Gates. Retrieved from https://www.wbdg.org/FFC/DOD/UFC/ufc_4_022_03_2013.pdf.
3. U.S. Army Military Surface Deployment and Distribution Command Transportation Engineering Agency (2014). Pamphlet 55-15, Traffic and Safety Engineering for Better Entry Control Facilities. Retrieved from <https://www.sddc.army.mil/sites/TEA/Functions/SpecialAssistant/TrafficEngineeringBranch/Pages/default.aspx>.
4. U.S. Army Protective Design Center (n.d.). Publicly available documents pertaining to protective design. Retrieved from <https://usace.contentdm.oclc.org/utis/getfile/collection/p16021coll11/id/4503>.
5. U.S. Department of Defense (April 2008). UFGS 34 71 13.19, Active Vehicle Barriers. Retrieved from <https://www.wbdg.org/FFC/DOD/UFGS/UFGS%2034%2071%2013.19.pdf>.
6. U.S. Department of Defense (August 9, 2010). UFC 4-022-02, Security Engineering: Design and Selection of Vehicle Barriers, with Change 1. Retrieved from https://www.wbdg.org/FFC/DOD/UFC/ufc_4_022_02_2009_c1.pdf.
7. U.S. Department of Defense (July 27, 2017). UFC 4-022-01, Security Engineering: Entry Control Facilities/ Access Control Points. Retrieved from https://www.wbdg.org/FFC/DOD/UFC/ufc_4_022_01_2017.pdf.
8. U.S. Department of Defense (February 1, 2009). UFGS Section 34 41 26.00 10 Access Control Point Control Systems. Retrieved from http://www.wbdg.org/ffc/dod/unified-facilities-guide-specifications-ufgs?field_status_value=1&field_division_value_selective=34&=Apply.
9. ASTM International (n.d.). F2656/F2656M - 20 Standard Test Method for Vehicle Crash Testing of Vehicle Security Barriers.¹
10. Center for the Protection of National Infrastructure (CPNI) (2014). Integrated Security Guide, Second Edition, Version 1.0.

¹ Reprinted, with permission, from F2656/F2656M - 20 Standard Test Method for Crash Testing of Vehicle Security Barriers, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be obtained from ASTM, <http://www.astm.org>.

Appendix B: Calculating Vehicle Kinetic Energy and Determining Maximum Vehicle Velocity

This appendix provides examples of maximum vehicle velocity and vehicle kinetic energy calculations based on parameters such as vehicle acceleration, approach slope, approach distance, approach width, and other factors.

The kinetic energy (KE) of a moving vehicle is calculated by the following equation, where M is the vehicle mass and V is the vehicle velocity.

$$KE = \frac{1}{2}MV^2$$

The vehicle mass is calculated by the following equation, where W is the weight of the vehicle and g is the acceleration of gravity. The weight in pounds should be divided by 32.2 ft/sec² to calculate mass in U.S. units. The velocity should be expressed in ft/sec.

$$M = \frac{W}{g}$$

As an example, the kinetic energy of a 10,000-pound vehicle traveling at 50 miles per hour is calculated as follows:

Obtain the mass of the vehicle:

$$M = \frac{10,000 \text{ lbs}}{32.2 \text{ ft/sec}^2} = 310.6 \frac{\text{lbs-sec}^2}{\text{ft}} = 310.6 \text{ slug}$$

Convert the value of velocity into the corresponding units:

$$M = 50 \text{ mph} \times \frac{5,280 \text{ ft/mile}}{3,600 \text{ sec/hour}} = 73.3 \text{ ft/sec}$$

Calculate the vehicle's kinetic energy:

$$KE = \frac{1}{2} 310.6 \text{ lb-sec}^2/\text{ft} \times (73.3 \text{ ft/sec})^2 = 836,357 \text{ ft-lb} \cong 836 \text{ [ft-kips]}$$

Table B1 shows the levels of kinetic energy associated with different velocities for a 15,000-pound vehicle. The table also highlights the significant influence of velocity on the resulting kinetic energy, which is proportional to the square of velocity.

Table B1: Values of Kinetic Energy for Different Velocities for a Given Vehicle

Vehicle Weight (lbs)	Velocity (mph)	Kinetic Energy (ft-lbs)
15,000	30	451,327
15,000	40	802,359
15,000	50	1,253,685

The general type of hostile vehicles to be considered in the analysis is required for the development of the corresponding attack scenarios. Some reference vehicle types and loaded weights are shown in Table B2.

Table B2: Vehicle Weight Information (GVWR: Gross Vehicle Weight Rating)

Threat	Threat Description	GVWR ¹ (lbs)
	Sedan	5,000
	Passenger/ Cargo Van	10,000
	Mid-Size Truck	35,000
	Water Truck	66,000
	Semi-Trailer	80,800

Source: U.S. Army Corps of Engineers

When analyzing the time/distance performance of vehicles accelerating from a stopped position, a constant acceleration rate is often assumed. However, acceleration is not constant and generally decreases with velocity. An average value can be determined using the 0-60 mph times. The following table shows average acceleration values for a range of 0-60 mph times:

Table B3: Average Acceleration as a Function of 0-60 Times

0-60 mph Time (sec)	Average Acceleration (g)
6	14.7
8	11.0
10	8.8
12	7.3
14	6.3

The following tables summarize sample calculations of maximum velocity and corresponding kinetic energy for two attack scenarios using a spreadsheet developed by the U.S. Department of the Interior, Bureau of Reclamation. This spreadsheet, which serves as a simple tool for preliminary analysis purposes, is available on the HSIN-CI Dams Portal.

The spreadsheet accounts for parameters such as vehicle acceleration, distance, road slope, road width, radius of curvature, bank angle, and coefficient of friction. Input values required for each case are highlighted by shaded cells. In addition to the kinetic energy values, the spreadsheet also provides the corresponding “K” ratings that would be notionally required in each case. This information is included in the tables below for general reference purposes.

Table B4 summarizes the parameters adopted for the two vehicles used in the example calculations.

Table B4: Vehicle Parameters

Vehicle Parameters	Weight (lbs)	Mass (slug)	Acceleration (ft/sec ²)
Truck	15,000	466.3	6.3
Car	4,000	124.3	11.0

Table B5 shows the calculation of maximum velocity that could be achieved by each vehicle traveling a certain distance with a given initial velocity.

Table B5: Maximum Velocity for a Given Initial Velocity, Distance, and Slope

Initial Velocity (mph)	15	V_{max} (ft/sec)	V_{max} (mph)	Kinetic Energy (ft-lbs)	Required Barrier K Rating
Distance (ft)	440				
Road Slope + or - (deg)	0				
Coefficient of Friction	0.8				
Truck		78	53	1,405,347	N/A
Car		100	69	615,791	K8

Table B6 shows the calculation of maximum velocity (at threshold of sliding) that could be reached by each vehicle while traveling along a curve with a given radius of curvature and bank angle.

Table B6: Maximum Velocity through a Curve for a Given Radius of Curvature and Bank Angle

Curve Radius (ft)	160	V_{max} (ft/sec)	V_{max} (mph)	Kinetic Energy (ft-lbs)	Required Barrier K Rating
Bank Angle + or - (deg)	0				
Coefficient of Friction	0.8				
Truck		64	44	960,895	K12
Car		64	44	256,239	K4

Table B7 shows the calculations for the case in which the vehicle is traveling with a given velocity along a road of a given width and executes a turn with the intent of hitting a barrier parallel to the road. The table shows the minimum turning radius (at threshold of sliding) as well as the calculation of the corresponding maximum angle of impact. In addition, the table shows the magnitude of the component of velocity perpendicular to the barrier (factored velocity) and the associated kinetic energy value.

Table B7: Minimum Turning Radius and Maximum Angle of Impact for a Given Velocity and Road Width

Road Width (ft)	80	Velocity (mph)	Minimum Radius (ft)	Angle of Impact (deg)	Factored Velocity (ft/sec)	Factored Kinetic Energy (ft-lbs)	Required Barrier K Rating
Coefficient of Friction	0.8						
Truck		52	225	50	40	790,672	K8
Car		60	300	43	41	222,143	K4

Appendix C: Notional Site of Areas Requiring Barriers

This appendix depicts notional site areas that may require barriers and demonstrates the importance of a continuous ring of active and passive vehicle barriers around an area to be protected. The figures—provided by the U.S. Army Corps of Engineers—are to be used as an example only and do not necessarily meet any specific certification or standards.

In order to properly satisfy security requirements, active vehicle barriers such as those depicted below must be capable of operating continuously and with minimal maintenance and downtime.

Prior to implementing active vehicle barriers, the owner/operator should determine whether to allow security staff to operate the barrier from a control room or require that its operation remain near the actual access point. This will be primarily dependent on the security requirements set forth for the dam site based on traffic flow and the availability of security personnel. Backup generators or manual override systems should be in place to operate the barriers in case of a breakdown or power failure.

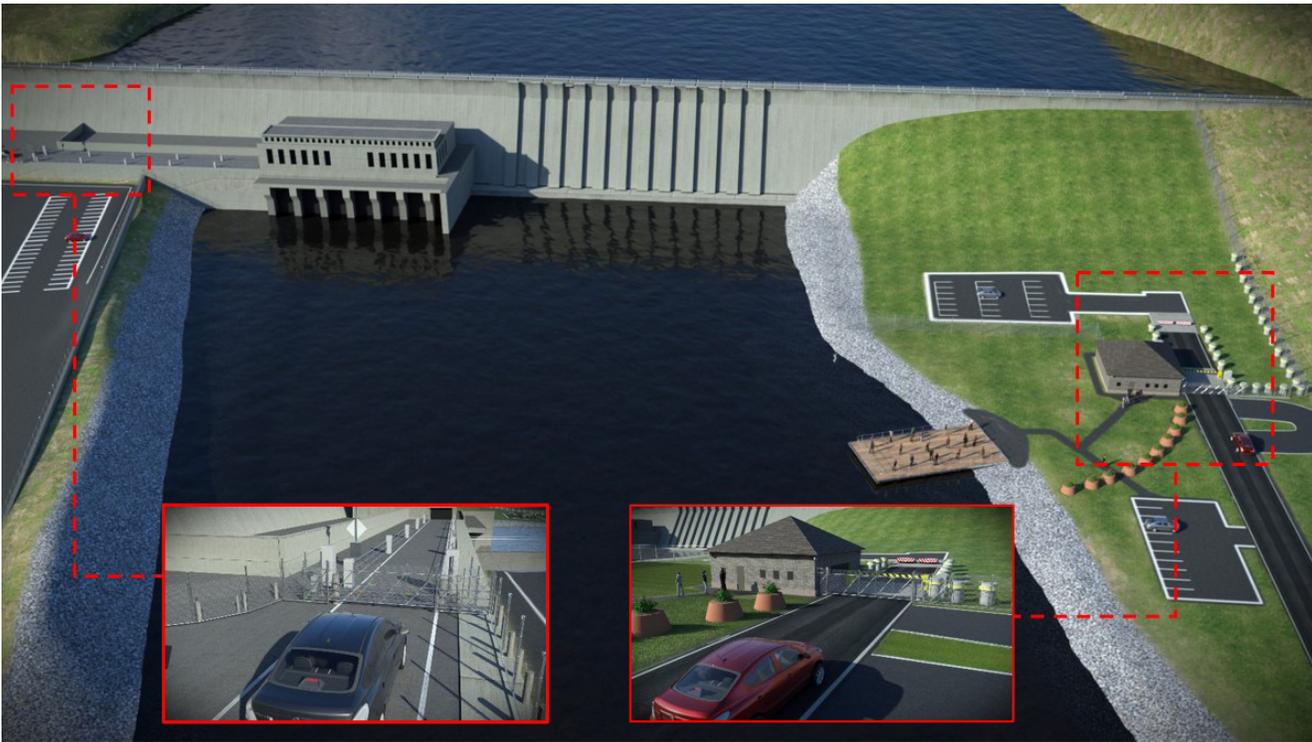
Another aspect that should be considered to the maximum extent possible is the overall appearance of the barrier. It is important to attempt to assimilate the barrier with the surroundings as much as possible to ensure an aesthetic look. This is more easily accomplished when terrain is incorporated into the barrier design.

Figure C1: Full View of Notional Dam Site and Recreational Facility



Source: U.S. Army Corps of Engineers

Figure C2: Notional Site Showing Areas that Could Require Barriers (Example Only)



Source: U.S. Army Corps of Engineers

Figure C3: Inset 1 from Figure C2 (Active Vehicle Barrier)



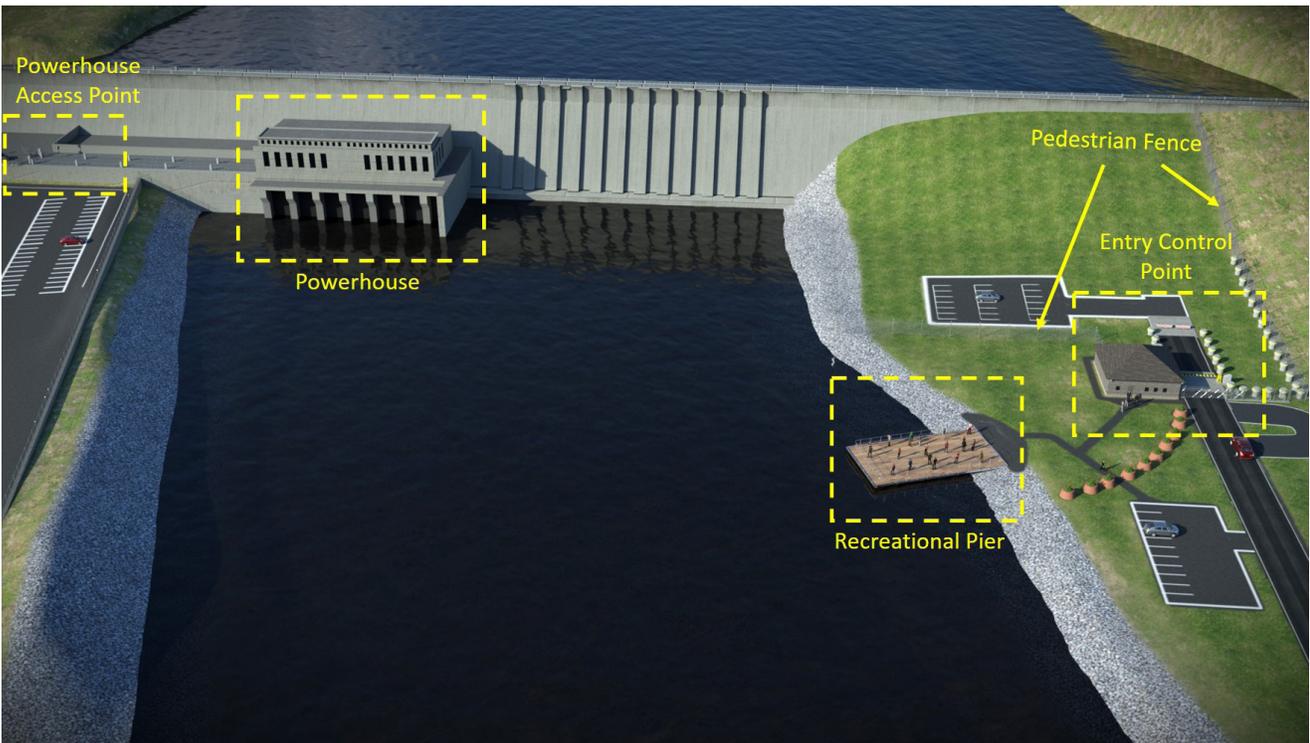
Source: U.S. Army Corps of Engineers

Figure C4: Inset 2 from Figure C2 (Entry Control Point with Active Barriers)



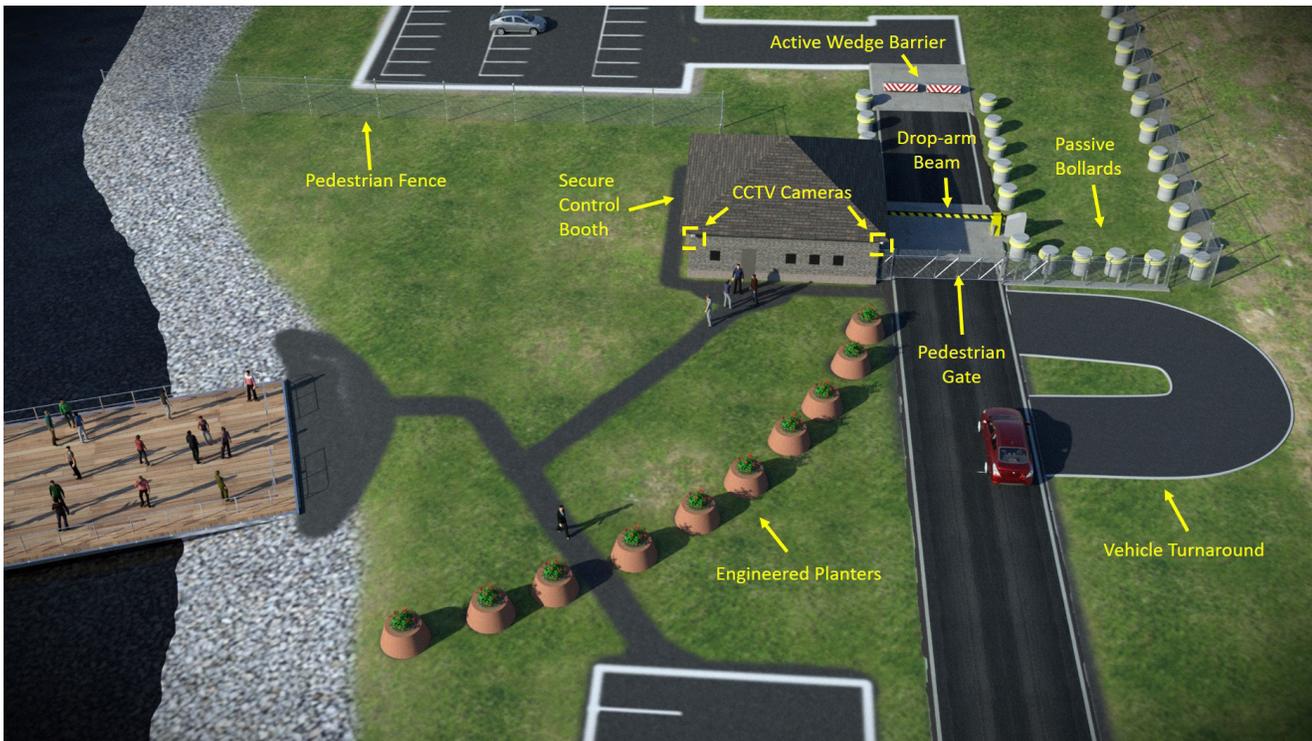
Source: U.S. Army Corps of Engineers

Figure C5: Example Layout of Dam and Recreational Facility



Source: U.S. Army Corps of Engineers

Figure C6: Example of an Entry Control Point



Source: U.S. Army Corps of Engineers

