PUERTO RICO TRANSPORTATION
TECHNOLOGY TRANSFER CENTER

INTRODUCTION TO THE ROADSIDE DESIGN GUIDE

Historical Archives of the Autonomous Municipality of Ponce
Ponce, Puerto Rico / June 3, 2016.

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UPR – Recinto Universitario de Mayagüez

Local & Tribal Technical Assistance Program

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

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Highway Safety Definitions and Fundamentals

It is important to establish a program of safety evaluation to:

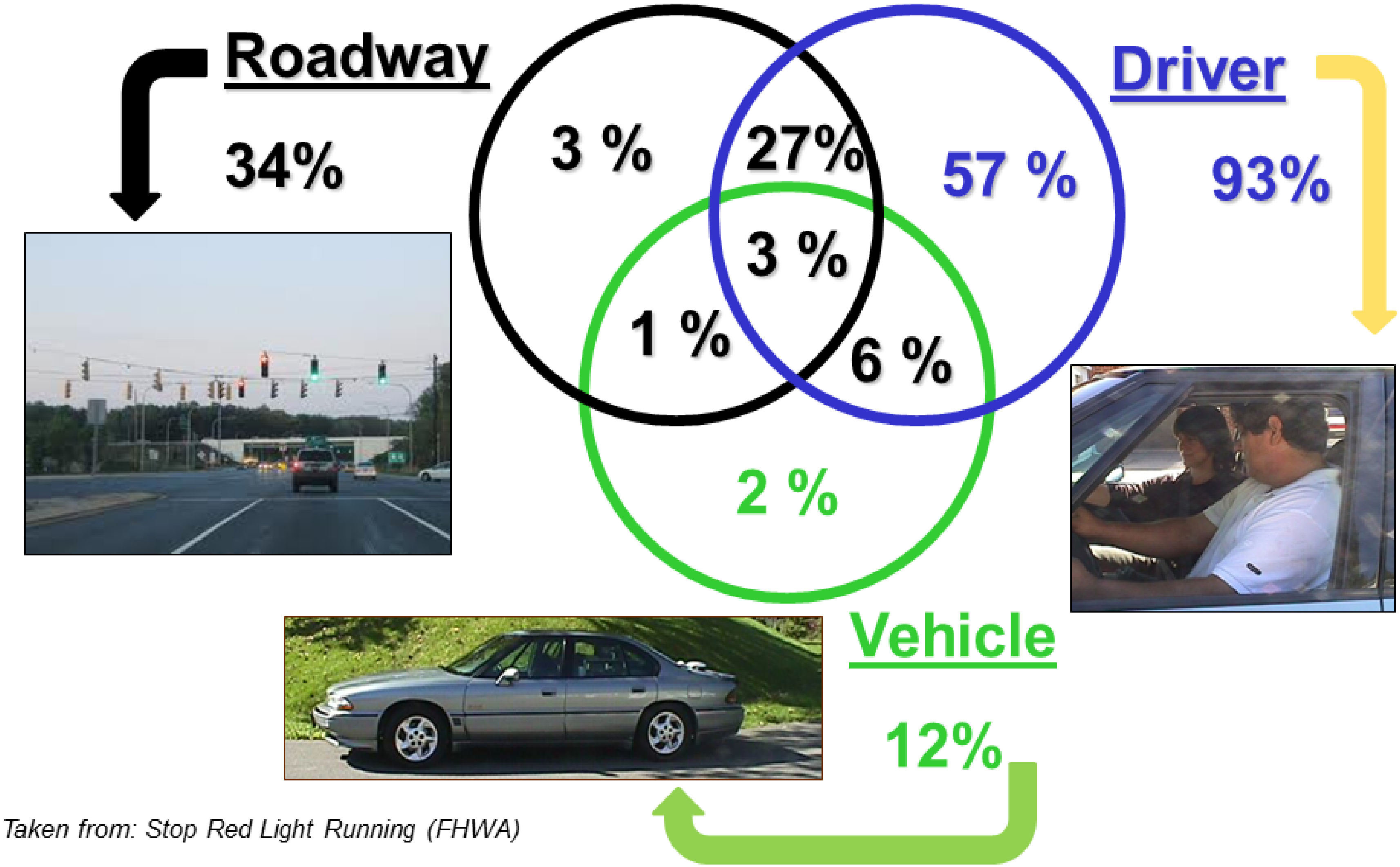
- identify risks (safety issues) and
- evaluate the effectiveness of alternatives or improvements.

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



Taken from: Stop Red Light Running (FHWA)



US 41/45 Wisconsin, Dec 9/2013
60 vehicles were involved
FOX6.com

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

"FAST Act" Fixing America's Surface Transportation Act

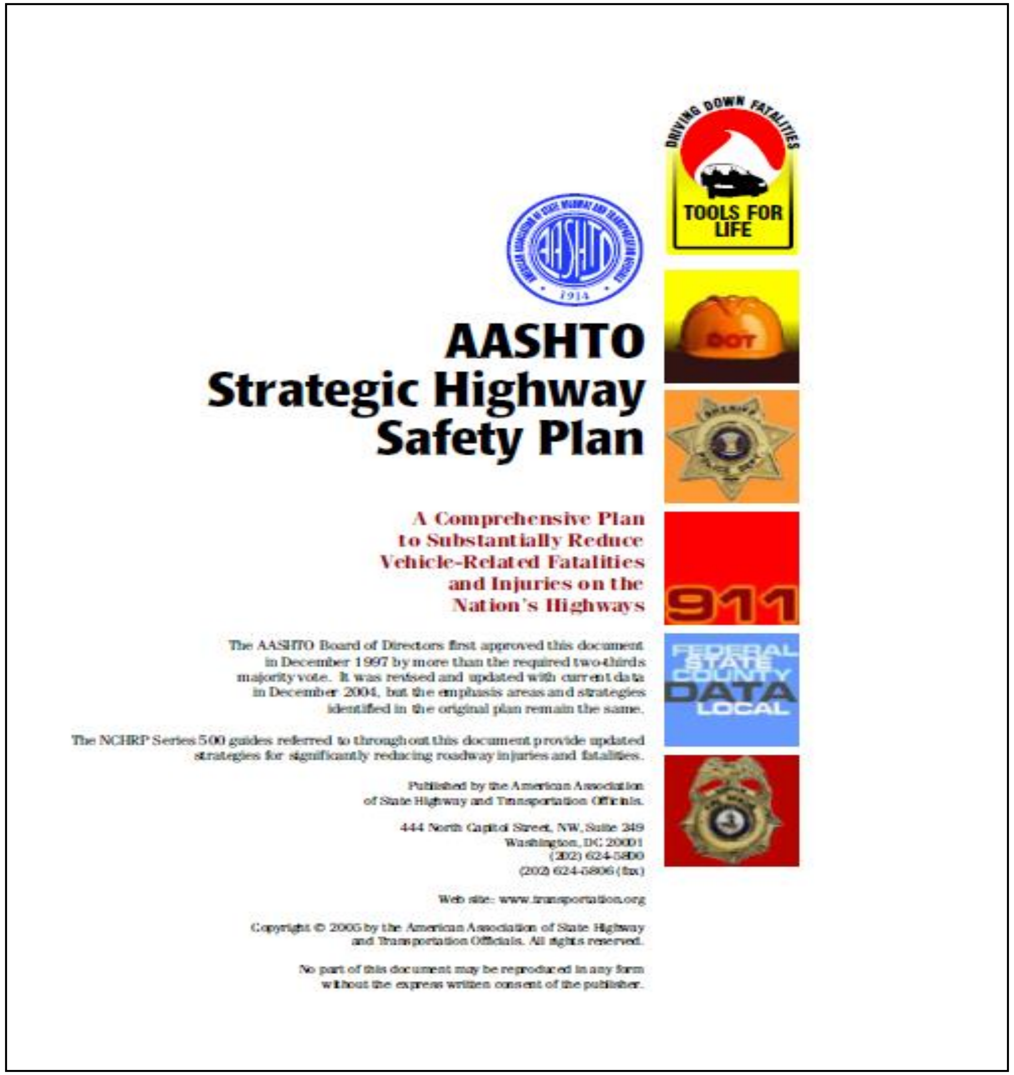
- On December 4, 2015, President Obama signed into law "FAST Act"
- The FAST Act authorizes $305 billion over fiscal years 2016 through 2020 for the:
  - Department's highway,
  - highway and motor vehicle safety,
  - public transportation,
  - motor carrier safety,
  - hazardous materials safety,
  - rail, and
  - research, technology and statistics programs.

"FAST Act" Fixing America's Surface Transportation Act (Cont.)

FAST Act continues the HSIP as a main Federal-aid program and the requirement for States to develop, implement, evaluate and update an SHSP that identifies and analyzes highway safety problems and opportunities on all 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.


DRIVING DOWN FATALITIES
TOOLS FOR LIFE

AASHTO
Strategic Highway
Safety Plan

A Comprehensive Plan
to Substantially Reduce
Vehicle-Related Fatalities
and Injuries on the
Nation's Highways

The AASHTO Board of Directors first approved this document in December 1997 by more than the required two-thirds majority vote. It was revised and updated with current data in December 2004, but the emphasis areas and strategies identified in the original plan remain the same.

The NCHRP Series 500 guides referred to throughout this document provide updated strategies for significantly reducing roadway injuries and fatalities.

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2014-2018

PUERTO RICO Strategic Highway Safety Plan

"Working together toward HIGHWAY SAFETY ... TO SAVE MORE LIVES"

Performance Measure	Base Number (2013)	Objective (2018)
Total fatalities	344	< 300
5-year moving average of total fatalities	355	318
5-year moving average of total serious injuries	6,091	5,456
5-year moving average of fatality rate	1.93	1.85
5-year moving average of serious injury rate	33.02	31.70

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.

In Puerto Rico, the number of fatalities associated with roadway departure represents approximately 25% of the total fatalities caused by traffic crashes.

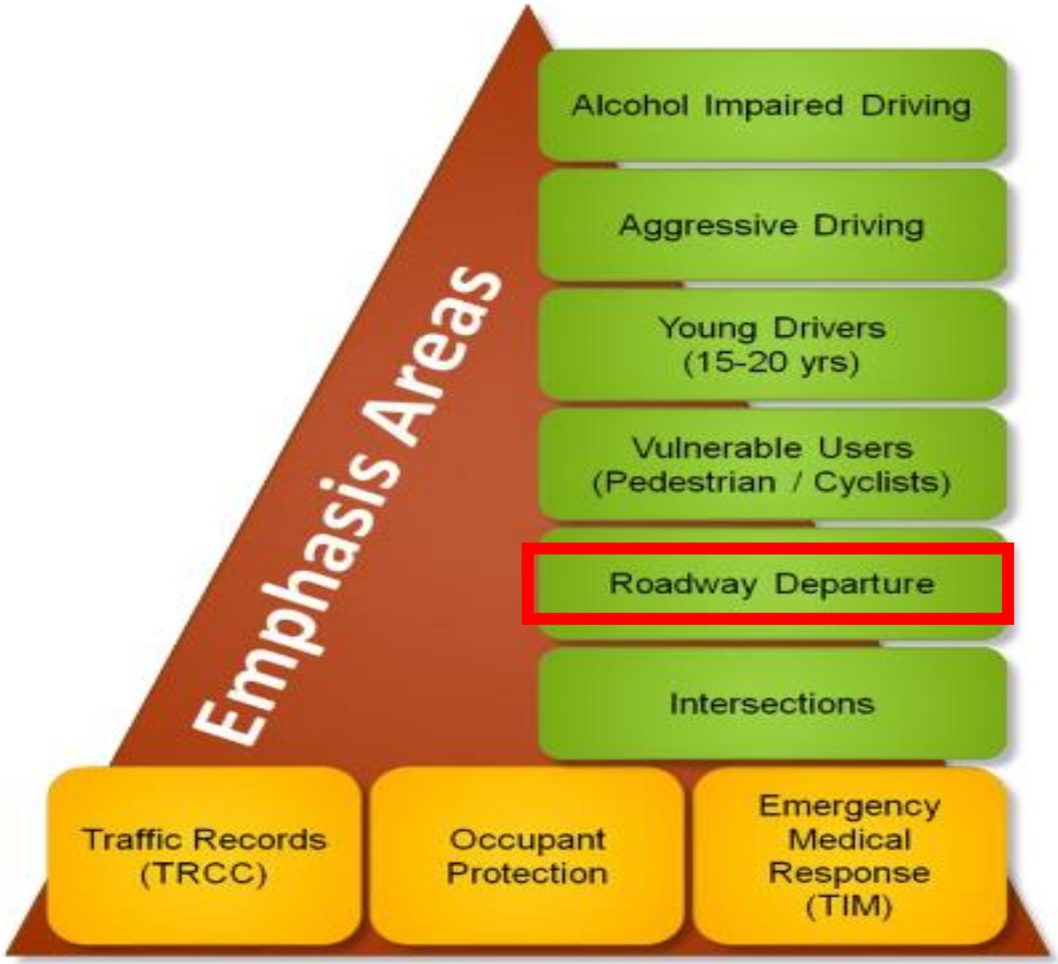

Table 10: Roadway Departure Goals, Performance Measures, Objectives, and Strategies

Roadway Departure	
Strategic Goal	Reduce fatalities involving roadway departure
Performance Measures	5-year moving average of fatalities involving roadway departure
Objective (Performance Goal)	Reduce fatalities involving roadway departure using 5-year moving average from 134 to 124 within the next 5 years
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.	

PUERTO RICO TRANSPORTATION
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STRATEGIC PLAN FOR IMPROVING ROADSIDE SAFETY

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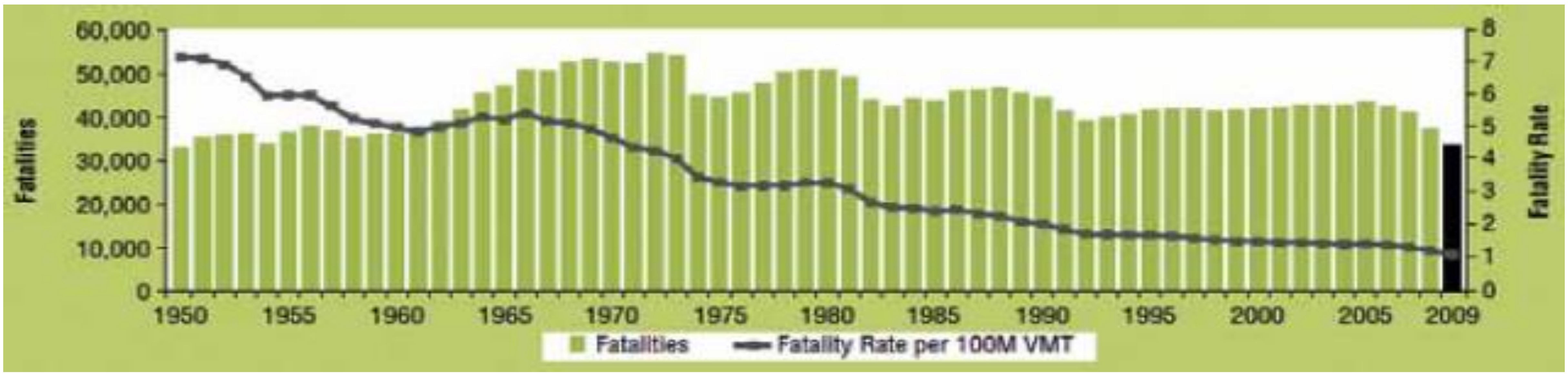
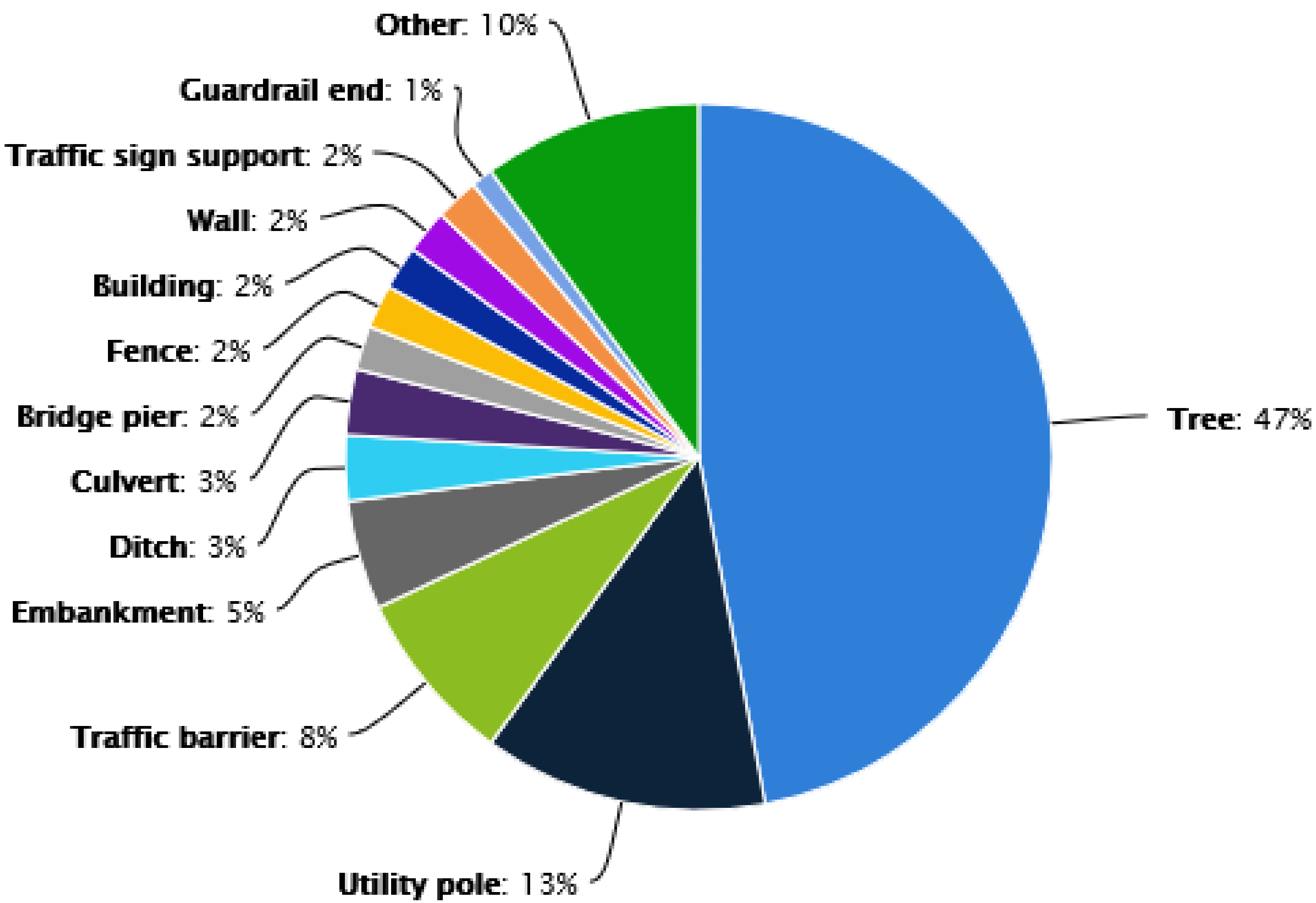
Motor Vehicle Crash Deaths and Deaths Per 100 Million Vehicle Miles Traveled, 1950–2009

- 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, 2014



Source: Insurance Institute for Highway safety

Why Would a Vehicle Leave the Highway?

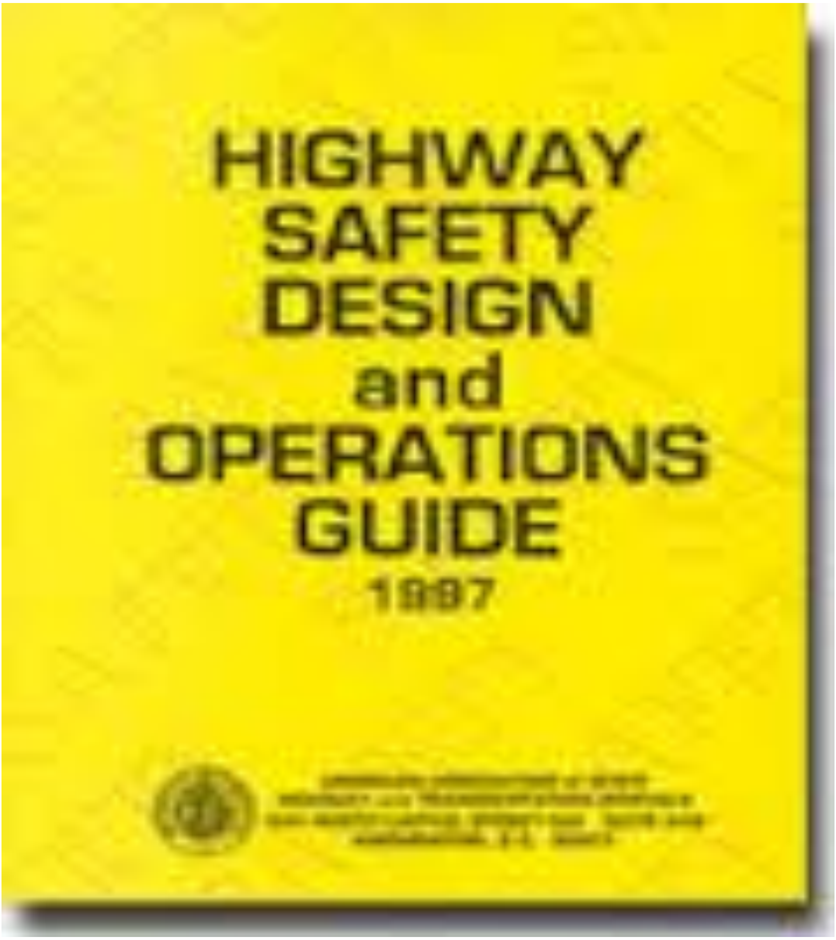
- Driver fatigue
- Driver distractions or inattention
- Excessive speed
- Driving under the influence of drugs or alcohol
- Crash avoidance
- Adverse roadway conditions, such as ice, snow, or rain
- Vehicle failure
- Poor visibility

Roadside Design Options for mitigation of objects within the design clear zone

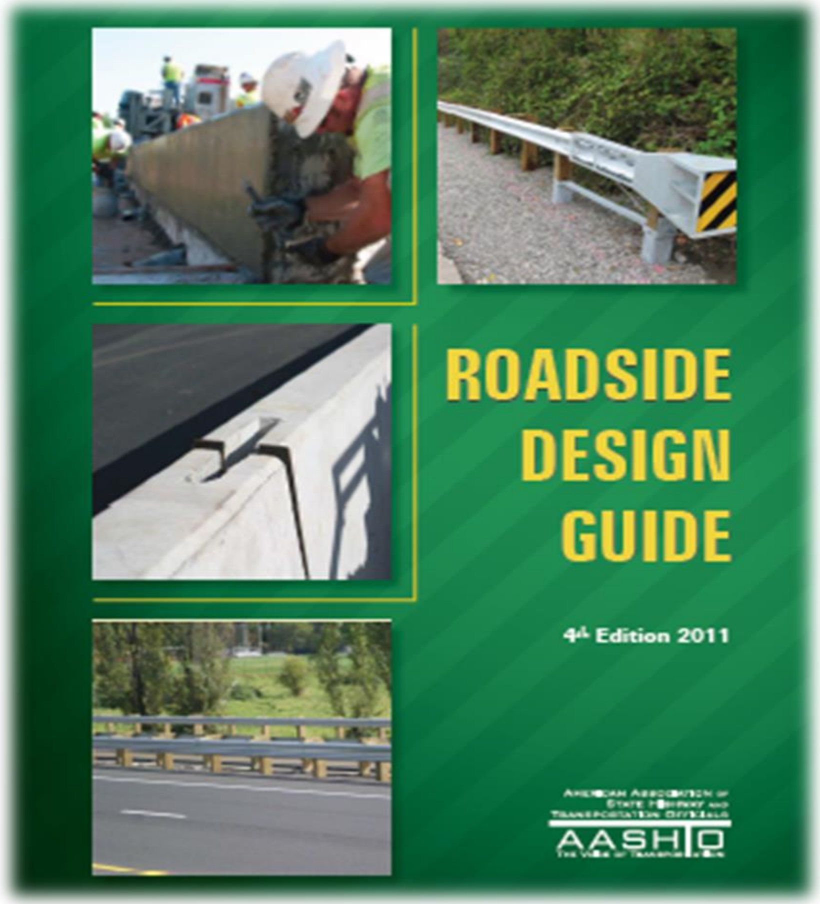
1. Remove the obstacle
2. Redesign the obstacle
3. Relocate the obstacle
4. Reduce impact severity
5. Shield the obstacle
6. Delineate the obstacle

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

Proposed Solution



1967; 1974



1989

Its main focus are safety treatments that can minimize the chance of serious injury when a driver off the road.

Roadside Design Guide Distribution

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

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Roadside Definition

Roadside design might be defined as the design of the area outside the traveled way.

Roadside Definition

1. <u>Clear Zones</u>:

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

shoulders

auxiliary lanes

Roadside Definition(cont.)

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.

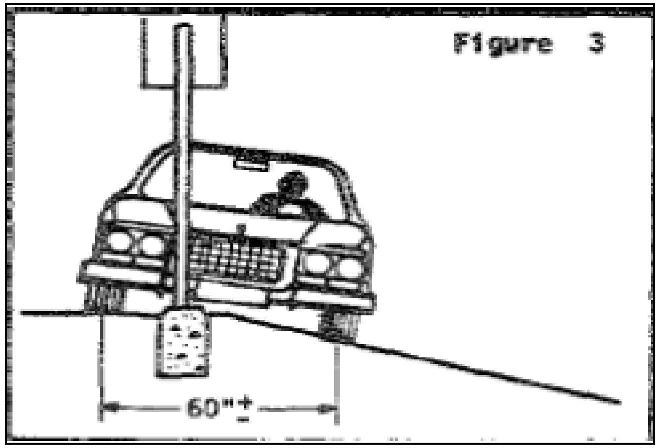
Roadside Definition(cont.)

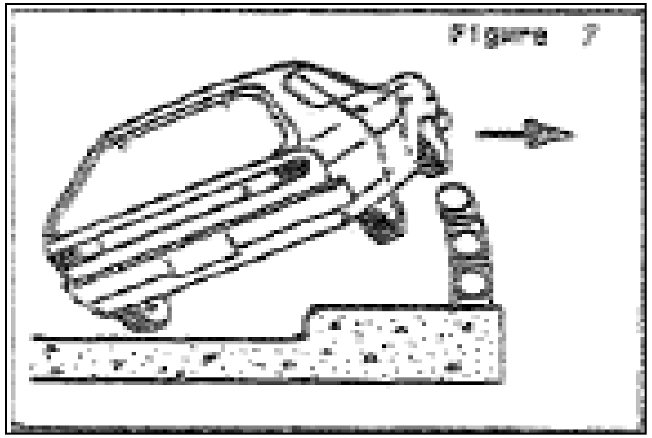
- Lateral offset to obstructions helps to:
  - Avoid opposing impacts on vehicle lane position and invasions into opposing or adjacent lanes;
  - Improve driveway and horizontal sight distances;
  - Reduce the travel lane invasions from occasional parked and immobilized vehicles;
  - Improve travel lane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

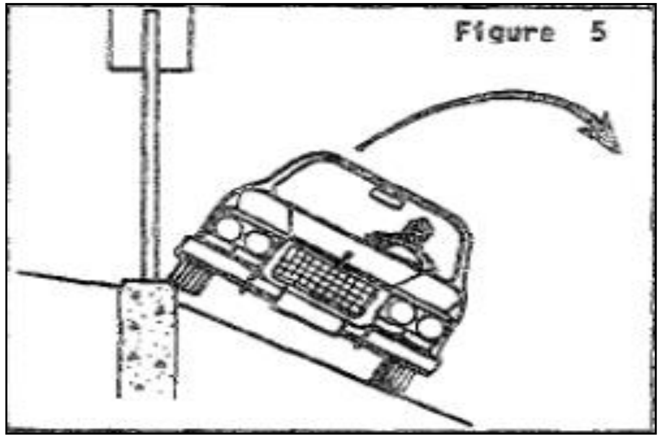
Roadside Hazard

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 more than 4 inches can cause vaulting (jumping)







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ROADSIDE GEOMETRY AND DRAINAGE FEATURES

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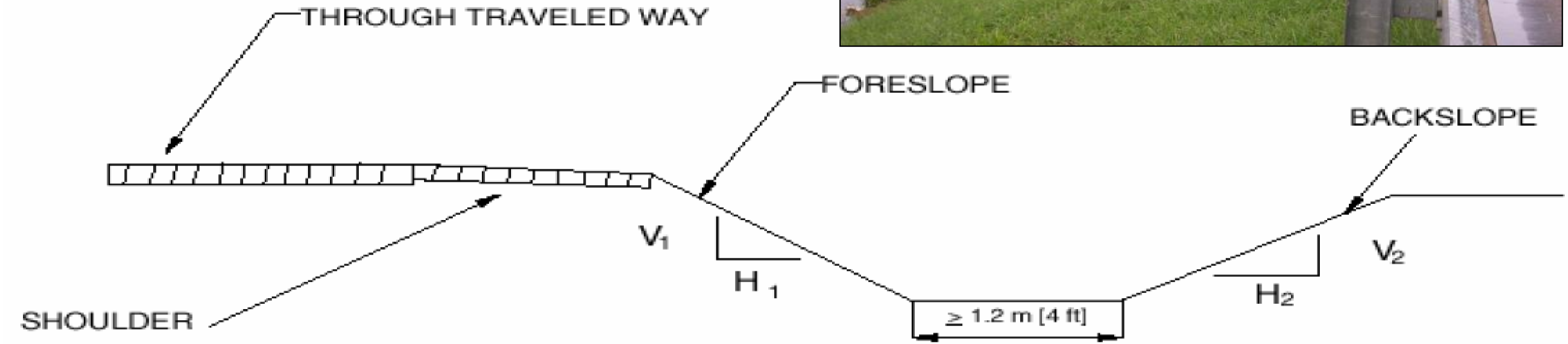
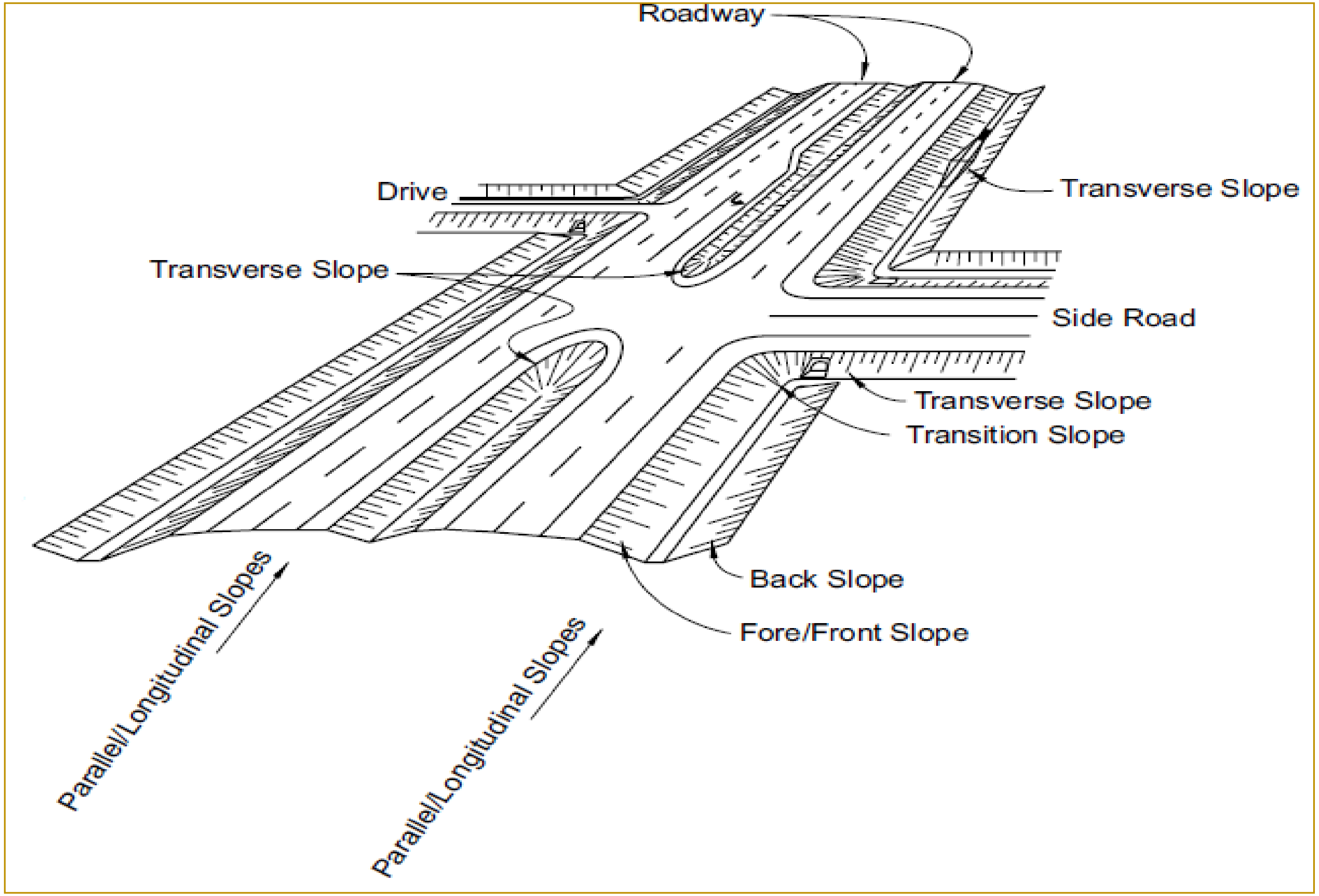
Roadside Geometry

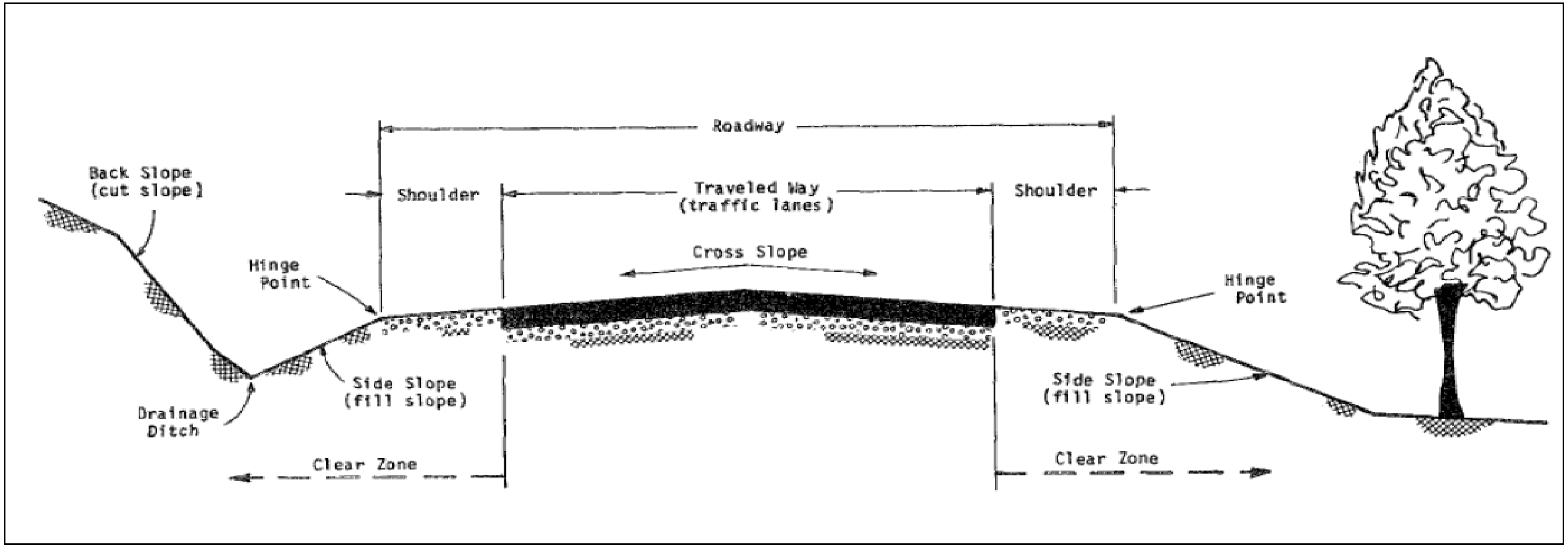
1. Foreslope (fill slope)
2. Backslope (cut slope)
3. Transverse slope
4. Drainage Structures



Roadway Geometry Features

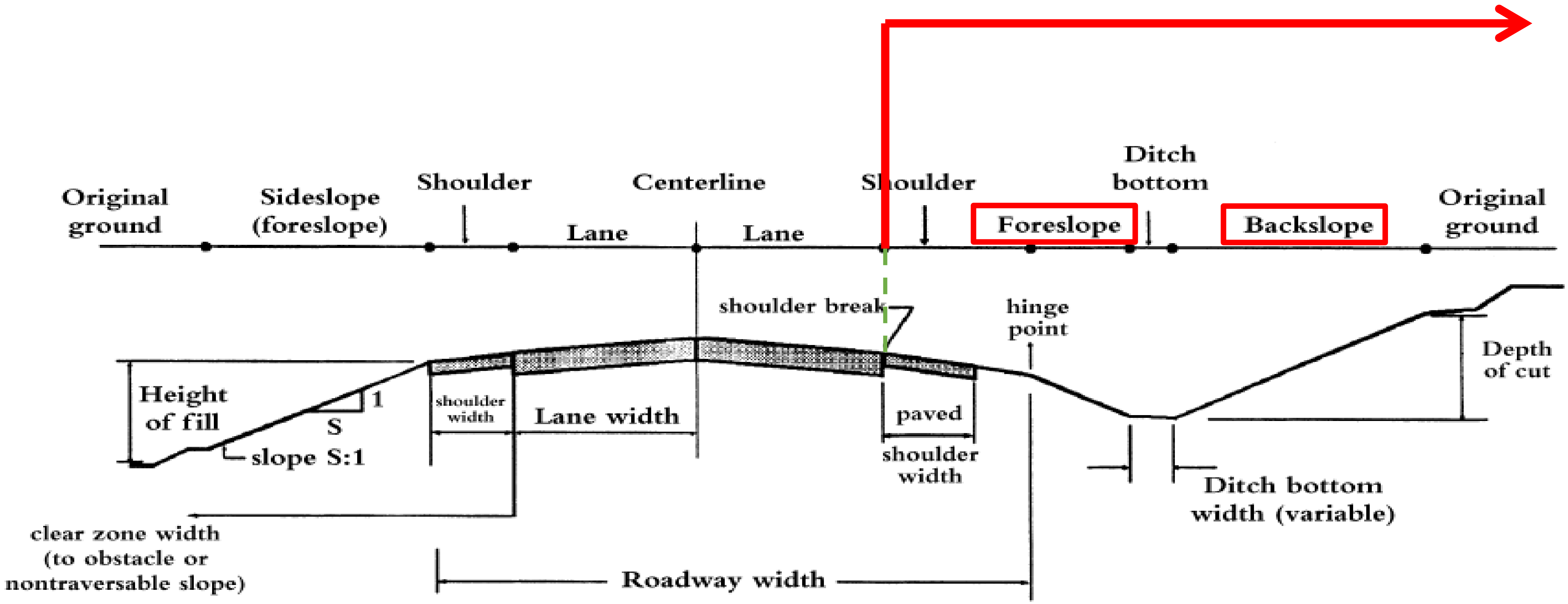


Rural Roadway Cross Section Elements



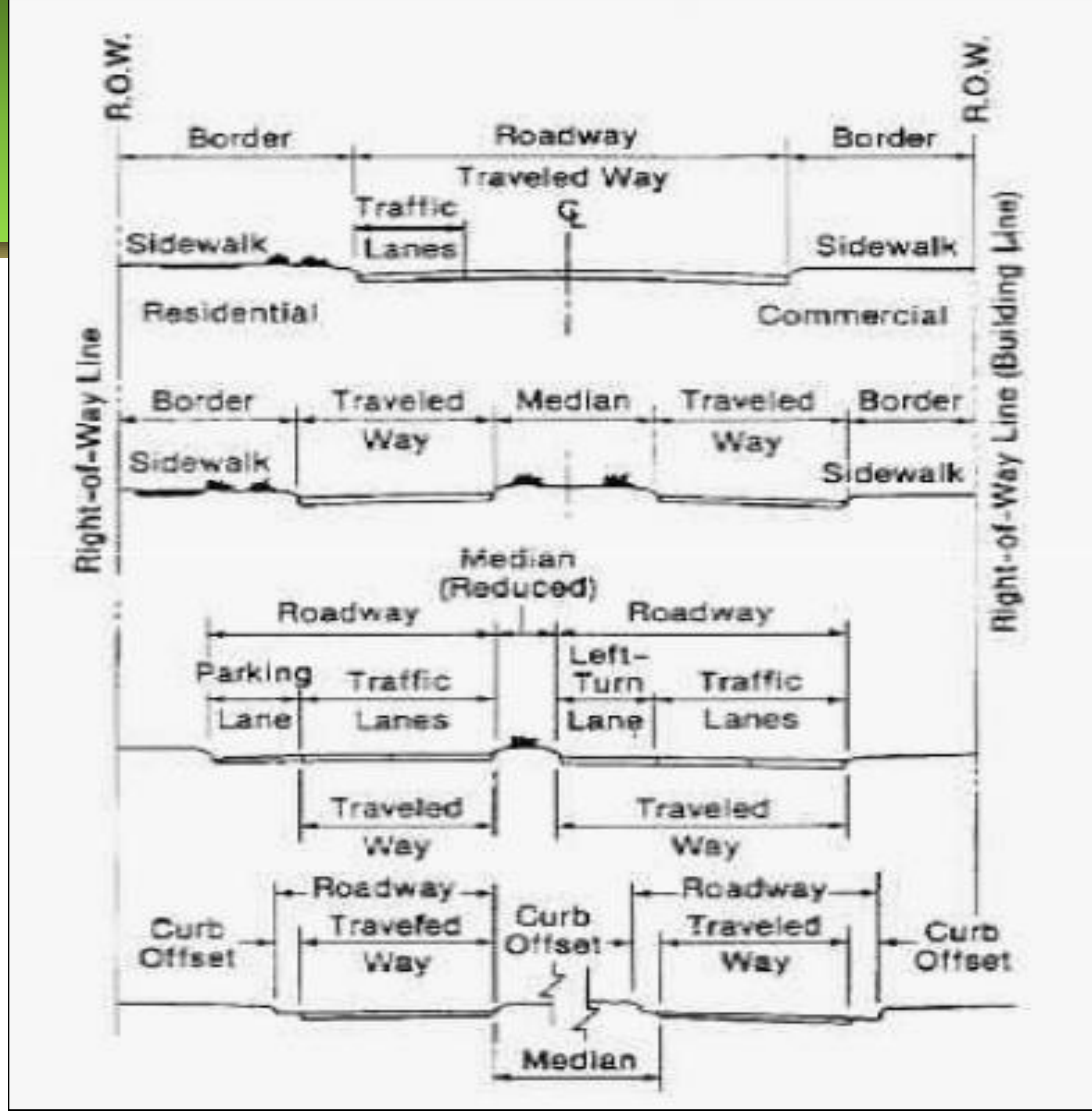
In roadside design, two major elements should be controlled by the designer: roadside slopes and rigid obstacles

Cross Section Elements for Rural Two-Lane Highway



SOURCE: *Safety Effectiveness of Highway Design Features,* Volume III, U.S. DOT, FHWA Washington, D.C., November 1992.

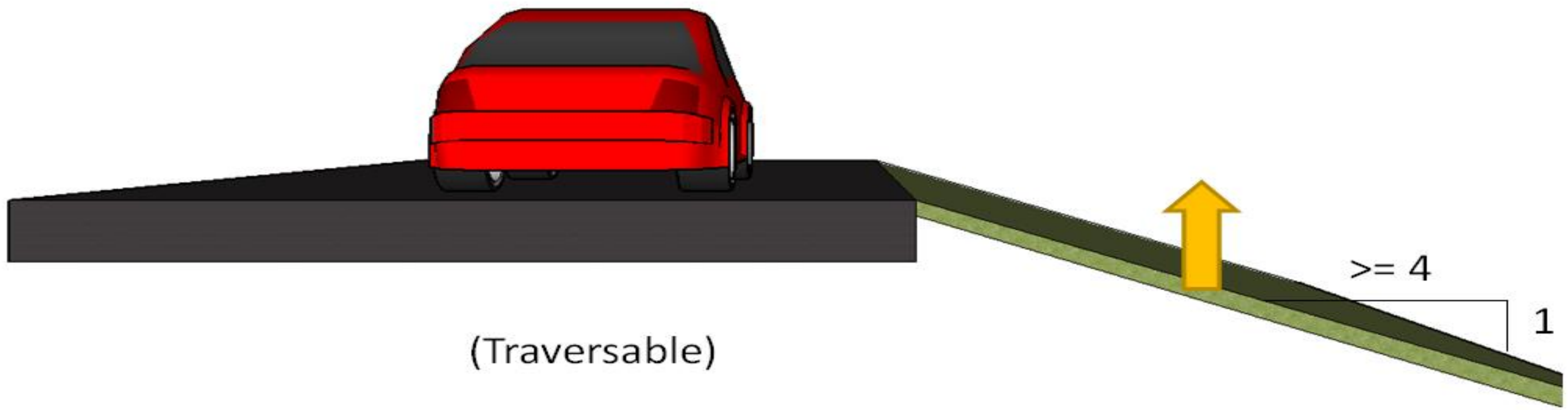
Urban Cross-section Elements



1. Steepness Categories of Foreslopes

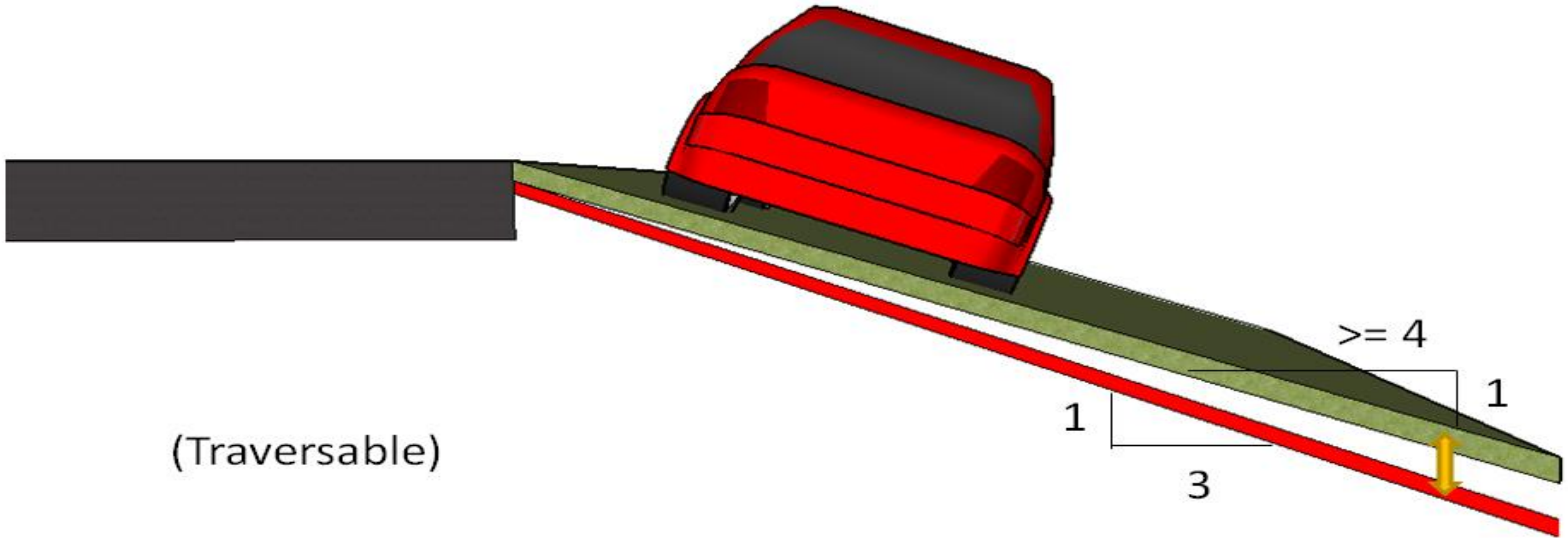
1. Recoverable
2. Non-Recoverable
3. Critical

Recoverable Foreslope



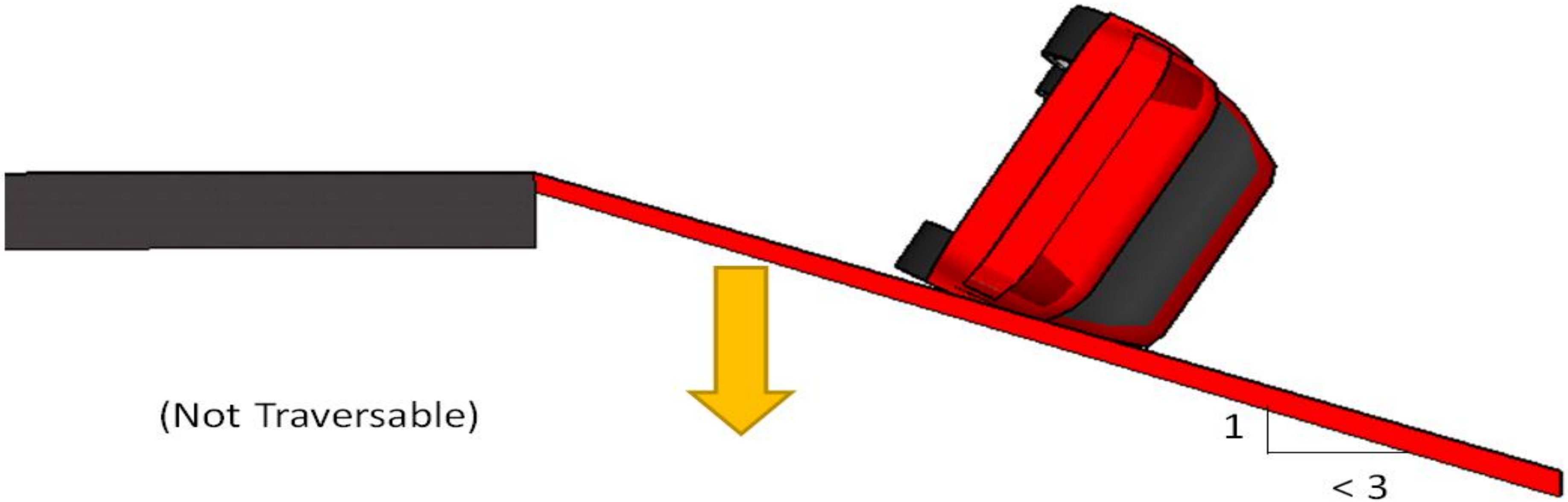
- 1V:4H or flatter
- Car driver who invade on recoverable foreslope can generally stop their vehicles or slow them enough to return the roadway safety.

Non-Recoverable Foreslope



- Foreslopes between 1V:3H
- Is traversable, but from which most vehicles will be unable to stop or return to the roadway easily
- Vehicles in such slope typically can be expected to reach the bottom

Critical Foreslope



- Foreslopes steeper than 1V:3H
- If > 1V:3H, begins closer to the through traveled way, a barrier might be warranted

Expected Crash Reduction Because a Change in Lateral Slope

Crash Reduction (%)

Sideslope in Before Condition	Sideslope in After Condition				
	3:1	4:1	5:1	6:1	7:1 or Flatter
2:1	2	10	15	21	27
3:1	0	8	14	19	26
4:1	–	0	6	12	19
5:1	–	–	0	6	14
6:1	–	–	–	0	8

2. Backslope (Cut Slope)

- When a highway is located in a cut section, the <u>backslope</u> 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.

Creado por cruces, medianas, paseos, calzadas o caminos secundarios de intersección.

Estas comunmente estan limitadas por las restricciones del ancho y problemas de mantenimiento de los extremos cónicos y largos de alcantarilla.

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

A non-traversable drainage ditch such as this is a safety hazard

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.

Channel Treatment on Embankment Foreslope (1V:6H)

Culvert Treatment on Transverse Slope

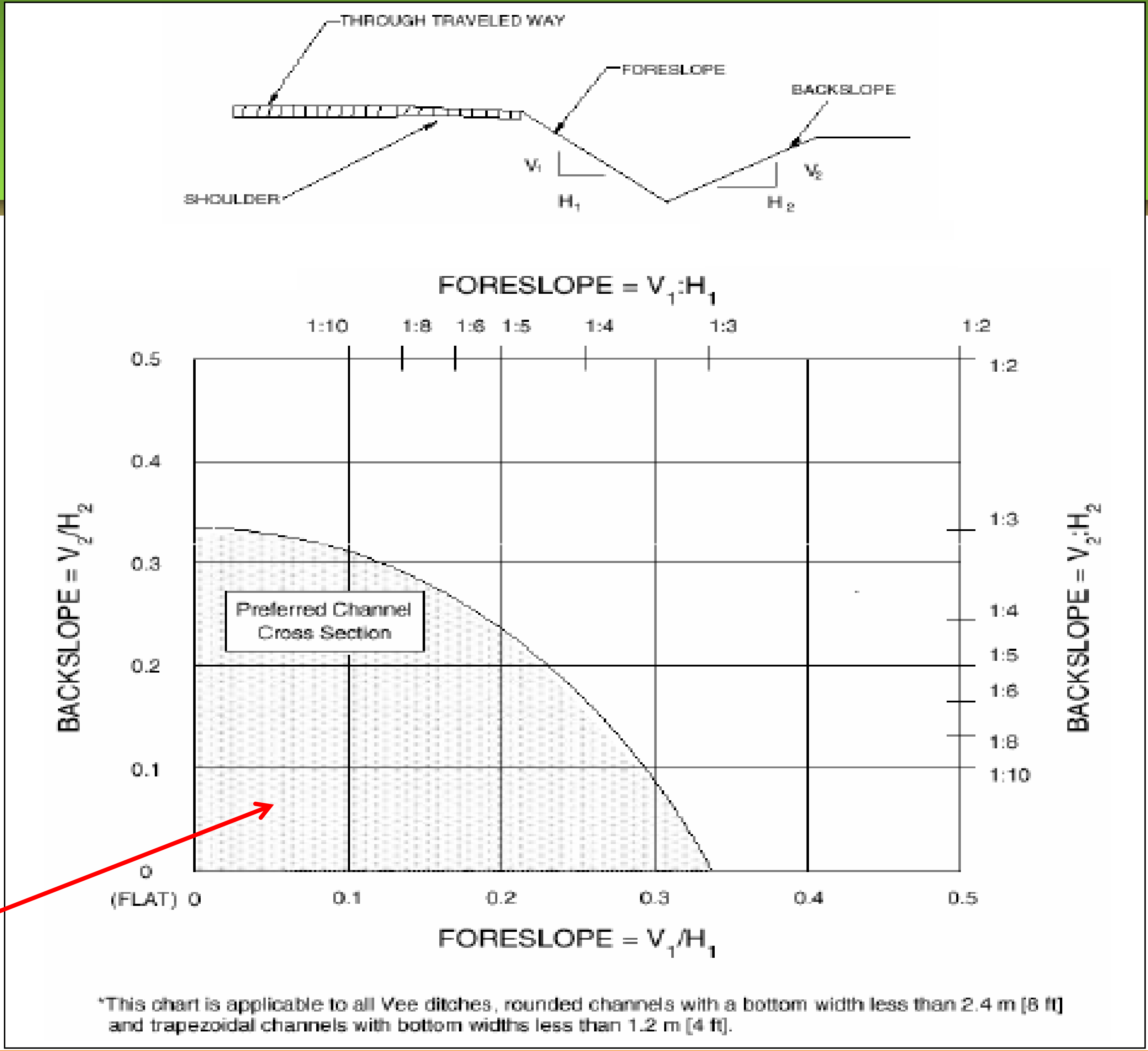
Safety Treatment for Parallel Drainage Pipe

Drainage channels must be designed, constructed and maintained considering the effects they will have on the environment.

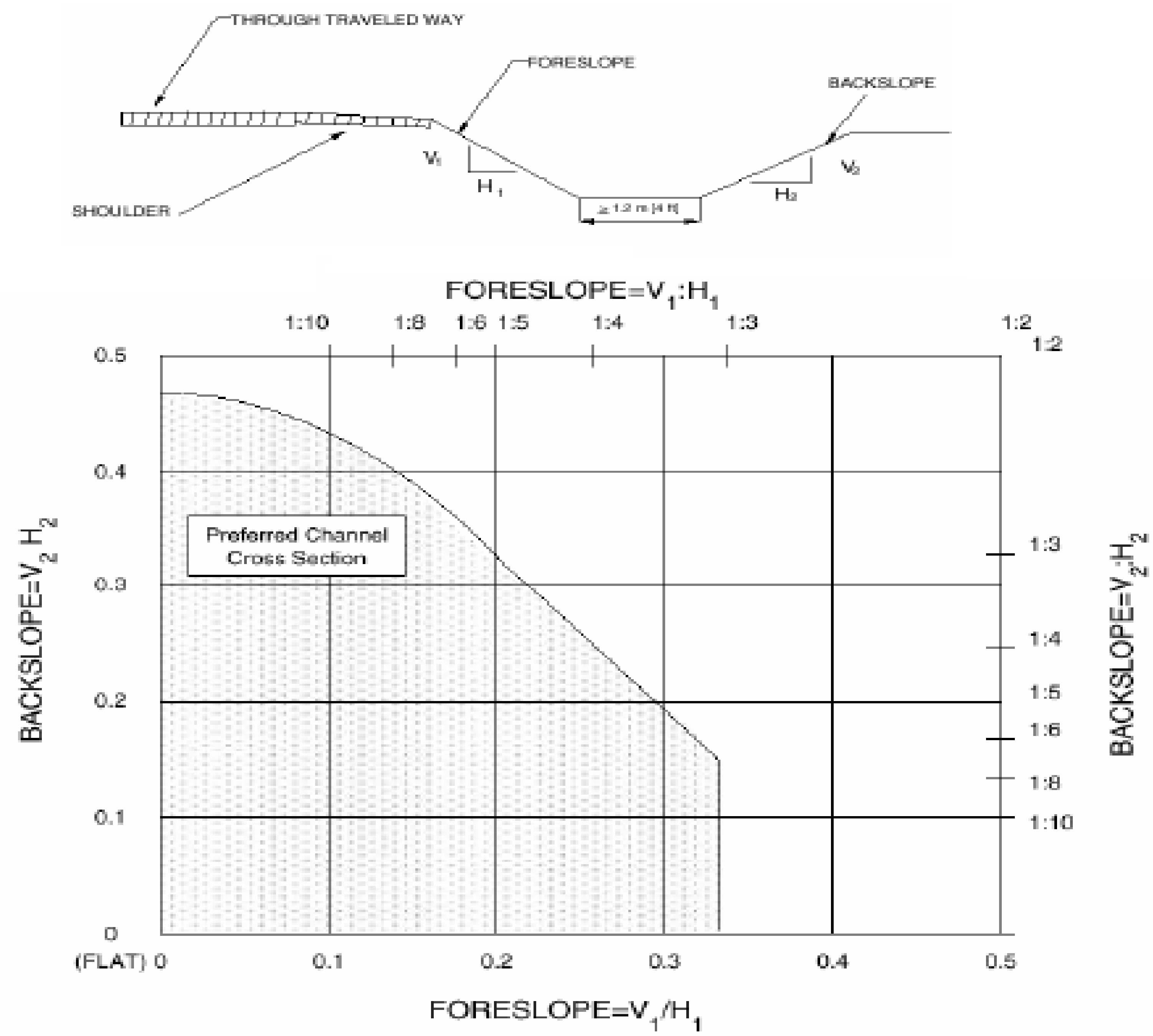
Preferred Cross Sections for Channels with Abrupt Slope Changes

Figure 3.6 (RDG)

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

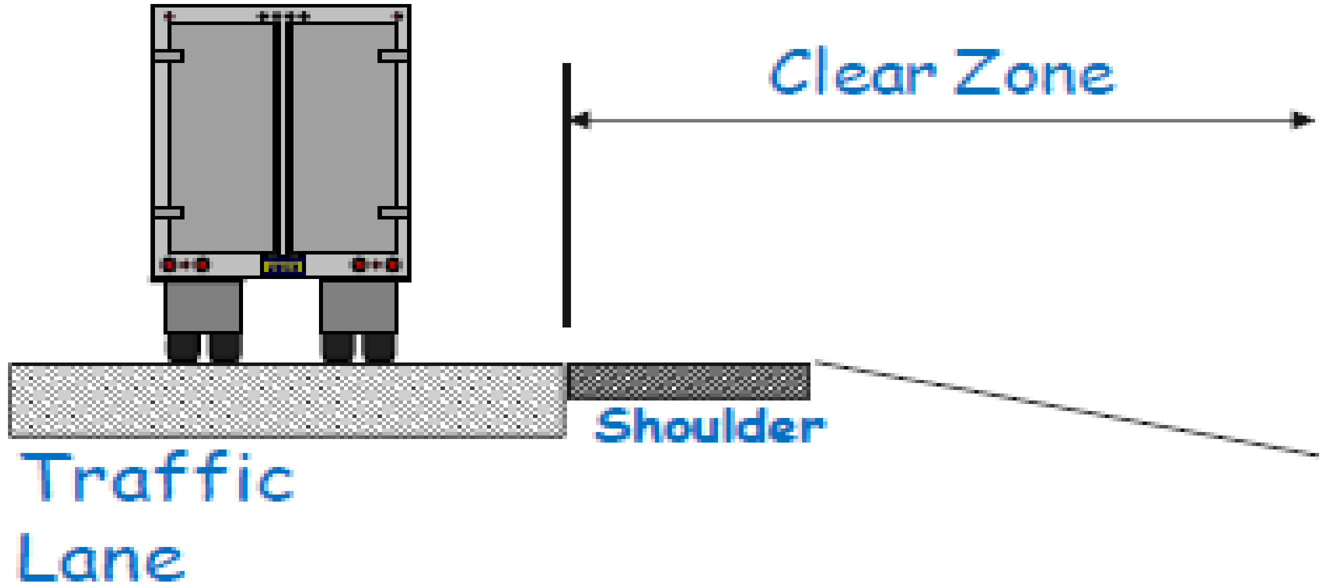


*This chart is applicable to rounded channels with bottom widths of 2.4 m [8 ft] or more and to trapezoidal channels with bottom widths equal to or greater than 1.2 m [4 ft].

Figure 3.7 (RDG)

Roadside Clear Zone Distance

- Determined by:
  - design speed,
  - traffic volume and
  - side slopes



EXAMPLE #1
6H:1V FORESLOPE
(FILL SLOPE)
60 mph
5000 vpd

Clear Zone Distance Curves (AASHTO RDG)

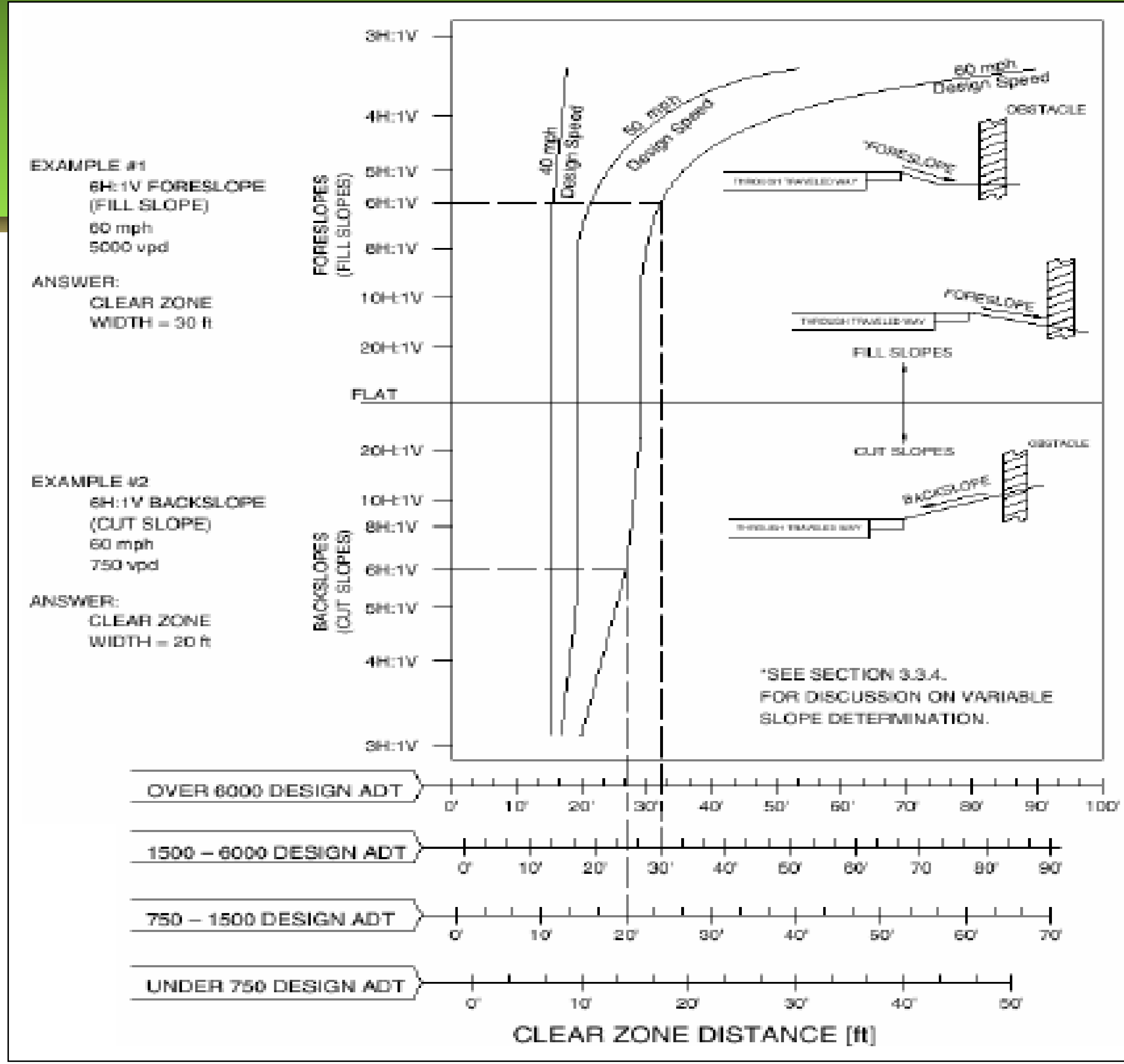


Figure 3.1 (RDG)

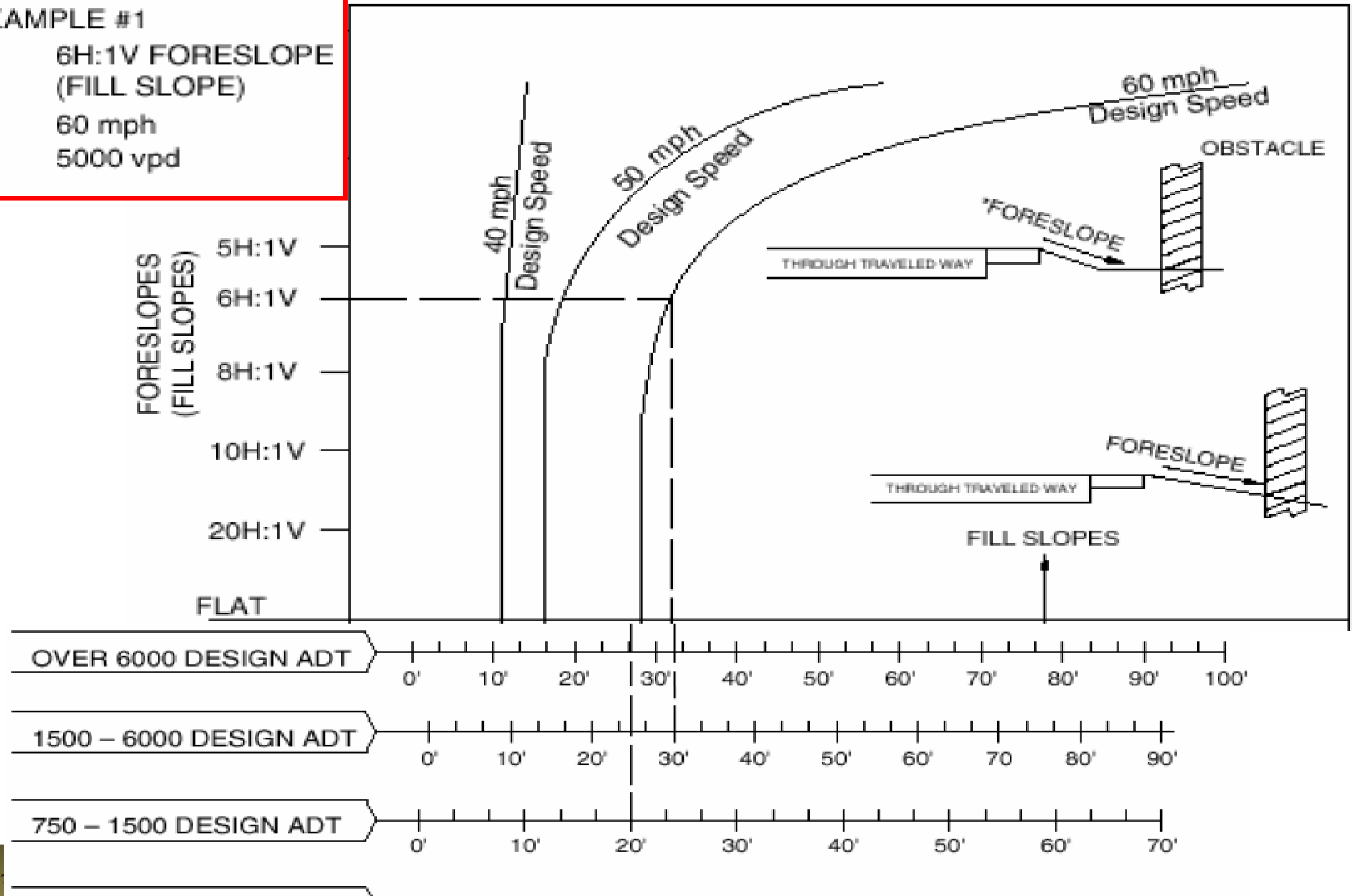
EXAMPLE #2
6H:1V BACKSLOPE
(CUT SLOPE)
60 mph
750 vpd

EXAMPLE #1

6H:1V FORESLOPE (FILL SLOPE)

60 mph

5000 vpd



Clear Zone Distance (ft) From Edge of Through Traveled Way (RDG AASHTO)

U.S. Customary Units

Design Speed (mph)	Design ADT	Foreslopes			Backslopes		
		1V:6H or flatter	1V:5H to 1V:4H	1V:3H	1V:3H	1V:5H to 1V:4H	1V:6H or flatter
≤40	UNDER 750[c]	7–10	7–10	[b]	7-10	7-10	7-10
	750–1500	10–12	12–14	[b]	10-12	10-12	10-12
	1500–6000	12–14	14–16	[b]	12-14	12-14	12-14
	OVER 6000	14–16	16–18	[b]	14-16	14-16	14-16
45–50	UNDER 750[c]	10–12	12–14	[b]	8–10	8–10	10–12
	750–1500	14–16	16–20	[b]	10–12	12–14	14–16
	1500–6000	16–18	20–26	[b]	12–14	14–16	16–18
	OVER 6000	20–22	24–28	[b]	14–16	18–20	20–22
55	UNDER 750[c]	12–14	14–18	[b]	8–10	10–12	10–12
	750–1500	16–18	20–24	[b]	10–12	14–16	16–18
	1500–6000	20–22	24–30	[b]	14–16	16–18	20–22
	OVER 6000	22–24	26–32[a]	[b]	16–18	20–22	22–24
60	UNDER 750[c]	16–18	20–24	[b]	10–12	12–14	14–16
	750–1500	20–24	26–32[a]	[b]	12–14	16–18	20–22
	1500–6000	26–30	32–40[a]	[b]	14–18	18–22	24–26
	OVER 6000	30–32[a]	36–44[a]	[b]	20–22	24–26	26–28
65–70[d]	UNDER 750[c]	18–20	20–26	[b]	10–12	14–16	14–16
	750–1500	24–26	28–36[a]	[b]	12–16	18–20	20–22
	1500–6000	28–32[a]	34–42[a]	[b]	16–20	22–24	26–28
	OVER 6000	30–34[a]	38–46[a]	[b]	22–24	26–30	28–30

Notes:

a) When a site-specific investigation indicates a high probability of continuing crashes or when such occurrences are indicated by crash history, the designer may provide clear-zone distances greater than the clear zone shown in Table 3-1. Clear zones may be limited to 30 ft for practicality and to provide a consistent roadway template if previous experience with similar projects or designs indicates satisfactory performance.

** 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

- Based on a history of crashes and inadequate superelevation, the designer may decide to modify the curvature CZ for circular curves.
- This setting applies only to the outside of the curve.

Adjustment of Clear Zone Because of Horizontal Curve (AASHTO RDG)

Table 3-2. Horizontal Curve Adjustment Factor

Radius, m [ft]	Design Speed km/h [mph]					
	60 [40]	70 [45]	80 [50]	90 [55]	100 [65]	110 [70]
900 [2,950]	1.1	1.1	1.1	1.2	1.2	1.2
700 [2,300]	1.1	1.1	1.2	1.2	1.2	1.3
600 [1,970]	1.1	1.2	1.2	1.2	1.3	1.4
500 [1,640]	1.1	1.2	1.2	1.3	1.3	1.4
450 [1,475]	1.2	1.2	1.3	1.3	1.4	1.5
400 [1,315]	1.2	1.2	1.3	1.3	1.4	—
350 [1,150]	1.2	1.2	1.3	1.4	1.5	—
300 [985]	1.2	1.3	1.4	1.5	1.5	[illegible]
250 [820]	1.3	1.3	1.4	1.5	—	—
200 [660]	1.3	1.4	1.5	—	[illegible]	—
150 [495]	1.4	1.5	—	—	—	—
100 [330]	1.5	—	—	—	—	—

$CZ_c = (L_c)*(K_{cz})$

where:

CZ_c = Clear zone on outside of curvature, meters [feet]

L_c = Clear zone distance, meters [feet] (see Table 3-1)

K_{cz} = Curve correction factor

Based on crash history and inadequate superelevation

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.

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

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Example 1

Determine the Clear Zone for a road with a design speed of 50 mph, ADT of 4800 vpd, and a backslope of 1V: 7H.

Table 3.1

V_D = 50 mph

Design Speed (mph)	Design ADT	Foreslopes			Backslopes		
		1V:6H or flatter	1V:5H to 1V:4H	1V:3H	1V:3H	1V:5H to 1V:4H	1V:6H or flatter
≤40	UNDER 750[c]	7–10	7–10	[b]	7-10	7-10	7-10
	750–1500	10–12	12–14	[b]	10-12	10-12	10-12
	1500–6000	12–14	14–16	[b]	12-14	12-14	12-14
	OVER 6000	14–16	16–18	[b]	14-16	14-16	14-16
45–50	UNDER 750[c]	10–12	12–14	[b]	8–10	8–10	10–12
	750–1500	14–16	16–20	[b]	10–12	12–14	14–16
	1500–6000	16–18	20–26	[b]	12–14	14–16	16–18
	OVER 6000	20–22	24–28	[b]	14–16	18–20	20–22
55	UNDER 750[c]	12–14	14–18	[b]	8–10	10–12	10–12
	750–1500	16–18	20–24	[b]	10–12	14–16	16–18
	1500–6000	20–22	24–30	[b]	14–16	16–18	20–22
	OVER 6000	22–24	26–32[a]	[b]	16–18	20–22	22–24
60	UNDER 750[c]	16–18	20–24	[b]	10–12	12–14	14–16
	750–1500	20–24	26–32[a]	[b]	12–14	16–18	20–22
	1500–6000	26–30	32–40[a]	[b]	14–18	18–22	24–26
	OVER 6000	30–32[a]	36–44[a]	[b]	20–22	24–26	26–28
65–70[d]	UNDER 750[c]	18–20	20–26	[b]	10–12	14–16	14–16
	750–1500	24–26	28–36[a]	[b]	12–16	18–20	20–22
	1500–6000	28–32[a]	34–42[a]	[b]	16–20	22–24	26–28
	OVER 6000	30–34[a]	38–46[a]	[b]	22–24	26–30	28–30

Example 1

ADT = 4800 vpd,

Backslope 1V:7H

1V:7H

Backslope

Design Speed (mph)	Design ADT	Foreslopes			Backslopes		
		1V:6H or flatter	1V:5H to 1V:4H	1V:3H	1V:3H	1V:5H to 1V:4H	1V:6H or flatter
≤40	UNDER 750[c] 750–1500 1500–6000 OVER 6000	7–10 10–12 12–14 14–16	7–10 12–14 14–16 16–18	[a] [a] [a] [a]	7-10 10-12 12-14 14-16	7-10 10-12 12-14 14-16	7-10 10-12 12-14 14-16
45–50	UNDER 750[c] 750–1500 1500–6000 OVER 6000	10–12 14–16 16–18 20–22	12–14 16–20 20–26 24–28	[a] [a] [a] [a]	8–10 10–12 12–14 14–16	8–10 12–14 14–16 18–20	10–12 14–16 16–18 20–22

ADT = 4800 vpd

$CZ_{mín}$

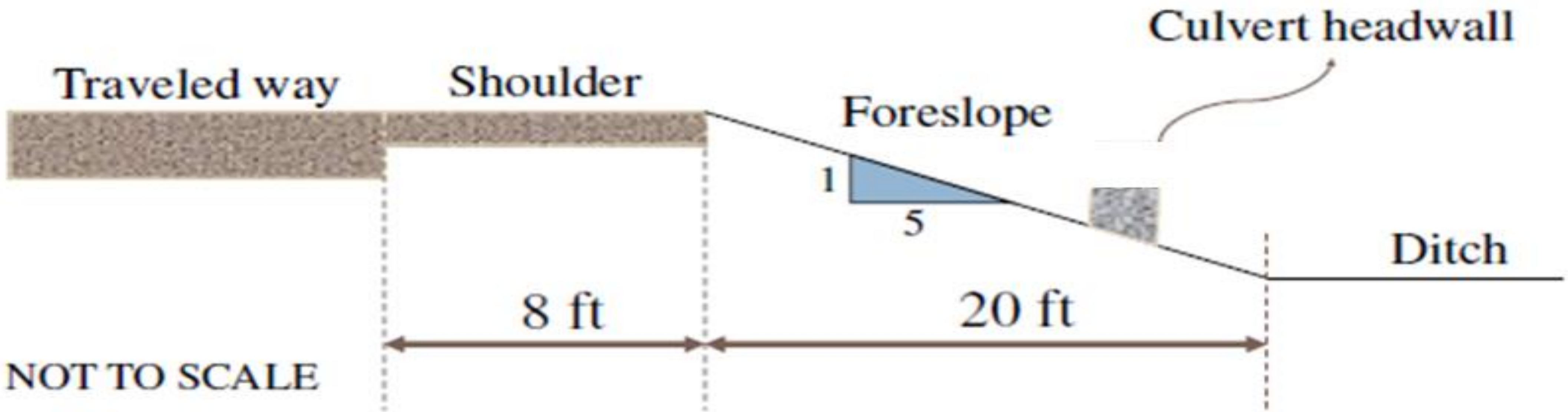
Example 1 (cont.)

Análisis:

- El Valor requerido para $CZ_{mín}$ es de 16 a 18 pies, dentro de este rango, se selecciona el valor mínimo para carreteras más seguras con menor incidencia de choques. El valor máximo se utiliza para vías de rodajes en las cuales haya un historial mayor de choques o donde exista algún obstáculo.
- El juicio ingenieril es importante.

Example 2: Single Foreslope with Obstacle

- Given ADT = 4,000 vpd, Design Speed=60mph, and the following roadside geometry:



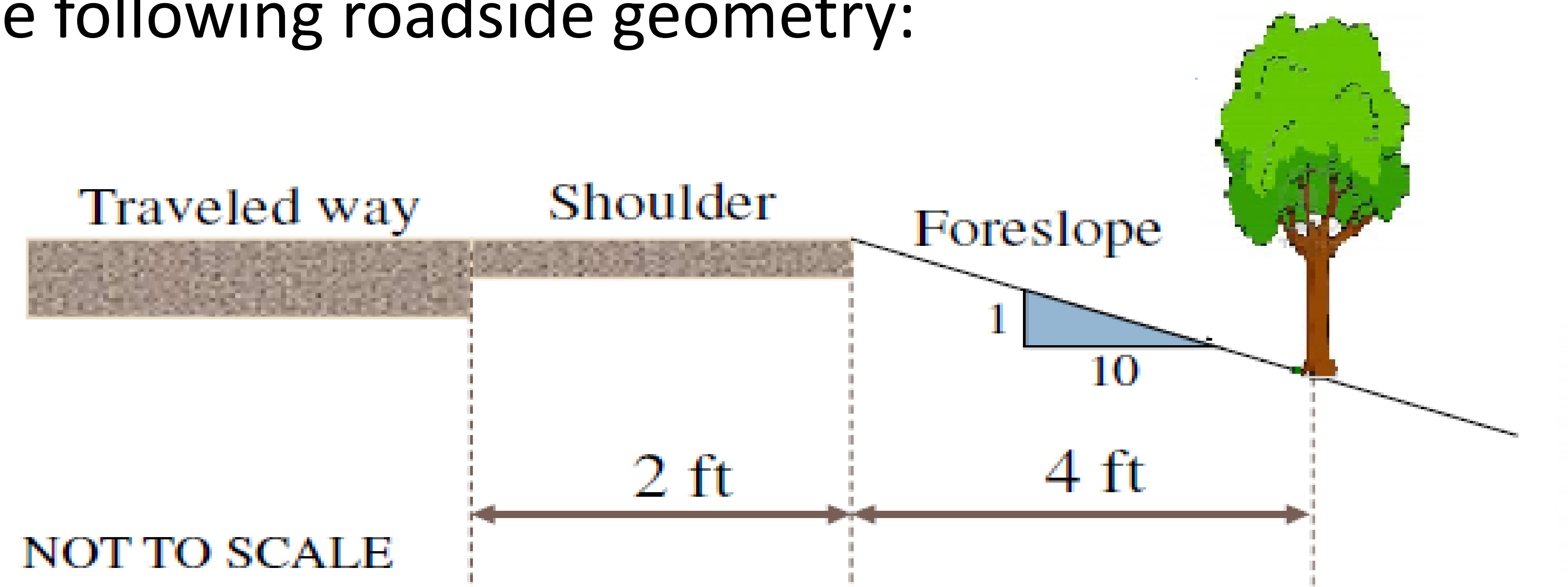
- Is the culvert headwall a roadside hazard?
- It is located within the clear zone?

Example 2: Single Foreslope with Obstacle (cont.)

- El área de recuperación es menor que la recomendada 28 ft versus 32 a 40 pies ,
- Si la pared de la alcantarilla es más alta de 4 pulgadas y es la única obstrucción en el "foreslope", podría ser removida y modificada a una pendiente de 1V:5H.
- Si el "foreslope" es rugoso y la pared no significa una obstrucción al conductor, se podría considerar no hacer nada.
- Habría que estudiar el historial de accidentes para ver la naturaleza y extensión de los choques y sitios que necesiten especial tratamiento.

Example 3: Single Foreslope with Obstacle

- Given ADT = 300 v/d, Design Speed = 40 mph, and the following roadside geometry:



- Is the tree a roadside hazard?
- It is located within the clear zone?

Example 3

U.S. Customary Units

Design Speed (mph)	Design ADT	Foreslopes			Backslopes		
		1V:6H or flatter	1V:5H to 1V:4H	1V:3H	1V:3H	1V:5H to 1V:4H	1V:6H or flatter
≤40	UNDER 750[c] 750–1500 1500–6000 OVER 6000	7–10 10–12 12–14 14–16	7–10 12–14 14–16 16–18	[b] [b] [b] [b]	7-10 10-12 12-14 14-16	7-10 10-12 12-14 14-16	7-10 10-12 12-14 14-16
45–50	UNDER 750[c] 750–1500 1500–6000 OVER 6000	10–12 14–16 16–18 20–22	12–14 16–20 20–26 24–28	[b] [b] [b] [b]	8–10 10–12 12–14 14–16	8–10 12–14 14–16 18–20	10–12 14–16 16–18 20–22
55	UNDER 750[c] 750–1500 1500–6000 OVER 6000	12–14 16–18 20–22 22–24	14–18 20–24 24–30 26–32[a]	[b] [b] [b] [b]	8–10 10–12 14–16 16–18	10–12 14–16 16–18 20–22	10–12 16–18 20–22 22–24
60	UNDER 750[c] 750–1500 1500–6000 OVER 6000	16–18 20–24 26–30 30–32[a]	20–24 26–32[a] 32–40[a] 36–44[a]	[b] [b] [b] [b]	10–12 12–14 14–18 20–22	12–14 16–18 18–22 24–26	14–16 20–22 24–26 26–28
65–70[d]	UNDER 750[c] 750–1500 1500–6000 OVER 6000	18–20 24–26 28–32[a] 30–34[a]	20–26 28–36[a] 34–42[a] 38–46[a]	[b] [b] [b] [b]	10–12 12–16 16–20 22–24	14–16 18–20 22–24 26–30	14–16 20–22 26–28 28–30

Notes:

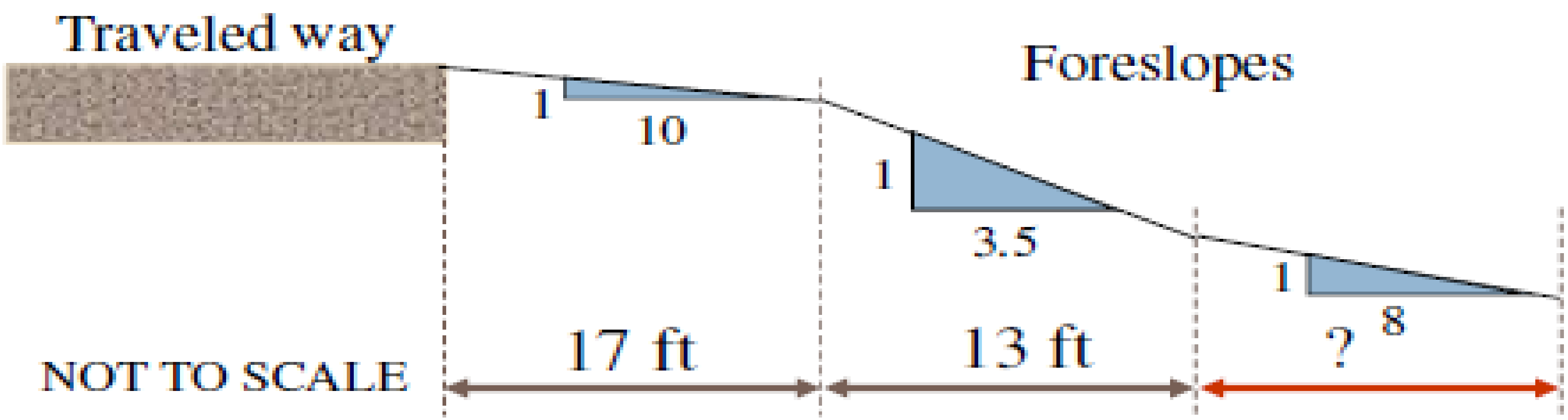
a) When a site-specific investigation indicates a high probability of continuing crashes or when such occurrences are indicated by crash history, the designer may provide clear-zone distances greater than the clear zone shown in Table 3-1. Clear zones may be limited to 30 ft for practicality and to provide a consistent roadway template if previous experience with similar projects or designs indicates satisfactory performance.

Example 3 (cont.)

- La distancia del árbol a la carretera es de 6 pies. Debido a que la distancia mínima requerida es 7 pies, se concluye que no cumple con el CZ. El árbol está dentro del CZ.
- Estudiar el historial de choques y utilizar el juicio ingenieril para determinar si se debe remover el árbol.
- Si hay una fila de árboles y el historial de choques y es significativo, sería apropiado proteger la fila de árboles con una barrera o removerlos.
- Si los demás arboles están lejos de la carretera (15 pies por ejemplo) este árbol solo representa una obstrucción significativa y debería ser removido.

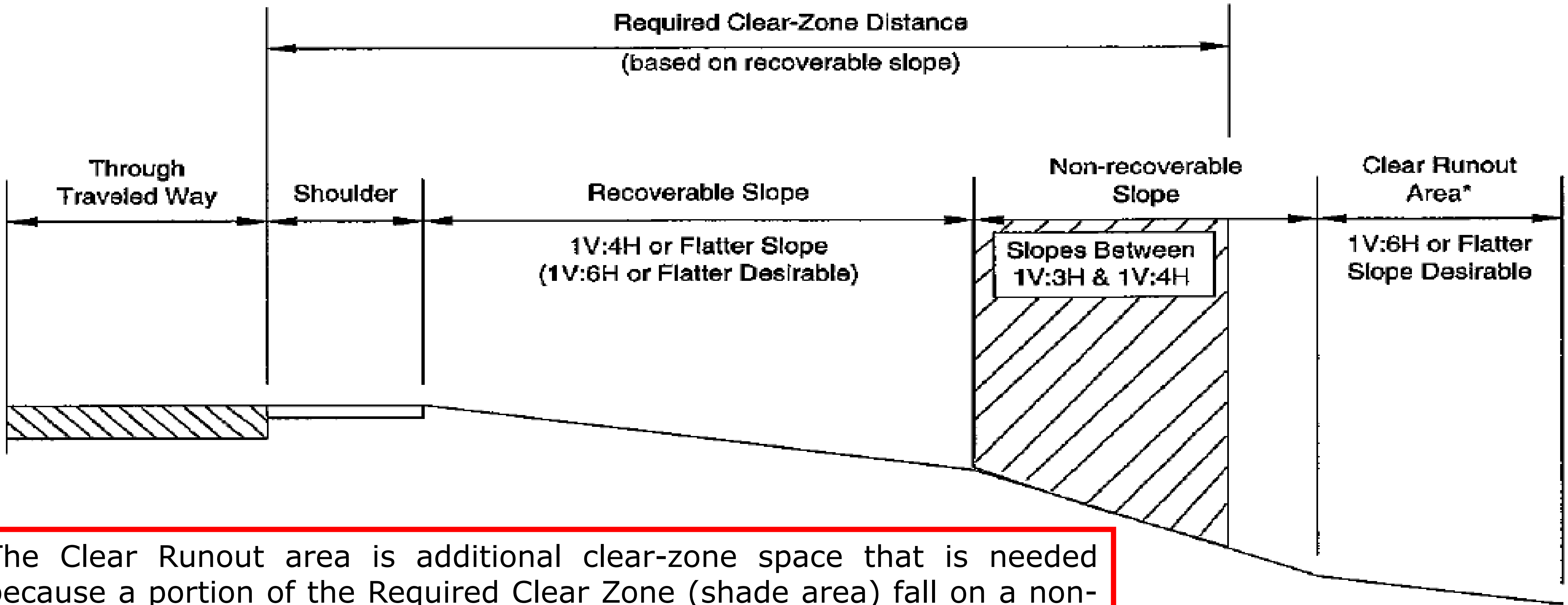
Example 4: Multiple Foreslopes

- Given ADT = 7,000 vpd, Design Speed=60 mph, and the following roadside geometry:



- Is the clear zone provided adequate?
- What distance is needed for the 1:8 foreslope?

Example 4: Clear Runout Area



The Clear Runout area is additional clear-zone space that is needed because a portion of the Required Clear Zone (shade area) fall on a non-recoverable slope. The width of the Clear Runout Area is equal to that portion of the Clear Zone Distance that is located on non-recoverable slope.

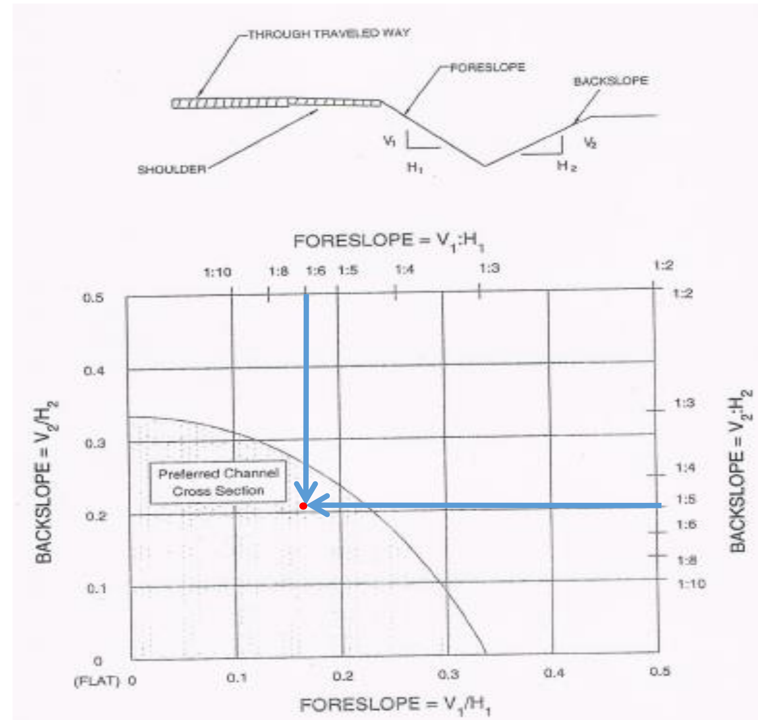
Example 5

Use Figure 3.6 of the Road AASHTO Design Guide (RDG) to determine whether the design of a channel with backslope 1: 5 and foreslope 1: 6 is safe.

<u>Solution:</u>

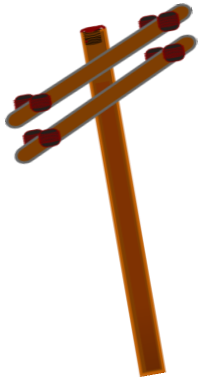
The point is within the graph area.

Therefore, the design is safe.



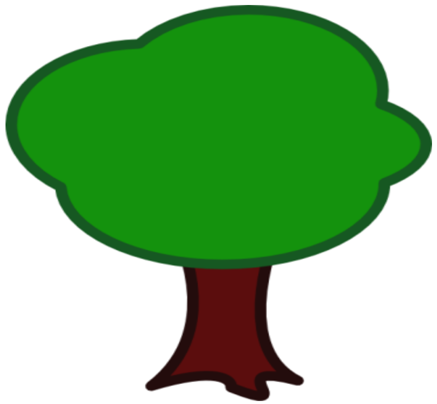
*This chart is applicable to all Vee ditches, rounded channels with a bottom width less than 2.4 m [8 ft] and trapezoidal channels with bottom widths less than 1.2 m [4 ft].

FIGURE 3.6 Preferred cross sections for channels with abrupt slope changes



ROADSIDE FEATURES

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



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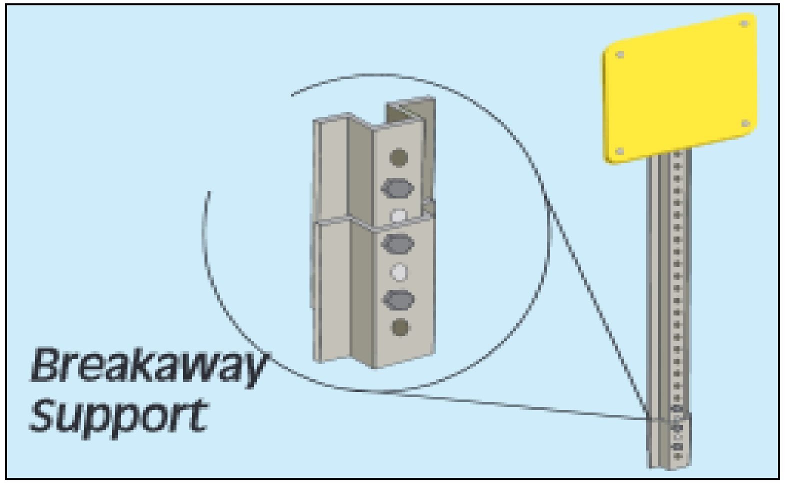
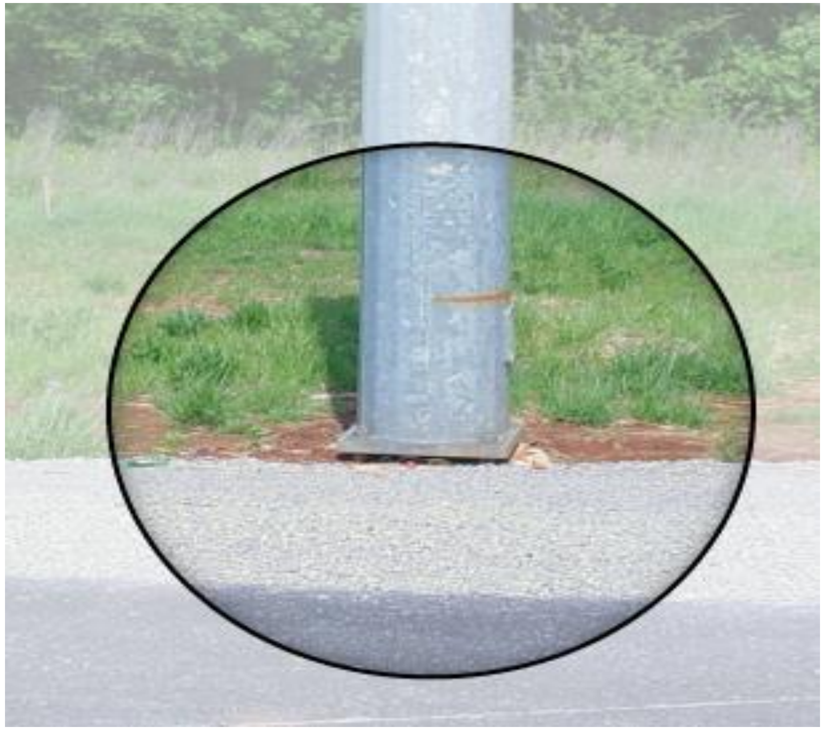
The Six options Still Apply:

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

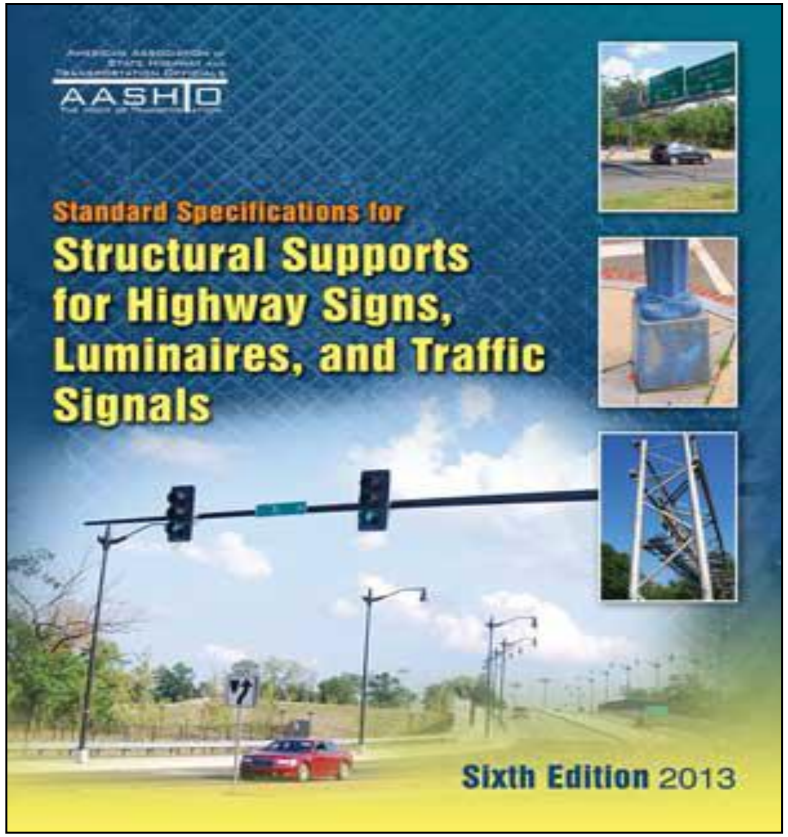
- <u>Breakaway Support</u>: designed to yield, fracture, or separate when impacted by a vehicle.
- Types of release mechanism:
  - slip plane,
  - plastic hinge,
  - fracture element, or
  - A combination of them.



http://www.sddc.army.mil

Acceptance Criteria For Breakaway Supports

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 they 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
  - 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.)

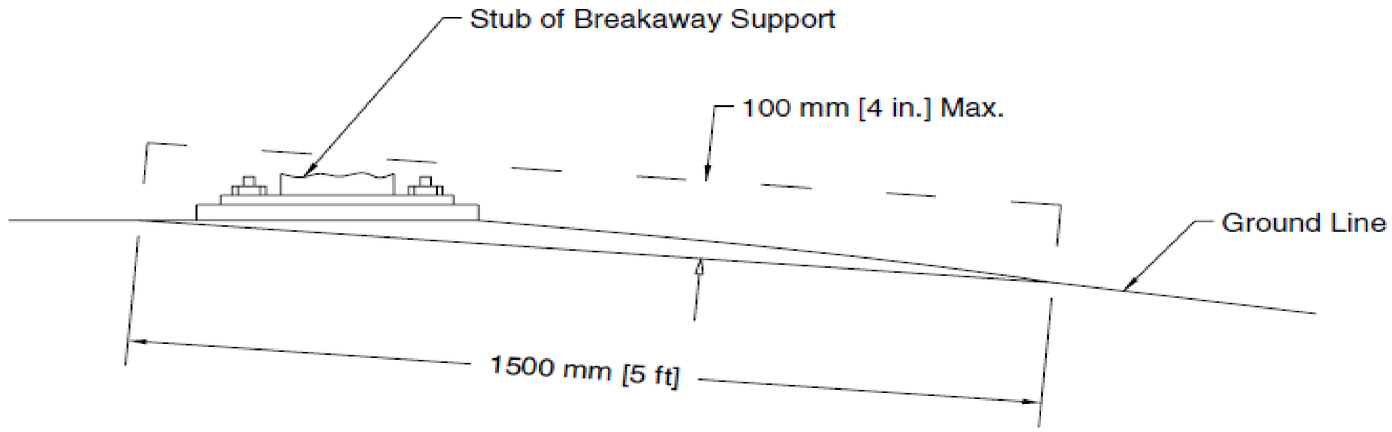


Figure 4-1. Breakaway Support Stub Height Measurements

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

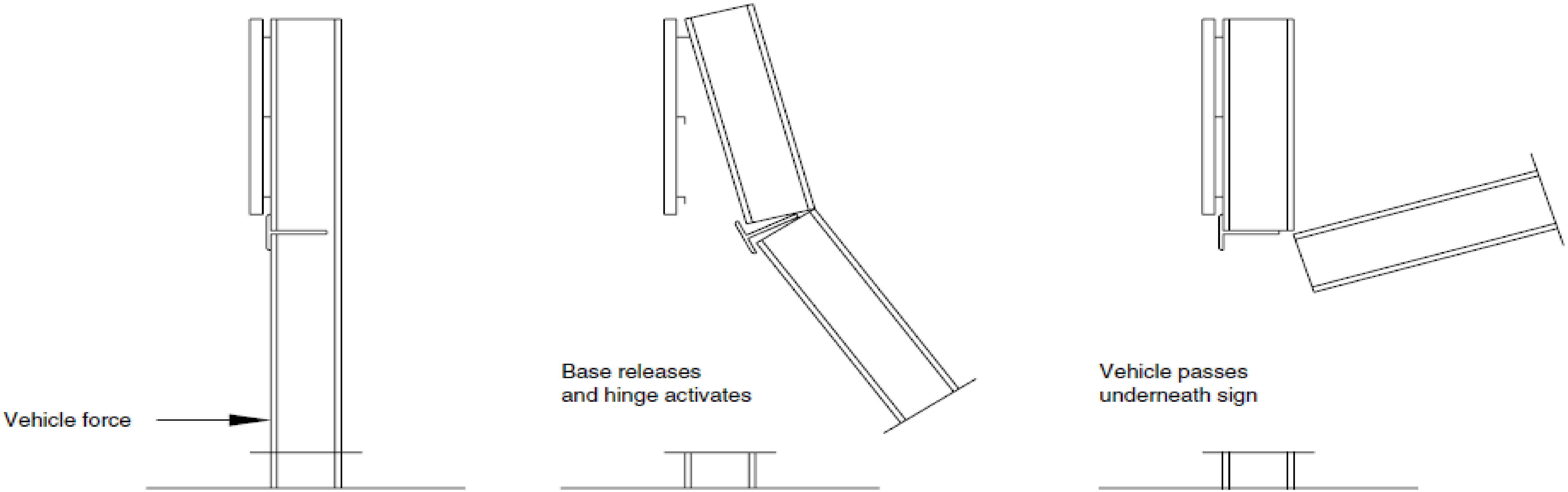
Overhead Signs

Source:www.interstate-guide.com

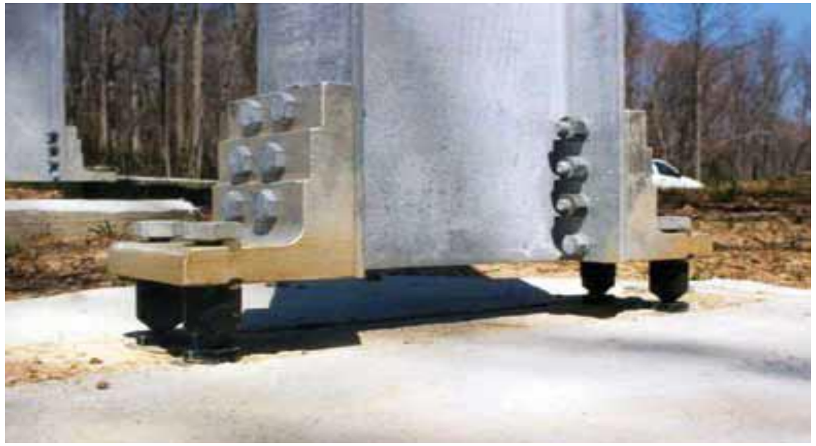
Large Roadside Signs

- Greater than 5 m^2 (50 ft^2) in area
- Typically have two or more breakaway support posts
- Hinge at least 2 m (7 ft) 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



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

Cast Aluminum Frangible

Slip Base Design

Frangible Coupling

Considerations

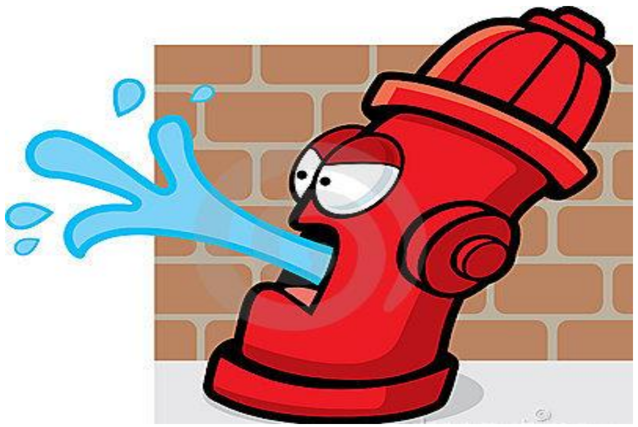
- When impacted, should fall near the path of the vehicle
- The mast should rotate so it points away from the roadway when resting on the ground
- Heights should not exceed 18.5 m (60 ft)

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 breakaway should be within 4 in. of the ground.

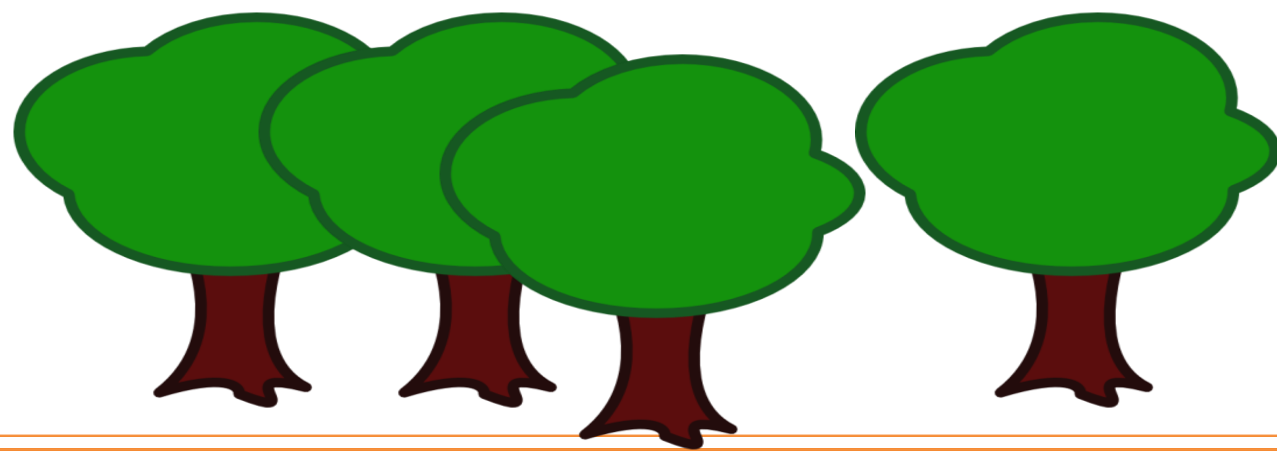


Objectives a Strategies for Reducing Utility Pole Crashes

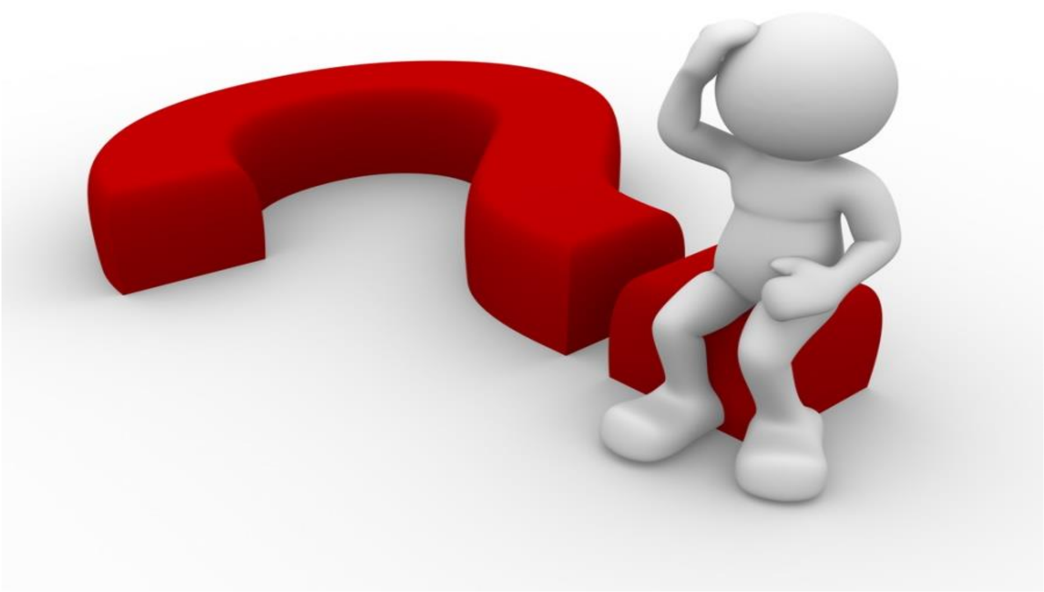
Objectives		Strategies
A	Treat specific poles in high-crash and high-risk locations	A1 Remove poles in hazardous locations
		A2 Relocate poles further away or to less vulnerable location
		A3 Use breakaway poles
		A4 Shield drivers from poles
		A5 Improve drivers' abilities to see poles
		A6 Apply traffic 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

Objectives		Strategies
A	Prevent trees from growing in hazardous locations.	A1 Develop, revise, and implement planting guidelines to prevent placing trees in hazardous location.
		A2 Develop mowing and vegetation control guidelines.
B	Eliminate the hazardous condition and/or reduce the severity of the crash.	B1 Remove trees in hazardous locations.
		B2 Shield motorists from striking trees.
		B3 Modify roadside clear zone in the vicinity of trees.
		B4 Delineate trees in hazardous locations.



QUESTIONS?



Fabiola Buitrago G. Ph.D.

SAFETY BARRIERS

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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.

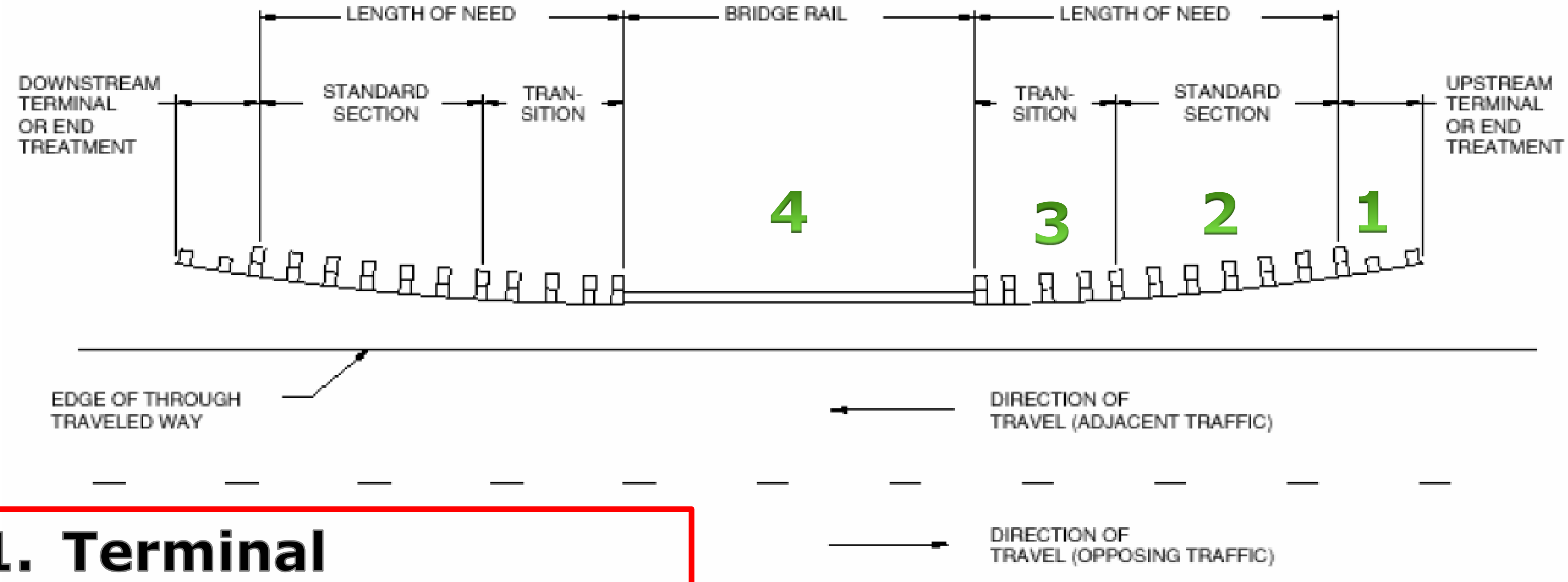
Bridge Railings

- 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

Roadside Barrier System



1. **Terminal**
2. **Standard section**
3. **Transition section**
4. **Bridge Railing**

<u>AASHTO, (MASH)</u>
Manual for Assessing Safety Hardware

<u>Standards for Testing Crashes with Barriers</u>

1993

2009

<u>NCHRP 350</u>, 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 <u>different impact conditions</u>
- 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

Test Level	Selection Criteria
TL-1	Work zones with low posted speed, and low volume local streets
TL-2	Work zones, and most local and collector roads with low posted speeds and a low number of heavy vehicles expected
TL-3	High speed arterials with low mixtures of heavy vehicles and with favorable site conditions
TL-4	High speed highways, freeways, expressways, and Interstate highways with a mixture of trucks and heavy vehicles
TL-5	Same locations as TL-4 where a significant percent of the ADT is made of large trucks or where there are unfavorable site conditions
TL-6	Same locations as TL-4 where a significant percent of the ADT is made of tanker trucks, and unfavorable site conditions exist

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
- <u>Redirection, controlled penetration, or controlled stopping</u>

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

QUESTIONS?

Fabiola Buitrago G. Ph.D.

DESIGN AND LOCATION OF SAFETY BARRIERS

Fabiola Buitrago G. Ph.D.

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

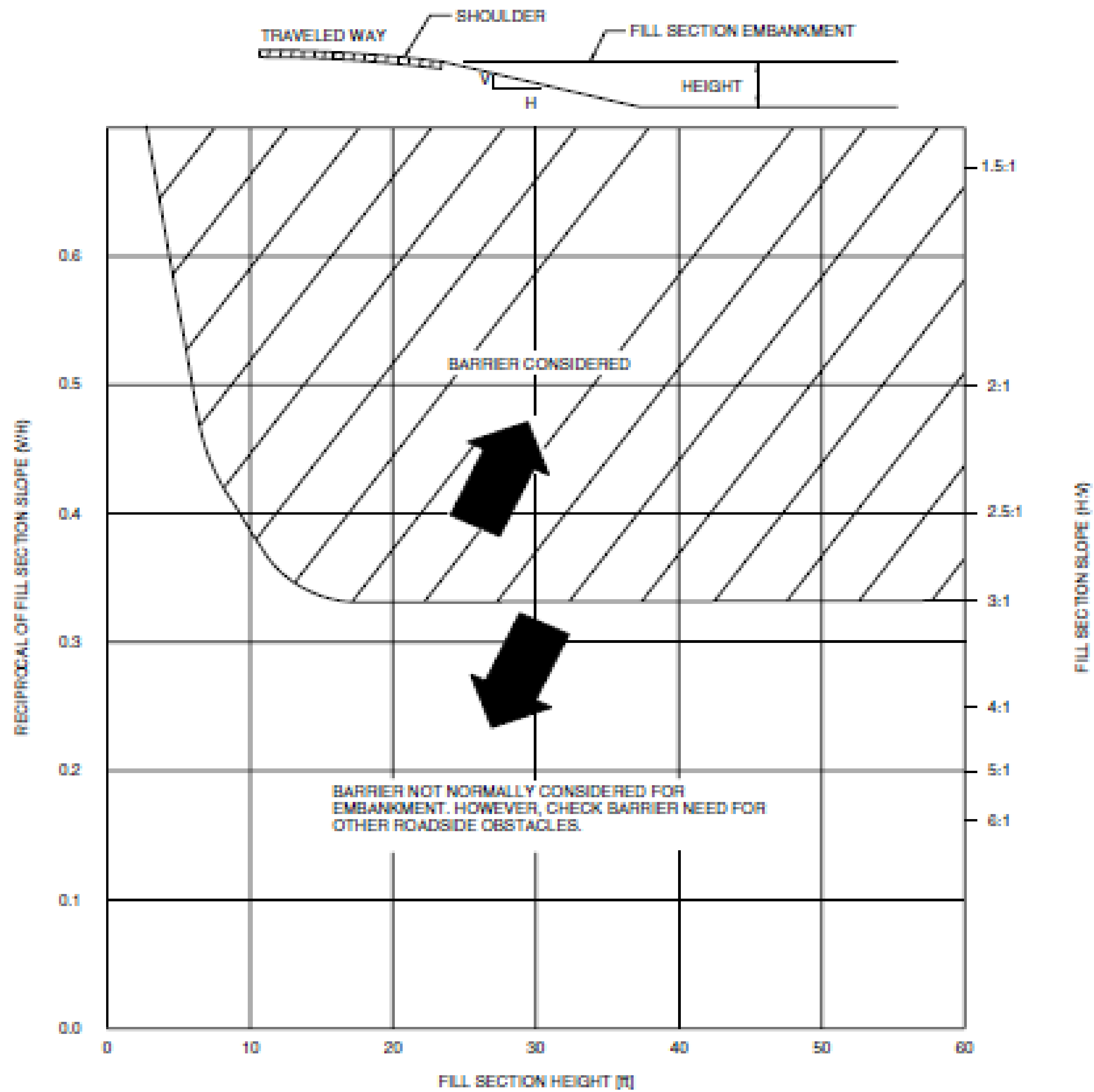
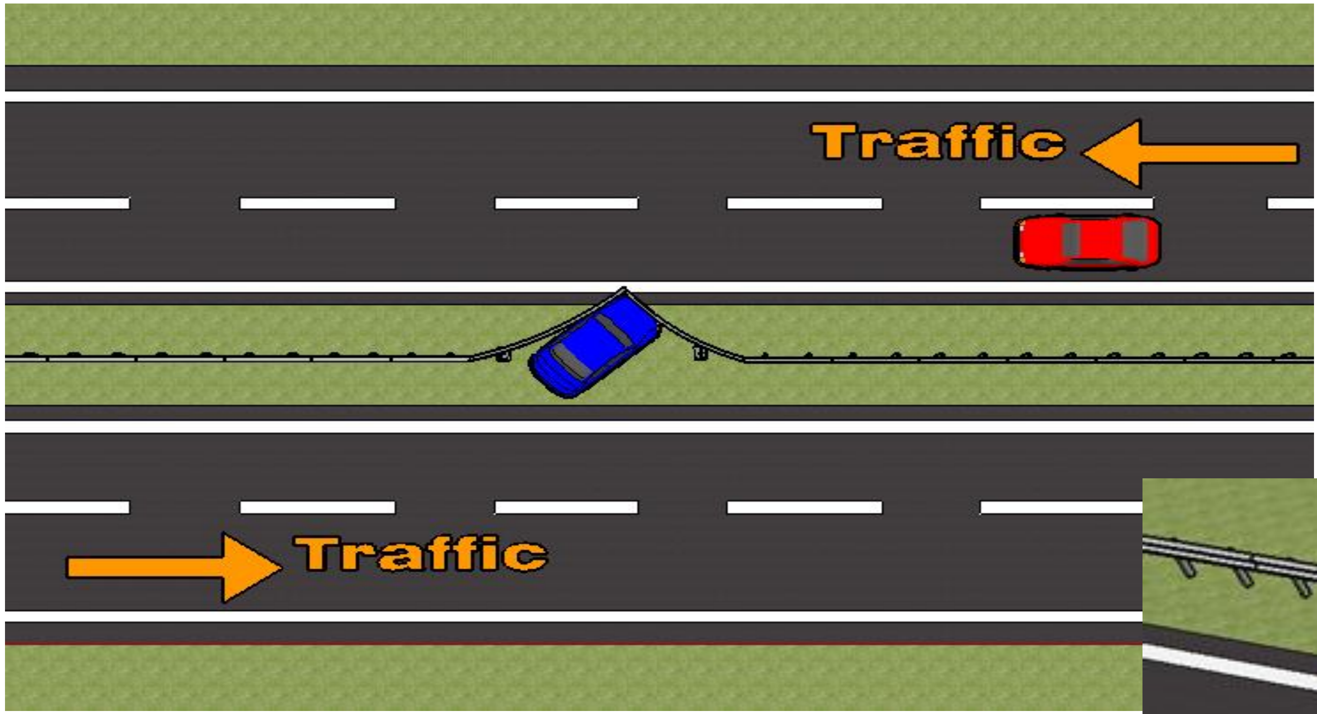
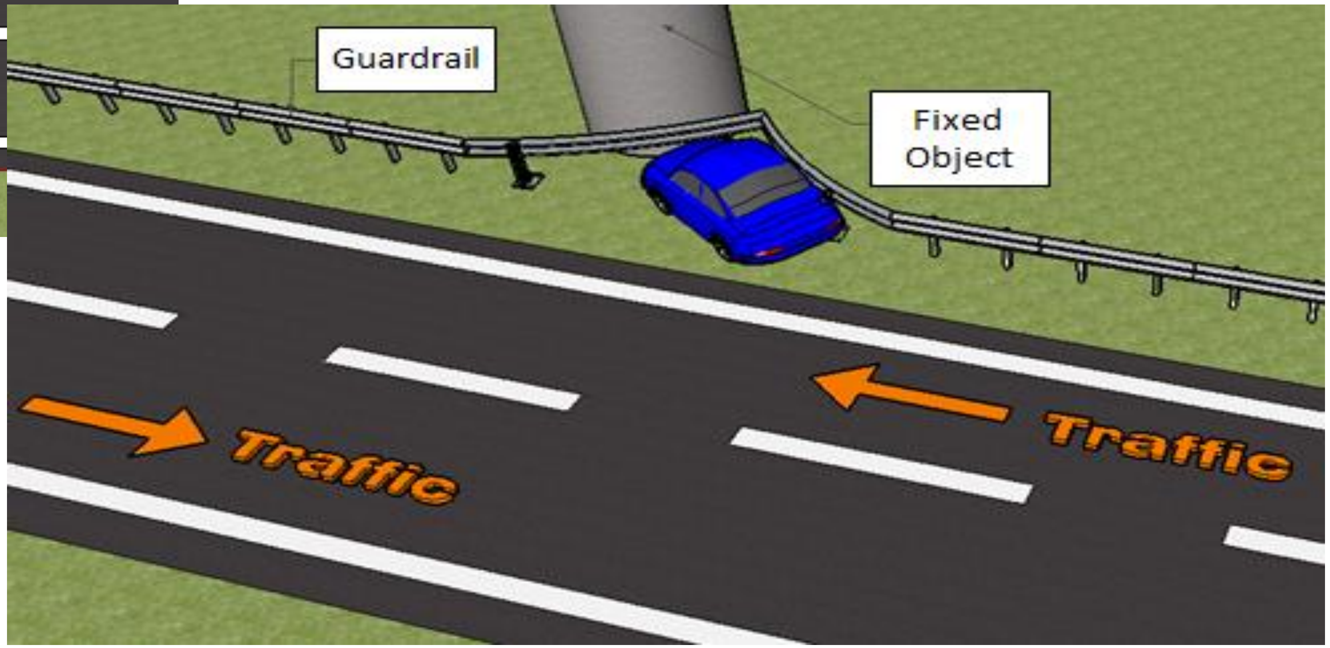


Figure 5-1(b). Comparative Barrier Consideration for Embankments (U.S. Customary Units) *(15)*

Obstacle	Guidelines
Bridge piers, abutments, and railing ends	Shielding generally needed.
Boulders	Judgment decision based on nature of fixed object and likelihood of impact.
Culverts, pipes, headwalls	Judgment decision based on size, shape and location of obstacle.
Foreslopes and backslopes (smooth)	Shielding not generally needed.
Foreslopes and backslopes (rough)	Judgment decision based on likelihood of impact.
Ditches (parallel)	Refer to Figures 3-6 and 3-7.
Ditches (transverse)	Shielding generally needed if likelihood of head-on impact is high.
Embankment	Judgment decision based on fill height and slope (see Figure 5-1).
Retaining walls	Judgment decision based on relative smoothness of wall and anticipated maximum angle of impact.
Sign/luminaire supports[c]	Shielding generally needed for non-breakaway supports.
Traffic signal supports[d]	Isolated traffic signals within clear zone on high-speed rural facilities may need shielding.
Trees	Judgment decision based on site-specific circumstances.
Utility poles	Shielding may be needed on a case-by-case basis.
Permanent bodies of water	Judgment decision based on location and depth of water and likelihood of encroachment.

Deflection





Distance that traveled a lateral barrier after an impact. (NCHRP 350)

Barrier Stiffness

Barriers are divided into three groups, based on the amount they deflect when struck by a vehicle and the mechanism the barrier uses to resist the impact forces:

- Flexible barriers
- Semi-Rigid Barriers
- Rigid Barriers

Table 5-6

Post Spacing (in.)	Beam Description	Maximum Deflection (in) – Field Test
75	Single W-Beam	29.7
38	Single W-Beam	23.5
75	Double W-Beam	35.5
38	Double W-Beam	19.6

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

System	Test Level	FHWA Acceptance Letter
	FLEXIBLE SYSTEMS	
W-Beam (Weak Post)	2	B-64
Three-Strand Cable (Weak Post)	3	B-64
High-Tension Cable Barriers	3 and 4	Various
Modified W-Beam (Weak Post)	3	B-64
Ironwood Aesthetic Barrier	3	B-56, 56-A, and 56-B

Gibraltar Cable Barriers

Flexible systems

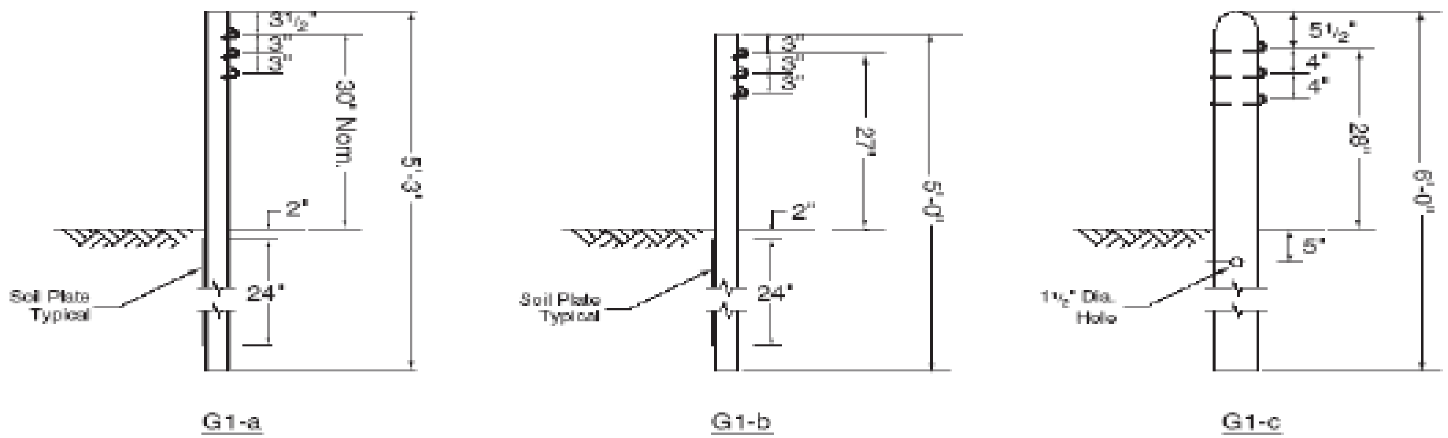


FIGURE B.1b Three-strand cable [U.S. customary units]

AASHTO Designation	G1-a	G1-b	G1-c
Post Type:	S3 x 5.7 steel	4 lb/ft steel U-channels	5 ½-in. dia. modified wood
Post Spacing:	16 ft	16 ft	12 ft-6 in.
Beam Type:	3/4-in. dia. steel cables	3/4-in. dia. steel cables	3/4-in. dia. steel cables
Maximum Dynamic Deflection:	11 ft-6 in.	11 ft-6 in.	11 ft-6 in.

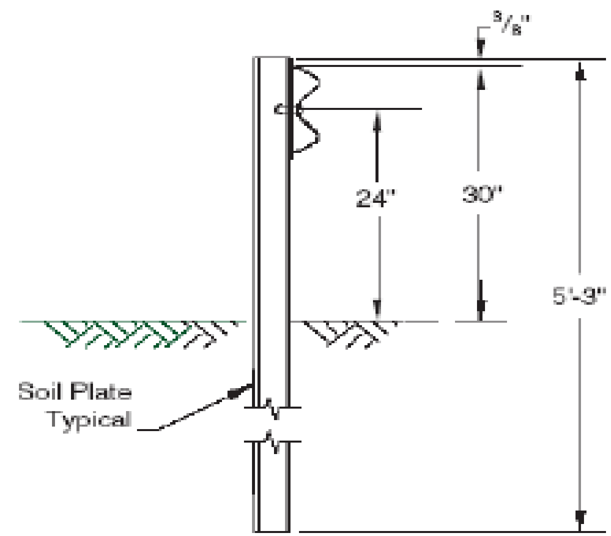


FIGURE B.2b W-beam (weak post) [U.S. customary units]

AASHTO Designation	G2
Post Type:	S3 x 5.7 steel
Post Spacing:	12 ft
Beam Type:	12 gage W-beam
Maximum Dynamic Deflection:	approximately 6 ft-6 in.

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

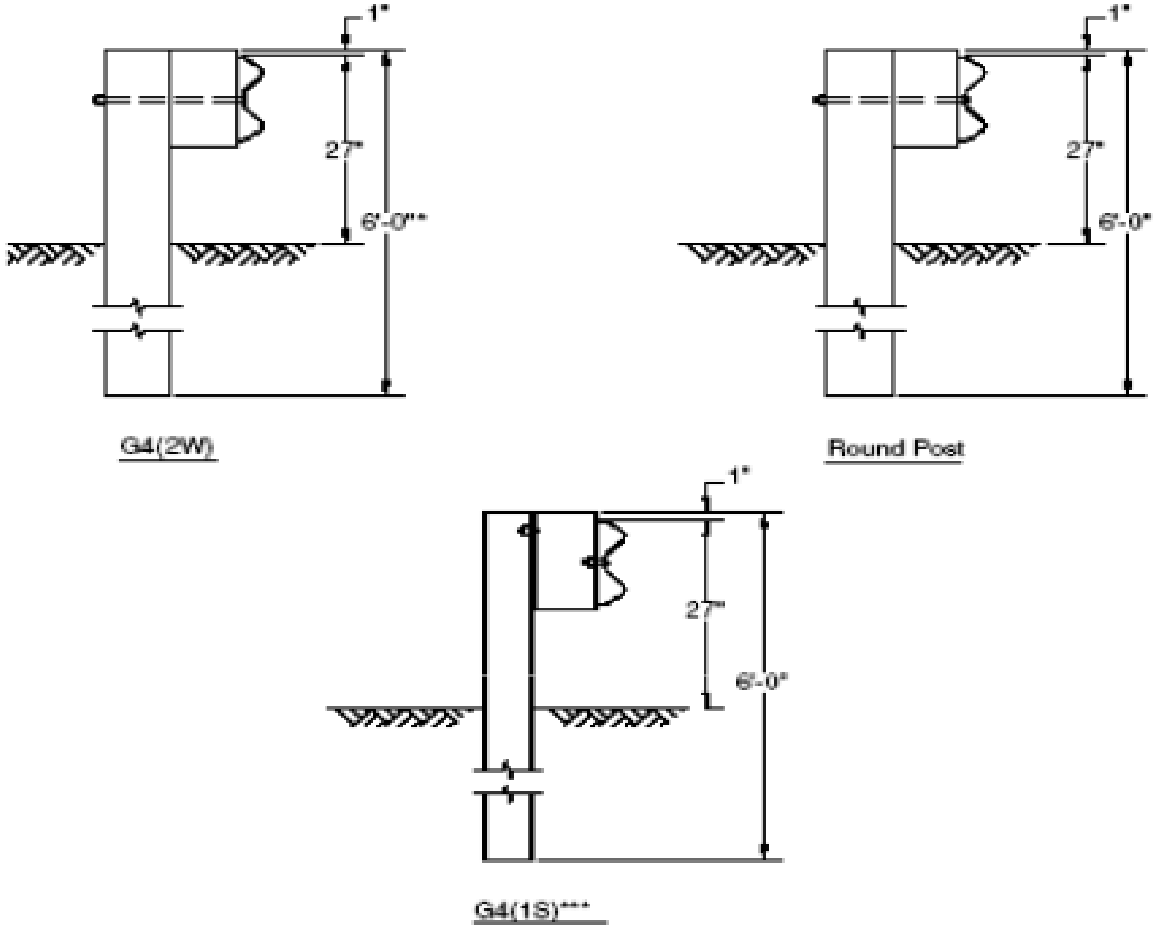


FIGURE B.4b Blocked-out W-beam (strong post) [U.S. customary units]

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

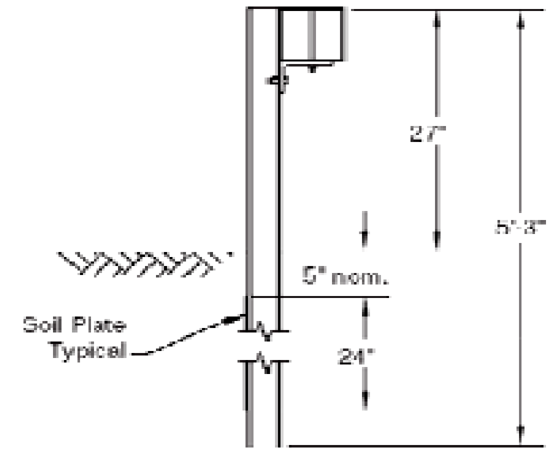


FIGURE B.3b Weak-post box beam [U.S. customary units]

AASHTO Designation	G3
Post Type:	S3 x 5.7 steel
Post Spacing:	6 ft
Beam Type:	6 in. x 6 in. x 0.19 in. steel tube
Maximum Dynamic Deflection:	approximately 5 ft

Semi-Rigid Barriers

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

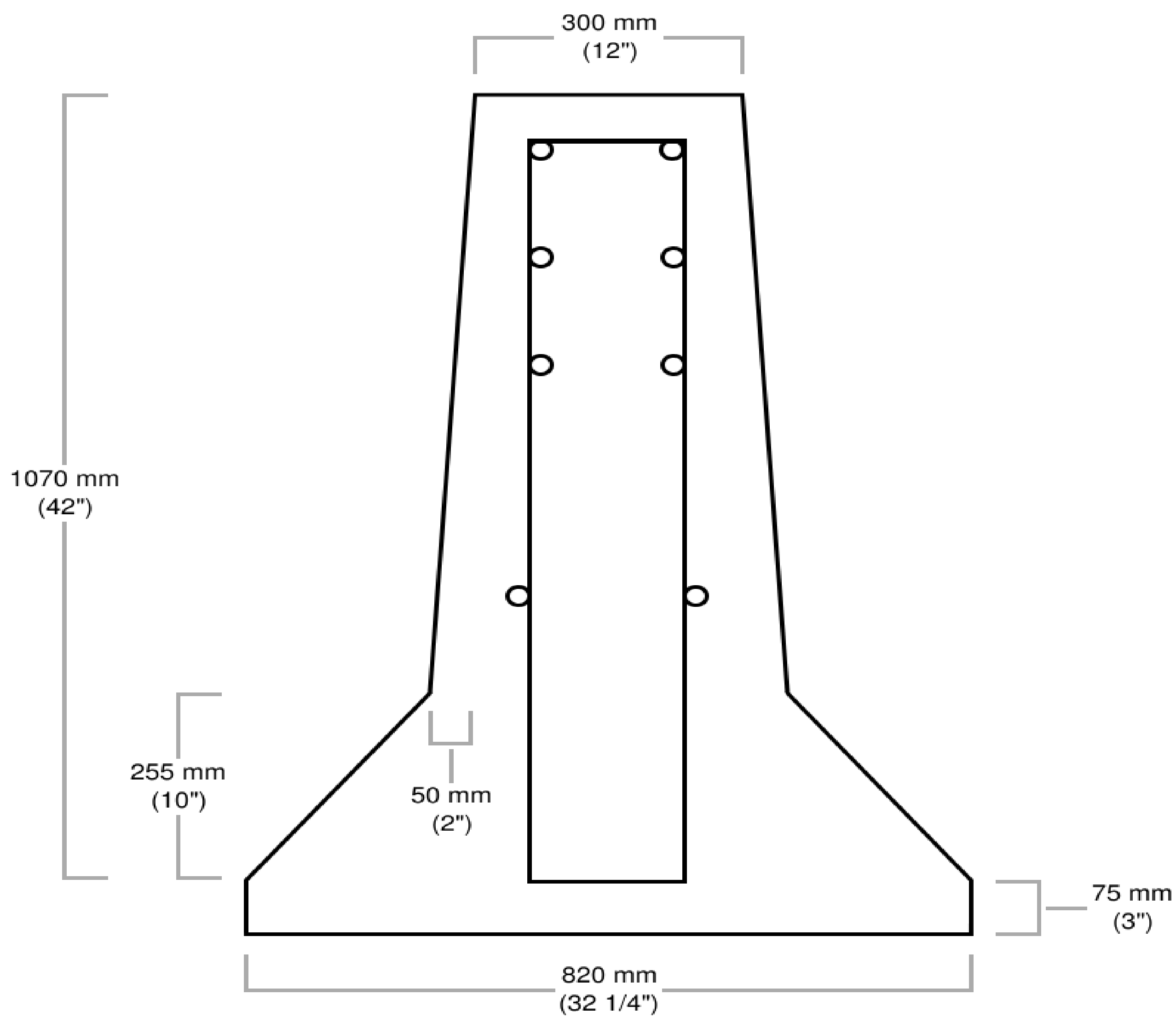
Rigid Barriers

- 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

System	Test Level	FHWA Acceptance Letter
RIGID SYSTEMS (Concrete and Masonry)		
Stone Masonry Wall/Precast Masonry Wall	3	B-64-D
New Jersey Safety-Shape Barrier		
• 810 mm [32 in.] tall	4	B-64
• 1070 mm [42 in.] tall	5	B-64
F–Shape Barrier		
• 810 mm [32 in.]	4	B-64
• 1070 mm [42 in.]	5	B-64
Vertical Concrete Barrier		
• 810 mm [32 in.]	4	B-64
• 1070 mm [42 in.]	5	B-64
Single Slope Barrier		
• 810 mm [32 in.]	4	B-17, B-45
• 1070 mm [42 in.]	5	Note 1
Ontario Tall Wall Median Barrier	5	B-19

Typical Section of Jersey Barrier



Selection Criteria of Barriers

1. <u>Performance:</u> the barrier has to contain and redirect the design vehicle
2. <u>Deflection:</u> should not exceed the distance of deflection available
3. <u>Site Conditions</u>: side slope and distance from the roadway
4. <u>Compatibility:</u> Compatible with terminal and able to transition to other systems (example: bridge raillings)
5. <u>Cost:</u> 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 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.

Design of Barriers

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

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

Flare Rate

- 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

Design Speed		Flare Rate for Barrier Inside Shy Line	Flare Rate for Barrier at or Beyond Shy Line	
km/h	[mph]		A	B
110	[70]	30:1	20:1	15:1
100	[60]	26:1	18:1	14:1
90	[55]	24:1	16:1	12:1
80	[50]	21:1	14:1	11:1
70	[45]	18:1	12:1	10:1
60	[40]	16:1	10:1	8:1
50	[30]	13:1	8:1	7:1

Notes:

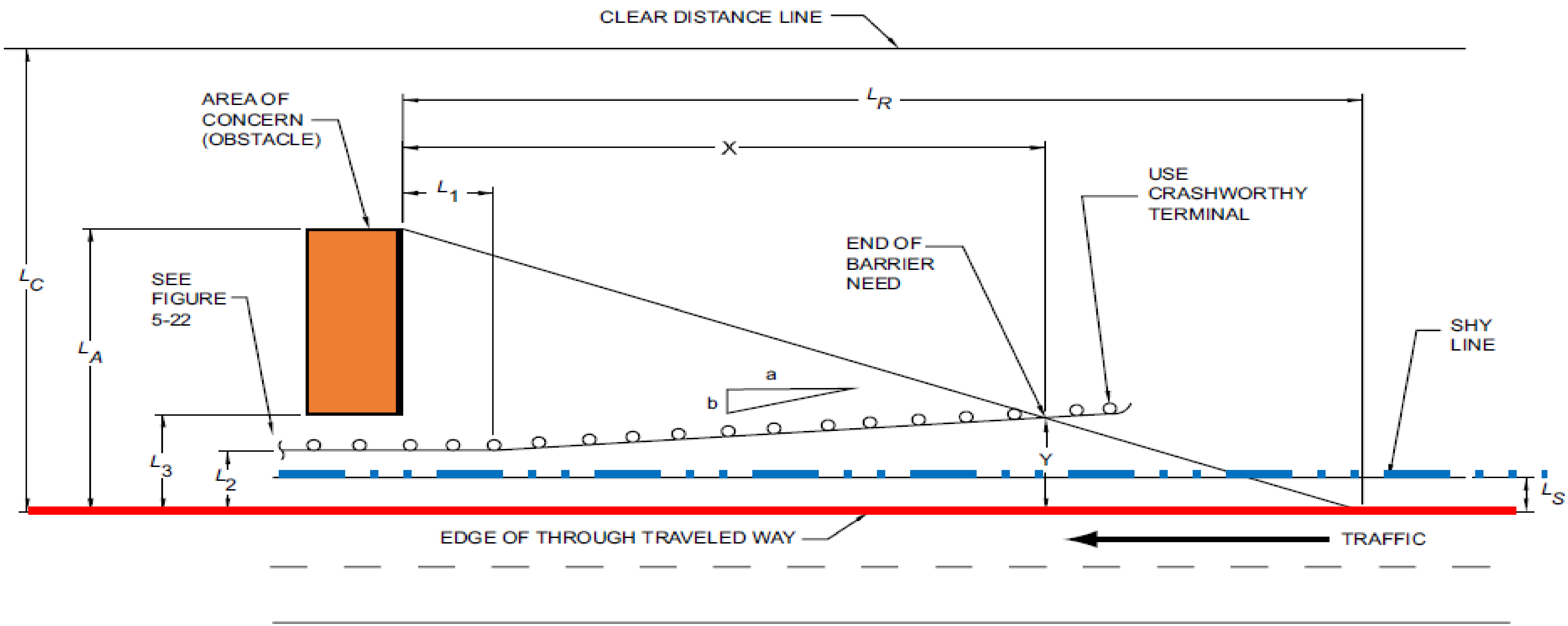
A = Suggested maximum flare rate for rigid barrier system.

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



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 5-10(b). Suggested Runout Lengths for Barrier Design (U.S. Customary Units)

Design Speed (mph)	Runout Length (L_R) Given Traffic Volume (ADT) (ft)			
	Over 10,000 veh/day	5,000 to 10,000 veh/day	1,000 to 5,000 veh/day	Under 1,000 veh/day
80	470	430	380	330
70	360	330	290	250
60	300	250	210	200
50	230	190	160	150
40	160	130	110	100
30	110	90	80	70

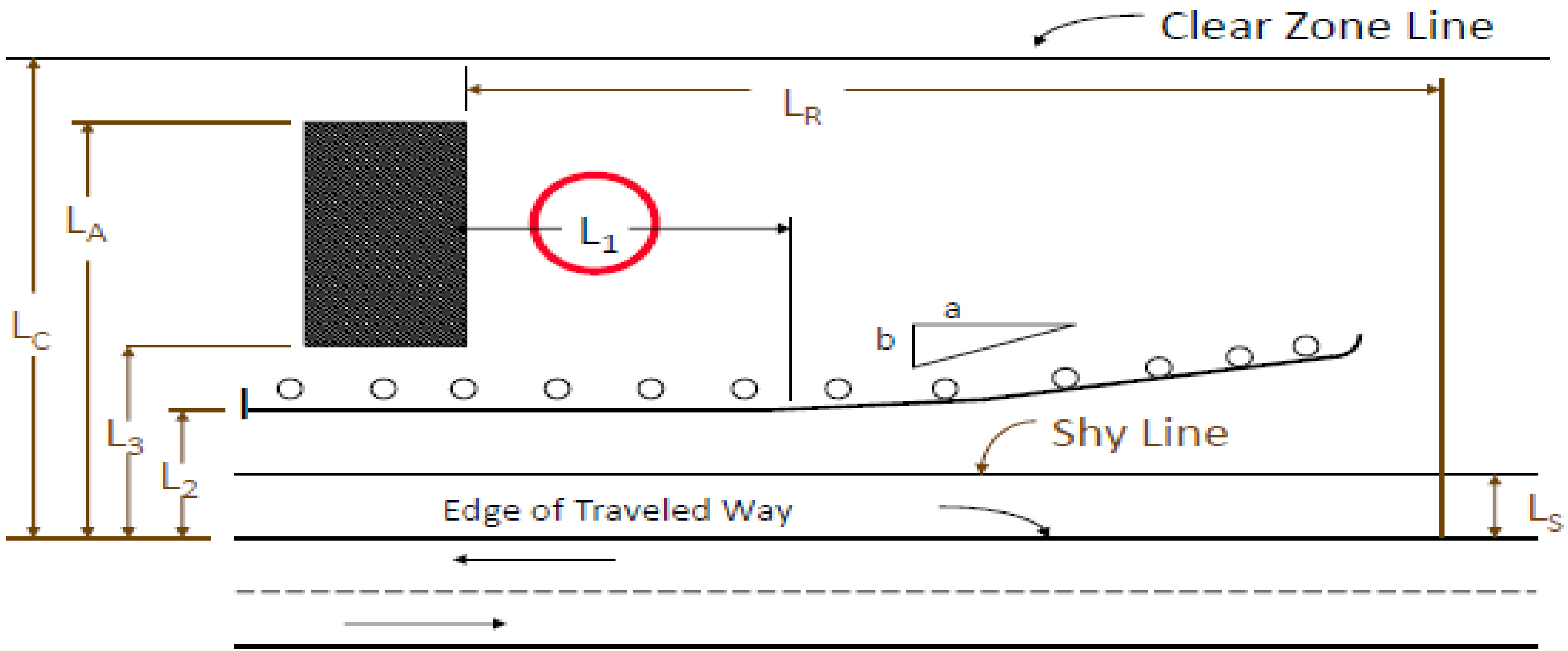
Shy-Line Offset, L_s

- 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

Design Speed		Shy-Line Offset (L_S)	
km/h	[mph]	m	[ft]
130	[80]	3.7	[12]
120	[75]	3.2	[10]
110	[70]	2.8	[9]
100	[60]	2.4	[8]
90	[55]	2.2	[7]
80	[50]	2.0	[6.5]
70	[45]	1.7	[6]
60	[40]	1.4	[5]
50	[30]	1.1	[4]

Design Factors: L_1



If a semi-rigid railing is connected to a rigid barrier, the tangent length should be at least as long as the transition section to reduce the possibility of pocketing at the transition and to increase the likelihood of a smooth redirection if the guardrail is struck immediately adjacent to the rigid barrier.

Transition Length

- It is necessary to provide continuity of protection when two different types of barriers are joined (semi-rigid and rigid example), the two must be tied, or when a roadside barrier is attached to a rigid object (i.e., concrete barrier or bridge railings).
- The transition length should be such that significant changes in the lateral strength not occur in a short distance.
- The transition length should be about 12 times the difference between the dynamic deflection barriers.

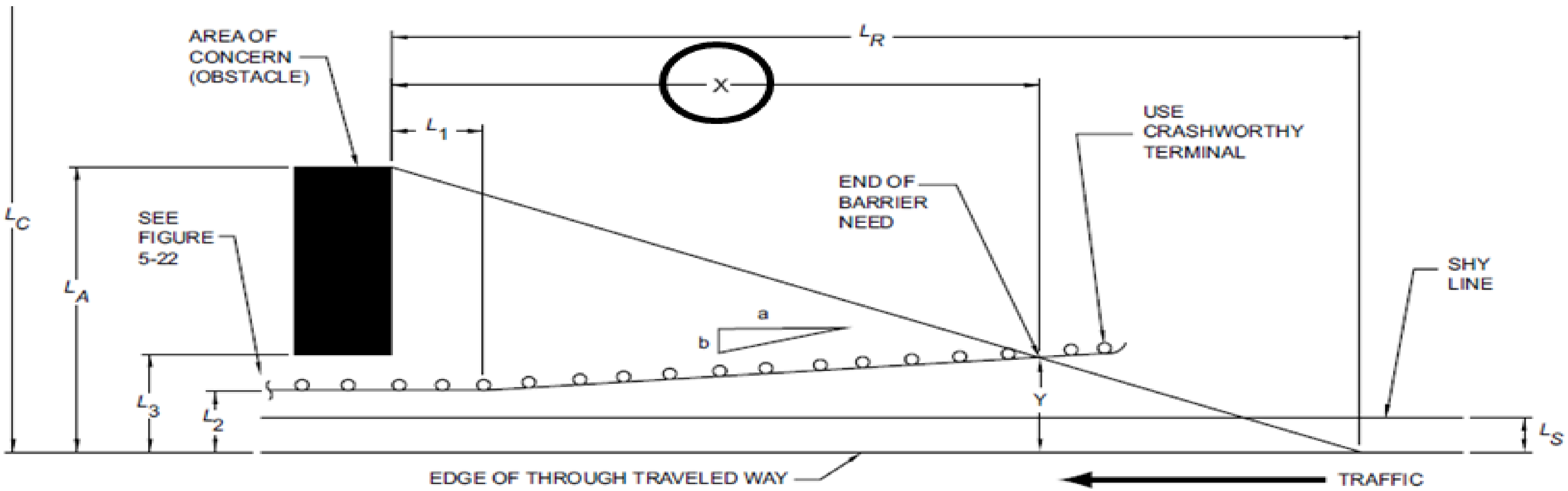
Required Length of Need Before the Area of Concern

With Flare Rate

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

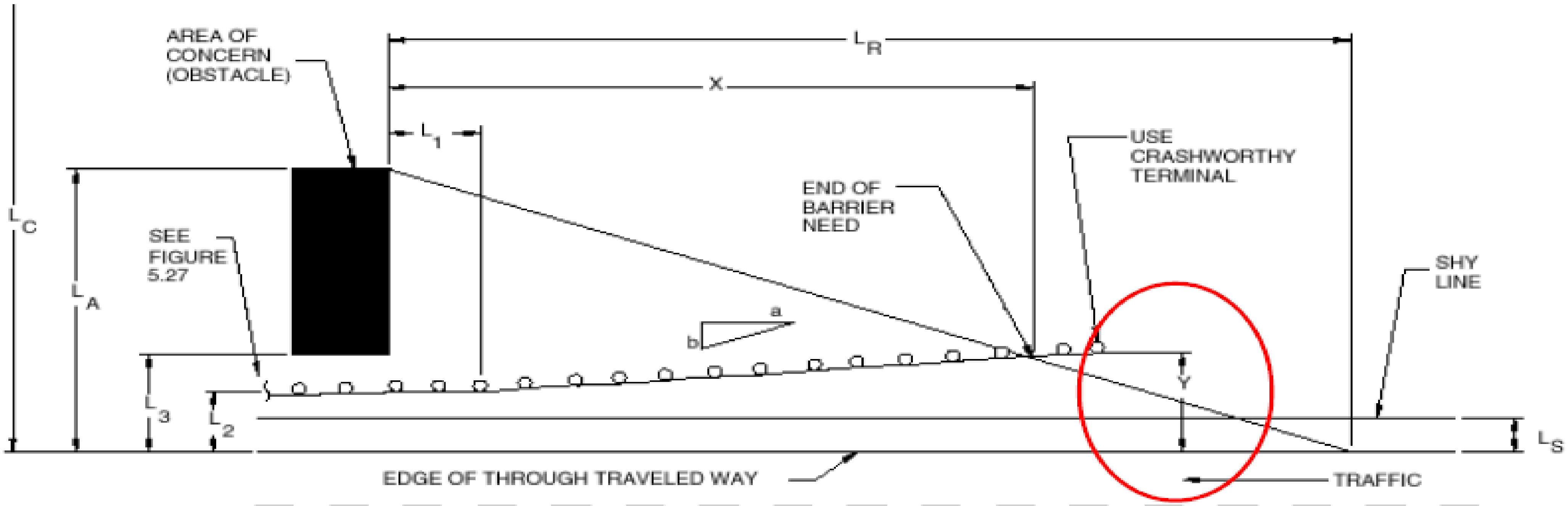
Without Flare Rate

$$X = \frac{L_A - L_2}{(L_A)/(L_R)}$$



Lateral Offset Y

$$Y = L_A - \frac{L_A}{L_R} X$$



The lateral offset (Y): Distance from the edge of the traveled way to the beginning of the length-of-need

Example

- Design the roadside semi-rigid barrier installation for a bridge approach

  Given:

  ADT = 6,200 vpd

  Speed = 70 mph

  Embankment slopes = 1V:6H (right);

  Shoulder = 10 ft (right);

  L_1 (Assumed) = 43.75 ft

Example (cont.)

1. Clear Zone Distance L_C (RDG Table 3.1)
2. Lateral Area of Concern L_A
3. Suggested Runout Length L_R (RDG Table 5.10)
4. Tangent Length from the Area of Concern L_1
5. Shy Line L_S (RDG Table 5.5)
6. Lateral Offset L_2
7. Flare rate (RDG Table 5.7)
8. Length of need X
9. Lateral Offset Y

[U.S. Customary Units]

DESIGN SPEED	DESIGN ADT	FORESLOPES			BACKSLOPES		
		1V:6H of flatter	1V:5H TO 1V:4H	1V:3H	1V:3H	1V:5H TO 1V:4H	1V:6H or Flatter
40 mph or less	UNDER 750	7 – 10	7 – 10	**	7 – 10	7 – 10	7 – 10
	750 – 1500	10 – 12	12 – 14	**	10 – 12	10 – 12	10 – 12
	1500 – 6000	12 – 14	14 – 16	**	12 – 14	12 – 14	12 – 14
	OVER 6000	14 – 16	16 – 18	**	14 – 16	14 – 16	14 – 16
45–50 mph	UNDER 750	10 – 12	12 – 14	**	8 – 10	8 – 10	10 – 12
	750 – 1500	12 – 14	16 – 20	**	10 – 12	12 – 14	14 – 16
	1500 – 6000	16 – 18	20 – 26	**	12 – 14	14 – 16	16 – 18
	OVER 6000	18 – 20	24 – 28	**	14 – 16	18 – 20	20 – 22
55 mph	UNDER 750	12 – 14	14 – 18	**	8 – 10	10 – 12	10 – 12
	750 – 1500	16 – 18	20 – 24	**	10 – 12	14 – 16	16 – 18
	1500 – 6000	20 – 22	24 – 30	**	14 – 16	16 – 18	20 – 22
	OVER 6000	22 – 24	26 – 32 *	**	16 – 18	20 – 22	22 – 24
60 mph	UNDER 750	16 – 18	20 – 24	**	10 – 12	12 – 14	14 – 16
	750 – 1500	20 – 24	26 – 32 *	**	12 – 14	16 – 18	20 – 22
	1500 – 6000	26 – 30	32 – 40 *	**	14 – 18	18 – 22	24 – 26
	OVER 6000	30 – 32 *	36 – 44 *	**	20 – 22	24 – 26	26 – 28
65–70 mph	UNDER 750	18 – 20	20 – 26	**	10 – 12	14 – 16	14 – 16
	750 – 1500	24 – 26	28 – 36 *	**	12 – 16	18 – 20	20 – 22
	1500 – 6000	28 – 32 *	34 – 42 *	**	16 – 20	22 – 24	26 – 28
	OVER 6000	30 – 34 *	38 – 46 *	**	22 – 24	26 – 30	28 – 30

* Where a site specific investigation indicates a high probability of continuing crashes, or such occurrences are indicated by crash history, the designer may provide clear-zone distances greater than the clear-zone shown in Table 3.1. Clear zones may be limited to 30 ft for practicality and to provide a consistent roadway template if previous experience with similar projects or designs indicates satisfactory performance.

1. Clear Zone Distance Lc = 30 ft = Lateral area of concern L_A

Suggested Runout Lengths L_R (RDG Table 5.10)

Design Speed (mph)	Runout Length (L_R) Given Traffic Volume (ADT) (ft)			
	Over 10,000 veh/day	5,000 to 10,000 veh/day	1,000 to 5,000 veh/day	Under 1,000 veh/day
80	470	430	380	330
70	360	330	290	250
60	300	250	210	200
50	230	190	160	150
40	160	130	110	100
30	110	90	80	70

Shy Line Offset L_S (Table 5.7)

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

Design Speed		Shy-Line Offset (L_S)	
km/h	[mph]	m	[ft]
130	[80]	3.7	[12]
120	[75]	3.2	[10]
110	[70]	2.8	[9]
100	[60]	2.4	[8]
90	[55]	2.2	[7]
80	[50]	2.0	[6.5]
70	[45]	1.7	[6]
60	[40]	1.4	[5]
50	[30]	1.1	[4]

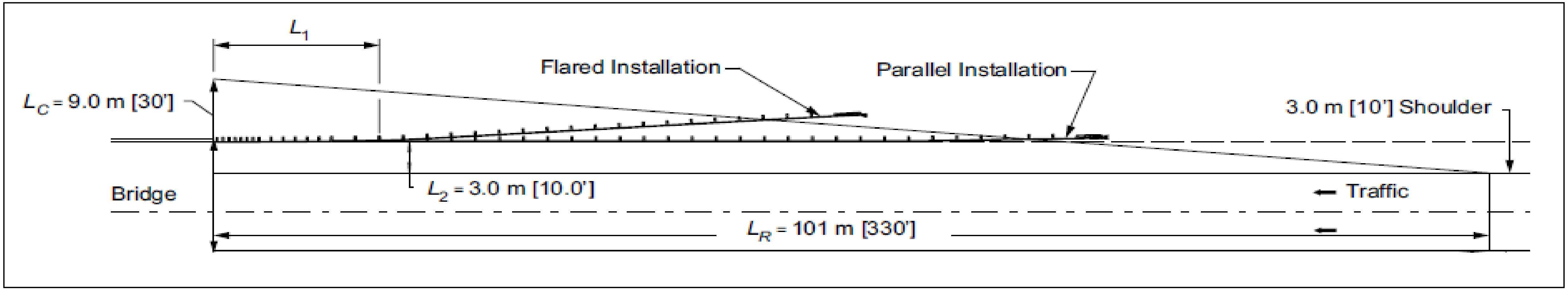
Suggested Flare Rates (Table 5.9)

Design Speed km/h	Design Speed [mph]	Flare Rate for Barrier Inside Shy Line	Flare Rate for Barrier at or Beyond Shy Line A	Flare Rate for Barrier at or Beyond Shy Line B
110	[70]	30:1	20:1	15:1
100	[60]	26:1	18:1	14:1
90	[55]	24:1	16:1	12:1
80	[50]	21:1	14:1	11:1
70	[45]	18:1	12:1	10:1
60	[40]	16:1	10:1	8:1
50	[30]	13:1	8:1	7:1

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.

Example Barrier Design for Bridge Approach

- Clear Zone Distance L_C = 30 ft (RDG Table 3.1)
- Lateral Area of Concern $L_A = L_C$ = 30 ft (selected)
- Suggested Runout Length L_R = 330 ft (RDG Table 5.10)
- Transition L_1 = 43.75 ft
- Barrier offset, L_2 = 10 ft (shoulder = 10 ft)
- Shy Line L_S= 9.0 ft (RDG Table 5.5)



Length Needed

With Flare Rate

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

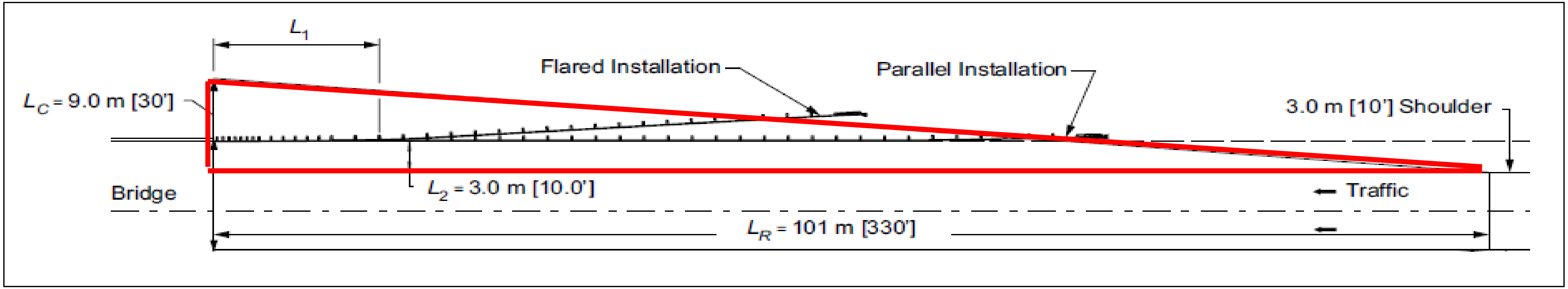
$$X = \frac{30 + \left(\frac{1}{15}\right)43.75 - 10}{\left(\frac{1}{15}\right) + \left(\frac{30}{330}\right)} = \frac{22.92}{0.158} = 145.4\ ft$$

Lateral Offset Y

$$Y = L_A - \frac{L_A}{L_R} X$$

$$Y = 30 - \frac{30}{330} 145.54 = 16.8\ ft$$

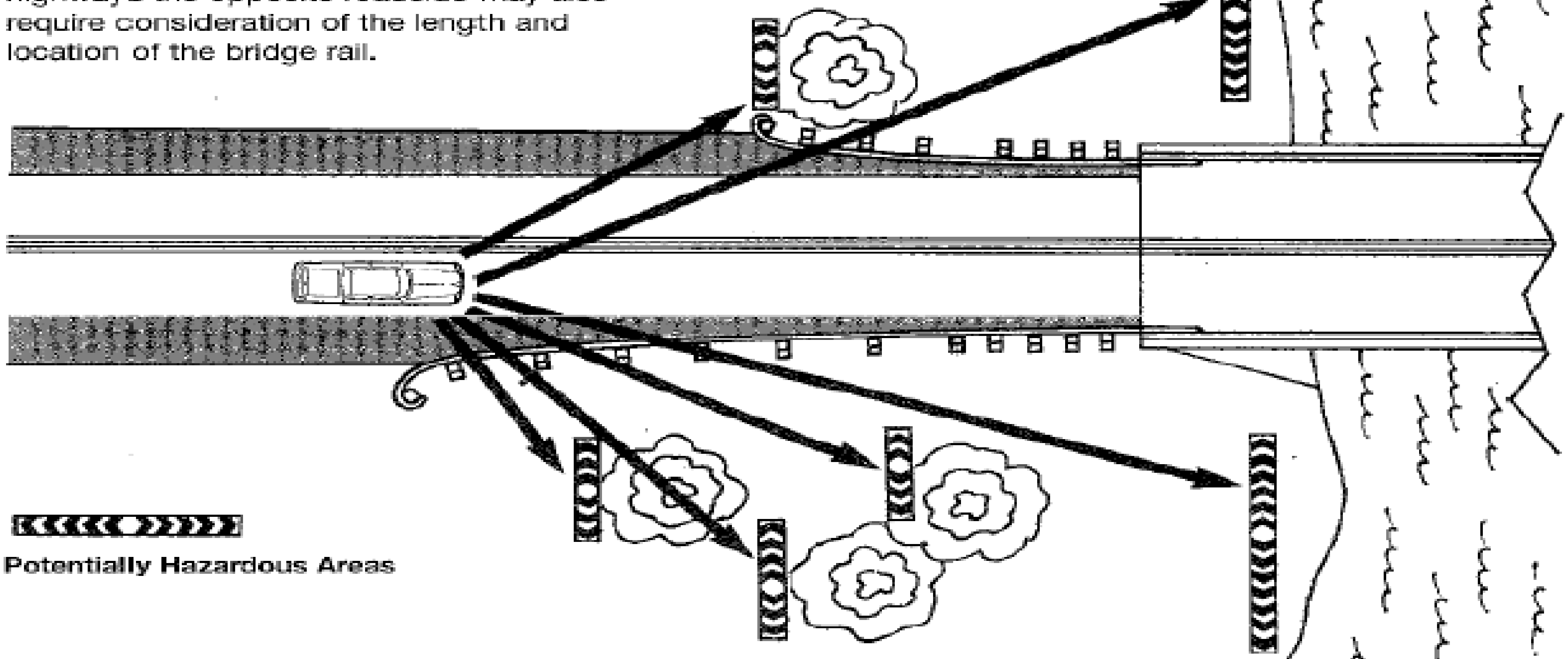
Discussion



- For the right-shoulder installation, the designer can measure 330 ft back from the bridge rail end and 30 ft laterally from the same point.
- The hypotenuse of this triangle approximates a vehicle's runout path. To shield the bridge end and the river to the edge of the clear zone, the barrier installation should intersect this line. Based on the variables selected, a barrier length of 145.4 ft is needed.
- If a parallel installation was utilized, the length of need would be 220 ft.

Approach Guardrail Length of Need

Approach guardrail must be of sufficient length and located correctly to shield the errant motorist from entering into any of the hazardous area at a bridge approach. Remember: on undivided highways the opposite roadside may also require consideration of the length and location of the bridge rail.



Information on determining where to locate the bridge approach guardrails and how long they should be is provided in the "Roadside Design Guide."

Ref. FHWA Improving Highway Safety at Bridges on Local Roads and Streets

Review

- 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.

Review

QUESTIONS?

Fabiola Buitrago G. Ph.D.

PUERTO RICO TRANSPORTATION
TECHNOLOGY TRANSFER CENTER

TERMINAL BARRIERS AND CRASH CUSHIONS

Fabiola Buitrago G. Ph.D.

Before

"Fish Tail" = No treatment

Source: www.crashforensics.com

The Problem

Terminals




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

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

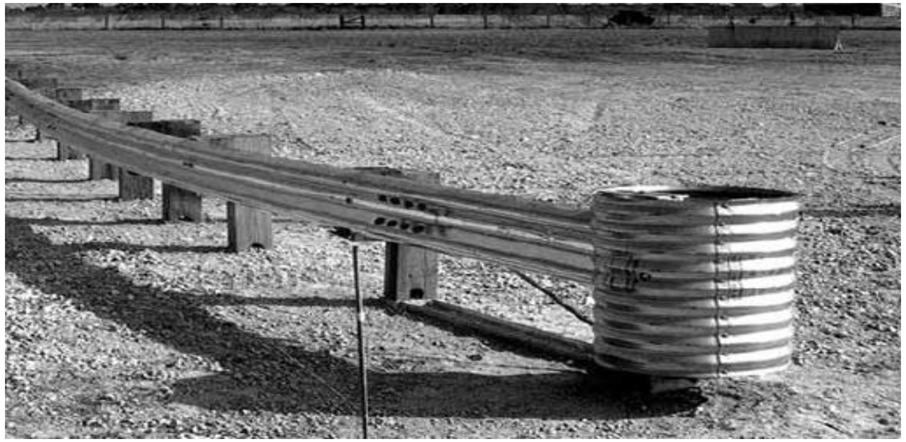
Three-Strand Cable Terminal

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

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

CASS™ Cable Terminal (CCT)

Types of Terminals



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

Crash Cushion Attenuating Terminal

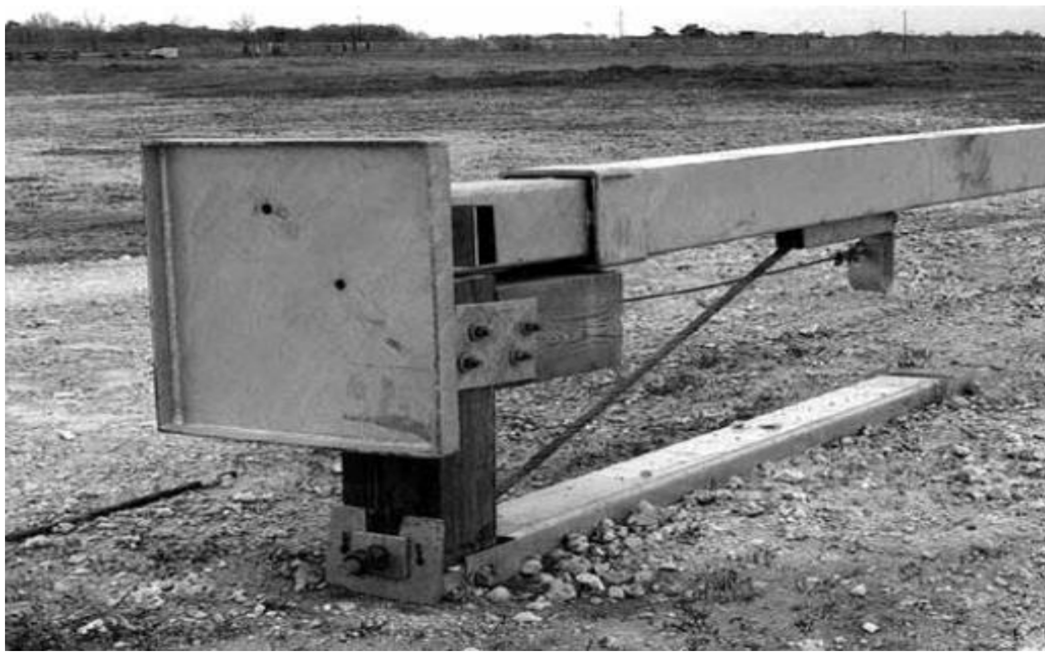
Flared Energy-Absorbing Terminal

Terminals for Cable Barrier Systems

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

Types of Terminals

Terminal	NCHRP Report 350 Test Level	FHWA Acceptance Letter	System Designation	Manufacturer	Reference Section
Wyoming Box-Beam End Terminal (WY-BET™)	3	CC-60 CC-60A	SEB03 SEB04 Median	Trinity Highway Products, LLC	8.3.7.1
Bursting Energy Absorbing Terminal (BEAT™) and (BEAT-MT™)	3	CC-69 CC-69A	SEB05 SEB06 Median	Road Systems, Inc.	8.3.7.2



Wyoming Box-Beam End Terminal (WY-BET™)

Performance Characteristics of the Terminal

- Non-Energy-Absorbing Terminals
- Energy-Absorbing

Energy Absorbing Terminals

Have the ability to stop head-on vehicles in relatively short distances, in about 50 feet.

Non-Energy Absorbing Terminals

- Allow an un-braked vehicle to travel over 250 feet behind and parallel to the rail.
- Vehicle speed is not significantly reduced.

Flared versus Tangent Terminals

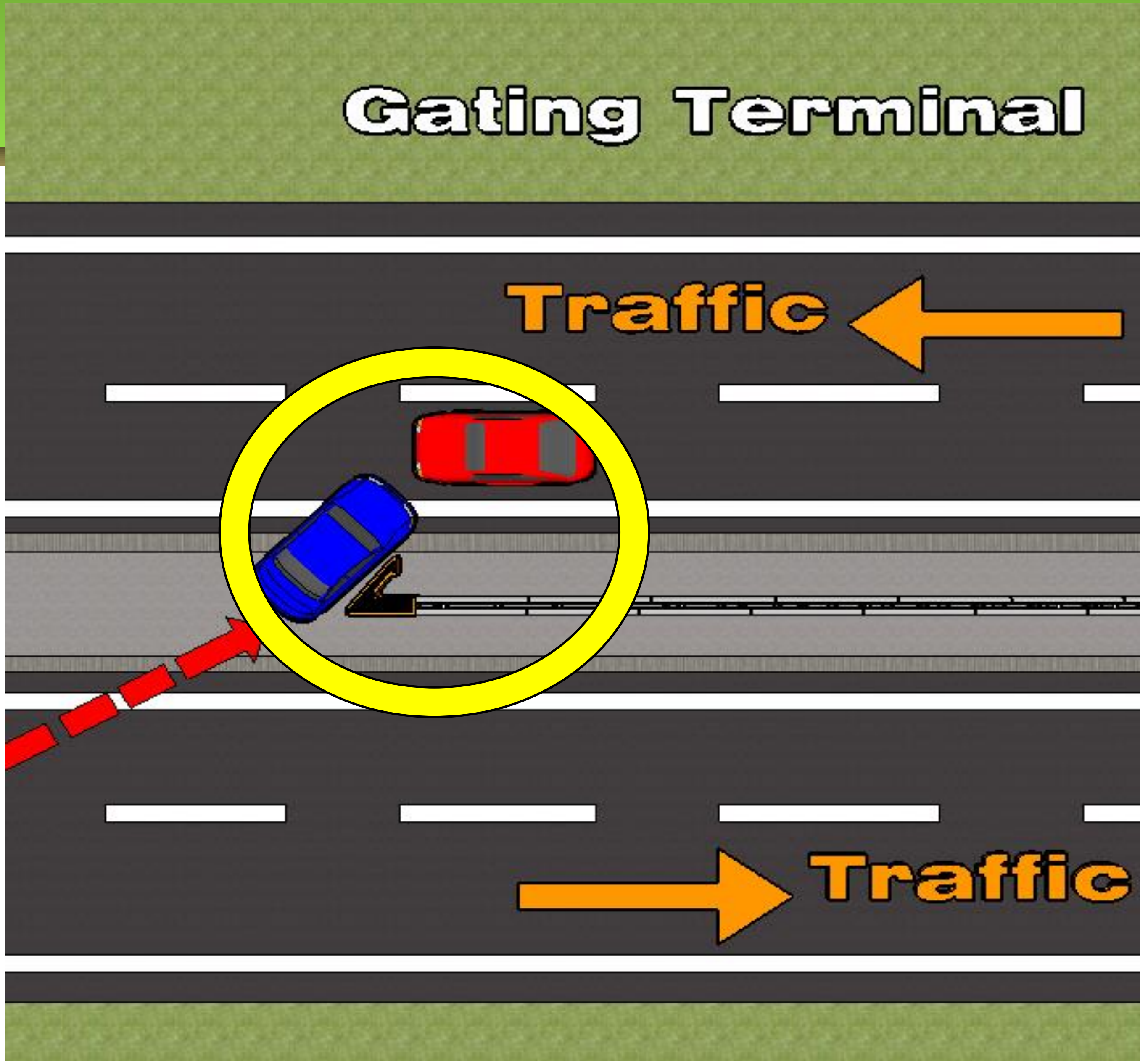
- Non- flared terminals may be installed with a 1-ft to 2-ft offset from the line of barrier proper (over the entire terminal length) to minimize nuisance hits

- Flared terminals generally require 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

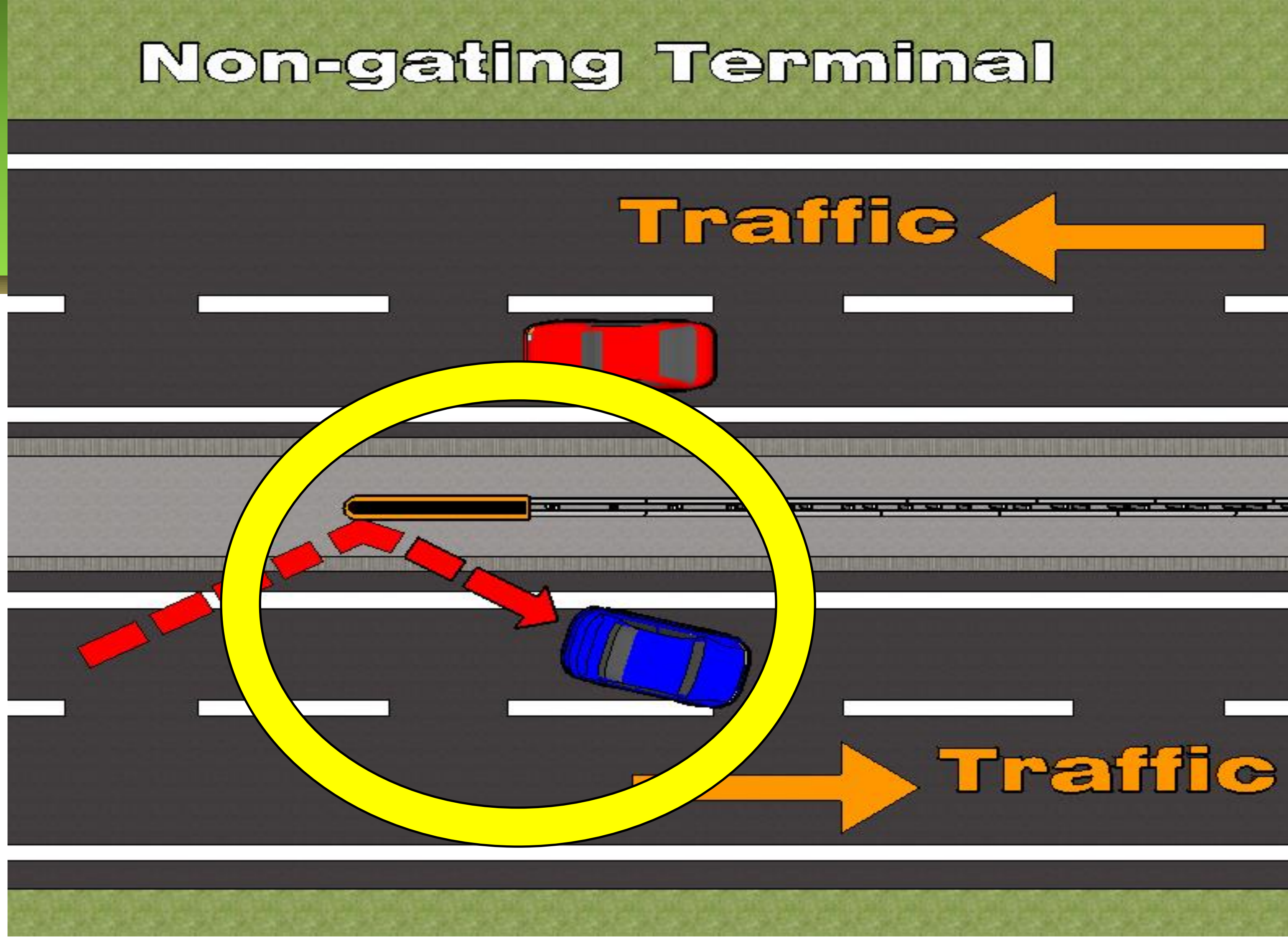
- Gating: terminals that are designed to break away, pivot or hinge, and that allow a vehicle to pass through when impacted at an angle to the end, or at a point upstream of the beginning length - of-need of the safety barrier system.

- 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.



- If an errant vehicle can pass through a terminal beyond the nose and into an area behind the system it is classed as a “gating” terminal.

- These terminals are not suitable for use where there is a high potential that an errant vehicle may travel through the end treatment and into a hazard or into opposing traffic lanes.



- Non-Gating terminals do not allow vehicles to pass through the leading section of the terminal.
- They either capture vehicles when they are impacted directly on the end, or redirect them along the travelled way when they are impacted at any point on the side of the barrier.

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

Departamento de Transportación y Obras Públicas
Autoridad de Carreteras y Transportación
Directoría de Infraestructura

DIRECTRIZ DE DISEÑO 408
Uso de Terminales Propietarios en el "National Highway System"

La Administración Federal de Carreteras (FHWA, por sus siglas en inglés) y el Departamento de Transportación y Obras Públicas (DTOP) a través de la Autoridad de Carreteras y Transportación han decidido utilizar tres (3) terminales propietarios para barreras de seguridad en el Sistema Nacional de Carreteras (NHS por sus siglas en inglés).

Los sistemas y su aplicación son como se describen a continuación:

1. **FLEAT™ 350** (Flared Energy Absorbing Terminal) para instalación tipo "Flared" dentro de la Zona Libre (según definida en el "Roadside Design Guide").

2. **SKT™ 350** (Sequential Kinking Terminal) para instalación tipo tangente dentro de la zona libre (según definida en el "Roadside Design Guide").

3. **QuadGuard® Elite™** a usarse como "Crash Cushion" en condiciones de tráfico en ambos lados, como es en una mediana, en un "Gore Area" o en una Plaza de Peaje entre otras.

La instalación de estos sistemas de terminales propietarios está limitada a condiciones en el NHS donde no es posible:

1. Remover el obstáculo
2. Rediseñar el obstáculo para que sea seguro
3. Relocalizar el obstáculo
4. Reducir la severidad de los impactos utilizando sistemas "breakaway" (quebradizos)
5. Hacer "flattening" (allanamiento) en las pendientes para eliminar la necesidad de barreras
6. Instalar atenuadores de impacto
7. Instalar bermas en tierra
8. Alcanzar la distancia de zona libre por lo tanto no se puede instalar el Terminal tipo MB según definido en los Planos Modelo o no se puede relocalizar el obstáculo fuera de esta zona.

El diseñador seguirá todos los principios de las Directrices de Diseño así como los contenidos en la versión más reciente del "Roadside Design Guide".

Esta directriz tiene vigencia inmediatamente.

José E. Hernández Borges
Director Ejecutivo Auxiliar para
Infraestructura

16 mar 05
Fecha

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

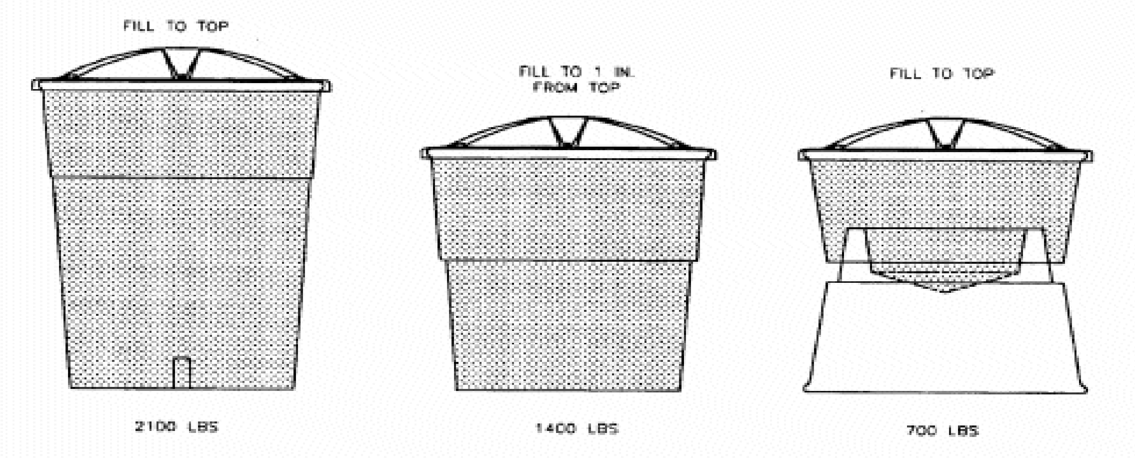
www.ct.gov

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

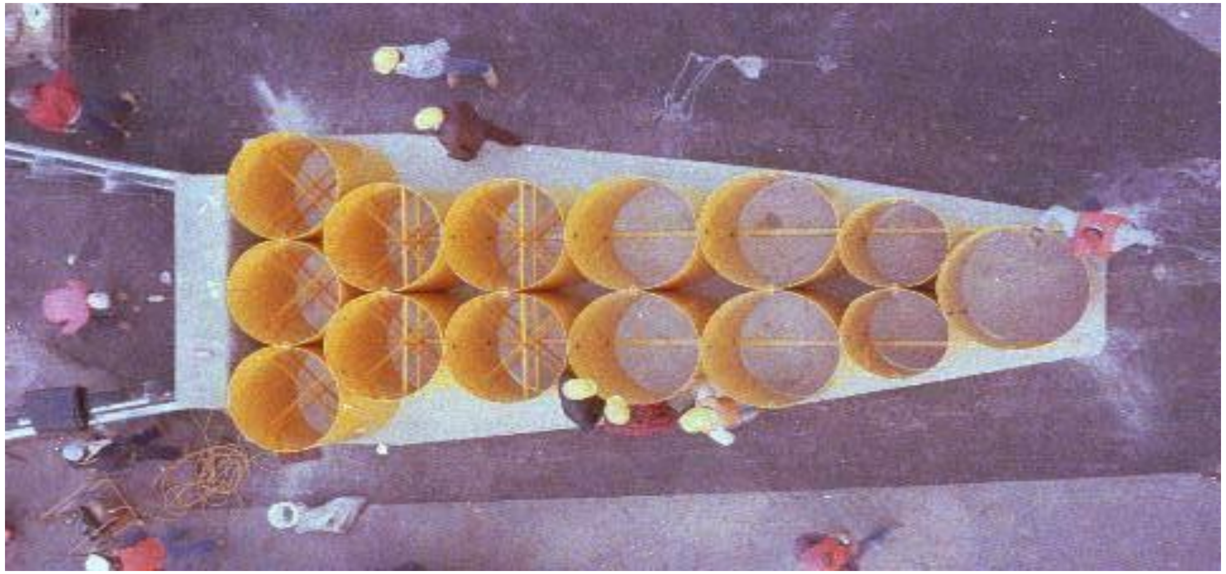
- Momentum:
  - Quantity expressing the motion of a body and its resistance to reduce the velocity.
  - It is the product of its mass and its velocity.

- 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.

Crash Cushion

- Impact Attenuators: device used to reduce the damage done to structures, vehicles and drivers during a collision.

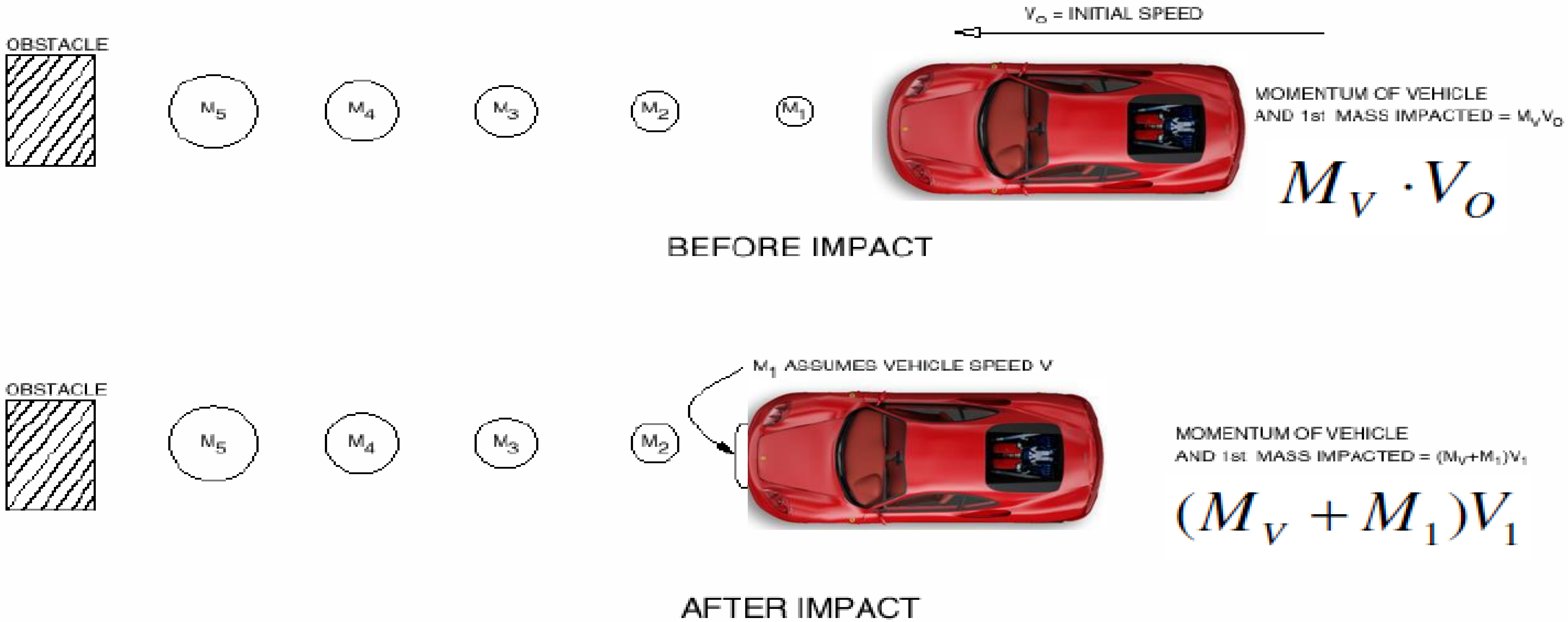
- "Bulldozer effect": Each barrel has a fraction of velocity reduction every time is impacted.



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

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

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

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)

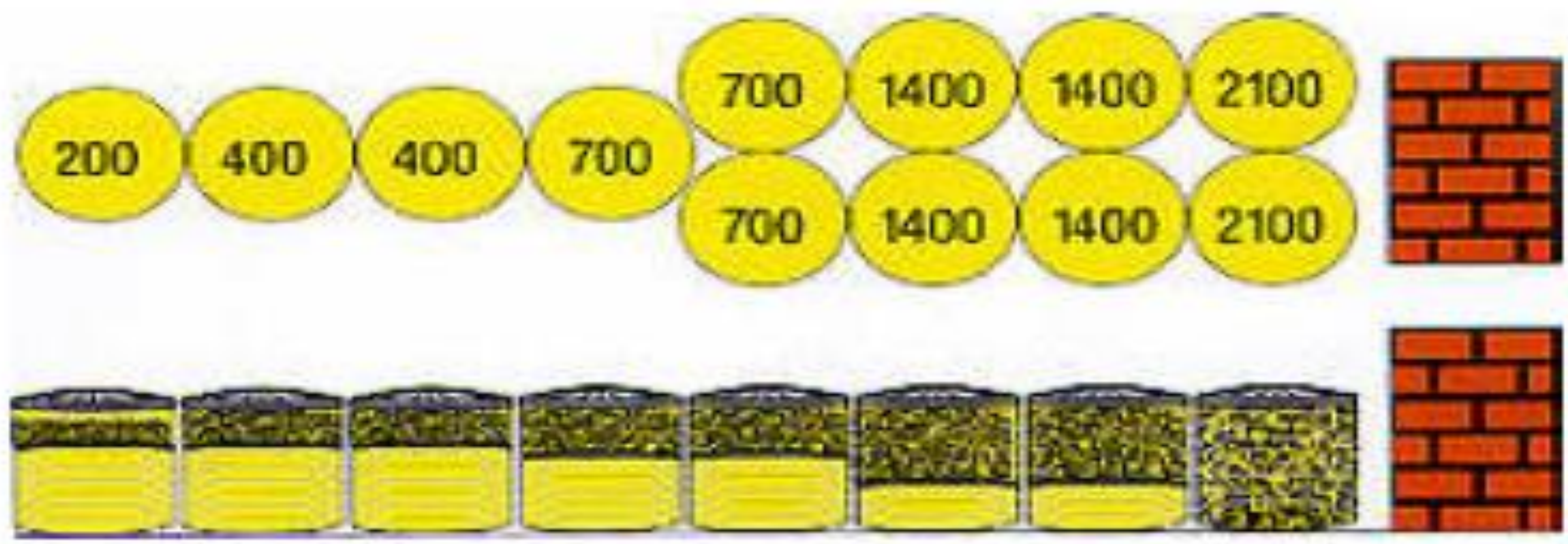
t = time of event

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.

Sand Barrel Systems

Terminal	Test Level	FHWA Acceptance Letter	Manufacturer
Fitch Universal Barrel	3	CC-28	Energy Absorption Systems, Inc.
ENERGITE III	3	CC-29	Energy Absorption Systems, Inc.
Big Sandy	3	CC-52, 52A and 52B	TrafFix Devices, Inc.
CrashGard	3	CC-97	Plastic Safety Systems, Inc.

QUESTIONS?

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WORK ZONES

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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

W21-1a

W20-1

W20-7a

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 traffic lanes and work area

Concrete barrier separating opposing traffic

Quickchange® Barrier System

Type of Barrier

- Flexible barriers (channelizing devices)
  - Provide nominal protection for workers
  - Flexible and deformable, do not cause damage if struck

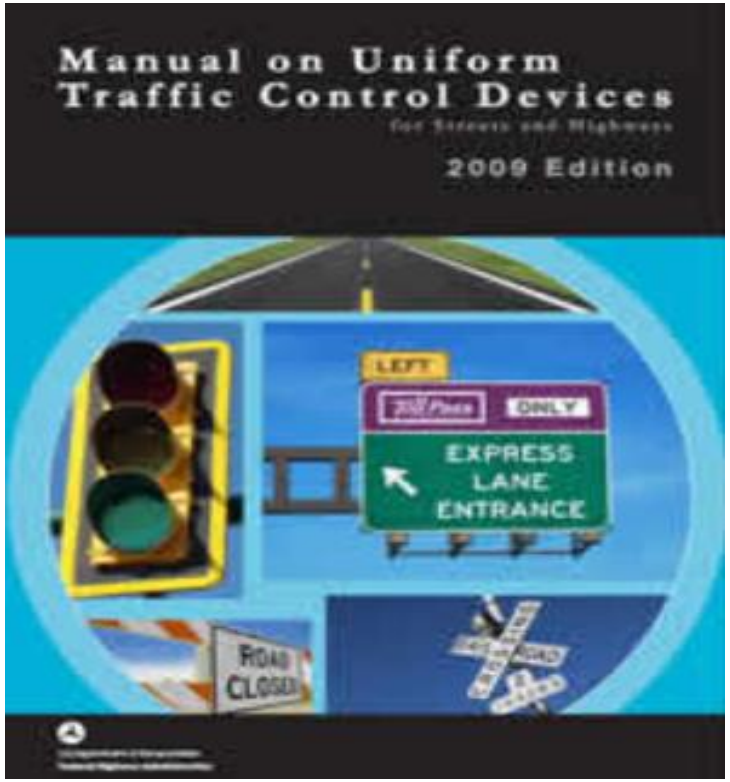
Flexible barrier separating traffic lanes and work area

Concrete barriers to separate work area

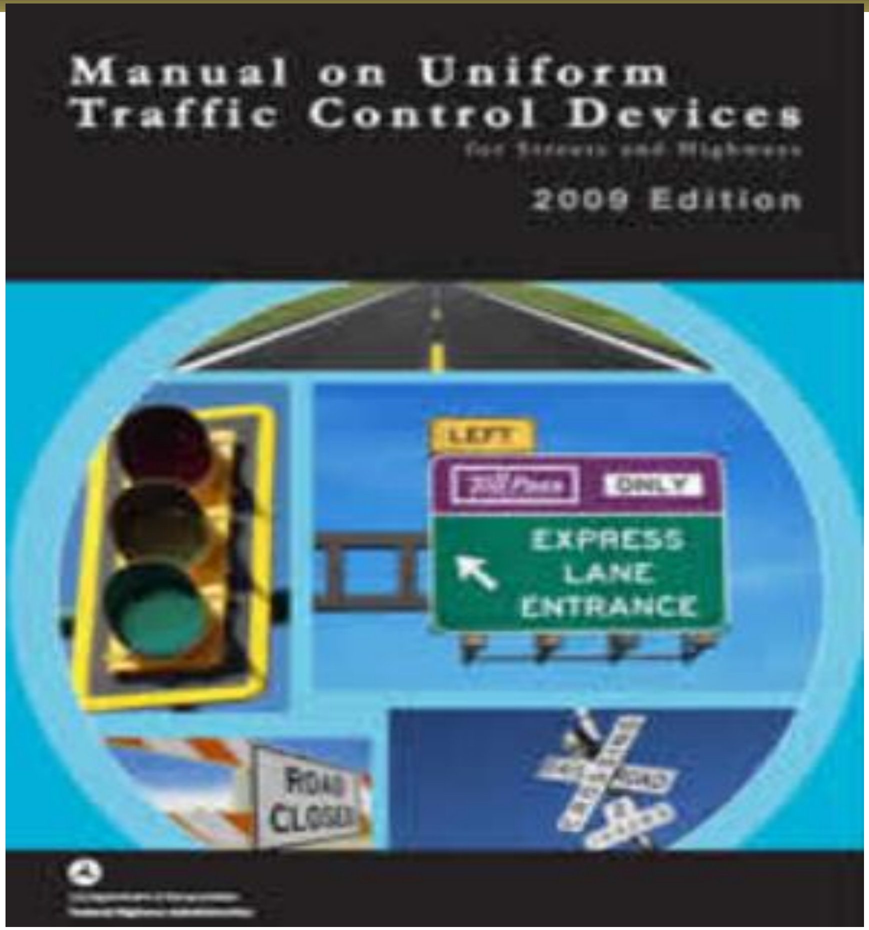
Channelizing devices for delineation

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



MUTCD- Part 6:
Temporary Traffic Control (TTC)



Primary function of Temporary Traffic Control:

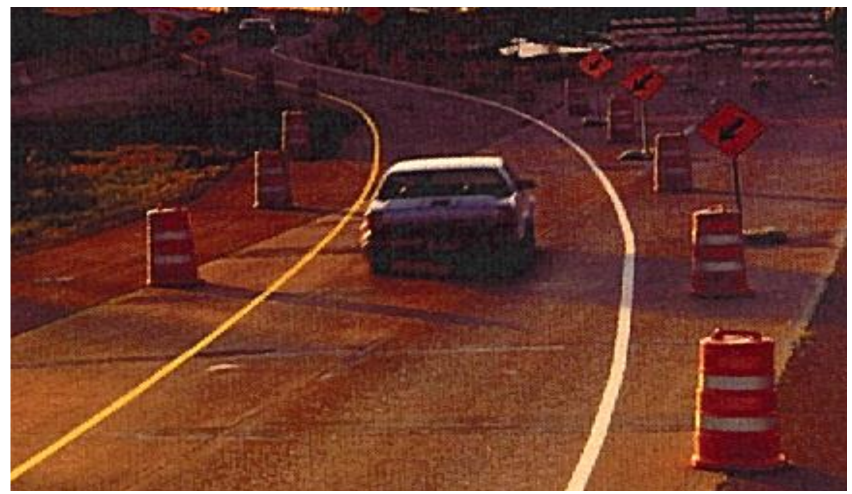
"To provide for reasonably safe and efficient movement of road users through or around temporary traffic control zones <u>while reasonably protecting workers, responders to traffic incidents, and equipment</u>"

<u>Estandard</u>: Enunciado mandatorio o que prohibe una práctica (**<u>SHALL or MUST</u>**)
<u>Guidance</u>: Enunciado que recomienda una práctica (**<u>SHOULD</u>**)
<u>Option</u>: No implica recomendación o requerimiento (**<u>MAY</u>**)

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

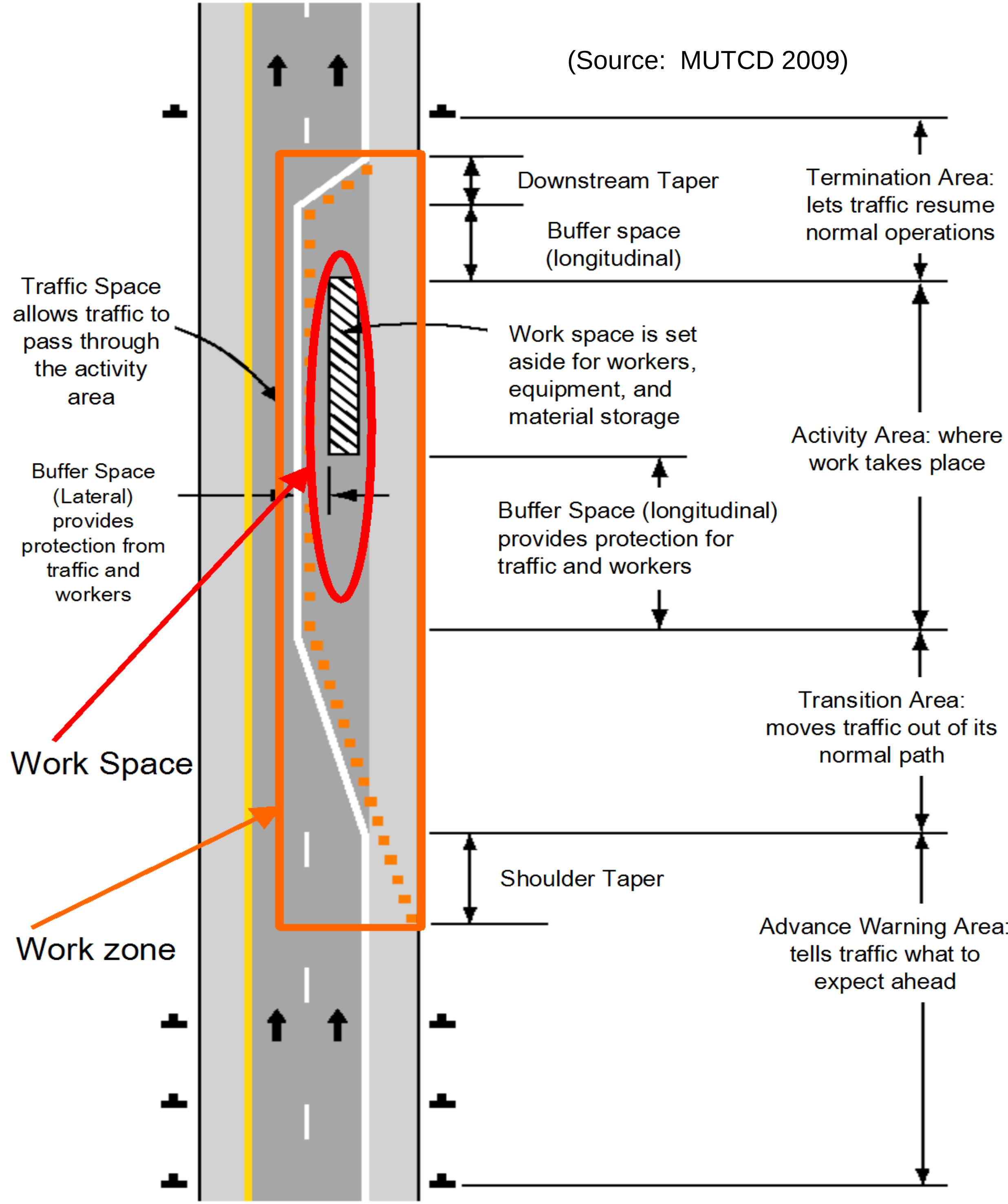
TTC Through Traffic Incident Management Areas

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



QUESTIONS?

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Thank you!