INTRODUCTION TO THE ROADSIDE DESIGN GUIDE


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Objectives

✓ Apply the concept of the clear zone to improve road safety.

✓ Identify practical strategies and safety treatments that minimize the likelihood of serious injuries when a driver does run off the road.

✓ Learn the technical aspects in select, design and locate safety barriers and other elements on a highway.

✓ Inspect safety barriers to evaluate installation, operational condition and recognize unsafe conditions.
INTRODUCTION
It is important to establish a program of safety evaluation to:

- identify risks (safety issues) and
- evaluate the effectiveness of alternatives or improvements.
Factors Involved in Transportation Crashes

While the causes of crashes are usually complex and involve several factors, they can be considered in four separate categories:

• Actions by the driver or operator,
• Mechanical condition of the vehicle,
• Geometric characteristics of the roadway, and
• Physical or climatic environment in which the vehicle operates.
Crash Cause by Factor

- **Roadway**: 34%
- **Driver**: 93%
- **Vehicle**: 12%

Taken from: Stop Red Light Running (FHWA)
Strategic Highway Safety Plans

• SAFETEA-LU: The Safe Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users legislation of 2005
  • New “Core” Highway Safety Improvement Program SAFETEA-LU Doubles TEA-21 Safety Apportionment
  • Requires that each state develop a Strategic Highway Safety Plan (SHSP).
  • Purpose: to achieve a significant reduction in traffic fatalities and serious injuries on public roads
The purpose of a Strategic Highway Safety Plan (SHSP)

Each state is required to have a SHSP, which includes engineering, management, education, enforcement, and emergency service elements of highway safety as key factors in evaluating highway safety projects.
"Working together toward HIGHWAY SAFETY ... TO SAVE MORE LIVES"
The overall objective and public policy adopted by the commonwealth of Puerto Rico is to achieve about 13% annual reduction in the number of fatalities and serious injuries in the highways of Puerto Rico over the next five years.
# Table 10: Roadway Departure Goals, Performance Measures, Objectives, and Strategies

<table>
<thead>
<tr>
<th>Roadway Departure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strategic Goal</strong></td>
</tr>
<tr>
<td><strong>Performance Measures</strong></td>
</tr>
<tr>
<td><strong>Objective (Performance Goal)</strong></td>
</tr>
</tbody>
</table>

## Strategies

1. Integrate and coordinate targeted enforcement and prevention initiatives being implemented by various law enforcement agencies.
2. Promote and support activities for targeted enforcement in corridors with a high incidence of run-off-road crashes.
3. Improve enforcement for vehicle maintenance and inspection violations, including support for law enforcement training activities.
4. Promote driver education about risky behaviors leading to run-off-road crashes.
5. Implement engineering measures to remove and/or shield fixed-objects located within roadside clear recovery area in accordance with current standards.
6. Promote the revision of roadside safety engineering policies and standards.
7. Educate transportation professionals on new and innovative roadway departure countermeasures.
STRATEGIC PLAN
FOR IMPROVING
ROADSIDE SAFETY
• In 2008, 23.1% of the fatal crashes were single-vehicle, run-off-the-road crashes.

• These statistics mean that the roadside environment comes into play in a very significant percentage of fatal and serious-injury crashes.
Percent Distribution of Fixed-Object Fatalities by Object Struck, 2013

- Tree: 50%
- Utility pole: 13%
- Traffic barrier: 8%
- Embankment: 5%
- Ditch: 4%
- Culvert: 3%
- Fence: 2%
- Building: 2%
- Bridge pier: 2%
- Wall: 2%
- Highway sign support: 2%
- Other: 7%

Source: Insurance Institute for Highway safety
Why Would a Vehicle Leave the Highway?

- Driver fatigue
- Driver distractions or inattention
- Excessive speed
- Driving under the influence of drugs or alcohol
- Crash avoidance
- Adverse roadway conditions, such as ice, snow, or rain
- Vehicle failure
- Poor visibility
Roadside Design Options for mitigation of objects within the design clear zone

1. Remove the obstacle
2. Redesign the obstacle
3. Relocate the obstacle
4. Reduce impact severity
5. Shield the obstacle
6. Delineate the obstacle

The designer of the road is in charge of providing the safest possible installation with the restrictions provided.
Proposed Solution

Its main focus are safety treatments that can minimize the chance of serious injury when a driver off the road.
1. Introduction
2. Benefits and Economics
3. Topography and Drainage
4. Sign, Poles and Trees
5. Roadside Barriers
6. Median Barriers
7. Bridges
8. End Treatments
9. Work Zones
10. Urban Environments
11. Mailboxes
12. Roadside Safety on Low-Volume Roads and Streets
Roadside design might be defined as the design of the area outside the traveled way.
1. **Clear Zones:**

Unobstructed, traversable area provided outside the edge of the traveled way for the recovery of errant vehicles. Includes:

- shoulders
- auxiliary lanes
2. **Lateral Offsets**: necessary distance to obstructions outside the edge of the traveled way.

In urban environments for arterials, a lateral offset to vertical obstructions is needed to accommodate motorists operating on the highway.
Roadside Definition (cont.)

Obstructions like:
- signs,
- utility poles,
- luminaire supports,
- fire hydrants, etc.
Roadside Definition (cont.)

- Lateral offset to obstructions helps to:
  - Avoid opposing impacts on vehicle lane position and invasions into opposing or adjacent lanes;
  - Improve driveway and horizontal sight distances;
  - Reduce the travel lane invasions from occasional parked and immobilized vehicles;
  - Improve travel lane capacity; and
  - Minimize contact between obstructions and vehicle mirrors, car doors, and trucks that extend the edge when turning.
Roadside Hazard

A roadside object is considered potentially hazardous when one or more of the following events occur:

- passenger compartment is penetrated by some external object
- vehicle becomes unstable, snags, vaults or rolls over
  - objects more than 4 inches above the terrain surface can cause snagging;
  - Curb height of no more 4 inches can cause vaulting (jumping)
Clear Zone Distance Curves (AASHTO RDG)

Figure 3.1 (RDG)
EXAMPLE #1

6H:1V FORESLOPE (FILL SLOPE)
60 mph
5000 vpd
Clear Zone Distance (ft) From Edge of Through Traveled Way (RDG AASHTO)

** Since recovery is less likely on the unshielded, transversable 1V:3H slopes, fixed objects should not be present in the vicinity of the toe of these slopes.
Adjustment of Clear Zone Because of Horizontal Curve (AASHTO RDG)

Table 3-2. Horizontal Curve Adjustment Factor

<table>
<thead>
<tr>
<th>Radius, m [ft]</th>
<th>Design Speed km/h [mph]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60 [40]</td>
</tr>
<tr>
<td>900 [2,950]</td>
<td>1.1</td>
</tr>
<tr>
<td>700 [2,300]</td>
<td>1.1</td>
</tr>
<tr>
<td>600 [1,970]</td>
<td>1.1</td>
</tr>
<tr>
<td>500 [1,640]</td>
<td>1.1</td>
</tr>
<tr>
<td>450 [1,475]</td>
<td>1.2</td>
</tr>
<tr>
<td>400 [1,315]</td>
<td>1.2</td>
</tr>
<tr>
<td>350 [1,150]</td>
<td>1.2</td>
</tr>
<tr>
<td>300 [985]</td>
<td>1.2</td>
</tr>
<tr>
<td>250 [820]</td>
<td>1.3</td>
</tr>
<tr>
<td>200 [660]</td>
<td>1.3</td>
</tr>
<tr>
<td>150 [495]</td>
<td>1.4</td>
</tr>
<tr>
<td>100 [330]</td>
<td>1.5</td>
</tr>
</tbody>
</table>

\[ C_{Z_c} = (L_c)^* (K_{cc}) \]

where:

- \( C_{Z_c} \) = Clear zone on outside of curvature, meters [feet]
- \( L_c \) = Clear zone distance, meters [feet] (see Table 3-1)
- \( K_{cc} \) = Curve correction factor

Note: The clear-zone correction factor is applied to the outside of curves only. Curves flatter than 900-m [2,950-ft] radius do not require an adjusted clear zone.
ROADSIDE GEOMETRY AND DRAINAGE FEATURES
Roadside Geometry

1. Foreslope (fill slope)
2. Backslope (cut slope)
3. Transverse slope
4. Drainage Structures
Roadway Geometry Features

- Roadway
- Transverse Slope
- Side Road
- Transition Slope
- Fore/Front Slope
- Back Slope
- Drive
- Parallel/Longitudinal Slopes
Rural Roadway Cross Section Elements

In roadside design, two major elements should be controlled by the designer: roadside slopes and rigid obstacles.
Cross Section Elements for Rural Two-Lane Highway

Urban Cross-section Elements
1. Steepness Categories of Foreslopes

1. Recoverable
2. Non-Recoverable
3. Critical
2. Backslope (Cut Slope)

• When a highway is located in a cut section, the backslope may be traversable depending upon its relative smoothness and the presence of fixed obstacles.

• Traversable

• 1V:3H or flatter

• Free of obstacles
3. Transverse Slopes

• Minimum slope for high speed: 1V:6H or flatter
• Desirable: 1V:10H
• Transverse slope steeper than 1V:6H may be considered for urban areas or for low speed facilities.

Created by crosses, medians, shoulders, roadway or side roads intersection.

These are commonly limited by restrictions on the width and maintenance problems and long ends taper sewer.
4. Drainage Structures

• A drainage channel is an open channel usually paralleling the roadway.

• The primary function of drainage channels is to collect surface runoff from the roadway and areas that drain to the right-of-way and transport the accumulated runoff to acceptable outlet points.
Design Options of Drainage Structures

• Eliminate non-essential drainage structures
• Design or modify drainage structures so they are traversable or present a minimal hazard to an errant vehicle
• If a major drainage feature cannot effectively be redesign or relocated, it should be shielded by a suitable traffic barrier if it is in a vulnerable location
The headwall is sticking up almost a foot in a relatively flat recoverable area. It can snag a vehicle and bring it to an abrupt stop or cause it to overturn.

A non-traversable drainage ditch such as this is a safety hazard.
Channel Treatment on Embankment Foreslope (1V:6H)
Culvert Treatment on Transverse Slope

Safety Treatment for Parallel Drainage Pipe
Preferred Cross Sections for Channels with Abrupt Slope Changes

If it is within the shaded region it is considered that the channel will provide a transitable cross section.
Preferred Cross Sections for Channels with Gradual Slope Changes

Figure 3.7 (RDG)
Review

- The "Clear Zone" is a minimum lateral distance that allows for the determination of the necessity for a safety barrier.
- The area should be safe for any driver who loses control of the vehicle and veers off the road.
- In the interest of safety, the area should be traversable (objects that could be impacted should not be present) and should have a slope of 1V: 4H or flatter.
- If the lateral area does not meet the requirements then a safety barrier should be installed.
EXAMPLES OF APPLICATION
ROADSIDE FEATURES

Sign, Signal, and Luminaire Supports, Utility Poles, Trees

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The Six options Still Apply:

1. Remove the obstacle
2. Redesign the obstacle
3. Relocate the obstacle
4. Reduce impact severity
5. Shield the obstacle
6. Delineate the obstacle
Acceptance Criteria For Breakaway Supports

- **Breakaway Support**: designed to yield, fracture, or separate when impacted by a vehicle.
- Types of release mechanism:
  - slip plane,
  - plastic hinge,
  - fracture element, or
  - A combination of them.

http://www.sddc.army.mil
The criteria used to determine if a support is considered breakaway are found in the:

NCHRP 350 Report and MASH criteria require that a breakaway support perform in a predictable manner when struck head-on by an 2420 lb and/or 5000 lb vehicle, or its equivalent, at speed from 19 mph to 62 mph.
Design and Location Criteria

• Sign, luminaire, and other supports should be:
  • structurally adequate to support the device mounted on them
  • structurally adequate to resist ice and wind loads
• MUTCD states that if located in the clear zone – it should be shielded or breakaway
Design and Location Criteria

- Sign, luminaire, and other supports:
  - Should not be placed where are going to get damaged, such as ditches (erosion)
  - If is not needed, remove it
  - If needed, place it where is less likely to be hit
  - If you can, place it behind a barrier or on an existing structure
  - If not, make it breakaway
Design and Location Criteria

- Sign, luminaire, and other supports:
  - Should avoid placing in areas with high concentrations of pedestrians.
- Supports placed on a foreslope of $1:6$ or flatter are acceptable.
- Maximum stub height: 10 cm (4 in.)

Figure 4-1. Breakaway Support Stub Height Measurements
Design and Location Criteria

Sign, luminaire, and other supports:

• if electrical:
  • Must have electrical disconnects to reduce the risk of fire and electrical hazards
  • It should disconnect as close to the pole base as possible

• Designed to be impacted at bumper height

• Not located in places near ditches, on steep slopes where a vehicle can airborne at the time of impact

• Type of soil can also affect the mechanism some support might be sensitive to foundation movement
Sign Supports

• Roadway signs can be divided into three main categories:
  • overhead signs
  • large roadside signs
  • small roadside signs
Overhead Signs

• They are fixed (not breakaway)
• Should be located behind barriers or mounted on structures
• If located within the clear zone: shielded with a crashworthy barrier
Overhead Signs

Source: www.interstate-guide.com
Large Roadside Signs

• Greater than 5 m\(^2\) (50 ft\(^2\)) in area
• Typically have two or more breakaway support posts
• Hinge at least 2 m (7 in) over the ground
• No supplementary signs below the hinge
• The breakaway mechanism should be fracture or slip base---type
Impact Performance of a Multiple-Post Sign Support

Vehicle force

Base releases and hinge activates

Vehicle passes underneath sign
Large Roadside Signs Supports

Multidirectional Coupler

Typical Unidirectional Slip Base

Slotted Fuse Plate Design

Perforated Fuse Plate Design
Small Roadside Sign Supports

- Defined as those having a sign panel area not greater than 5 m$^2$ [50 ft$^2$].
- Supported by one or more posts
- Mechanisms are either base, bending, fracture, or slip- base design
Supports of Small Roadside Signs

Unidirectional Slip Base

Multidirectional Slip Base

Oregon 3-Bolt Slip Base
Luminaire Supports

• Either breakaway or fixed
• Breakaway can be:
  • frangible base
  • slip base
  • frangible coupler
Considerations

• When impacted, should fall near the path of the vehicle
• The mast should rotate so it points away from the roadway when resting on the ground
• Heights should not exceed 18.5 m (60 ft)
Traffic Signal Supports

• Include structures for post mounted traffic signals, structures with cantilevered arms, overhead mounted traffic signals, and span wire mounted traffic signals.

• The support post should be placed as far away from the roadway as practicable.
Fire Hydrants

- Whenever possible, should be located sufficiently far away from the roadway.
- They do not become obstructions for the motorist, yet are still readily accessible to and usable by emergency personnel.
- Any portion of the hydrant not designed to break away should be within 4 in. of the ground.
## Objectives and Strategies for Reducing Utility Pole Crashes

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Strategies</th>
</tr>
</thead>
</table>
| **A** Treat specific poles in high-crash and high-risk locations | A1 Remove poles in hazardous locations  
A2 Relocate poles further away or to less vulnerable location  
A3 Use breakaway poles  
A4 Shield drivers from poles  
A5 Improve drivers' abilities to see poles  
A6 Apply traffic calming techniques to reduce speeds |
| **B** Prevent placing poles in high-risk locations | B1 Develop, revise, and implement policies to prevent placing or replacing poles within the recovery area |
| **C** Treat poles to minimize ROR crashes        | C1 Place utilities underground  
C2 Relocate poles further away or to less vulnerable location  
C3 Decrease the number of poles |
## Trees

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong> Prevent trees from growing in hazardous locations.</td>
<td>A1 Develop, revise, and implement planting guidelines to prevent placing trees in hazardous location.</td>
</tr>
<tr>
<td><strong>B</strong> Eliminate the hazardous condition and/or reduce the severity of the crash.</td>
<td>A2 Develop mowing and vegetation control guidelines.</td>
</tr>
<tr>
<td></td>
<td>B1 Remove trees in hazardous locations.</td>
</tr>
<tr>
<td></td>
<td>B2 Shield motorists from striking trees.</td>
</tr>
<tr>
<td></td>
<td>B3 Modify roadside clear zone in the vicinity of trees.</td>
</tr>
<tr>
<td></td>
<td>B4 Delineate trees in hazardous locations.</td>
</tr>
</tbody>
</table>
QUESTIONS?
Barrier Types

Roadside Barriers

Median Barriers

Bridge Railings
Roadside Barriers

• A roadside barrier is a longitudinal barrier used to shield motorists from natural or man-made obstacles located along either side of a traveled way.
• It also may be used to protect bystanders, pedestrians, and cyclists from vehicular traffic under special conditions.
Median Barriers

• Installed in medians of divided highways to prevent errant vehicles from entering the opposing roadway of traffic and help to reduce head-on-collisions.

• Designed to be struck from either side.
Bridge Railings

• Bridge railings differ from other longitudinal roadside barriers because they are physically connected to the bridge structure, and are not usually designed to deflect when struck by a vehicle.

• Bridge railings are very important components of roadway safety systems and play an important role in preventing and mitigating crashes.

• Since the primary purpose of a bridge railing is to prevent penetration, it must be strong enough to redirect an impacting vehicle.
Purpose of Safety Barriers

• Provide a shield / prevent vehicle penetration to the hazard area
• Redirect the vehicle after the impact occurs
• Reduce the severity of the potential impact if not exist barrier
• Protect from:
  • Deep embankment
  • A tree or pole
  • A bridge
  • A bridge column
  • Vehicles in the other direction
  • A label bracket
Roadside Barrier System

1. Terminal
2. Standard section
3. Transition section
4. Bridge Railing
Standards for Testing Crashes with Barriers

AASHTO, (MASH) Manual for Assessing Safety Hardware

NCHRP 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features

The purpose of this report is to present criteria for crash tests of permanent and temporary features for highway safety and evaluation criteria recommended for evaluating the test results.
NCHRP 350 Crash Tests

• Describes:
  • the vehicles to be used in testing,
  • the test conditions, and
  • the equipment that will be used in testing the hardware

• Testing criteria are hardware-specific that require multiple tests under different impact conditions

• Six levels of testing (TL1 to TL6)
  • Levels 1, 2, and 3: applicable for both permanent and temporary barriers used in work zones for car and pickup trucks
  • Levels 4, 5, and 6: intended for permanent barriers and considers truck vehicles
### NCHRP 350 TL Suggested Applications

<table>
<thead>
<tr>
<th>Test Level</th>
<th>Selection Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>TL-1</td>
<td>Work zones with low posted speed, and low volume local streets</td>
</tr>
<tr>
<td>TL-2</td>
<td>Work zones, and most local and collector roads with low posted speeds and a low number of heavy vehicles expected</td>
</tr>
<tr>
<td>TL-3</td>
<td>High speed arterials with low mixtures of heavy vehicles and with favorable site conditions</td>
</tr>
<tr>
<td>TL-4</td>
<td>High speed highways, freeways, expressways, and Interstate highways with a mixture of trucks and heavy vehicles</td>
</tr>
<tr>
<td>TL-5</td>
<td>Same locations as TL-4 where a significant percent of the ADT is made of large trucks or where there are unfavorable site conditions</td>
</tr>
<tr>
<td>TL-6</td>
<td>Same locations as TL-4 where a significant percent of the ADT is made of tanker trucks, and unfavorable site conditions exist</td>
</tr>
</tbody>
</table>
Changes to Test Vehicles in MASH (Manual for Assessing Safety Hardware)

- Small car mass of 1,800 lb increased to 2,420 lb
- Pickup truck mass of 4,400 lb increased to 5,000 lb
  - Quadcab truck: higher bumper height and center of gravity
- Single unit truck unit mass of 18,000 lb to 22,000 lb
  Minimum center of gravity height of 28 inches
Evaluation Criteria

• Structural acceptability of the tested feature:
  • Occupant risk
  • Vehicle trajectory after impact
Structural Capability, MASH

• Depending on its proposed function, the feature:
  • Should contain and redirect the vehicle, or bring the vehicle to a controlled stop
  • Should not allow the vehicle to penetrate, underride, or override the installation
  • Should operate in a expectable manner by breaking away, fracturing, or yielding

• Redirection, controlled penetration, or controlled stopping
Post Impact Vehicle Trajectory

- Should not intrude into adjacent traffic lanes
- Vehicle should remain upright during and after collision (not essential for TL3-6 trucks)
- Exit angle should be less than 60% of the impact angle
Evaluation Criteria

• Crashworthiness is currently accepted if either of the following conditions are met:
  • A barrier system has met all of the evaluation criteria listed in MASH or NCHRP Report 350 for each of the required crash tests, or
  • A barrier system has been evaluated and found acceptable as a result of an operating performance evaluation
DESIGN AND LOCATION OF SAFETY BARRIERS

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Barrier Warrants

• Barrier warrants are based on the premise that a traffic barrier should be installed only if it reduces the severity of potential crashes.

• A barrier may be appropriate if:
  • There is a reasonable probability of a vehicle leaving the road at that location, and
  • The cumulative consequences of those departures significantly outweigh the cumulative consequences of impacts with the barrier
Barrier Warrants
Roadside Obstacles

• Roadside obstacles may be either man-made (such as culvert inlets) or natural (such as trees)

• Barrier recommendations for roadside obstacles are a function of the obstacle itself and the likelihood that it will be hit

• However, a barrier should be installed only if it is clear that the result of a vehicle striking the barrier will be less severe than the crash resulting from hitting the unshielded object
<table>
<thead>
<tr>
<th>Obstacle</th>
<th>Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridge piers, abutments, and railing ends</td>
<td>Shielding generally needed.</td>
</tr>
<tr>
<td>Boulders</td>
<td>Judgment decision based on nature of fixed object and likelihood of impact.</td>
</tr>
<tr>
<td>Culverts, pipes, headwalls</td>
<td>Judgment decision based on size, shape and location of obstacle.</td>
</tr>
<tr>
<td>Foreslopes and backslopes (smooth)</td>
<td>Shielding not generally needed.</td>
</tr>
<tr>
<td>Foreslopes and backslopes (rough)</td>
<td>Judgment decision based on likelihood of impact.</td>
</tr>
<tr>
<td>Ditches (parallel)</td>
<td>Refer to Figures 3-6 and 3-7.</td>
</tr>
<tr>
<td>Ditches (transverse)</td>
<td>Shielding generally needed if likelihood of head-on impact is high.</td>
</tr>
<tr>
<td>Embankment</td>
<td>Judgment decision based on fill height and slope (see Figure 5-1).</td>
</tr>
<tr>
<td>Retaining walls</td>
<td>Judgment decision based on relative smoothness of wall and anticipated maximum angle of impact.</td>
</tr>
<tr>
<td>Sign/luminaire supports*</td>
<td>Shielding generally needed for non-breakaway supports.</td>
</tr>
<tr>
<td>Traffic signal supports*</td>
<td>Isolated traffic signals within clear zone on high-speed rural facilities may need shielding.</td>
</tr>
<tr>
<td>Trees</td>
<td>Judgment decision based on site-specific circumstances.</td>
</tr>
<tr>
<td>Utility poles</td>
<td>Shielding may be needed on a case-by-case basis.</td>
</tr>
<tr>
<td>Permanent bodies of water</td>
<td>Judgment decision based on location and depth of water and likelihood of encroachment.</td>
</tr>
</tbody>
</table>
Deflection

Distance that traveled a lateral barrier after an impact.
(NCHRP 350)
<table>
<thead>
<tr>
<th>Post Spacing (in.)</th>
<th>Beam Description</th>
<th>Maximum Deflection (in) – Field Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>Single W-Beam</td>
<td>29.7</td>
</tr>
<tr>
<td>38</td>
<td>Single W-Beam</td>
<td>23.5</td>
</tr>
<tr>
<td>75</td>
<td>Double W-Beam</td>
<td>35.5</td>
</tr>
<tr>
<td>38</td>
<td>Double W-Beam</td>
<td>19.6</td>
</tr>
</tbody>
</table>
Flexible Barriers

• Include cable barriers and weak post corrugated guide rail systems.
• These are referred to as flexible barriers because they will deflect 4.6 ft to 11 ft when struck by a typical passenger car or light truck.
• Impact energy is dissipated through tension in the rail elements, deformation of the rail elements, posts, soil and vehicle bodywork, and friction between the rail and vehicle.
### Flexible Barriers

<table>
<thead>
<tr>
<th>System</th>
<th>Test Level</th>
<th>FHWA Acceptance Letter</th>
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</thead>
<tbody>
<tr>
<td>Flexible Systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-Beam (Weak Post)</td>
<td>2</td>
<td>B-64</td>
</tr>
<tr>
<td>Three-Strand Cable (Weak Post)</td>
<td>3</td>
<td>B-64</td>
</tr>
<tr>
<td>High-Tension Cable Barriers</td>
<td>3 and 4</td>
<td>Various</td>
</tr>
<tr>
<td>Modified W-Beam (Weak Post)</td>
<td>3</td>
<td>B-64</td>
</tr>
<tr>
<td>Ironwood Aesthetic Barrier</td>
<td>3</td>
<td>B-56, 56-A, and 56-B</td>
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</tbody>
</table>

![Flexible Barriers Image](image-url)
Gibraltar Cable Barriers

Source: http://www.gibraltarus.com
### Flexible systems

#### FIGURE B.1b Three-strand cable [U.S. customary units]

<table>
<thead>
<tr>
<th>AASHTO Designation</th>
<th>G1-a</th>
<th>G1-b</th>
<th>G1-c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Type:</td>
<td>S3 x 5.7 steel</td>
<td>4 lb/ft steel U-channels</td>
<td>5½-in. dia. modified</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>wood</td>
</tr>
<tr>
<td>Post Spacing:</td>
<td>16 ft</td>
<td>16 ft</td>
<td>12 ft-6 in.</td>
</tr>
<tr>
<td>Beam Type:</td>
<td>3½-in. dia. steel cables</td>
<td>3½-in. dia. steel cables</td>
<td>3½-in. dia. steel cables</td>
</tr>
<tr>
<td>Maximum Dynamic Deflection:</td>
<td>11 ft-6 in.</td>
<td>11 ft-6 in.</td>
<td>11 ft-6 in.</td>
</tr>
</tbody>
</table>

#### FIGURE B.2b W-beam (weak post) [U.S. customary units]

<table>
<thead>
<tr>
<th>AASHTO Designation</th>
<th>G2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Type:</td>
<td>S3 x 5.7 steel</td>
</tr>
<tr>
<td>Post Spacing:</td>
<td>12 ft</td>
</tr>
<tr>
<td>Beam Type:</td>
<td>12 gage W-beam</td>
</tr>
<tr>
<td>Maximum Dynamic Deflection:</td>
<td>approximately 6 ft-6 in.</td>
</tr>
</tbody>
</table>
Semi-Rigid Barriers

- Include:
  - box beam guide rail,
  - heavy post blocked out corrugated guide rail and
  - thrie-beam guide rail (Thrie-beam is similar to corrugated rail, but it has three ridges instead of two)

- They deflect 3 to 6 feet more than rigid barriers, but less than flexible barriers.

- Box beam systems also extent the impact force over a number of posts due to the stiffness of the steel tube.
Semi-rigid systems

FIGURE B.4b Blocked-out W-beam (strong post) [U.S. customary units]

AASHTO Designation varies with post type as noted below:

- **Post Type:**
  - G4(2W)–6 in. x 8 in. wood**
  - Round Post–7-in. diameter wood
  - G4(1S)–6 x 9 steel***

- **Post Spacing:**
  - 6 ft-3 in.

- **Beam Type:**
  - 12 gage W-beam

- **Maximum Dynamic Deflection:**
  - approximately 3 ft

- **G3**
  - 5.5 x 5.7 steel
  - 6 ft
  - 6 in. x 6 in. x 0.19 in. steel tube
  - approximately 3 ft
## Semi-Rigid Barriers

<table>
<thead>
<tr>
<th>System</th>
<th>Test Level</th>
<th>FHWA Acceptance Letter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel Post with Steel Blockout</td>
<td>2</td>
<td>B-64</td>
</tr>
<tr>
<td>Box Beam (Weak Post)</td>
<td>3</td>
<td>B-64</td>
</tr>
<tr>
<td>Steel or Wood Post with Wood or Plastic Blockout</td>
<td>3</td>
<td>B-64</td>
</tr>
<tr>
<td>NU-GUARD by Nucor Marion</td>
<td>3</td>
<td>B-162</td>
</tr>
<tr>
<td>Trinity T-31 and Trinity Guardrail System</td>
<td>3</td>
<td>B-140</td>
</tr>
<tr>
<td>Gregory (GMS)</td>
<td>3</td>
<td>B-150</td>
</tr>
<tr>
<td>Midwest Guardrail System (MGS)</td>
<td>3</td>
<td>B-133</td>
</tr>
<tr>
<td>Blocked-out Thrie-Beam (Strong Post)</td>
<td>3</td>
<td>B-64</td>
</tr>
<tr>
<td>Merritt Parkway Aesthetic Guardrail</td>
<td>3</td>
<td>B-38</td>
</tr>
<tr>
<td>Steel-Backed Timber Guardrail</td>
<td>2 and 3</td>
<td>B-64-D</td>
</tr>
<tr>
<td>Modified Thrie-Beam (Strong Post)</td>
<td>4</td>
<td>B-64</td>
</tr>
<tr>
<td>Trinity T-39 Non-Blocked-Out Thrie Beam</td>
<td>4</td>
<td>B-148</td>
</tr>
</tbody>
</table>
Rigid Barriers

• Usually constructed of reinforced concrete.
• A permanent concrete barrier will only deflect a negligible amount when struck by a vehicle.
• The shape of a concrete barrier is designed to redirect a vehicle into a path parallel to the barrier.
• Impact energy is dissipated through redirection and deformation of the vehicle itself. New Jersey barriers and F-shape also lift the vehicle as the tires ride up on the angled lower section.
## Rigid Barriers

<table>
<thead>
<tr>
<th>System</th>
<th>Test Level</th>
<th>FHWA Acceptance Letter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone Masonry Wall/Precast Masonry Wall</td>
<td>3</td>
<td>B-64-D</td>
</tr>
<tr>
<td>New Jersey Safety-Shape Barrier</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• 810 mm [32 in.] tall</td>
<td>4</td>
<td>B-64</td>
</tr>
<tr>
<td>• 1070 mm [42 in.] tall</td>
<td>5</td>
<td>B-64</td>
</tr>
<tr>
<td>F-Shape Barrier</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• 810 mm [32 in.]</td>
<td>4</td>
<td>B-64</td>
</tr>
<tr>
<td>• 1070 mm [42 in.]</td>
<td>5</td>
<td>B-64</td>
</tr>
<tr>
<td>Vertical Concrete Barrier</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• 810 mm [32 in.]</td>
<td>4</td>
<td>B-64</td>
</tr>
<tr>
<td>• 1070 mm [42 in.]</td>
<td>5</td>
<td>B-64</td>
</tr>
<tr>
<td>Single Slope Barrier</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• 810 mm [32 in.]</td>
<td>4</td>
<td>B-17, B-45</td>
</tr>
<tr>
<td>• 1070 mm [42 in.]</td>
<td>5</td>
<td>Note 1</td>
</tr>
<tr>
<td>Ontario Tall Wall Median Barrier</td>
<td>5</td>
<td>B-19</td>
</tr>
</tbody>
</table>
Typical Section of Jersey Barrier

- 300 mm (12"
- 1070 mm (42"
- 255 mm (10"
- 50 mm (2"
- 75 mm (3"
- 820 mm (32 1/4")
Selection Criteria of Barriers

1. **Performance**: the barrier has to contain and redirect the design vehicle
2. **Deflection**: should not exceed the distance of deflection available
3. **Site Conditions**: side slope and distance from the roadway
4. **Compatibility**: Compatible with terminal and able to transition to other systems (example: bridge railings)
5. **Cost**: higher performance, higher cost of barrier
Selection Criteria of Barriers

6. **Maintenance:**
   a) Routine: Minimum
   b) After a collision: flexible and semi-rigid require more maintenance
   c) Storage: a greater variety of systems, more inventory will be required
   d) Simplicity: simple designs, lower cost, ease of repair or replacement

7. **Aesthetics:** sometimes it is an important consideration.

8. **Experience in field:** monitoring existing systems to identify problems that can be solved with other barrier systems.
Selection Criteria

• The available deflection distance may dictate the performance level of the barrier utilized for the installation.

• If the distance between the barrier and the shielded object or terrain feature is relatively large, a flexible barrier that deflects upon impact, thereby imposing lower impact forces on the vehicle and its occupants, may be utilized.

• If the obstacle is immediately adjacent to the barrier, a semi-rigid or rigid railing system may be the only choice available.
## Design of Barriers

### Selection Factors
1. Impact velocity
2. Penetration angle of the vehicle
3. Vehicle of design
4. Maximum deflection of the barrier
5. Costs

### Design Variables
1. Distance of the object from the roadway, ("Lateral offset")
2. "Shy Line"
3. Terrain side slopes
4. Divergence angle ("flare rate")
5. Required length ("length of need")
Placement Recommendations

The major factors that should be considered include the following:

- Lateral offset from the edge of traveled way; barrier to obstacle separation; terrain effects; flare rate; length-of-need; terminals

Example Guardrail and Embankment Layout Sheet
Flare Rate

• Barrier is considered flared when it is not parallel to the edge of the roadway
• Flare is normally used to locate the barrier terminal farther from the roadway
  • Pros
    • Locate the barrier farther from the roadway
    • Minimize driver’s reaction to an obstacle
    • Reduce total length of rail needed
  • Cons
    • The greater the flare rate, the higher the approach angle, the higher the severity
    • Vehicle can be redirected back to roadway
The flared barrier is normally used to:

- locate the terminal further barrier of the roadway
- to minimize the reaction of the driver to an obstacle near the road
- to provide a transition from the barrier an obstacle near the road as a rail bridge
- to reduce the total required length of the barrier
- The use of a flared barrier also provides a space for auxiliary driving errant motorist can recover.
Shy-Line Offset, $L_s$

- The distance beyond which a driver will not react to an object near the roadway.

- Some rigid objects such as safety barriers, if they are very close to the pavement, tend to intimidate the drivers causing them to slow down or change lanes. This can result in a loss of capacity for concern high-speed roads.
- It is prefer to install the barrier beyond the "Shy Line".
- It depends on the site conditions.
Suggested Flare Rates

<table>
<thead>
<tr>
<th>Design Speed</th>
<th>Flare Rate for Barrier Inside Shy Line</th>
<th>Flare Rate for Barrier at or Beyond Shy Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>km/h [mph]</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>110 [70]</td>
<td>30:1</td>
<td>20:1</td>
</tr>
<tr>
<td>100 [60]</td>
<td>26:1</td>
<td>18:1</td>
</tr>
<tr>
<td>90 [55]</td>
<td>24:1</td>
<td>16:1</td>
</tr>
<tr>
<td>80 [50]</td>
<td>21:1</td>
<td>14:1</td>
</tr>
<tr>
<td>70 [45]</td>
<td>18:1</td>
<td>12:1</td>
</tr>
<tr>
<td>60 [40]</td>
<td>16:1</td>
<td>10:1</td>
</tr>
<tr>
<td>50 [30]</td>
<td>13:1</td>
<td>8:1</td>
</tr>
</tbody>
</table>

Notes:
- A = Suggested maximum flare rate for rigid barrier system.
- B = Suggested maximum flare rate for semi-rigid barrier system.

The MGS has been tested in accordance with NCHRP Report 350 TL-3 at 5:1 flare. Flatter flare rates for the MGS installations also are acceptable. The MGS should be installed using the flare rates shown or flatter for semi-rigid barriers beyond the shy line when installed in rock formations.
Barrier Design

CLEAR DISTANCE LINE

AREA OF CONCERN (OBSTACLE)

SEE FIGURE 5-22

END OF BARRIER NEED

USE CRASHWORTHY TERMINAL

SHY LINE

EDGE OF THROUGH TRAVELED WAY

TRAFFIC
Primary Variables

• **Lateral Extent of the Area of Concern LA:** distance from the edge of the traveled way to the far side of the fixed object or to the outside edge of the clear zone of an embankment or a fixed object that extends beyond the clear zone.

• **Runout Length LR:** distance from the object being shielded to the location where the vehicle departs from the traveled way (assumed).

• **Tangent length from the Area of Concern L1:** selected by the designer (zero if no flare)
## Recommended Runout lengths ($L_R$)

<table>
<thead>
<tr>
<th>Design Speed (mph)</th>
<th>Over 10,000 veh/day</th>
<th>5,000 to 10,000 veh/day</th>
<th>1,000 to 5,000 veh/day</th>
<th>Under 1,000 veh/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>470</td>
<td>430</td>
<td>380</td>
<td>330</td>
</tr>
<tr>
<td>70</td>
<td>360</td>
<td>330</td>
<td>290</td>
<td>250</td>
</tr>
<tr>
<td>60</td>
<td>300</td>
<td>250</td>
<td>210</td>
<td>200</td>
</tr>
<tr>
<td>50</td>
<td>230</td>
<td>190</td>
<td>160</td>
<td>150</td>
</tr>
<tr>
<td>40</td>
<td>160</td>
<td>130</td>
<td>110</td>
<td>100</td>
</tr>
<tr>
<td>30</td>
<td>110</td>
<td>90</td>
<td>80</td>
<td>70</td>
</tr>
</tbody>
</table>
Shy-Line Offset, $L_s$

- The distance beyond which a driver will not react to an object near the roadway.

Table 5-7. Suggested Shy-Line Offset ($L_s$) Values

<table>
<thead>
<tr>
<th>Design Speed</th>
<th>Shy-Line Offset ($L_s$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[m]</td>
</tr>
<tr>
<td>km/h</td>
<td>[mph]</td>
</tr>
<tr>
<td>130</td>
<td>[80]</td>
</tr>
<tr>
<td>120</td>
<td>[75]</td>
</tr>
<tr>
<td>110</td>
<td>[70]</td>
</tr>
<tr>
<td>100</td>
<td>[60]</td>
</tr>
<tr>
<td>90</td>
<td>[55]</td>
</tr>
<tr>
<td>80</td>
<td>[50]</td>
</tr>
<tr>
<td>70</td>
<td>[45]</td>
</tr>
<tr>
<td>60</td>
<td>[40]</td>
</tr>
</tbody>
</table>
Required Length of Need Before the Area of Concern

**With Flare Rate**

\[ X = \frac{L_A + (b|a)(L_1) - L_2}{b|a + (L_A)/(L_R)} \]

**Without Flare Rate**

\[ X = \frac{L_A - L_2}{(L_A)/(L_R)} \]
The lateral offset (Y): Distance from the edge of the traveled way to the beginning of the length-of-need.
Barrier Placement

• The most direct method to determine the length-of-need is to scale the barrier layout directly on the highway plan sheets.

• By selecting an appropriate runout length and the lateral distance to be shielded, the designer can specify a guardrail installation (i.e., lateral offset and flare) that satisfies all placement criteria.
General Rules of Longitudinal Guardrail Location

- Minimum lateral distance between rail and hazard 2 feet (0.6 m)
- Longitudinal distance between barriers shielding isolated hazards (utility poles each 150 feet)
  - Avoid installing individual guardrails with gaps less than 200 feet
• A traffic barrier should be set as far as practical from the traveled way. This practice minimizes the likelihood that the barrier will be hit by providing a motorist with the maximum amount of traversable, unobstructed recovery area.

• It is critical that a vehicle makes contact with most types of barriers with its center-of-gravity at or near its normal position. This reduces the tendency for a vehicle to wedge under or go over the barrier.

• The slopes between a barrier installation and the roadway should be 1V:10H or flatter, or the barrier should be far enough from the road that a vehicle is on the ground with its suspension system neither compressed nor extended at the time of contact.
QUESTIONS?
TERMINAL BARRIERS AND CRASH CUSHIONS
Before

“Fish Tail” = No treatment

Source: www.crashforensics.com
The Problem
Solution: Terminals
Terminals

www.team-bhp.com
Be Careful
Flying cars

Source: http://www.youtube.com/watch?v=aSbfY6yJjSA
Terminal Design and Warrants

• Minimize injury to vehicle occupants in the event of a crash into the end of the guardrail
  • Crashworthy terminals MUST be used on the National Highway System
  • Recommended for use on all public roads
Evaluation Criteria

Crashworthiness is assumed if an end treatment has met all of the evaluation criteria set forth in either MASH or NCHRP Report 350 for each of the specified crash tests.
Performance Requirements

• Gradually decelerates vehicle to a stop or redirects it when impacting end-on
• Safely redirecting vehicle that impacts side of device, at mid-length and near the nose
• Test levels w/ 1.8k car and 4.4k pick-up
  • TL-1: 30 mph
  • TL-2: 45 mph
  • TL-3: 60 mph
A terminal is considered essential if the end of a barrier is located within the clear zone or in an area where it is likely to be struck by an errant motorist.
Terminal Design Concepts

• Considerations in selecting an appropriate terminal for a given flexible or semi-rigid barrier installation:
  • Compatibility of the terminal with the barrier system;
  • Performance characteristics of the terminal
    • energy-absorption potential,
    • configuration (tangent vs. flared), and
    • location of the length-of-need point
  • Site-grading considerations.
Types of Terminals

Three-Strand Cable Terminal

All flexible and semi-rigid barriers have to be terminated with an anchoring system at both ends.

CASS™ Cable Terminal (CCT)

Anchors at each end of the barrier serve as bases for transferring these tension forces to the ground.
Types of Terminals

Flared W-Beam Terminals: Eccentric Loader Terminal (ELT)

Crash Cushion Attenuating Terminal

Flared Energy-Absorbing Terminal
## Terminals for Cable Barrier Systems

<table>
<thead>
<tr>
<th>Terminal</th>
<th>Test Level (TL)</th>
<th>FHWA Acceptance Letter</th>
<th>System Designation</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three-Strand Cable Terminal</td>
<td>3</td>
<td>CC-63</td>
<td>SEC01</td>
<td>Generic</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>CC-76</td>
<td>SEC07a</td>
<td>Trinity Highway Products, LLC (CASS), and Nucor Steel Marion, Inc. (NU-CABLE)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>CC-86 CC-86A CC-86B</td>
<td>SEC07b</td>
<td>Brifen USA, Inc.</td>
</tr>
<tr>
<td>Terminals for High-Tension Cable Barriers</td>
<td>3</td>
<td>CC-92 CC-92A</td>
<td>Not posted</td>
<td>Gibraltar Cable Barrier Systems, L.P</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>CC-98</td>
<td>SEC07c</td>
<td>Barrier Systems, Inc.</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>CC-93 CC-93A</td>
<td>Not posted</td>
<td>Gregory Industries, Inc. (SAFENCE)</td>
</tr>
</tbody>
</table>
# Types of Terminals

<table>
<thead>
<tr>
<th>Terminal</th>
<th>NCHRP Report 350 Test Level</th>
<th>FHWA Acceptance Letter</th>
<th>System Designation</th>
<th>Manufacturer</th>
<th>Reference Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wyoming Box-Beam End Terminal</td>
<td>3</td>
<td>CC-60</td>
<td>SEB03</td>
<td>Trinity Highway Products, LLC</td>
<td>8.3.7.1</td>
</tr>
<tr>
<td>(WY-BET™)</td>
<td></td>
<td>CC-60A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bursting Energy Absorbing Terminal</td>
<td>3</td>
<td>CC-09</td>
<td>SEB05</td>
<td>Road Systems, Inc.</td>
<td>8.3.7.2</td>
</tr>
<tr>
<td>(BEAT™) and (BEAT-MT™)</td>
<td></td>
<td>CC-69</td>
<td>SEB06 Median</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Performance Characteristics of the Terminal

- Non-Energy-Absorbing Terminals
- Energy-Absorbing
Flared versus Tangent Terminals

• Non-flared terminals may be installed with a 1-ft to 2-ft offset from the line of barrier proper (over the entire terminal length) to minimize nuisance hits.

• Flared terminals generally require a 4-ft offset although some designs have been successfully tested with offsets less than 3 ft. Because the flared terminal is located further from the traveled way, head-on impacts are less likely.
Gating Classification

• **Gating**: terminals that are designed to break away, pivot or hinge, and that allow a vehicle to pass through when impacted at an angle to the end, or at a point upstream of the beginning length - off-need of the safety barrier system.

• **Non-Gating**: terminals that are designed to re-direct and absorb part of the energy of an impacting vehicle at any point along the terminal without allowing it to pass behind the safety barrier system.
Anchorage Design Concepts

• All flexible and semi-rigid barriers need to be terminated with an anchor system at both ends.

• Anchorages at each end of the barrier serve as foundations to transfer these tension forces to the ground.

• If the barrier end treatment is not required to be crashworthy (e.g., a trailing end on a one-way roadway or an end located outside of the clear zone), a lower-cost anchorage system may be used.
Strut and Cable Anchor

- Helps to develop the full tensile strength of the W beam rail element when hit along its side
  - Typically occurs at the third pole
  - Allows the vehicle to be contained and redirected
CRASH CUSHIONS

Fabiola Buitrago G. Ph.D.
Crash Cushions

Sand-filled plastic barrels, sometimes called inertial crash cushions or inertial barriers, often are used in both temporary and permanent installations to shield the ends of longitudinal barriers or other fixed objects.

www.ct.gov  www.viewgoods.com
Crash Cushions

- Gradually decelerates vehicle to a stop, in a relatively short distance
- Shield fixed objects on either side of roadway
- Shield end of median barrier or fixed object on gore area
- Protection of highway work zones
- Absorb impact energy at a controlled rate
  - Kinetic energy
  - Transfer of momentum

www.ct.gov
Crash Cushions

• Commonly are applied at an exit ramp gore on an elevated or depressed structure in which a bridge rail end or a pier merits shielding

• Frequently used to shield the ends of median barriers
Crash Cushions

- Inert system, the initial velocity is zero
- Plastic barrels filled with sand
- Dissipate the kinetic energy of a vehicle by transferring momentum (impulse)
- The vehicle speed decreases with each row of barrels impact as a result of conservation of momentum
Law of Conservation of Momentum

• **Momentum:**
  - Quantity expressing the motion of a body and its resistance to reduce the velocity.
  - It is the product of its mass and its velocity.

• **Conservation of Momentum:**
  - For a collision between two objects in an isolated system, the total momentum of the two objects before the collision equals the momentum after the collision.
  - The momentum that lost the first object is the momentum that wins the second object.
Impact Attenuators

“SCI Smart Cushion”

“Truck-mounted Attenuator”

www.cdc.gov
Conservation of Momentum

• Assumptions
  • The barrels with sand transfer the kinetic energy of the vehicle under the following assumptions:
    1. Head-on collision
    2. The vehicle speed is constant
    3. The arrangements are inert modules
    4. The vehicle will going design speed
Law of Conservation of Momentum

MOMENTUM BEFORE IMPACT = MOMENTUM AFTER IMPACT

Final speed about 10 mph

Fabiola Buitrago G. Ph.D.
Principle of Conservation of Momentum

\[ M_V \cdot V_o = (M_V + M_1) \cdot V_1 \]

\[ V_n = \frac{M_V \cdot V_{n-1}}{M_V + M_n} \]

- \( M_v \) = mass of vehicle, kg or pounds
- \( V_o \) = original impact velocity, m/s or ft/s
- \( M_1 \) = mass of sand, kg or pounds, in first barrel
- \( V_1 \) = velocity, m/s or ft/s, after first impact
- \( M_n \) = mass of sand in the nth container
Design of Barrel System

\[
a = \frac{V_{n-1}^2 - V_n^2}{2D}
\]
\[
G = \frac{a}{g}
\]
\[
t = \frac{V_{n-1} - V_n}{a}
\]

Where:
- \(a\) = deceleration rate
- \(D\) = deceleration distance (diameter)
- \(G\) = deceleration force
- \(g\) = aceleración gravitacional (32.2 ft/s\(^2\) o 9.81 m/s\(^2\))
- \(t\) = time of event
Weight of Modules

- Each barrel has a particular weight to design the geometric arrangement.

- The most common weights are:
  - 90 kgs [200 lbs]
  - 180 kgs [400 lbs]
  - 320 kgs [700 lbs]
  - 640 kgs [1400 lbs]
  - 960 kgs [2100 lbs]
Standard Array for a 2000 kg (4400lb) Pickup Truck Traveling at 45 mph; Head-On Collision
Technical Aspects

• The first row always has a single barrel.
• The last row may have up to five barrels, but in most cases four.
• At high speeds a barrel of 200 pounds can be used, while for low speeds a 400 pound barrel can be used.
• Most arrangements end with one 400 pound barrels.
• The recommended spacing between barrels is between 6-12 inches.
• They must be on a 10H : 1V slope.
• The barrels are designed to support the weight of the sand and resist climate change.
• For very cold weather, the moisture content of the sand must be controlled to prevent freezing of the sand.
Technical Aspects

• The arrangement of barrels is designed as a result of "trial and error"

• The specific weight of the sand used is 99-101 pcf

• The minimum distance between the last barrel and the stationary object must be at least one foot.

• Neither system is designed to redirect vehicles during side impacts.

• The barrels should be established as far from the road to minimize interference with other vehicles.

• If space is available, more rows of modules can be placed at the corners to attenuate angle impacts.

• The space that must be provided after the last row should be sufficient to not produce the ramp effect.
<table>
<thead>
<tr>
<th>Terminal</th>
<th>Test Level</th>
<th>FHWA Acceptance Letter</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fitch Universal Barrel</td>
<td>3</td>
<td>CC-28</td>
<td>Energy Absorption Systems, Inc.</td>
</tr>
<tr>
<td>ENERGITE III</td>
<td>3</td>
<td>CC-29</td>
<td>Energy Absorption Systems, Inc.</td>
</tr>
<tr>
<td>Big Sandy</td>
<td>3</td>
<td>CC-52, 52A and 52B</td>
<td>TrafFix Devices, Inc.</td>
</tr>
<tr>
<td>CrashGard</td>
<td>3</td>
<td>CC-97</td>
<td>Plastic Safety Systems, Inc.</td>
</tr>
</tbody>
</table>
QUESTIONS?
WORK ZONES
Work Zone Traffic Control

- Influences drivers’ perception of risk
  - Provides information on potential hazards
  - Minimizes aggressive behavior
  - Assists in navigation

- Engineering concerns for work zones
  - Primary focus: Safe and efficient movement of vehicles through work zone
  - Relatively less emphasis on safety of construction workers
Type of Barrier

• Rigid Barriers
  • Provide separation between
    • Opposing traffic lanes
    • Traffic lanes and work area
  • Cause damage to motorists if struck

Concrete barrier separating opposing traffic
Concrete barrier separating traffic lanes and work area
Quickchange® Barrier System
Type of Barrier

• Flexible barriers (channelizing devices)
  – Provide nominal protection for workers
  – Flexible and deformable, do not cause damage if struck
MUTCD: Manual on Uniform Traffic Control Devices

- Recognized as the national standard
- Enforcement agencies often adopt it by reference
- Provides guidance, options and supporting materials
  - To assist professionals in making decisions regarding the use of traffic control on streets and highways
Primary function of Temporary Traffic Control:

“To provide for reasonably safe and efficient movement of road users through or around temporary traffic control zones while reasonably protecting workers, responders to traffic incidents, and equipment”

**Estandard:** Enunciado mandatorio o que prohíbe una práctica (SHALL or MUST)

**Guidance:** Enunciado que recomienda una práctica (SHOULD)

**Option:** No implica recomendación o requerimiento (MAY)
Temporary Traffic Control Devices

• (TTC) devices include
  • Signs
  • Signals
  • Markings
  • Other devices

• Used to regulate, warn, or guide road users
Types of TTC Applications

• Each TTC zone is different
• Many variables affect the needs of each zone:
  • Location of work
  • Duration of work
  • Highway type
  • Geometrics
    • Vertical and horizontal alignment, intersections, interchanges, etc.
• Road user volumes
  • Road vehicle mix (buses, trucks, and cars) and road user speeds
Work Duration

• Main factor in determining the number and types of devices used in TTC zones

• As per the MUTCD, five categories of work duration are defined:

  1. Long-term stationary
  2. Intermediate-term stationary
  3. Short-term stationary
  4. Short duration
  5. Mobile
Temporary Traffic Control Zones
Activities: Work Duration

Standard

1. **Long-term**: stationary work that occupies a location more than 3 days
2. **Intermediate term**: stationary work that occupies a location more than one daylight period up to 3 days, or nighttime work lasting more than 1 hour
3. **Short-term**: stationary daytime work that occupies a location for more than 1 hour within a single daylight period
4. **Short duration**: work that occupies a location up to 1 hour
5. **Mobile**: work that moves intermittently or continuously
Traffic incidents can be divided into three general classes of duration, each of which has unique traffic control characteristics and needs:

- **Major**: expected duration of more than 2 hours
- **Intermediate**: expected duration of 30 minutes to 2 hours
- **Minor**: expected duration under 30 minutes
Components of Temporary Traffic Control Zones

• Advanced Warning Area
• Transition Area
• Activity Area
  • Work space
  • Traffic space
  • Buffer space
• Termination Area

(Source: MUTCD 2009)
QUESTIONS?

Thank you!

Fabiola Buitrago G. Ph.D.