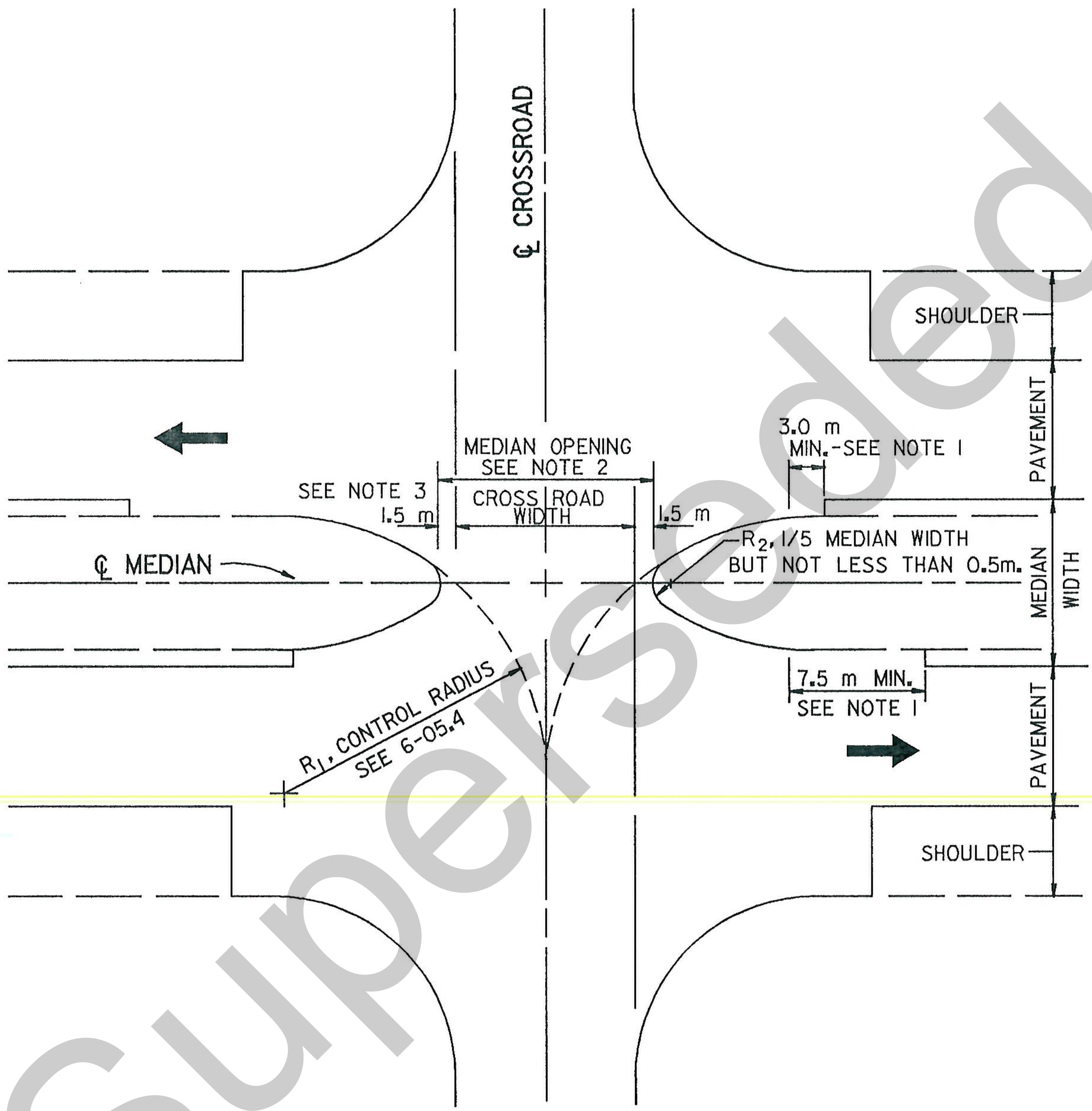
GRASS MEDIAN OPENING

FIGURE: 6-0

DATE: 12/18/95



NOT TO SCALE

NOTE 1: WHERE LANE AND SHOULDER PAVEMENT ARE DIFFERENT, USE THE MINIMUM OFFSETS SHOWN ABOVE.

NOTE 2: IN NO CASE SHALL THE LENGTH OF THE MEDIAN OPENING BE LESS THAN 12.0 m.

NOTE 3: PROVIDE 3.0 m WHERE THERE IS A MARKED OR UNMARKED PEDESTRIAN CROSSWALK. AS AN ALTERNATE, PROVIDE MEDIAN CUT THROUGH FOR PEDESTRIAN TRAFFIC.

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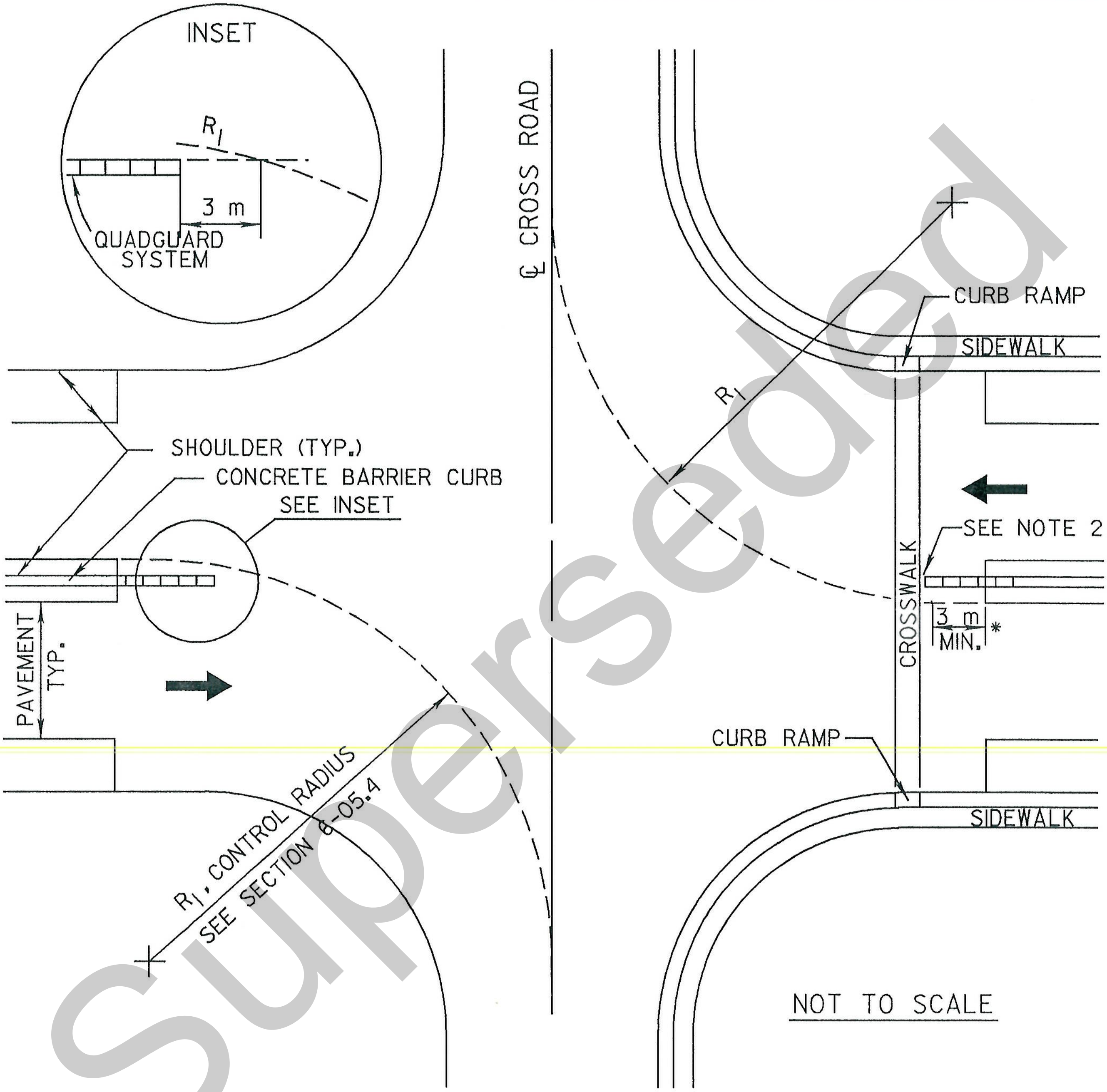
NEW LOCATIONS OF CONCRETE BARRIER CURB AT MEDIAN OPENING

FIGURE: 6-P

DATE: 05/29/98



NOTE 1: USE CONTROL RADIUS TO SET LOCATION OF QUADGUARD SYSTEM

NOTE 2: ADJUST LOCATION OF QUADGUARD SYSTEM SO IT DOES NOT INTERFERE WITH MARKED OR UNMARKED CROSSWALKS.

* NOTE 3: WHERE LANE AND SHOULDER PAVEMENT ARE DIFFERENT, USE THE MINIMUM OFFSET SHOWN ABOVE TO SET BEGINNING OF INSIDE SHOULDER.

NOTE 4: USE QUADGUARD SYSTEM WHERE POSTED SPEED IS GREATER THAN 60 km/h.

NOTE 5: SEE SECTION 8 FOR DISCUSSION OF END TREATMENTS FOR CONCRETE BARRIER CURB.

6-05.5 Median Openings For Emergency Vehicles

Although it is desirable to require all "U" turns by official vehicles to be accomplished at intersections or interchanges, experience demonstrates that some emergency median openings are necessary for proper law enforcement, fire-fighting apparatus, ambulances and maintenance activities. Where median openings are provided for use by official vehicles only, they shall be limited in number and carefully located in accordance with this section and the needs of local authorities.

On freeways and Interstate highways where the spacing of interchanges is greater than approximately 4.8 km, a "U" turn median opening may be provided at a favorable location halfway between the interchanges. Where the spacing of interchanges is greater than about 9.6 km, "U" turn median openings may be provided so that the distance between such openings or interchange is not greater than about 4.8 km.

In general, "U" turn median openings should not be provided on urban freeways due to the close spacing of interchanges. Due to the close proximity of intersections on divided arterials, emergency "U" turn median openings are not normally provided. However when emergency facilities are located between intersections, there may be a need for direct access to the highway.

See Figures 6-Q & 6-R for typical emergency median opening treatments.

6-06 MEDIAN LEFT-TURN LANE

6-06.1 General

A median lane is provided at an intersection as a deceleration and storage lane for vehicles turning left to leave the highway. Median lanes may be provided at intersections and other median openings where there is a high volume of left-turns, or where vehicular speeds are high on the main roadway. Median lanes may be operated with traffic signal control, with stop signs, or without either, as traffic conditions warrant. Figure 6-S shows a typical median left-turn lane.

6-06.2 Lane Width

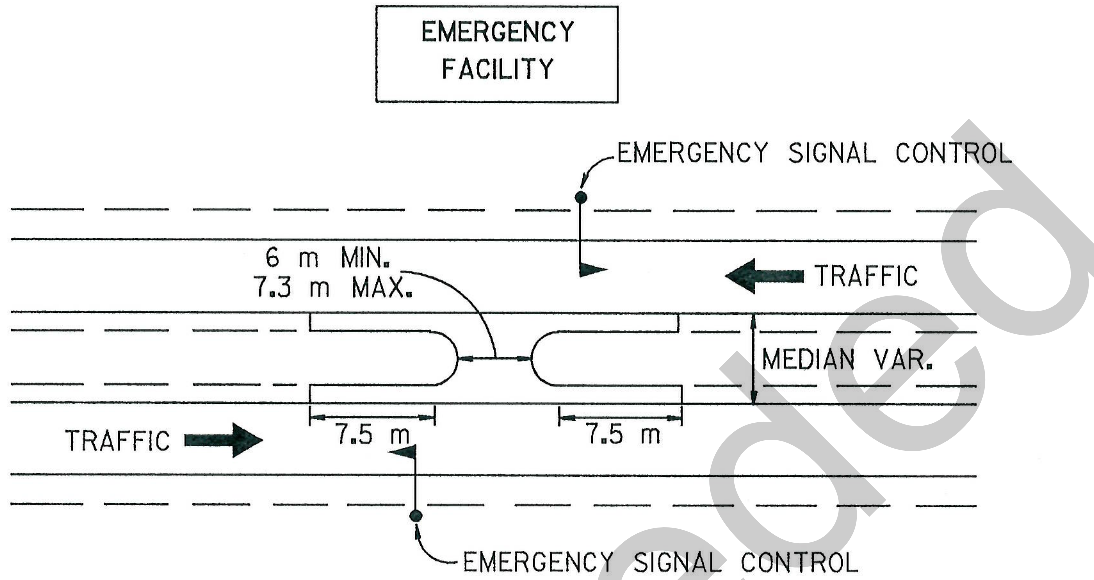
Left-turn lanes with median curbing should be 3.3 m wide and desirably 4.2 m wide. The lane width is measured from the curb face to the edge of through lane. Left-turn lanes without median curbing should be at least 3.3 m wide and preferably 3.6 m wide.

Median widths of 6 m to 7.5 m or more are desirable at intersections with a single left-turn lane, but widths of 4.5 m to 5.4 m are acceptable.

EMERGENCY MEDIAN OPENINGS ON LAND-SERVICE ROADWAYS

FIGURE: 6-Q

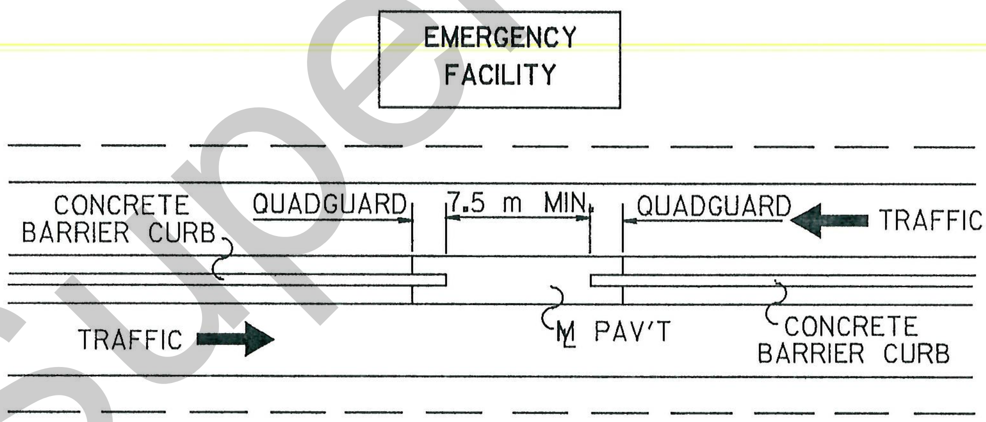
DATE: 05/29/98



NOTE: 1.) GRADING TO BE DONE AT 8% AROUND MEDIAN OPENING.

2.) IF NECESSARY, PONDING WATER IS TO BE ELIMINATED BY PROVIDING AN 'E' INLET IN THE MEDIAN ℄, AND CONNECTING TO EXISTING DRAINAGE LINE.

3.) ADEQUATE STOPPING SIGHT DISTANCE MUST BE AVAILABLE.



NOTE 1.) EMERGENCY SIGNAL CONTROL MAY BE PLACED IN CONCRETE BARRIER CURB, OR OUTSIDE THE SHOULDER AREA AS SHOWN ABOVE.

2.) ADEQUATE STOPPING SIGHT DISTANCE MUST BE AVAILABLE.

3.) AS AN ALTERNATIVE TO USING QUADGUARD SYSTEMS, A REMOTE CONTROLLED 'BARRIER GATE' MAY BE USED TO PROVIDE A 7.9 m OR 12.2 m OPENING IN CONCRETE BARRIER CURB DURING EMERGENCY RESPONSE TIMES.

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 use on Departmental projects are:

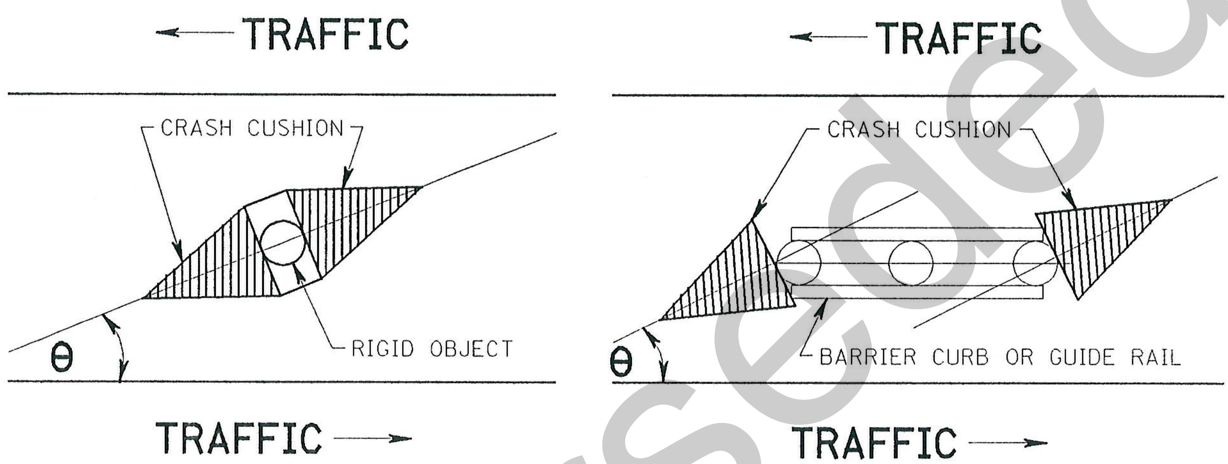
1. Inertial Barrier:
   a. Fitch Inertial Barrier
   b. Energite Inertial Barrier

2. Hi-Dro Cell Cluster

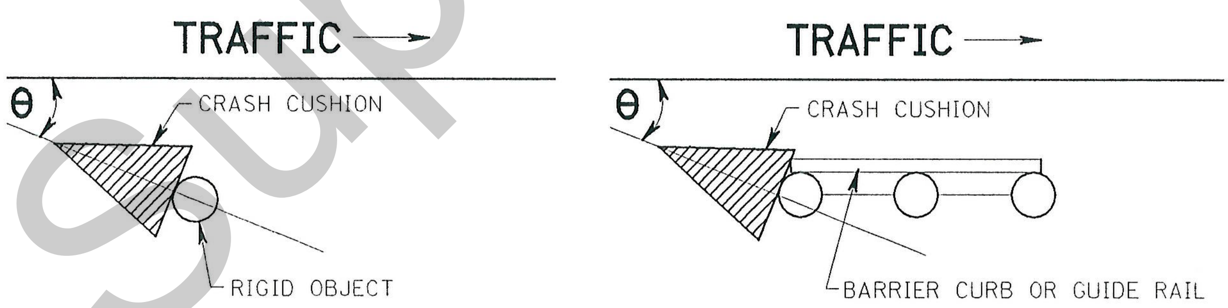
3. QuadGuard System - new installations at wide and narrow obstructions and replacement of damaged Guard Rail Energy Absorbing Terminal (GREAT) Systems, Hi-Dro Sandwich Systems, Hex-Foam Sandwich Systems and Advanced Dynamic Impact Extension Modules (ADIEM)

CRASH CUSHION	FIGURE : 9-A
	DATE: Ø5/29/98

FLAT * MEDIANS



FLAT * ROADSIDE AREA



θ = 1Ø DEGREES MAX
* = SLOPE 5% OR LESS

4. QuadGuard Low Maintenance Crash Cushion (LMC) 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 610 mm to a maximum of 2285 mm. The 610 mm wide QuadGuard System will be used as a crash cushion treatment for barrier curb. The QuadGuard LMC System is used to shield obstructions approximately 915 mm wide at locations where a high frequency of impacts can be expected. Hi-Dro Cell Clusters are usually used to shield obstructions up to 900 mm to 1200 mm in width.

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

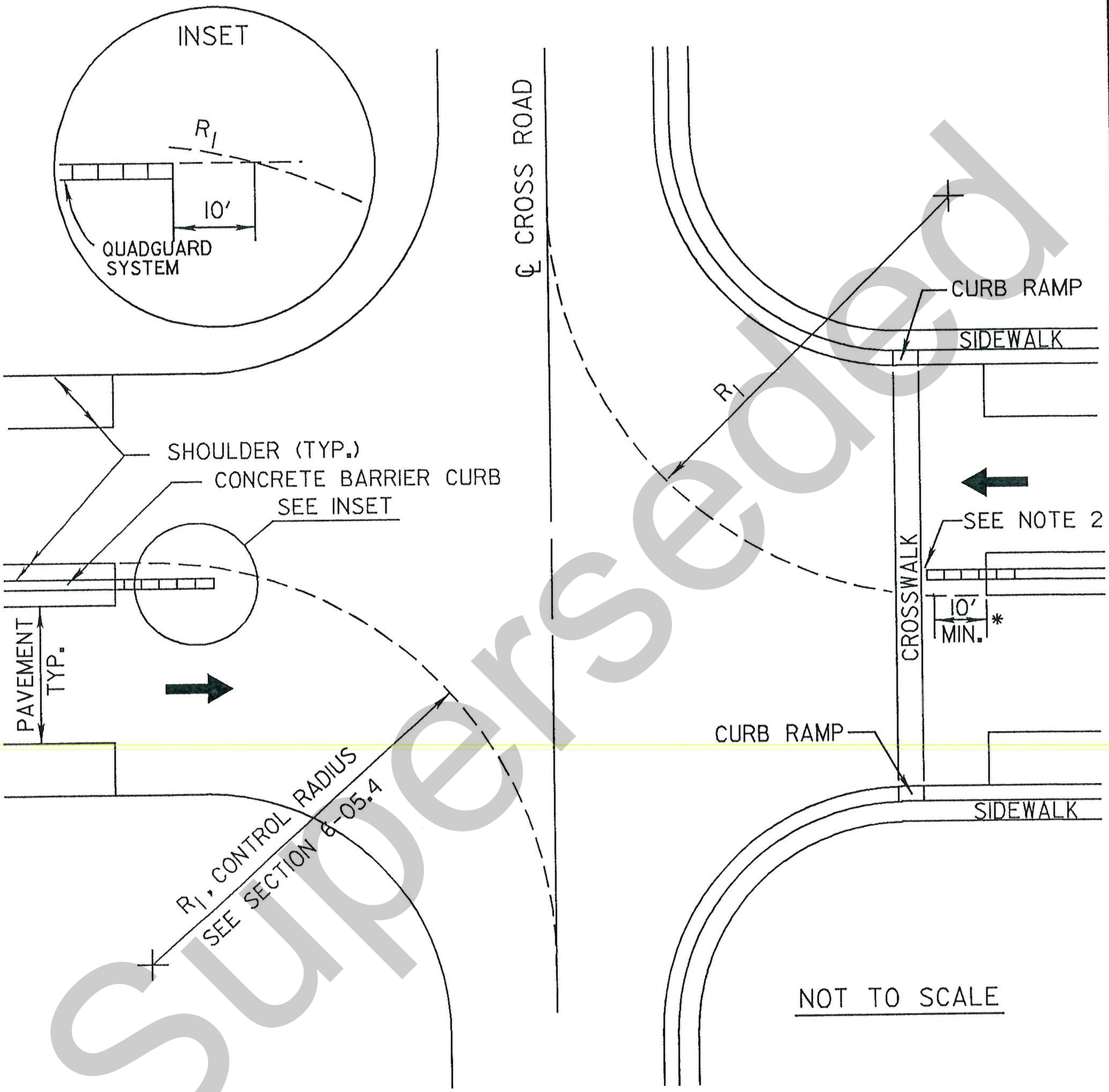
1. Area occupied by the crash cushion

   The Hi-Dro Cell Cluster occupies the least amount of space. 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 1970 mm (two barrels each at 910 mm wide plus a 150 mm space between them). The QuadGuard Systems are available in five standard widths of 610 mm, 760 mm, 915 mm, 1750 mm and 2285 mm 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.

NEW LOCATIONS OF CONCRETE BARRIER CURB AT MEDIAN OPENING

FIGURE: 6-P

DATE: 05/29/98



NOTE 1: USE CONTROL RADIUS TO SET LOCATION OF QUADGUARD SYSTEM.

NOTE 2: ADJUST LOCATION OF QUADGUARD SYSTEM SO IT DOES NOT INTERFERE WITH MARKED OR UNMARKED CROSSWALKS.

*NOTE 3: WHERE LANE AND SHOULDER PAVEMENT ARE DIFFERENT, USE THE MINIMUM OFFSET SHOWN ABOVE TO SET BEGINNING OF INSIDE SHOULDER.

NOTE 4: USE QUADGUARD SYSTEM WHERE POSTED SPEED IS GREATER THAN 40 MPH.

NOTE 5: SEE SECTION 8 FOR DISCUSSION OF END TREATMENTS FOR CONCRETE BARRIER CURB.

Provisions shall be made where pedestrian traffic is present at median openings, see Figures 6-O and 6-P.

The use of a 40 foot minimum length of opening without regard to the width of median, the cross road width, pedestrian traffic or the control radius should not be considered except at very minor crossroads. The 40 foot minimum length of opening does not apply to openings for “U” turns. Consult *A Policy on Geometric Design of Highways and Streets,* AASHTO, 1990, for the design of “U” turn median openings.

On urban divided roadways, median openings for “U” turns should not be provided. “U” turn movements may be permitted at signalized intersections where there is sufficient pavement width to accommodate the movement. Provisions for “U” turns should be made on rural divided roadways where intersections are spaced in excess of one-half mile apart. Median widths in such cases should be at least 20 feet and desirably 30 feet to provide adequate protection for the vehicle executing the “U” turn movement from the median. It is highly desirable to construct a median left-turn lane in advance of the “U” turn opening to eliminate stopping on the through lanes.

6-05.5 Median Openings For Emergency Vehicles

Although it is desirable to require all “U” turns by official vehicles to be accomplished at intersections or interchanges, experience demonstrates that some emergency median openings are necessary for proper law enforcement, fire-fighting apparatus, ambulances and maintenance activities. Where median openings are provided for use by official vehicles only, they shall be limited in number and carefully located in accordance with this section and the needs of local authorities.

On freeways and Interstate highways where the spacing of interchanges is greater than approximately 3 miles, a “U” turn median opening may be provided at a favorable location halfway between the interchanges. Where the spacing of interchanges is greater than about 6 miles, “U” turn median openings may be provided so that the distance between such openings or interchange is not greater than about 3 miles.

In general, “U” turn median openings should not be provided on urban freeways due to the close spacing of interchanges. Due to the close proximity of intersections on divided arterials, emergency “U” turn median openings are not normally provided. However when emergency facilities are located between intersections, there may be a need for direct access to the highway.

See Figures 6-Q & 6-R for typical emergency median opening treatments.

6-06 MEDIAN LEFT-TURN LANE

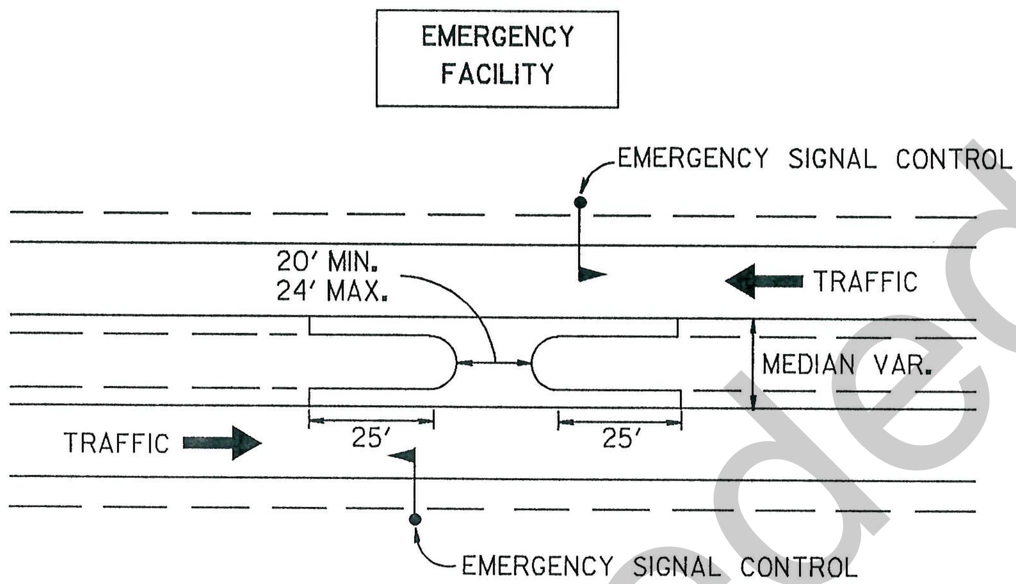
6-06.1 General

A median lane is provided at an intersection as a deceleration and storage lane for vehicles turning left to leave the highway. Median lanes may be provided at intersections and other median openings where there is a high volume of left-turns, or where vehicular speeds are high on the main roadway. Median lanes may be operated with traffic signal control, with stop signs, or without either, as traffic conditions warrant. Figure 6-S shows a typical median left-turn lane.

EMERGENCY MEDIAN OPENINGS ON LAND-SERVICE ROADWAYS

FIGURE: 6-Q

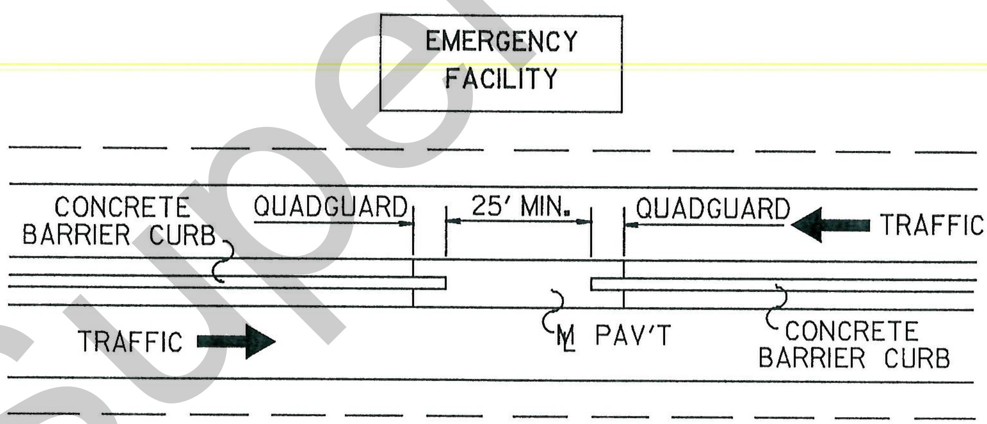
DATE: 05/29/98



NOTE: 1.) GRADING TO BE DONE AT 8% AROUND MEDIAN OPENING.

2.) IF NECESSARY, PONDING WATER IS TO BE ELIMINATED BY PROVIDING AN 'E' INLET IN THE MEDIAN ℄, AND CONNECTING TO EXISTING DRAINAGE LINE.

3.) ADEQUATE STOPPING SIGHT DISTANCE MUST BE AVAILABLE.



NOTE 1.) EMERGENCY SIGNAL CONTROL MAY BE PLACED IN CONCRETE BARRIER CURB, OR OUTSIDE THE SHOULDER AREA AS SHOWN ABOVE.

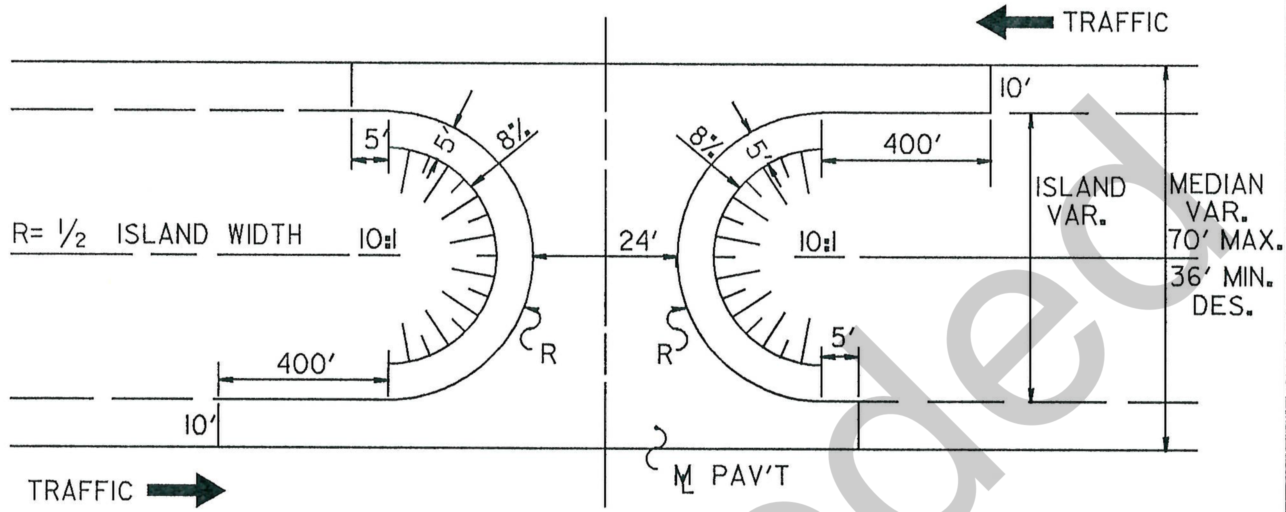
2.) ADEQUATE STOPPING SIGHT DISTANCE MUST BE AVAILABLE.

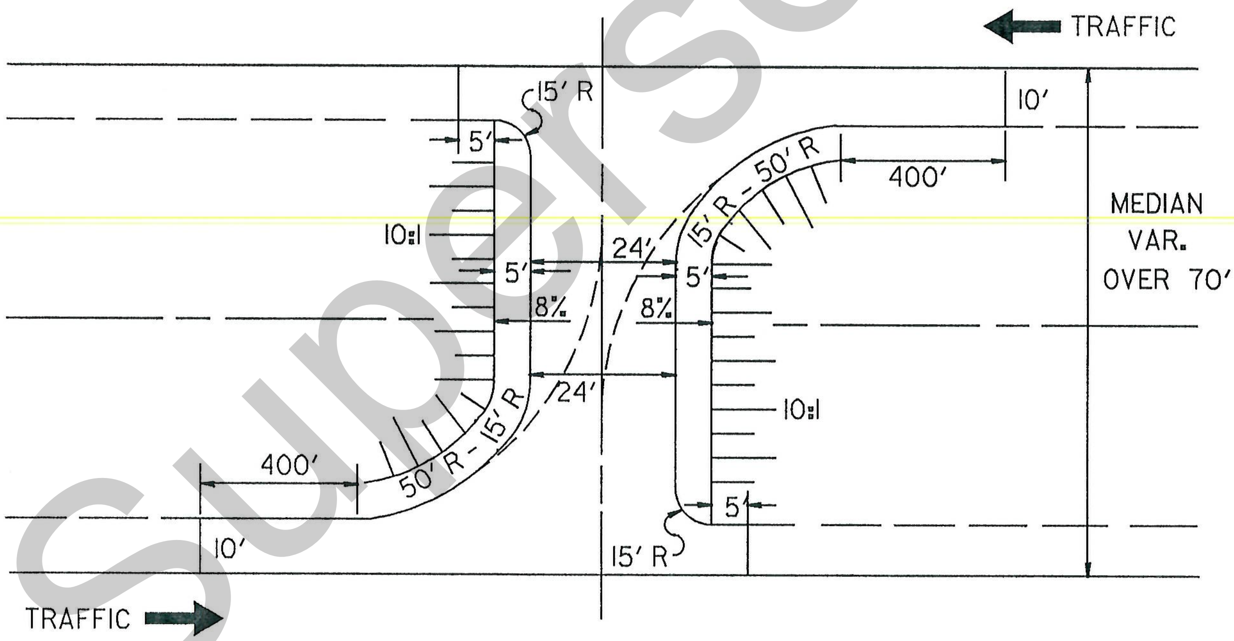
3.) AS AN ALTERNATIVE TO USING QUADGUARD SYSTEMS, A REMOTE CONTROLLED 'BARRIER GATE' MAY BE USED TO PROVIDE A 26′ OR 40′ OPENING IN CONCRETE BARRIER CURB DURING EMERGENCY RESPONSE TIMES.

EMERGENCY MEDIAN OPENINGS ON FREEWAYS OR INTERSTATE HIGHWAYS

FIGURE: 6-R

DATE: 11/18/94





NOTE: 1.) PONDING OF RUNOFF IS TO BE ELIMINATED BY CONVENTIONAL MEANS.

2.) THE MEDIAN OPENING IS TO BE LOCATED WHERE ADEQUATE STOPPING SIGHT DISTANCE MAY BE PROVIDED.

3.) THE MEDIAN OPENING SHOULD BE LOCATED 1/2 MILE FROM ANY FREEWAY UNDERPASS AND AT LEAST ONE MILE FROM ANY RAMP TERMINAL.

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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 use on Departmental projects are:

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

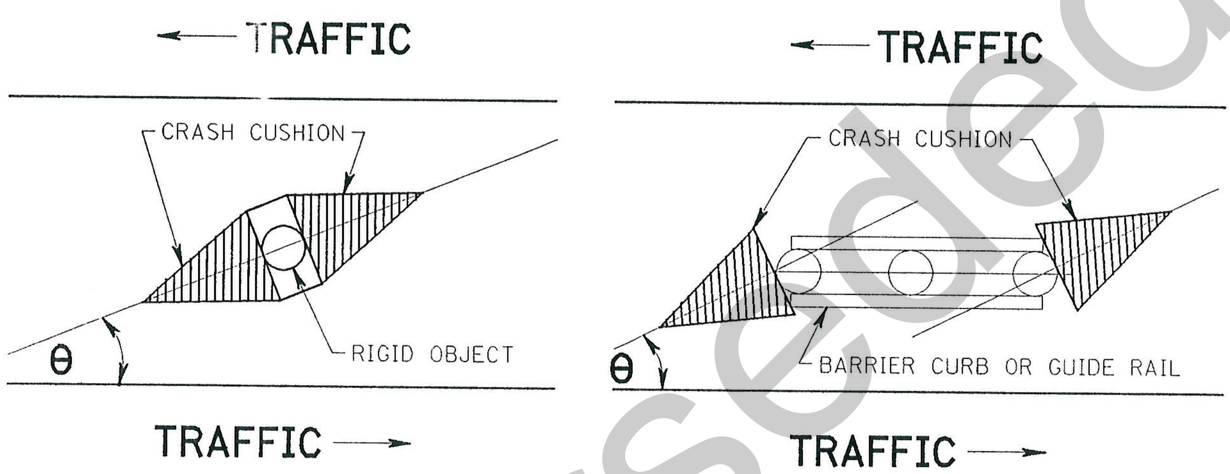
2. Hi-Dro Cell Cluster

3. 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)

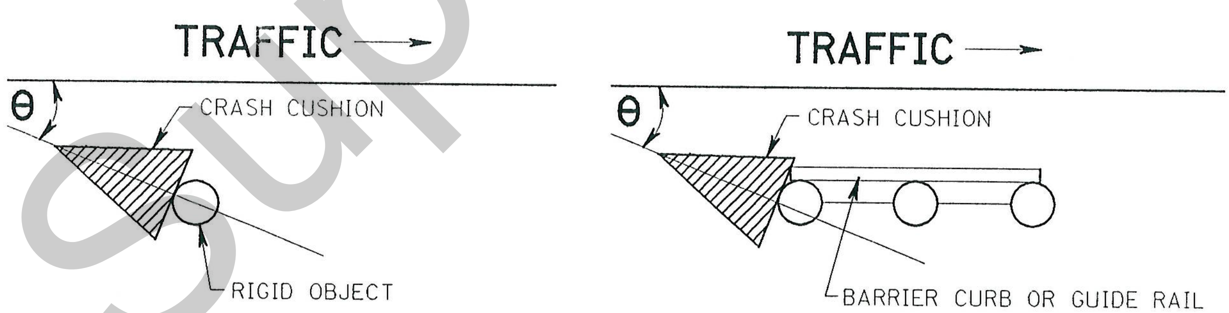
4. QuadGuard Low Maintenance Crash Cushion (LMC) System - use is to be limited to locations where numerous incidents occur requiring excessive maintenance

CRASH CUSHION	FIGURE : 9-A
	DATE: 03/05/93

FLAT * MEDIANS



FLAT * ROADSIDE AREA



θ = 10 DEGREES MAX
* = SLOPE 5% OR LESS

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 feet to a maximum of 7.5 feet. The 2 foot 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 feet wide at locations where a high frequency of impacts can be expected. Hi-Dro Cell Clusters are usually used to shield obstructions up to 3 to 4 feet in width.

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

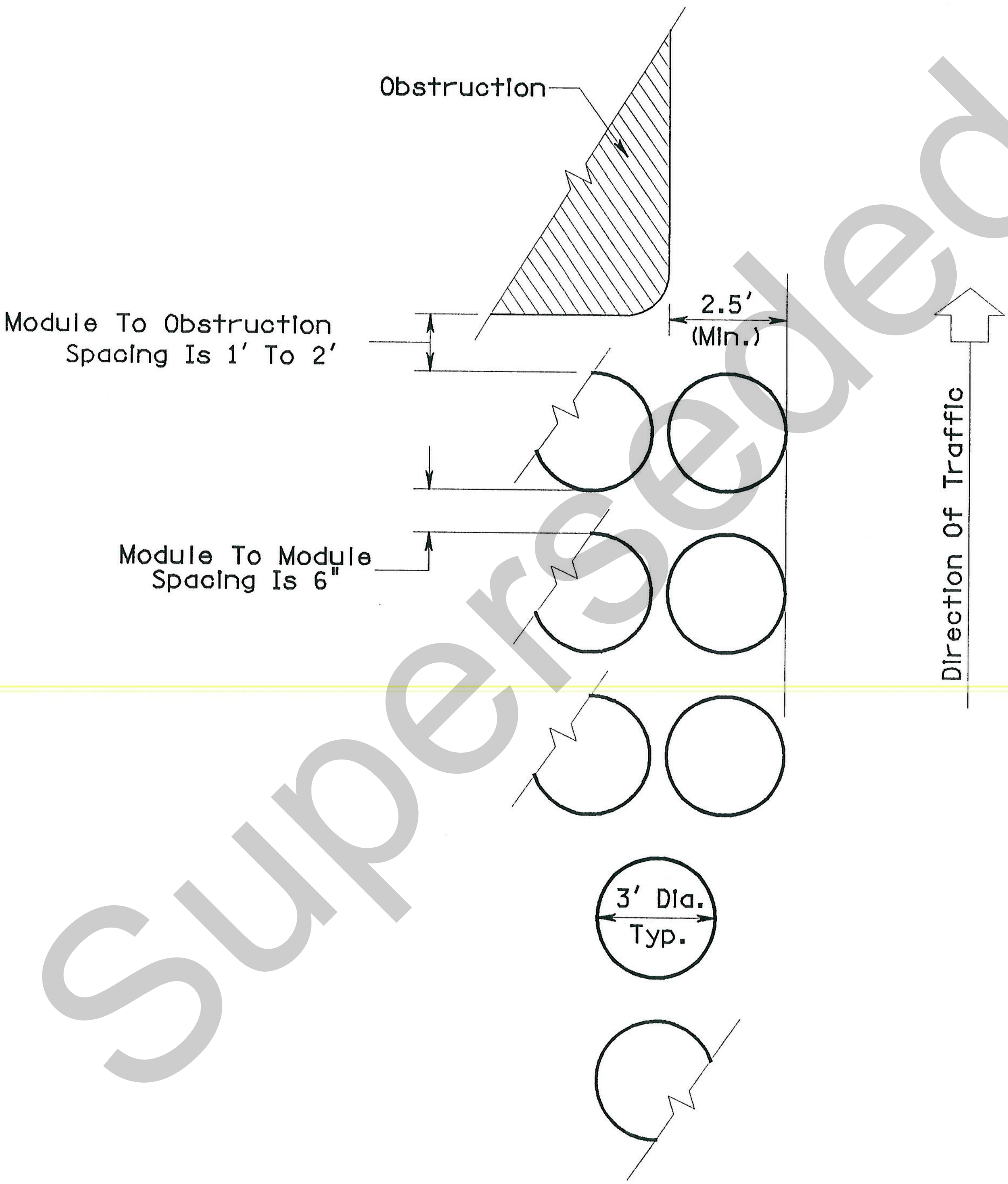
1. Area occupied by the crash cushion:

   The Hi-Dro Cell Cluster occupies the least amount of space. 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 6.5 feet (two barrels each at 3 feet wide plus a 6 inch space between them). The QuadGuard Systems are available in five standard widths of 2.0 feet, 2.5 feet, 3.0 feet, 5.75 feet and 7.5 feet, 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.

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:

SUGGESTED LAYOUT FOR LAST THREE MODULE ROWS IN AN INERTIAL BARRIER	FIGURE : 9-B DATE: 05/29/98

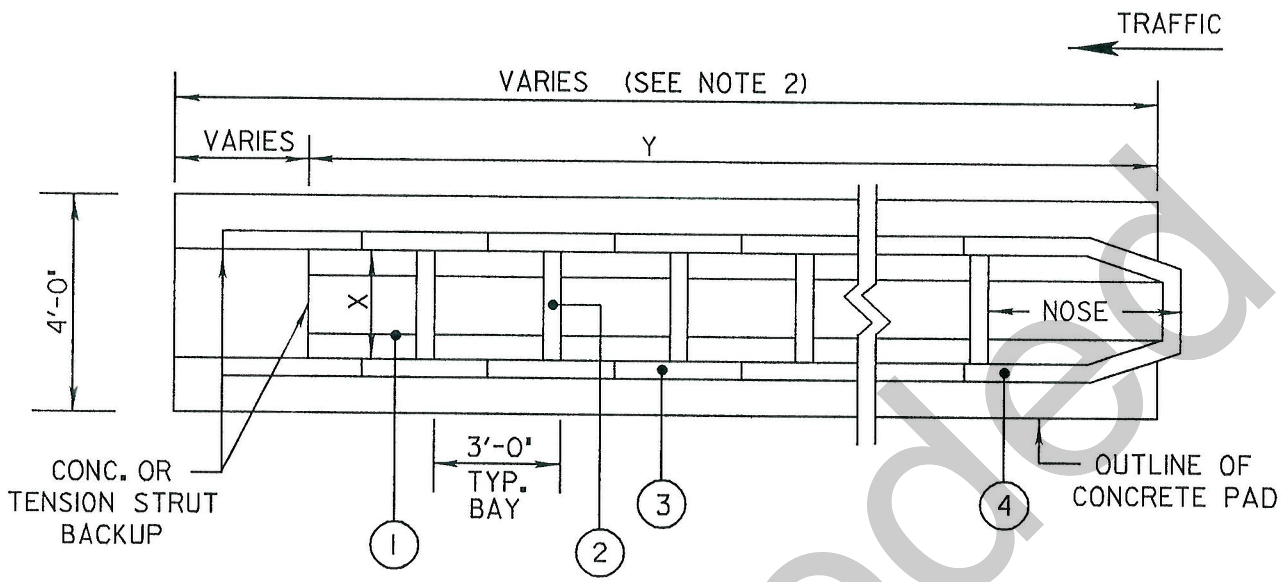


NOTE: A Minimum Of Two Modules Must Be Provided In The Last Three Rows

QUADGUARD SYSTEM

FIGURE: 9-C

DATE: 05/29/98



PLAN

KEY

1. QUADGUARD CARTRIDGE
2. DIAPHRAGM
3. FENDER PANEL
4. NOSE ASSEMBLY

DESIGN DATA			
DESIGN SPEED (MPH)	NUMBER OF BAYS	EFFECTIVE LENGTH OF UNIT Y	NOMINAL WIDTH X
25	1	5'-8"	2'-0", 2'-6" 3'-0", 5'-9" or 7'-6"
35	2	8'-8"	
45	3	11'-8"	
50	4	14'-8"	
55	5	17'-8"	
60	6	20'-8"	
60	7	23'-8"	
65	8	26'-8"	
70	9	29'-8"	
70	10	32'-8"	
70	11	35'-8"	
75	12	38'-8"	

NOTE 1: ONE BAY CONSISTS OF ONE CARTRIDGE, ONE DIAPHRAGM, TWO FENDER PANELS ETC. THE NOSE SECTION IS NOT CONSIDERED A BAY.

NOTE 2: LENGTH OF CONCRETE PAD DEPENDS ON THE TYPE OF BACKUP AND THE NUMBER OF BAYS USED.

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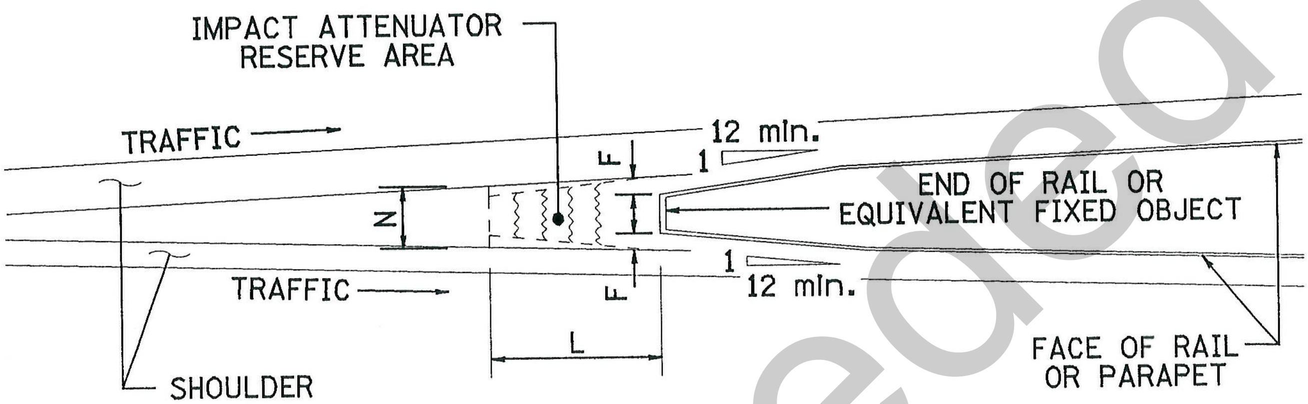
IMPACT ATTENUATOR RESERVE AREA DETAILS

FIGURE : 9-D

DATE: 05/29/98



DESIGN SPEED ON MAINLINE (M.P.H.)	DIMENSIONS FOR IMPACT ATTENUATOR RESERVE AREA ON NEW CONSTRUCTION (FEET)								
	MINIMUM						PREFERRED		
	RESTRICTED CONDITIONS			UNRESTRICTED CONDITIONS					
	N	L	F	N	L	F	N	L	F
30	6	8	2	8	11	3	12	17	4
50	6	17	2	8	25	3	12	33	4
70	6	28	2	8	45	3	12	55	4

NOTE:

FOR INTERMEDIATE DESIGN SPEEDS, USE THE VALUES FOR THE HIGHER DESIGN SPEED (i.e., FOR DESIGN SPEED OF 40 M.P.H. USE VALUES FOR 50 M.P.H. DESIGN SPEED)

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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 feet 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 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 terminal should be gently flared and/or ramped. Flares of 15 to 1 and ramps of 20 to 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 still 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 and Hi-Dro Cell Clusters 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

The Hi-Dro Cell Cluster should not be used where speeds will exceed 45 mph. The other approved crash cushions 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, 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, Hi-Dro Cell Clusters have a moderate initial cost, the QuadGuard System has a 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 to 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.

Although the Hi-Dro Cell Cluster is generally reusable after a collision, it requires periodic checks to assure the tubes are filled and have not lost water due to evaporation or vandalism.

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 barrels 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:

$$V_f = M[V_o/(M + M_s)] \qquad \text{Equation 1}$$

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
M = weight of vehicle, in lbs.
M_s = weight of sand actually impacted by a 6 foot 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 10 mph or less (l4.7 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).

$$G = (V_o^2 - V_f^2)/2Dg \qquad \text{Equation 2}$$

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 feet)
$g = 32.2\ ft/s^2$

The standard weights of modules used are 200 lbs., 400 lbs., 700 lbs., 1400 lbs. and 2100 lbs. However, the use of 2100 lb. module is not recommended unless site conditions are restricted and the use of 1400 lb. 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 foot criteria shown in Figure 9-B. An additional last row of 1400 lb. 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 feet apart. However, this spacing must be accounted for in the design. M_s in Equation 1 is the weight of sand impacted by a 6 foot wide vehicle. Therefore, if 1400 lb. modules (3 feet in diameter) were spaced 2 feet apart, M_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:

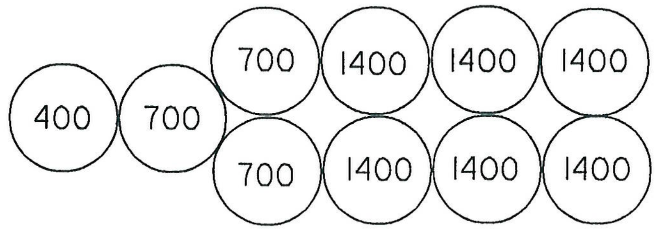
ROW	M_s	V_o	V_f*	G*
1	200	88.0	79.2	7.6**
2	200	79.2	71.3	6.2
3	200	71.3	64.2	5.0
4	400	64.2	52.5	7.1
5	700	52.5	37.8	6.9
6	700	37.8	27.2	3.6
7	1400	27.2	15.3	2.6
8	2800	15.3	6.0	1.0
9	2800	----	----	---
10	2800	----	----	---

* 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.

TYPICAL SAND BARREL CONFIGURATION

FIGURE: 9-E

DATE: 05/29/98



40 MPH DESIGN - 4500# VEHICLE

ROW	Ms (LB)	V_O	V_f	G
1	400	58.7	53.9	2.8
2	700	53.9	46.6	3.8
3	1400	46.6	35.5	4.7
4	2800	35.5	21.9	4.0
5	2800	21.9	13.5	1.5
6	2800	—	—	—

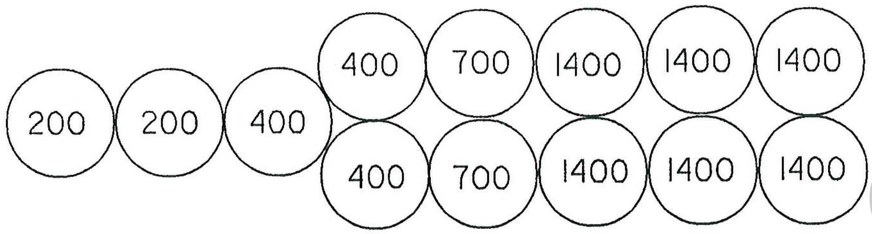
40 MPH DESIGN - 1800# VEHICLE

ROW	Ms (LB)	V_O	V_f	G
1	400	58.7	48.0	5.9
2	700	48.0	34.6	5.7
3	1400	34.6	19.5	4.2
4	2800	19.5	7.6	1.7
5	2800	—	—	—
6	2800	—	—	—

TYPICAL SAND BARREL CONFIGURATION

FIGURE: 9-F

DATE: 05/29/98



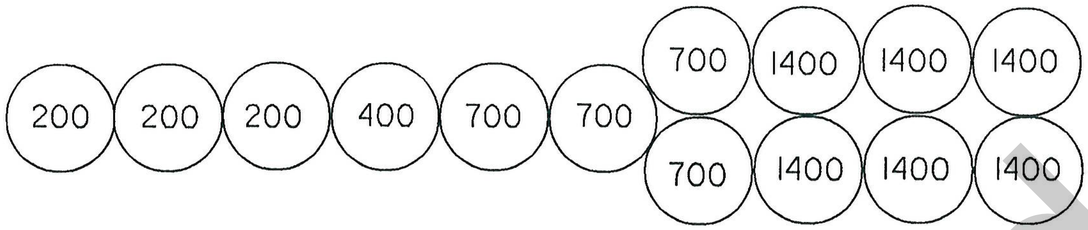
50 MPH DESIGN - 4500# VEHICLE				
ROW	Ms (LB)	V_O	V_f	G
1	200	73.3	70.2	2.3
2	200	70.2	67.2	2.1
3	400	67.2	61.7	3.7
4	800	61.7	52.4	5.5
5	1400	52.4	40.0	5.9
6	2800	40.0	24.7	5.1
7	2800	24.7	15.2	2.0
8	2800	—	—	—

50 MPH DESIGN - 1800# VEHICLE				
ROW	Ms (LB)	V_O	V_f	G
1	200	73.3	66.0	5.3
2	200	66.0	59.4	4.3
3	400	59.4	48.6	6.0
4	800	48.6	33.6	6.4
5	1400	33.6	18.9	4.0
6	2800	18.9	7.4	1.6
7	2800	—	—	—
8	2800	—	—	—

TYPICAL SAND BARREL CONFIGURATION

FIGURE: 9-G

DATE: 05/29/98



60 MPH DESIGN - 4500# VEHICLE

ROW	Ms (LB)	V_O	V_f	G
1	200	88.0	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	—	—	—

60 MPH DESIGN - 1800# VEHICLE

ROW	Ms (LB)	V_O	V_f	G
1	200	88.0	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	—	—	—

Example of Inertial Barrier Design
for 4500 lb. Vehicle:

ROW	M_s	V_o	V_f*	G*
1	200	88.0	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	----	----	---

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.

9-03.2 QuadGuard System

Because of the complex reaction of this crash cushion 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 feet wide and 31 feet 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.

9-03.3 Hi-Dro Cell Cluster

The Hi-Dro Cell Cluster occupies the least amount of space of any of the approved crash cushions. However, the Hi-Dro Cell Cluster is only approved for vehicle speeds up to 45 mph. The Cluster may be arranged to suit the object being shielded. Standard designs for backup structures are available from the manufacturer.

The following is an example of Hi-Dro Cell Cluster design. Assume a design speed of 30 mph (44 fps).

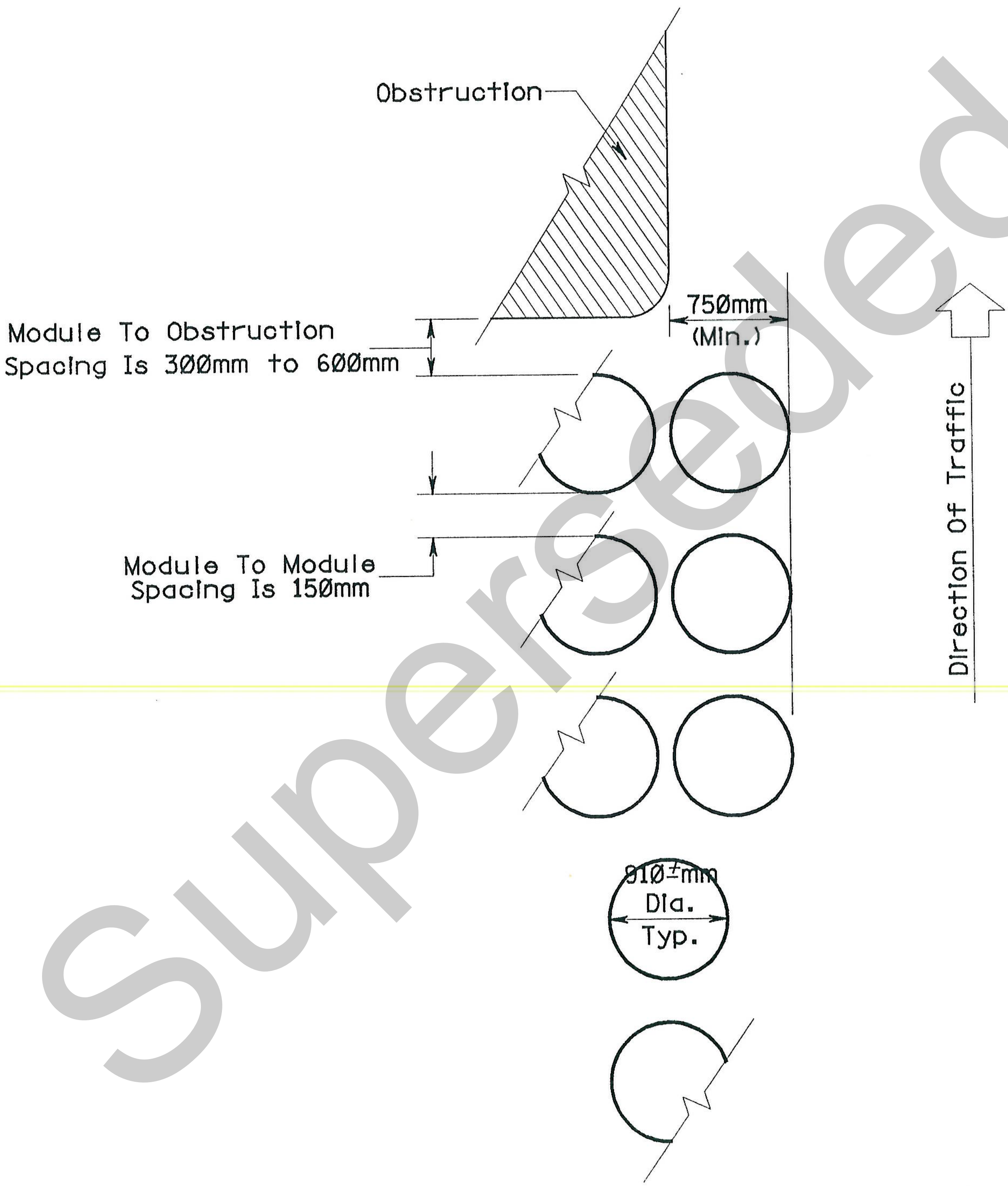
$$S = V^2/[2g(G)]$$

S = minimum stopping distance (feet)
V = design speed (fps)
G = Allowable deceleration force in G's (6G design, 8G maximum)
g = 32.2 ft/s^2

$$S = 44^2/[64.4(6)]$$
$$S = 1936/386.4$$
$$S = 5.01 \text{ ft.}$$

Each cell is 6 inches, therefore, use 10 rows. Usually a minimum of 5 cells should be used in each row, however, the number of cells per row will vary depending on the dimensions of the obstruction.

SUGGESTED LAYOUT FOR LAST THREE MODULE ROWS IN AN INERTIAL BARRIER	FIGURE : 9-B DATE: 05/29/98

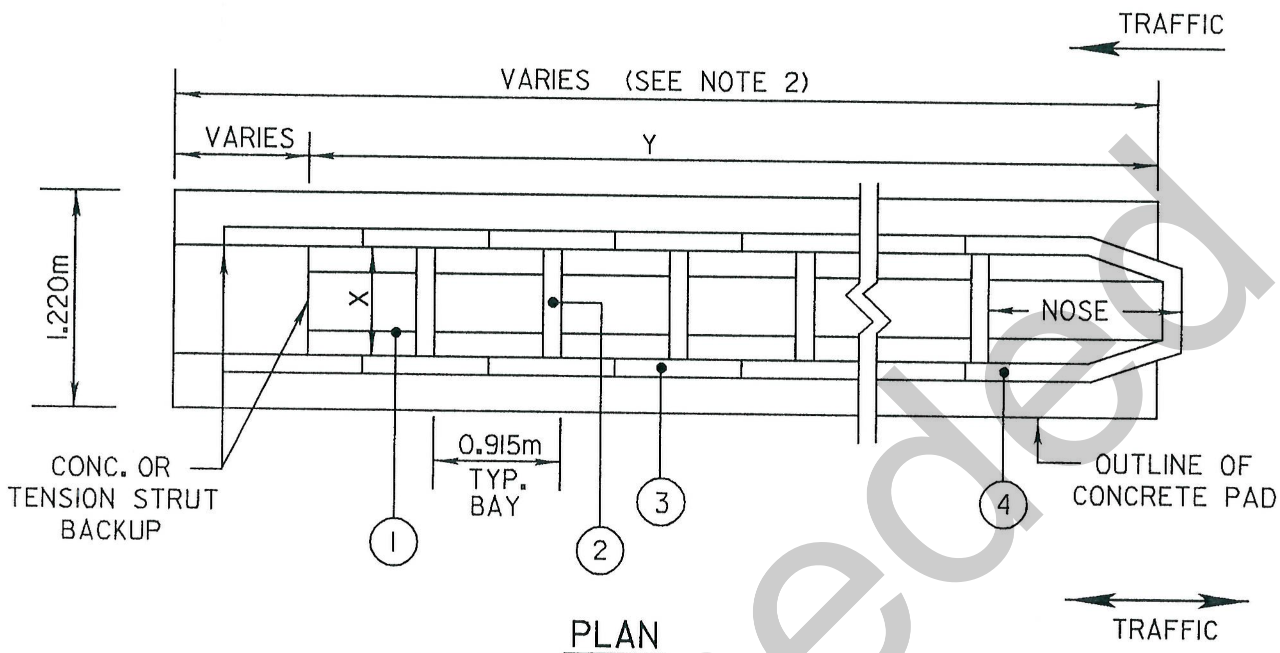


NOTE: A Minimum Of Two Modules Must Be Provided In The Last Three Rows

QUADGUARD SYSTEM

FIGURE: 9-C

DATE: 05/29/98



PLAN

KEY

1. QUADGUARD CARTRIDGE
2. DIAPHRAGM
3. FENDER PANEL
4. NOSE ASSEMBLY

DESIGN DATA			
DESIGN SPEED (km/h)	NUMBER OF BAYS	EFFECTIVE LENGTH OF UNIT Y	NOMINAL WIDTH X
40	1	1.74m	0.610m, 0.760m, 0.915m, 1.750m or 2.285m
50-60	2	2.66m	
70	3	3.57m	
80	4	4.49m	
90	5	5.40m	
100	6	6.32m	
100	7	7.23m	
110	8	8.15m	
115	9	9.06m	
115	10	9.98m	
115	11	10.89m	
120	12	11.81m	

NOTE 1: ONE BAY CONSISTS OF ONE CARTRIDGE, ONE DIAPHRAGM, TWO FENDER PANELS ETC. THE NOSE SECTION IS NOT CONSIDERED A BAY.

NOTE 2: LENGTH OF CONCRETE PAD DEPENDS ON THE TYPE OF BACKUP AND THE NUMBER OF BAYS USED.

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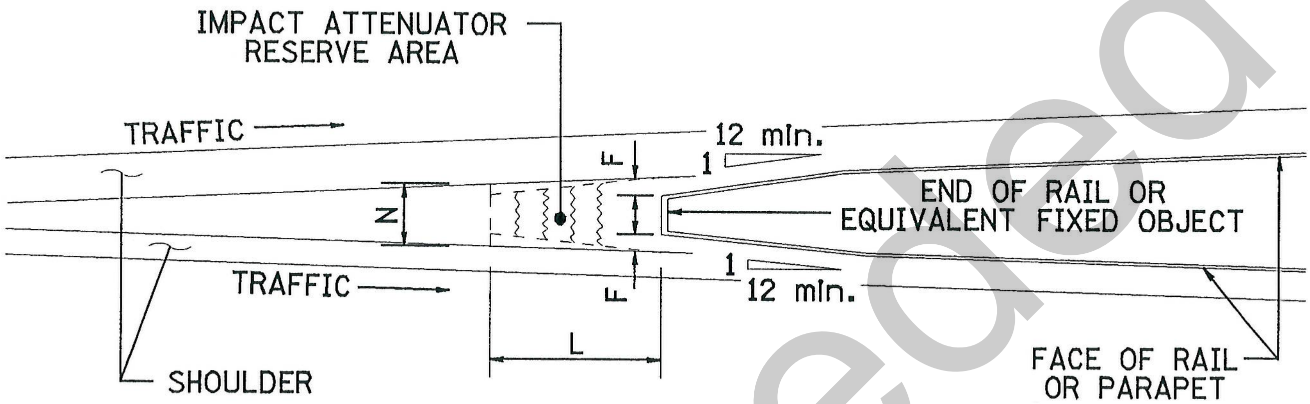
IMPACT ATTENUATOR RESERVE AREA DETAILS

FIGURE : 9-D

DATE: 05/29/98



DESIGN SPEED ON MAINLINE (km/h)	DIMENSIONS FOR IMPACT ATTENUATOR RESERVE AREA ON NEW CONSTRUCTION (M)								
	MINIMUM						PREFERRED		
	RESTRICTED CONDITIONS			UNRESTRICTED CONDITIONS					
	N	L	F	N	L	F	N	L	F
50	2.0	2.5	0.5	2.5	3.5	1.0	3.5	5.0	1.5
80	2.0	5.0	0.5	2.5	7.5	1.0	3.5	10.0	1.5
110	2.0	8.5	0.5	2.5	13.5	1.0	3.5	17.0	1.5
130	2.0	11.0	0.5	2.5	17.0	1.0	3.5	21.0	1.5

NOTE:

FOR INTERMEDIATE DESIGN SPEEDS, USE THE VALUES FOR THE HIGHER DESIGN SPEED (i.e., FOR DESIGN SPEED OF 60 KM/H USE VALUES FOR 80 KM/H DESIGN SPEED)

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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:

<u>Restricted Conditions</u> - 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.

<u>Unrestricted Conditions</u> - These dimensions should be considered as the <u>minimum</u> 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 15 m 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 100 mm in height. Curbs from 100 mm to 150 mm 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 150 mm 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 and Hi-Dro Cell Clusters 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

The Hi-Dro Cell Cluster should not be used where speeds will exceed 70 km/h. The other approved crash cushions 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, 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, Hi-Dro Cell Clusters have a moderate initial cost, the QuadGuard System has a 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.

Although the Hi-Dro Cell Cluster is generally reusable after a collision, it requires periodic checks to assure the tubes are filled and have not lost water due to evaporation or vandalism.

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:

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

V_f = velocity of vehicle after impact with M_s, in m/s
V_o = velocity of vehicle prior to impact with M_s, in m/s
M = weight of vehicle, in kg.
M_s = weight of sand actually impacted by a 1.8 m wide vehicle, in kg.

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 15 km/h or less (4.17 m/s) 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 meters per second (m/s).

$$G = (V_o^2 - V_f^2)/2Dg \qquad \text{Equation 2}$$

G = deceleration force in G's
V_o = velocity of vehicle prior to impact, in m/s
V_f = velocity of vehicle after impact with one row of modules, in m/s
D = distance traveled in decelerating from V_o to V_f
(Usually D = width of a module = 1 m)
g = 9.81 m/s^2

The standard weights of modules used are 90 kg, 180 kg, 320 kg, 640 kg and 960 kg. However, the use of 960 kg module is not recommended unless site conditions are restricted and the use of 640 kg, 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 750 mm criteria shown in Figure 9-B. An additional last row of 640 kg modules is provided after required reduction in speed is obtained. When a wide obstruction is being shielded, the modules may be spaced up to 910 mm apart.

However, this spacing must be accounted for in the design. M_s in Equation 1 is the weight of sand impacted by a 1.8 m. wide vehicle. Therefore, if 640 kg modules (910 mm diameter) were spaced 610 mm apart, M_s would equal 1,189 kg.

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 820 kg vehicle and then make the same check for a 2000 kg vehicle. Assume a design speed of 100 km/h.

Example of Inertial Barrier Design
for 820 kg Vehicle:

ROW	M_s	V_o	V_f*	G*
1	90	27.8	25.0	7.4**
2	90	25.0	22.6	6.0
3	90	22.6	20.3	4.9
4	180	20.3	16.7	6.9
5	320	16.7	12.0	6.8
6	320	12.0	8.6	3.5
7	640	8.6	3.5	2.6
8	1280	---	---	---
9	1280	---	---	---
10	1280	---	---	---

* 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 90 kg is the lightest module recommended for use, the 7.4 cannot be decreased.

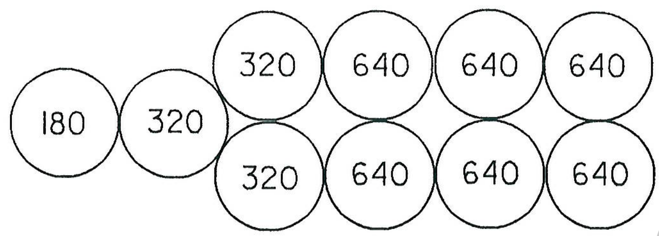
Example of Inertial Barrier Design
for 2000 kg. Vehicle:

ROW	M_s	V_o	V_f*	G*
1	90	27.8	26.6	3.3
2	90	26.6	25.4	3.0
3	90	25.4	24.3	2.8
4	180	24.3	22.3	4.8
5	320	22.3	19.3	6.5
6	320	19.3	16.6	4.8
7	640	16.6	12.6	6.0
8	1280	12.6	7.7	5.0
9	1280	7.7	4.9	1.9
10	1280	---	---	---

TYPICAL SAND BARREL CONFIGURATION

FIGURE: 9-E

DATE: 05/29/98



60 km/h DESIGN - 2000 kg VEHICLE

ROW	M_S (kg)	V_O	V_f	G
1	180	16.7	15.3	2.2
2	320	15.3	13.2	3.1
3	640	13.2	10.0	3.8
4	1280	10.0	6.1	3.2
5	1280	6.1	3.7	1.2
6	1280	—	—	—

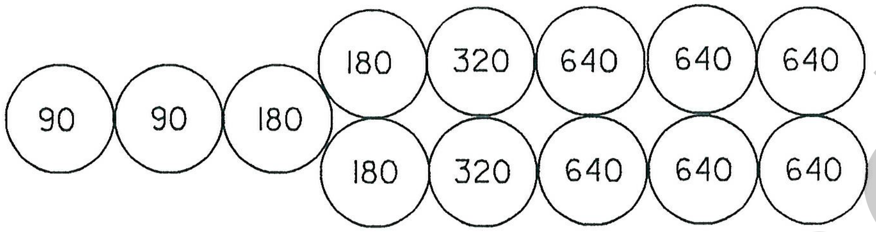
60 km/h DESIGN - 820 kg VEHICLE

ROW	M_S (kg)	V_O	V_f	G
1	180	16.7	13.7	4.6
2	320	13.7	9.8	4.6
3	640	9.8	5.5	3.4
4	1280	5.5	2.2	1.3
5	1280	—	—	—
6	1280	—	—	—

TYPICAL SAND BARREL CONFIGURATION

FIGURE: 9-F

DATE: 05/29/98



80 km/h DESIGN - 2000 kg VEHICLE

ROW	M_S (kg)	V_O	V_f	G
1	90	22.2	21.3	2.1
2	90	21.3	20.3	2.0
3	180	20.3	18.7	3.3
4	360	18.7	15.8	5.0
5	640	15.8	12.0	5.4
6	1280	12.0	7.3	4.6
7	1280	7.3	4.5	1.7
8	1280	—	—	—

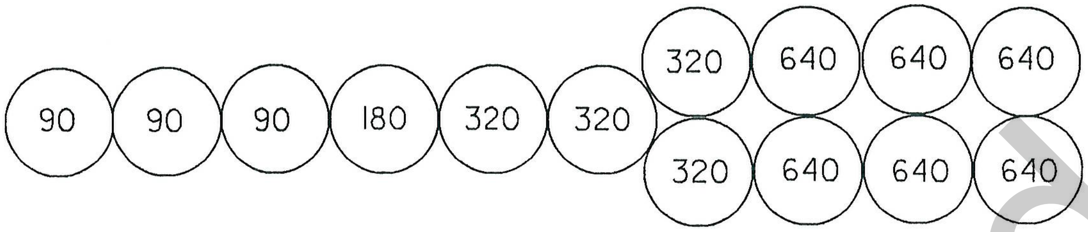
80 km/h DESIGN - 820 kg VEHICLE

ROW	M_S (kg)	V_O	V_f	G
1	90	22.2	20.0	4.7
2	90	20.0	18.0	3.8
3	180	18.0	14.8	5.4
4	360	14.8	10.3	5.8
5	640	10.3	5.8	3.7
6	1280	5.8	2.3	1.4
7	1280	—	—	—
8	1280	—	—	—

TYPICAL SAND BARREL CONFIGURATION

FIGURE: 9-G

DATE: 05/29/98



100 km/h DESIGN - 2000 kg VEHICLE

ROW	M_S (kg)	V_O	V_f	G
1	90	27.8	26.6	3.3
2	90	26.6	25.4	3.0
3	90	25.4	24.3	2.8
4	180	24.3	22.3	4.8
5	320	22.3	19.3	6.5
6	320	19.3	16.6	4.8
7	640	16.6	12.6	6.0
8	1280	12.6	7.7	5.1
9	1280	7.7	4.7	1.9
10	1280	—	—	—

100 km/h DESIGN - 820 kg VEHICLE

ROW	M_S (kg)	V_O	V_f	G
1	90	27.8	25.0	7.4
2	90	25.0	22.6	6.0
3	90	22.6	20.3	4.9
4	180	20.3	16.7	6.9
5	320	16.7	12.0	6.8
6	320	12.0	8.6	3.5
7	640	8.6	4.8	2.6
8	1280	4.8	1.9	1.0
9	1280	—	—	—
10	1280	—	—	—

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.

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 915 mm wide and 10 m long (11 bay unit only). This system has been successfully crash tested with vehicles traveling at speeds of approximately 100 km/h. The dimensions of the concrete pad, backup systems and detailed drawings are available from the manufacturer.

9-03.3 Hi-Dro Cell Cluster

The Hi-Dro Cell Cluster occupies the least amount of space of any of the approved crash cushions. However, the Hi-Dro Cell Cluster is only approved for vehicle speeds up to 70 km/h. The Cluster may be arranged to suit the object being shielded. Standard designs for backup structures are available from the manufacturer.

The following is an example of Hi-Dro Cell Cluster design. Assume a design speed of 50 km/h (13.9 m/s).

$$S = V^2/[2g(G_d)]$$

S = minimum stopping distance, in meters
V = design speed, in m/s
G_d = Allowable deceleration force in G's for design (6G design, 8G maximum)
g = 9.81 m/s^2

$$S = 13.9^2/[2(9.81)(6)]$$
$$S = 193.2/117.72 = 1.64 \text{ m}$$

Each cell is 150 mm, therefore, use 11 rows. Usually a minimum of 5 cells should be used in each row, however, the number of cells per row will vary depending on the dimensions of the obstruction.

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