SECTION 9

GUIDELINES FOR THE SELECTION AND DESIGN OF CRASH CUSHIONS

9-01 INTRODUCTION

Fixed objects within the clear distance should be removed, relocated or modified so as to be breakaway. When this is not practical, the obstruction should be shielded so as to prevent an impact of the obstruction by an errant vehicle.

A detailed discussion on warranting obstructions and clear distance can be found in Section 8, “Guidelines for Guide Rail Design and Median Barriers”.

A crash cushion is a type of traffic barrier that can be used to shield warranting obstructions such as overhead sign supports, bridge piers, bridge abutments, ends of retaining walls, bridge parapets, bridge railings, longitudinal barriers, etc. Due to the maintenance needs of crash cushions, the designer should when practical attempt to place obstructions beyond the clear zone, or provide designs that will avoid the need to require shielding by a crash cushion.

The most common use of a crash cushion is to shield a warranting obstruction in a gore. However, warranting obstructions in the median and along the roadside can also be shielded with a crash cushion (see Figure 9-A).

9-02 SELECTION GUIDELINES

9-02.1 General

Once it has been determined that a crash cushion is to be used to shield a warranting obstruction, a choice must be made as to which crash cushion is best for the particular location under consideration. The crash cushions presently recommended for permanent installations on Departmental projects are:

1. Inertial Barrier:
   a. Fitch Inertial Barrier
   b. Energite Inertial Barrier

2. QuadGuard System - new installations at wide and narrow obstructions and replacement of damaged Guard Rail Energy Absorbing Terminal (GREAT) Systems, Hi-Dro Sandwich Systems, Hex-Foam Sandwich Systems and Advanced Dynamic Impact Extension Modules (ADIEM)

INSERT FIGURE: 9-A

3. QuadGuard Low Maintenance Crash Cushion (LMC)gh System - use is to be limited to locations where numerous incidents occur requiring excessive maintenance

Existing crash cushions which are not of the type listed shall be evaluated to determine whether repairs or replacement are necessary.

Several factors must be evaluated when determining which of the recommended crash cushions should be used. The number and type of the factors to be evaluated precludes the development of a simple, systematic selection procedure.

The factors which normally should be considered are briefly discussed below. In many cases, evaluation of the first few items will establish the type of crash cushion to be used. When designing a crash cushion, take the time to review the design instructions and product limitations in the manufacturer's design manual thoroughly before performing the necessary work.

9-02.2 Dimensions of the Obstruction

Inertial barriers can be designed to shield obstructions of practically any width. Standard QuadGuard Systems are available in widths from 2 ft. to a maximum of 7.5 ft. The 2 ft. wide QuadGuard System will be used as a crash cushion treatment for barrier curb. The QuadGuard LMC System is used to shield obstructions approximately 3 ft. wide at locations where a high frequency of impacts can be expected.

Crash cushions are not ordinarily used along the length of an obstruction. Usually guide rail or barrier curb is used. Figure 9-A shows typical installations where a crash cushion is used in conjunction with a barrier curb or guide rail.

9-02.3 Space Requirement

1. Area occupied by the crash cushion

   The QuadGuard System will usually require about 20 percent less length than an inertial barrier. To meet the requirement of Figure 9-B, inertial barriers will have a minimum width of approximately 6.5 ft. (two barrels each at 3 ft. wide plus a 6 inches space between them). The QuadGuard Systems are available in five standard widths of 2 ft., 2.5 ft., 3 ft., 5.75 ft., and 7.5 ft. see Figure 9-C. Figure 9-C indicates the lengths of the QuadGuard System required to satisfy the allowable deceleration forces noted in Section 9-02.8.

INSERT FIGURE: 9-B

INSERT FIGURE: 9-C

INSERT FIGURE: 9-D

2. Reserve area for attenuator:

Figure 9-D shows dimensions to be used in determining if adequate space is available for the installation of a crash cushion. Although it depicts a gore location, the same recommendations will apply to other types of obstructions that require shielding by a crash cushion. Also, Figure 9-D shows a range of dimensions, the significance of which is as follows:

a. Minimum:

Restricted Conditions - These dimensions approximately describe the space required for installation of the current generation of impact attenuator devices without encroachment on shoulders and the nose of the device offset slightly back of the parapet or shoulder line. However, there are designs already developed that would not fit in the space provided by these dimensions and it is recognized that often it will not be possible to provide the recommended reserve area, particularly on existing roadways. In either case, the crash cushion should be designed so as not to encroach into the shoulder. In extreme cases, where the crash cushion must encroach into the shoulder, a reusable crash cushion should be given serious consideration since a higher than normal frequency of impacts could reasonably be expected when the crash cushion is so close to the traveled way.

Unrestricted Conditions - These dimensions should be considered as the minimum for all projects where plan development is not far advanced except for those sites where it can be shown that the increased cost for accommodating these dimensions, as opposed to those for Restricted Conditions, will be unreasonable. For example, if the use of the greater dimensions would require the demolishing of an expensive building or a considerable increase in construction costs then the lesser dimensions might be considered.

b. Preferred:

These dimensions, which are considerably greater than required for the present generation of impact attenuator devices should also be considered optimum. There is no intention to imply that if a space is provided in accordance with these dimensions that the space will be fully occupied by an impact attenuator device. The reason for proposing these dimensions is so that if experience shows that devices should be designed for greater ranges of vehicle weights and/or for lower deceleration forces there will be space available for installation of such devices in the future. In the meantime, the unoccupied reserved impact attenuator space will provide valuable additional recovery area.

9-02.4 Geometrics of the Site

The vertical and horizontal alignment, especially curvature of the road and sight distance, are important factors to be considered. Adverse geometrics could contribute to a higher than normal frequency of impacts.

9-02.5 Physical Conditions of the Site

The presence of a curb can seriously reduce the effectiveness of a crash cushion. It is recommended that all curbs and islands be removed approximately 50 ft. in front of a crash cushion and as far back as the unit's backup. While new curbs should not be built where crash cushions are to be installed, it is not essential to remove existing curbs less than 4 inches in height. Curbs from 4 inches to 6 inches in height should be removed unless consideration of the curb shape, site geometry, impending overlays that would reduce the curb height, and cost of removal indicates the appropriateness of allowing the curb to remain. Curbs over 6 inches high should be removed before installing a crash cushion. When a curb is terminated behind a crash cushion, the curb should be gently flared and/or ramped. Flares of 15:1 and ramps of 20:1 are recommended on high speed facilities.

All crash cushions should be placed on a concrete or asphalt surface as required by the manufacturer. However, a concrete footing is required at the backup and for the front cable anchorage of the QuadGuard System.

It is recommended that crash cushions be placed on a relatively flat surface. Longitudinal and transverse slopes in excess of 5 percent could adversely affect the performance of a crash cushion and should be avoided. If the cross slope varies more than 2 percent over the length of the unit, compensating alterations may have to be made at the site.

Joints, especially expansion joints, in the crash cushion area may require special design accommodations for those crash cushions that require anchorage.

9-02.6 Redirection Characteristics

The QuadGuard System has redirection capabilities. Since sandfilled plastic barrels have no redirection capabilities, it is important that the recommended placement details shown in Figure 9-B be adhered to so as to minimize the danger of a vehicle penetrating the barrier from the side and hitting the obstructions.

9-02.7 Maximum Impact Speed

Quad Guard and Inertial Barrier systems can be designed for any reasonable speed.

9-02.8 Allowable Deceleration Force

Where practical, crash cushions should be designed for a deceleration force of 6G's. Where space is limited, a crash cushion may be designed for a maximum of 8G's.

9-02.9 Backup Structure Requirements

The QuadGuard System, and QuadGuard LMC System and Hi-Dro Cell Cluster requires a backup structure that is capable of withstanding the forces of an impact.

9-02.10 Anchorage Requirements

The QuadGuard and QuadGuard LMC Systems require an anchorage which is capable of restraining the crash cushion during an impact. The manufacturer's standard designs of these crash cushions include the necessary anchorage.

9-02.11 Flying Debris Characteristics

Impact with an inertial barrier will produce some flying debris. However, this is not considered a serious drawback.

9-02.12 Initial Cost

The inertial barriers have the lowest initial cost. Compared to inertial barriers, the QuadGuard System has the higher initial cost. Assuming that about the same site preparations are required, the initial cost of a QuadGuard System will usually be 5 to 6 times higher than an inertial barrier. The initial cost of the QuadGuard LMC System is significantly higher than the standard QuadGuard System; however, due to its reusability after a crash, the cost to maintain the system is much less than the other systems.

9-02.13 Maintenance

Inertial barriers are particularly susceptible to damage during minor impacts. At locations where nuisance hits may be common or there is a high probability of accidents, crash cushions with redirection capabilities should be considered as a means of reducing maintenance requirements.

The QuadGuard System is generally reusable after a collision, however, the QuadGuard Cartridges must be replaced after the units are repositioned.

For most impacts with the QuadGuard LMC System, the main structural elements and energy absorbing materials do not require replacement. The unit is reusable after most impacts and can generally be placed back into service in approximately one hour.

9-03 DESIGN PROCEDURE

9-03.1 Fitch Inertial Barrier and Energite Inertial Barrier

Energite and Fitch inertial barriers are interchangeable in any array. The design of an inertial barrier is based on the law of conservation of momentum. It can be shown that:

$$V_f = W[Vo/(W+W_s)] \qquad \text{Equation 1}$$

V_f = velocity of vehicle after impact with M_s, in fps
V_o = velocity of vehicle prior to impact with M_s, in fps
W = weight of vehicle, in lbs
W_s = weight of sand actually impacted by a 6 ft. wide vehicle, in lbs.

This equation is used to calculate the velocity of a vehicle as it penetrates the inertial barrier. When a vehicle has been slowed to approximately 10 mph or less (14.7 fps) per Equation 1, it will actually have been stopped because of deceleration forces that have been neglected in Equation 1.

Slowing of the vehicle must take place gradually so that the deceleration force is 6G desirable, 8G maximum. The deceleration force is calculated using Equation 2. Note that velocity is in feet per second (fps).

$G = (V_o^2 - V_f^2)/2Dg$ Equation 2
G = deceleration force in G's
V_o = velocity of vehicle prior to impact, in fps
V_f = velocity of vehicle after impact with one row of modules, in fps
D = distance traveled in decelerating from V_o to V_f
(Usually D = width of a module = 3 ft.)
g = 32.2 ft/s^2

The standard weights of modules used are 200 lbs., 400 lbs., 700 lbs., 1400 lbs., and 2100 lbs. However, the use of 2100 lbs. module is not recommended unless site conditions are restricted and the use of 1400 lbs., modules would not stop the vehicle from striking the obstruction.

A minimum of 2 modules are required in the last 3 rows of the barrier array to meet the 2.5 ft. criteria shown in Figure 9-B. An additional last row of 1400 lbs. modules is provided after required reduction in speed is obtained. When a wide obstruction is being shielded, the modules may be spaced up to 3 ft. apart.

However, this spacing must be accounted for in the design. W_s in Equation 1 is the weight of sand impacted by a 6 ft. wide vehicle. Therefore, if 1400 lbs. modules (3 ft. diameter) were spaced 2 ft. apart, W_s would equal 1867 lbs.

Figures 9-E, 9-F and 9-G illustrate typical sand barrel configurations for narrow barrier arrays.

In the following two examples, first check the sand barrel configuration shown in Figure 9-G for an 1800 lb. vehicle and then make the same check for a 4500 lb. vehicle. Assume a design speed of 60 mph (88 fps).

Example of Inertial Barrier Design
for 1800 lb. Vehicle:

ROW	W_s	V_o	V_f*	G*
1	200	88	79.2	7.6
2	200	79.2	71.3	6.2
3	200	71.3	64.2	5.0
4	400	64.2	52.5	7.1
5	700	52.5	37.8	6.9
6	700	37.8	27.2	3.6
7	1400	27.2	15.3	2.6
8	2800	15.3	6.0	1.0
9	2800	---	---	---
10	2800	---	---	---

* V_f and G are calculated using Equations 1 & 2.

** It is desirable to limit G for each row to a maximum of 6. However, since 200 lbs. is the lightest module recommended for use, the 7.6 cannot be decreased.

Example of Inertial Barrier Design
for 4500 lb. Vehicle:

ROW	W_s	V_o	V_f*	G*
1	200	88	84.3	3.3
2	200	84.3	80.7	3.1
3	200	80.7	77.2	2.9
4	400	77.2	70.9	4.8
5	700	70.9	61.4	6.5
6	700	61.4	53.1	4.9
7	1400	53.1	40.5	6.1
8	2800	40.5	25.0	5.3
9	2800	25.0	15.4	2.0
10	2800	---	---	---

INSERT FIGURE: 9-E

INSERT FIGURE: 9-F

INSERT FIGURE: 9-G

Since the assumed configuration (shown in Figure 9-G) meets all the requirements specified in the previous examples, no changes are necessary.

Manufacturers of inertial barriers have developed designs for various obstructions. Most of these designs are based on a maximum deceleration force of 6G's. However, the space required for a 6G design will not always be available, especially in gore areas, in which case, a design for higher deceleration forces (8G's maximum) may be used.

A layout of the modules including the weight of each module must be included as a construction detail in the contract plans.

9-03.2 QuadGuard System

Because of the complex reaction of these crash cushions to an impact, a simple design procedure is not possible. The manufacturer has developed several standard arrangements. Figure 9-C shows the dimensions and operational characteristics of the standard models. Custom models can be designed but the costs thereof are very high. Standard designs for backup structures are available from the manufacturer.

The QuadGuard LMC System is 3 ft. wide and 31 ft. long (11 bay unit only). This system has been successfully crash tested with vehicles traveling at speeds of approximately 60 mph. The dimensions of the concrete pad, backup systems and detailed drawings are available from the manufacturer.