Chapter 5: Positive Protection (Temporary Barriers)

5.1 Introduction

The primary purpose of a temporary barrier is to prevent a vehicle from striking an obstacle or terrain feature that is considered more hazardous than the barrier itself in the work zone. Typical applications include: preventing traffic from entering work areas, providing positive protection for workers, separating two-way traffic, protecting construction and other exposed objects, and separating pedestrians from vehicular traffic.

5.2 Definitions & Abbreviations

Temporary Barrier – A device used to prevent vehicular access into construction or maintenance work zones and to redirect an impacting vehicle so as to minimize damage to the vehicle and injury to the occupants while providing worker protection.

ADT – Average Daily Traffic

Anchored PCB – PCB designed to accommodate mounting bolts to secure the barrier to the roadway.

Area of Concern – An object or roadside condition that may warrant safety treatment.

Clear Zone – The total roadside border area, starting at the edge of the traveled way, available for safe use by errant vehicles. This area may consist of a shoulder, a recoverable slope, a non-recoverable slope, and/or a clear run-out area. The desired width is dependent upon the traffic volumes and speeds and on the roadside geometry.

Crash Cushion – Device that prevents an errant vehicle from impacting fixed objects by gradually decelerating the vehicle to a safe stop or by redirecting the vehicle away from the obstacle.

Crashworthy – A feature that has been proven acceptable for use under specified conditions either through crash testing or in-service performance.

Deflection – The distance barrier moves (lateral displacement) when impacted.

Drainage PCB – PCB designed with a slot on the bottom to allow for rainwater drainage.

Flare Rate – Rate of diversion of barrier from traveled way, e.g., 12:1.

Impact Angle – The angle at which the vehicle strikes the barrier.

Impact Severity – The force at which the vehicle impacts the barrier.

Length of Need – Total length of a longitudinal barrier needed to shield an Area of Concern.

Longitudinal Barrier – Traffic barrier oriented parallel or nearly parallel to the roadway. Beam guardrail, cable barrier, bridge rail, and concrete barrier are longitudinal barriers.

MSE Wall – A mechanically stabilized earth wall constructed by various methods to hold back a fill section.

NCHRP Report 350 – National Cooperative Highway Research Program (NCHRP) Report 350, "Recommended Procedures for the Safety Performance Evaluation of Highway Features". FHWA policy requires that devices used on the National Highway System must be successfully tested in accordance with the guidelines contained in the report.

NCHRP 350 Test Level 2 and Test Level 3 – NCHRP Report 350 test level 2 (TL-2) and test level (TL-3) require successful tests of a 1,800 lb. car impacting a barrier at an angle of 20 degrees and a 4,400 lb. pickup truck impacting a barrier at an angle of 25 degrees at speeds of 45 mph and 60 mph, respectively.

NCHRP 350 Test Level 4 – NCHRP Report 350 test level 4 (TL-4) requires a successful test of a 17,650 lb. truck impacting a barrier at an angle of 15 degrees at a speed of 50 mph.

Non-Recoverable Slope - is a slope which is considered traversable but on which an errant vehicle will continue to the bottom. Embankment slopes between 1V:3H and 1V:4H may be considered traversable but non-recoverable if they are smooth and free of fixed objects.

Recoverable Slope - is a slope on which a motorist may, to a greater or lesser extent, retain or regain control of a vehicle by slowing or stopping. Slopes flatter than 1V:4H are generally considered recoverable.

Offset – Term used when defining either the lateral distance barrier will be placed from the traveled way or the lateral distance barrier will be placed from the Area of Concern it is protecting.

PCB – Portable Concrete Barrier

QMB – Quickchange Moveable Barrier (Zipper System)

Roadside Design Guide – A document developed by AASHTO that presents a combination of current information and operating practices related to roadside safety.

Runout Length – The theoretical distance required for a vehicle that has left the roadway to come to a stop.

Shy Distance – The distance from the edge of the traveled way beyond which a roadside object will not be perceived as an obstacle by the typical driver to the extent the driver will change the vehicle's placement or speed.

TMA – Truck Mounted Attenuator

Transition – A section of barrier between two different types of barrier or, more commonly, where a roadside barrier is connected to a bridge railing or to a rigid object such as a bridge pier.

Traversable Slope is a slope from which a motorist will be unlikely to steer back to the roadway but may be able to slow and stop safely. Slopes between 1V:3H and 1V:4H generally fall into this category**.**

Traveled Way – The portion of the roadway for the movement of vehicles, exclusive of shoulders.

5.3 Guidelines

INTRODUCTION

Positive protection is defined by Federal Highway Administration (FHWA) as *"devices that contain and/or redirect vehicles and meet the crashworthiness evaluation criteria contained in NCHRP Report 350."* By this definition, positive protection devices should then also prevent intrusion into the work area.

These guidelines address the use of positive protection devices in work zones to supplement the Work Zone Safety and Mobility Policy and comply with the Federal Highway Administration Final Rule Subpart K to CFR Part 630. These guidelines are not intended to be a rigid standard or policy; rather, they are guidance to be used in conjunction with engineering judgment. These guidelines are not a stand-alone document on work zone application of positive protection and must be used in conjunction with other traffic control standards and resources.

EXPOSURE CONTROL MEASURES

Prior to including positive protection in a transportation management plan, careful consideration must be given to alternatives which would avoid or minimize exposure for workers and road users. Alternatives that are often considered include detouring traffic, minimizing exposure time, or maximizing the separation between traffic and workers. A more inclusive list of potential exposure control measures include:

- Removal of the hazard from the clear zone
- Full road closure/ramp closure with traffic detoured
- Road closure with diversion (i.e. onsite detour, median crossover, temporary pavement)
- Performing work during off-peak periods when traffic volumes are lower
- Accelerated construction techniques
- Directional detours or alternate route detours
- Rolling road blocks

WARRANT

A warrant for using positive protection in a work zone is based on the premise that positive protection will reduce the severity of potential crashes. Positive protection in work zones is considered warranted whenever an engineering study indicates any of the following:

- Consequences of striking a fixed object or running off the road are believed to be more serious than striking the positive protection
- Consequences of striking a worker or pedestrian are believed to be more serious than striking the positive protection

TYPICAL APPLICATION

The following provides a list of areas where positive protection has been used in the past. However, this list is intended to provide guidance and should not be used in place of performing an engineering study.

- Objects that are within the clear zone such as:
  - Temporary shoring locations
  - Bridge piers
  - Overhead sign supports including foundations
  - Staged pipe or culvert construction
  - Stored construction material or equipment
  - Pavement edge drop offs
  - Non-traversable slope or steep/rough embankments within the clear zone
- Staged bridge construction
- Worker's or pedestrian safety is at risk due to the proximity of work to travel lanes
- Separation of opposing traffic

ENGINEERING STUDY AND ANALYSIS

An Engineering Study is a process which will integrate data, analysis, judgment, and creativity to determine the best strategy for a given scenario. An Engineering Study does not take the place of good engineering judgment, but should be used in conjunction with engineering judgment to guide the decision making process. It is most important to understand that one individual factor cannot independently determine if positive protection is needed. Considering all the factors will provide the fundamental information for the designer to analyze if an individual operation warrants the need for positive protection.

The Engineering Study performed to determine the need for positive protection shall take into consideration clear zone distances, roadway geometry, anticipated construction year traffic volumes, traffic speeds, roadside geometry, workers safety, pedestrian safety, etc. The following describes in more detail how these areas of concern are considered.

1. PRIMARY FACTORS TO CONSIDER

A. Clear Zone Distances

The *Roadside Design Guide* (RDG) defines the principles of clear zone. Objects outside the clear zone will generally not require positive protection. A designer must determine if a fixed object or worker will be within this lateral distance from the travel way. Clear zones can be determined using Table 3-1 from the *RDG*.

Chapter 9 of the *RDG* provides information specifically for work zones. Table 9-1 provides example work zone clear zones. This table can be considered, using good engineering judgment, when evaluating the need for positive protection.

The lateral distance from the travel way to a drop off or embankment could affect the need for positive protection. The height of a fill section is related to the slope a vehicle would have to travel toward the obstacle. Figure 5-1(b) of the *RDG* helps to determine if positive protection is needed for a given fill height.

B. Roadside Geometry

The depth and slope of the drop off or an embankment (roadside geometry) is an important factor to consider and will affect the decision to use positive protection.

- *Pavement Edge Drop off*

"Safety in Construction Zones Where Pavement Edges and Drop-Offs Exist", shown in the appendix as Figure 16, provides guidance on a correlation between the depth of a drop off, the distance the drop off is from the travel lane, and the roadside slope.

The Center for Transportation Research and Education (CTRE) in Iowa summarized the other state's drop-off criteria shown in the appendix from "Traffic Control Strategies in Work Zones with Edge Drop-Offs"

- *Embankment*

Figure 5-2(b) of the *Roadside Design Guide*, shown in the appendix indicates the relationship between the roadside slope, the height of an embankment and the traffic volume.

C. Anticipated Traffic Volumes

For best analysis, the construction year traffic volumes would provide a more realistic "anticipated" traffic volume than the current or the design year volumes. When analyzing the traffic volumes, the traffic mix should be considered. This includes the percent of truck traffic as well as motorists unfamiliar with area including seasonal tourists or for special events.

With higher traffic volumes, night work is often used as an exposure control measure. Night work may present unique challenges that must be taken into account such as, increased speeds, glare from portable lighting, driver's impaired visibility, and possible increase of inattentive drivers. Nightly installation and removal of positive protection devices will increase time and traffic exposure and may offset any advantage associated with the use of positive protection, except in cases where it can be installed and left in place for extended periods. These items need to be considered prior to requiring night work.

Higher volumes increase the risk to road users and roadway workers. Therefore, positive protection will more likely be used in locations with higher volumes.

D. Traffic speeds

For best analysis, the prevailing speed provides a more realistic speed than the speed limit or design speed for the roadway. If a speed study is available, use the 85th percentile speed. The higher the speed the more likely positive protection will be needed.

E. Roadway Geometry

The geometry of the roadway may affect the site distance for motorists, especially at entrance ramps. If the construction operation is on the outside curve of a road, the clear zone distance may be affected. Table 3-2 of the *RDG* provides adjustment factor for the clear zone. This data considers ADT, speed, and the roadway geometry. The tighter the curve, the clearer the zone distance is needed.

F. Duration

Duration is the length of time the hazard potentially requiring positive protection will be present. A designer must consider the exposure time associated with completing the operation versus the risk of installing the positive protection. In addition, the percent increase in duration must be considered when the installation of the barrier is included in the operation. If the duration to install the positive protection is longer than the construction operation itself, then positive protection may not be justified.

"Safety in Construction Zones Where Pavement Edges and Drop-Offs Exist" provides a figure to determine when temporary barrier may be justified to shield a drop-off as it relates to the ADT and duration/ exposure time of the drop off condition. This is shown in the appendix as Figure 16.

2. SPECIAL FACTORS TO CONSIDER

A. Worker's Safety
Where worker's exposure to traffic cannot be adequately managed through the application of an exposure control measure, positive protection should be considered. Consider positive protection in situations that place workers at increased risk from motorized traffic. Consideration must be given to an increase in worker's exposure during the installation and anchorage of positive protection.

B. Pedestrian Safety
Positive protection should be considered if there is a high potential for vehicle intrusion into pedestrian paths.

C. Separating Opposing Traffic
Positive separation should be considered in situations where multilane divided facilities are temporarily shifted to a 2-lane 2-way traffic pattern for periods lasting longer than three days. Conditions that may influence the decision to use positive protection would be high speed facilities, narrowed lanes, and high traffic volumes.

3. SECONDARY FACTORS TO CONSIDER
While the primary factors to consider are the driving force in the decision to use positive protection, secondary factors should not be dismissed especially in situations where a clear decision is not evident. The following are a list of secondary factors that may influence the decision to use positive protection:

- Crash History. Crash history of the area prior to construction Lessons learned from the crash history of previous work zone projects may be helpful in determining the need for positive protection. The Traffic Safety Unit is a good resource to help identify any potential areas of concern.
- Impacts on Project Cost and Duration. Positive protection will have an impact on the overall project duration and cost.
- Impacts on available lane widths. Restricted lane widths due to the use of positive protection may affect mobility for road users and the contractor. Consideration must be given to wide loads and equipment requirements to complete the work.
- Roadway Classification. The roadway classification is indicative of the characteristics of the road. Characteristics that may have an effect on the decision to use positive protection may include, speed, access, rural vs. urban, etc.
- Work Area Restrictions. Access to and from the work area for the delivery of materials and equipment should be considered. In addition, consideration should be given to the area needed for storage of equipment and materials and the area needed for equipment operation.

- Bridge Construction**.** Positive protection could affect the weight posting of the bridge for overweight vehicles. In addition, the ability to anchor positive protection to an existing bridge may be limited.

CONCLUSION

In conclusion, there are great benefits to using positive protection in appropriate situations. Positive protection techniques, when properly implemented, can help improve safety for workers and the motoring public. However, careful evaluation needs to be exercised before installing positive protection. The decision to use positive protection should be based on the best overall management of safety, mobility, constructability, cost, and overall project duration. These guidelines are meant to be coupled with engineering judgment in determining the use of positive protection.

5.4 Temporary Barrier Types

5.4.1 NC Standard Portable Concrete Barrier

The North Carolina approved Standard Portable Concrete Barrier (NC- PCB) meets NCHRP 350 test level 3. It is a "New Jersey Shape" free-standing, pre-cast concrete section that is 10 ft. long, 24 in. wide at the base, and 32 in. high, see Figure 1. A section weighs approximately 3,900 lbs., thus requiring heavy equipment for the installation and removal. PCB sections are joined end to end using a triple loop and drop-pin connection system. Adequate longitudinal reinforcement and positive connection ensure that the individual segments act as a smooth, continuous unit although the joint remains the weakest point.

The NC-PCB has two other versions- anchored and drainage. Anchored NC-PCB is a standard PCB designed to accommodate a maximum of 4 anchor bolts (2 on each side) and is used when the expected unanchored NC-PCB or other barrier deflections are greater than the space available. Drainage NC-PCB has a slot cast in the bottom designed to accommodate water flow under the barrier where surface water runoff could cause a hazardous accumulation of water on the traveled way.

5.4.2 Quickchange Moveable Barrier (QMB)

Quickchange Moveable Barrier (QMB) or zipper systems meets NCHRP 350 test level 3. It is a system composed of a chain of reinforced "F-Shape" pre-cast concrete sections that is designed to be moved laterally across the roadway quickly, safely and in one continuous operation. Each barrier section is 37 in. long, 24 in. wide at the base, and 32 in. high with a weight of approximately 1,500 lbs., see Figure 1. The top of the barrier is "T" shaped to permit it to be picked up by the transfer vehicle. A transfer vehicle is able to pick up and move continuous lengths of barrier a minimum of 4 feet to a maximum of 24 feet across the roadway at speeds up to 10 mph.

Quickchange Moveable Barrier (QMB) is designed to accelerate construction, improve traffic flow, and reduce work zone congestion by enabling more lanes to be open during peak hour traffic while safeguarding work crews and motorists. QMB is ideal for reconstruction, re-paving, and bridge and tunnel rehabilitation. Since the QMB system requires higher operating and maintenance costs, it should only be considered where the cost and/or impacts of the traditional freeway widening alternative is prohibitive.

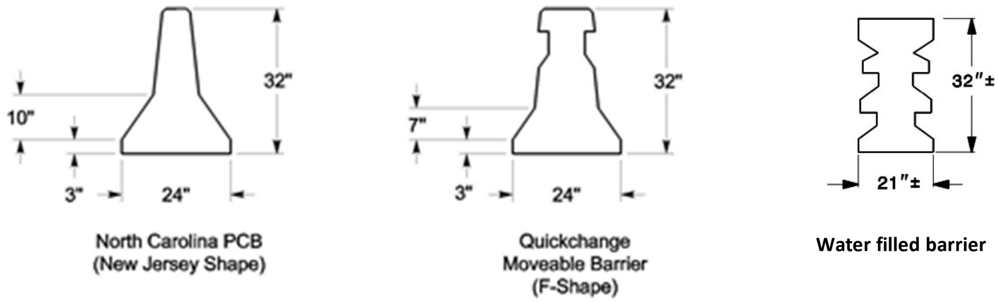


Figure 1 – PCB Standard Safety Shapes

5.4.3 Water-Filled Barrier

The only NCDOT approved water-filled barrier at this time is Triton Water- Filled Barrier. It has been approved for use only as a NCHRP 350 test level 2 device, which is for speed-zones of 45 mph or less. Each plastic barrier section is 7 ft. long, 21 in. wide at the base, and up to 43" tall. It weighs approximately 140 lbs. when empty and approximately 1,350 lbs. when filled. Water-Filled Barrier consists of alternating orange and white plastic barrier sections that are joined end to end with connection pins and then filled with water after being positioned at the project site. The first barrier section is turned upside down to serve as the crash cushion and does not receive any water.

The advantage of this type of system is the short installation and removal time. Each section can be unloaded and positioned by two people without the use of cranes or special equipment. The disadvantages are the cost and higher deflection as compared to concrete barrier.

5.4.4 Temporary Guardrail

Temporary guardrail most commonly consists of W-section rails of single or double rails with faces of different combinations attached to wood or steel posts. Although specified in the Traffic Control Plans for temporary conditions, guardrail is a function of the Roadway Design Unit. When specifying guardrail in the Traffic Control Plans, it should be closely coordinated with the Roadway Design Unit as it pertains to placement and calculation of quantities.

5.4.5 Other

Other types of barrier that may be used in work zone applications include thrice beam guiderail, 2 and 3 bar bridge rail, cable guiderail, single-face concrete barrier, earth berms, and various other permanent types of barrier. Consult with your supervisor and Roadway for help in choosing alternate barrier types.

5.5 Performance Attributes

The following chart is a quick reference for the barrier approved for use by the Work Zone Traffic Control Section. Support information to the chart can be found in the following subsections.

	North Carolina PCB	Quickchange Movable Barrier (QMB)	Water-Filled Barrier	W-Beam Guardrail
Maximum Deflection	See Note 1	53 in. (NCHRP 350 TL-3)	12 ft. 10 in. (NCHRP 350 TL-2) See Note 2	See Note 3
Installation Surface	Pavement	Pavement		Soil
Length of Barrier Tested See Note 4	200 ft.	250 ft.	100 ft.	Consult with Roadway

Figure 2 – Performance Attributes Chart

Notes:

1. See Figures 4 & 5 below for NC-PCB deflection distances derived from a crash data analysis program developed for the WZTCS by NC State University. Deflection distances can also be derived using the deflection program discussed in Section 2.5.5.2.
2. Water-Filled Barrier can only be used for speed zones of 45 mph or less.
3. Because of different construction elements of guardrail, deflection distances will vary with each manufacturer. Consult with Roadway to verify deflection distances after the barrier is chosen.
4. The distance shown is the total length of barrier tested during NCHRP 350 crash testing. It is also the same length used by NC State University for the deflection analysis of the NC-PCB. Use engineering judgment when using barrier less than what is shown because the barrier deflection distance could be greater and vehicle containment could be compromised.

5.5.1 NC-PCB Deflection Charts

The following charts, Figures 4 & 5, are the result of a crash data analysis program developed for the WZTCS by NC State University. Since the deflections shown are based on speed and impact angle, the designer will be able to better judge offset distances for barrier placement. The "Offset" distances shown and used to determine the "Impact Angle" are based on the assumption of 12-feet lane widths and a 2-foot offset of the barrier from the traveled way, see Figure 3. You will have to use the chart and interpolate for different distances or use the deflection program discussed in the next subsection.

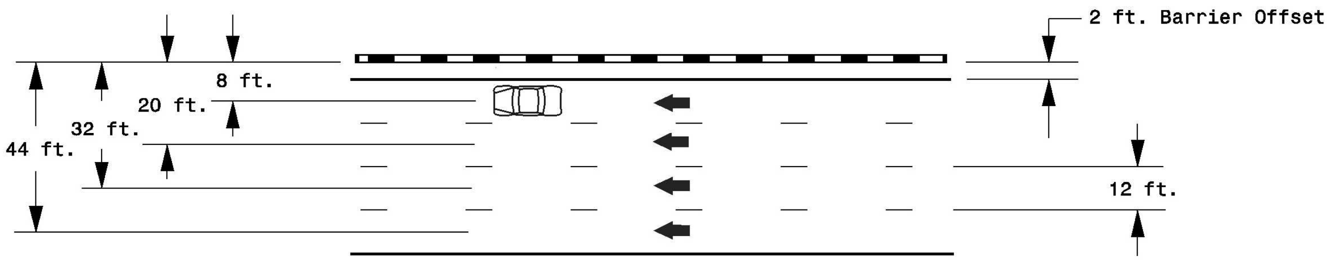


Figure 3 – Vehicle Lateral Distance

Impact Angle (degree)/ Maximum Deflection (in)			Design Speed (mph)					
			30	40	50	60	70	80
Offset (ft)	8	Impact Angle	11.1	10.4	9.6	8.7	7.7	6.7
		Maximum Deflection	23.00	25.86	28.04	31.86	35.72	39.12
	14	Impact Angle	12.7	12.1	11.4	10.5	9.3	8.0
		Maximum Deflection	25.16	27.42	30.43	34.25	37.02	41.45
	20	Impact Angle	13.2	12.8	12.2	11.5	10.9	10.3
		Maximum Deflection	26.52	28.94	33.30	35.89	38.77	42.51
	26	Impact Angle	13.3	12.9	12.6	12.0	11.3	10.5
		Maximum Deflection	27.14	30.11	34.68	37.62	39.74	43.14
	32	Impact Angle	13.3	13.0	12.7	12.4	12.1	11.8
		Maximum Deflection	28.56	30.71	35.99	38.82	41.56	44.38
	38	Impact Angle	13.3	13.1	13.0	12.6	12.2	12.0
		Maximum Deflection	29.34	33.23	37.92	40.31	42.89	45.51
	44	Impact Angle	13.4	13.2	13.0	12.8	12.7	12.6
		Maximum Deflection	30.45	33.93	40.14	42.12	44.53	47.21
	50	Impact Angle	13.4	13.2	13.0	12.9	12.9	12.8
		Maximum Deflection	30.95	34.62	40.92	42.89	46.00	48.70
	56	Impact Angle	13.6	13.2	13.0	13.0	12.9	12.9
		Maximum Deflection	31.42	35.24	41.34	43.78	46.27	49.53
	62	Impact Angle	13.6	13.2	13.0	13.0	12.9	12.9
		Maximum Deflection	31.87	35.86	41.62	44.56	46.72	50.18

Figure 4 – NC-PCB impact design table for ASPHALT pavement

Offset (ft)		Impact Angle (degree)/ Maximum Deflection (in)	Design Speed (mph) 30	40	50	60	70	80
Offset (ft)	8	Impact Angle	11.1	10.4	9.6	8.7	7.7	6.7
		Maximum Deflection	16.68	17.45	20.21	21.70	24.20	25.74
	14	Impact Angle	12.7	12.1	11.4	10.5	9.3	8.0
		Maximum Deflection	18.43	19.42	22.33	24.05	25.76	28.39
	20	Impact Angle	13.2	12.8	12.2	11.5	10.9	10.3
		Maximum Deflection	21.28	21.70	23.61	25.37	27.51	30.05
	26	Impact Angle	13.3	12.9	12.6	12.0	11.3	10.5
		Maximum Deflection	22.12	23.02	25.22	26.49	29.45	33.27
	32	Impact Angle	13.3	13.0	12.7	12.4	12.1	11.8
		Maximum Deflection	23.24	24.62	26.12	27.98	31.30	34.26
	38	Impact Angle	13.3	13.1	13.0	12.6	12.2	12.0
		Maximum Deflection	23.87	25.36	26.89	29.18	32.32	35.47
	44	Impact Angle	13.4	13.2	13.0	12.8	12.7	12.6
		Maximum Deflection	24.19	25.45	27.04	29.85	33.46	36.12
	50	Impact Angle	13.4	13.2	13.0	12.9	12.9	12.8
		Maximum Deflection	25.11	25.70	27.42	31.24	34.14	36.85
	56	Impact Angle	13.6	13.2	13.0	13.0	12.9	12.9
		Maximum Deflection	25.48	25.80	27.83	31.54	34.51	37.12
	62	Impact Angle	13.6	13.2	13.0	13.0	12.9	12.9
		Maximum Deflection	25.55	26.20	28.16	31.80	35.15	37.34

Figure 5 – NC-PCB impact design table for CONCRETE pavement

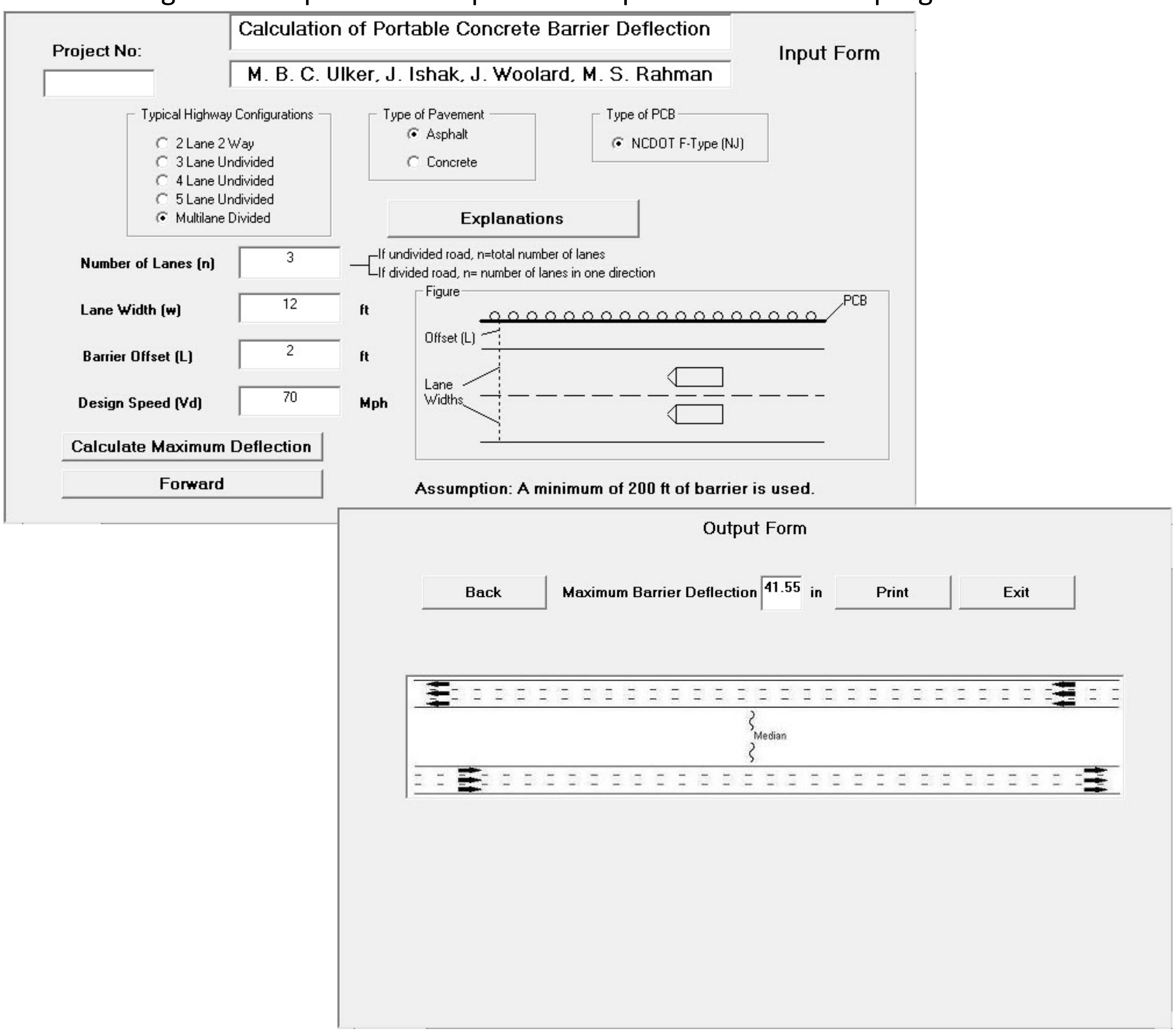
5.5.2 Barrier Deflection Calculation

The WZTCS has a computer program that will calculate the maximum deflection for NC-PCB. The Deflection program was developed for the unit by NC State University and can be found on your computer under the WZTCS Tools shortcut folder on your desktop.

The calculations are based on:

- Road type (divided or undivided)
- Number of lanes
- Type of pavement
- Type of barrier
- Lane widths
- Design speed

The following are examples of the input and output screens for the program:



5.6 Temporary Barrier Usage

5.6.1 Warrants for Temporary Barrier Usage

The Roadside Design Guide was introduced to promote the safety of the motorist that may inadvertently run off the roadway. With that purpose, the Roadside Design Guide established the concept of the Clear Zone (The total roadside border area, starting at the edge of the traveled way that is available for safe use by errant vehicles). While the principles governing the placement of barrier to protect the motorist from striking objects in the clear zone are generally the same, the work zone and permanent roadside environments are very different. Materials, equipment and workers are inherent of the work zone “clear zone” which is not the same as the objects found in the permanent roadside “clear zone”. Therefore, experience and judgment must be used to identify hazardous features. The following is a small list of hazards that may warrant the use of barrier in the work zone:

- Construction equipment and materials
- Existing permanent guardrail/concrete barrier
- Exposed ends of temporary barrier
- Bridge piers
- Bridge rail or parapet ends
- Culvert installations

In addition to shielding hazards, barrier may necessary for the following:

- Protect the workers.
- Separate two-way traffic.
- Shield and/or guide pedestrians around the work site.

5.6.2 Guidelines for Barrier Usage

In addition to the examples listed above, the following is a list of guidelines to help determine the need for temporary barrier.

5.6.2.1 Drop-offs

Drop-Offs greater than 3 inches need special attention when located within or near the traveled way. See Chapter 2.2 Drop-Offs in the WZTCS Design Manual for guidelines in the use of temporary barrier.

5.6.2.2 Roadside Slopes

If a roadside is not flat, a vehicle leaving the roadway will encounter an embankment slope (negative grade), a cut slope (positive grade), or a channel (change in slope from negative to positive). Each of these features has an effect on a vehicle’s lateral encroachment and trajectory. Embankment or fill slopes are categorized as recoverable, non-recoverable, or critical:

- Recoverable Slopes are 4H:1V or flatter where a vehicle may be stopped or slowed enough to return to the roadway safely.
- Non-Recoverable Slopes between 3H:1V and 4H:1V are traversable, but from which most motorists will be unable to stop or return to the roadway safely.
- Critical Slopes steeper than 3H:1V may cause vehicle overturn.

Slopes steeper than 3H:1V should be protected by some type of barrier.
See Chapter 2.2 Drop-Offs in the WZTCS Design Manual for guidelines in the use of temporary barrier to protect slopes.

5.6.2.3 Shoring and MSE Walls

Shoring or a MSE wall located in the Clear Zone may require temporary barrier to protect the motorist. See the Temporary Shoring Special Provision SP11R02 and WZTC Standard Drawing "Portable Concrete Barrier at Temporary Shoring Locations" for guidelines.

5.6.3 Assessing the use of Temporary Barrier

Even though a hazard has been identified, engineering judgment needs to be used to determine if temporary barrier should be utilized. It must be remembered that the installation of temporary barrier also represents a hazard to the motorist and it is a safety issue for the worker who must install and remove the barrier. The following are a few factors to consider when assessing the need for positive protection:

- Duration of the construction activity
- Traffic volumes (ADT)
- Work zone design speed
- Highway functional class
- Length of hazard
- Proximity between traffic and construction workers and/or equipment
- Adverse geometrics which may increase the likelihood of run-off-the-road vehicles

Consult with your supervisor for alternatives to barrier that can be used, e.g., drums for delineation, portable changeable message signs to alert the motorist and a TMA to shield the hazard. Other solutions may be a temporary detour or lane closure.

5.7 Selection Criteria

Once it has been decided to use temporary barrier, engineering judgment is needed in the selection and placement of temporary barrier in the work zone. The following summarizes some factors that should be considered before making the final selection:

- The barrier chosen must be structurally able to contain and redirect the vehicle
- Expected deflection of the barrier should not exceed available deflection distance
- Slope and surface may limit some barrier types
- The barrier chosen may have to be capable of transitioning to other barrier types and bridge railings
- Other considerations are the duration of construction activity, work zone speed, ADT and barrier cost

5.7.1 Surface

The type of surface the barrier will be installed on is an important design element in choosing the correct temporary barrier type.

5.7.1.1 Paved

PCB (including anchored and drainage), QMB (Zipper System) and water filled barrier must be installed on paved surfaces**. If necessary, temporary pavement may be placed on an unpaved area next to the travel lane for barrier installation. A paved surface is also required when the barrier is flared away from the traveled way.**

5.7.1.2 Unpaved

If placing temporary pavement is not an option, consider using temporary guardrail or guiderail. Coordinate the selection and placement of guardrail/guiderail with Roadway Design Unit.

5.7.1.3 Bridge Decks

PCB is predominantly used on bridge decks. Coordinate with Structure Design on whether the structure rating is sufficient to accommodate the weight of the barrier or if the barrier can be anchored to the bridge deck. If the existing structure is aged to the point where concrete barrier cannot be supported; then guardrail can be considered and should be coordinated with Structure Design and Roadway Design.

5.7.1.4 Slopes

The Roadside Design Guide does not recommend placing barrier on slopes steeper than 10H:1V. Per the Roadside Design Guide, "When barrier is placed on slopes steeper than 10H:1V, studies have shown that for certain encroachment angles and speeds an errant vehicle may go over many standard roadside barriers or impact them too low." Since PCB, QMB and water-filled barrier must be placed on a paved surface, slope will probably not be an issue. For Water-Filled Barrier it is recommended not to exceed slopes steeper than 20H:1V. When slopes are steeper than 10H:1V, consult with roadway for a guardrail or guiderail that may be suitable.

5.7.2 Performance

After the Area of Concern that needs to be protected has been identified, a barrier should be chosen that has a level of performance that can properly protect the area. The first concern will be to insure that the deflection of the barrier chosen will not encroach into Area of Concern when impacted. After reviewing the speed zone and lane width for worst case impact severity, refer to the charts in Section 2.5.5 Performance Attributes to find the deflection distance of the NC-PCB. (In the past, the designer could only use the deflection distances reported from the NCHRP 350 test data and use that distance as a worst case for deflection. The charts now give the designer the deflection distance that better matches the work zone). The designer can also use the deflection program. If the designer is using Water-Filled barrier, guardrail or another NCDOT approved barrier, the designer should use the deflection distance reported from the NCHRP 350 test data for that barrier as the worst case deflection.

Another consideration in the performance of the barrier is the type of traffic and work zone location. The PCB approved and most W-Beam guardrail meets NCHRP 350 TL-3 which has been crash tested for cars and light trucks. If your work zone is located in an urban area with a 35 mph speed zone, then Water-Filled barrier may be a better choice.

5.8 Installation Guidelines

The following guidelines are to be used whenever possible for the proper installation of barrier. When deviations are necessary, consult with your supervisor.

5.8.1 Lateral Offsets (General Information)

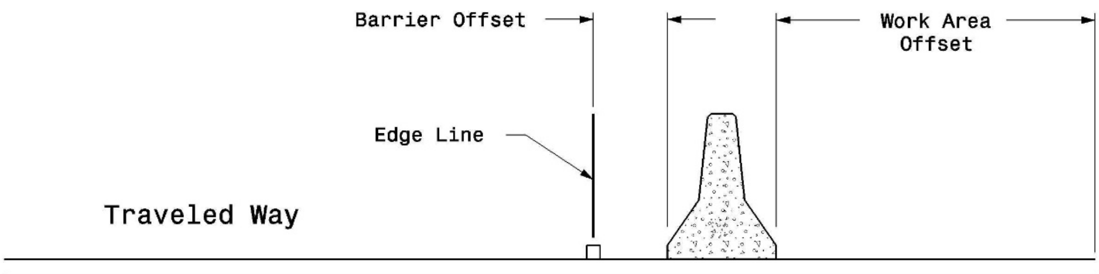


Figure 8 – Typical Barrier Layout

5.8.1.1 Maximum Lateral Offset from Traffic

There is no maximum lateral offset of barrier from traffic within the clear zone. A larger lateral offset gives an errant motorist more time to regain control of the vehicle and provides better sight distance around curves and intersections. However, larger lateral offsets may allow for a larger impact angle with the barrier, thus creating the potential for a more severe crash. Barrier placement beyond the clear zone is usually not necessary and engineering judgment should be used to determine if protecting the motorist from a hazard beyond the clear zone is warranted. Lateral offsets of 4 to 10 feet should be avoided, see False Shoulder Effect below.

Approach ends of the barrier should be flared beyond the clear zone if possible, see Flare Rate Chart on page 23. If this is not possible, the barrier approach ends should have acceptable crashworthy end treatments.

5.8.1.2 False Shoulder Effect

If a wide shoulder exists for barrier placement, a barrier offset of 4 to 10 feet from the traveled way should be avoided where possible. Offsets in this range may create an effect that can lure drivers into thinking there's a useable shoulder when in actuality there is not sufficient room to park in a safe manner. For example, a passenger car can normally fit in an 8-foot wide space, but this space does not allow room for opening a door.

5.8.1.3 Minimum Lateral Offset from Traffic

As a general rule, a minimum offset of 2 feet between the barrier and the traveled way is preferred. See Chapter 3 for minimum lane widths.

5.8.1.4 Lateral Offset from Work Area or Hazard

Barrier must be offset from the hazard to allow for deflection. If construction is being performed behind the barrier then the offset distance chosen must also provide adequate space for the work to be performed. The larger offset of the two should be the one used. For example, if the space needed for equipment to operate behind barrier exceeds that which is required for deflection, then that higher offset should be used. The offset from the barrier to the work area will vary depending on the type of work or hazard. During the design stage, construction procedures and equipment that will be used must be thoroughly analyzed before the barrier layout is finalized. Construction personnel, such as the Construction Unit, Division Personnel, Resident Engineer, and manufacturers should be contacted for details on construction procedures and equipment operations, so that the barrier offset can be correctly determined.

Common minimum offsets from barrier to work operations:

- Asphalt pavement widening: 1 ft.
- Concrete pavement widening: 2.5 ft.
- Temporary roadside slopes: – 1.5:1 slopes: 3.3 ft.
  – All other slopes: 2.5 ft.

5.8.2 Slopes

Special consideration has to be given when placing barrier on any slope since most roadside barriers are designed for and tested on level terrain. Per the Roadside Design Guide, “roadside barriers perform most effectively when they are installed on slopes of 10H:1V or flatter. Caution should be taken when considering installations on slopes as steep as 6H:1V and any such installations should be offset so that an errant vehicle is in its normal attitude at the moment of impact. Since PCB, QMB and water-filled barrier must be placed on a paved surface, slope will probably not be an issue. The Roadside Design Guide has recommendations for placement of barrier on roadside locations and median locations, but the information is too great to summarize in this chapter. Also, since the barrier to be used in this situation will probably be guardrail or guiderail, it is suggested to consult with Roadway for the proper choice and placement.

5.8.3 Curbs

The trajectory of a vehicle striking a curb will depend on the vehicle’s characteristics such as height, weight, suspension type, impact speed and impact angle, and the height and shape of the curb itself. Preferably, barriers should be placed in line with the curb face, or in front of the curb. If these conditions cannot be met, then the barrier should be located a minimum of 12 feet behind the face of the curb to eliminate vaulting.

5.8.4 Bridge Decks

PCB used on bridge decks should be anchored if the clearance from the back of the barrier to the edge of the deck is 6 feet or less as shown in Figure 10.

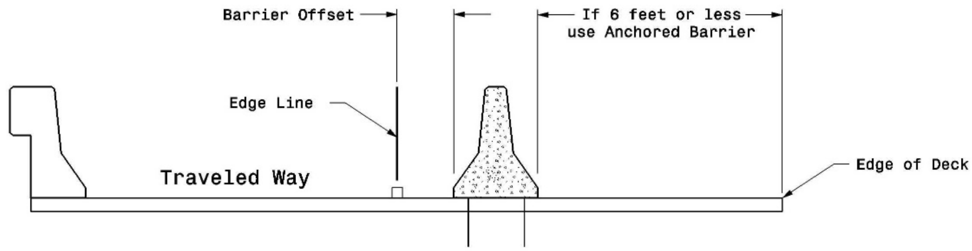


Figure 10 – Barrier installed on a Bridge Deck

5.8.5 Shoring and MSE Walls

See WZTC Standard Drawing "Portable Concrete Barrier at Temporary Shoring Locations" for installation guidelines.

5.8.6 Access Openings

Openings in barriers should be avoided if possible. Where necessary, PCB approach ends should have acceptable crashworthy end treatments. Refer to the Figures 11 and 12 for placement guidelines.

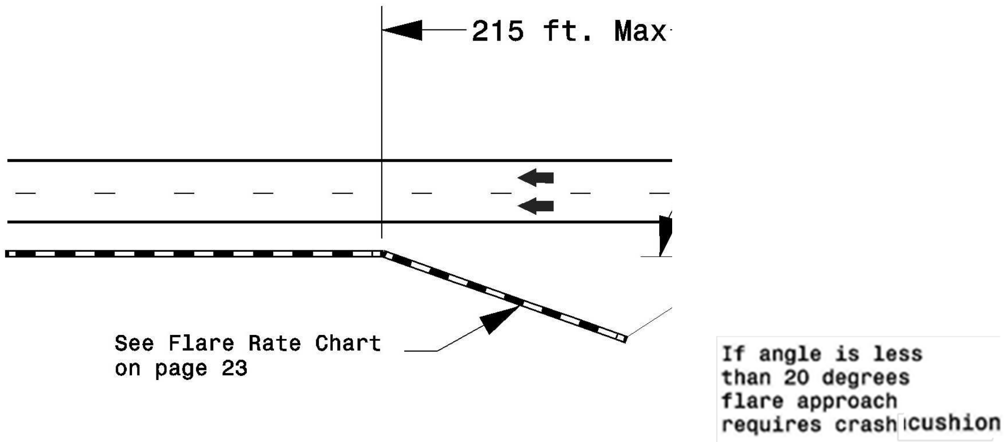


Figure 11 – Flared Installation

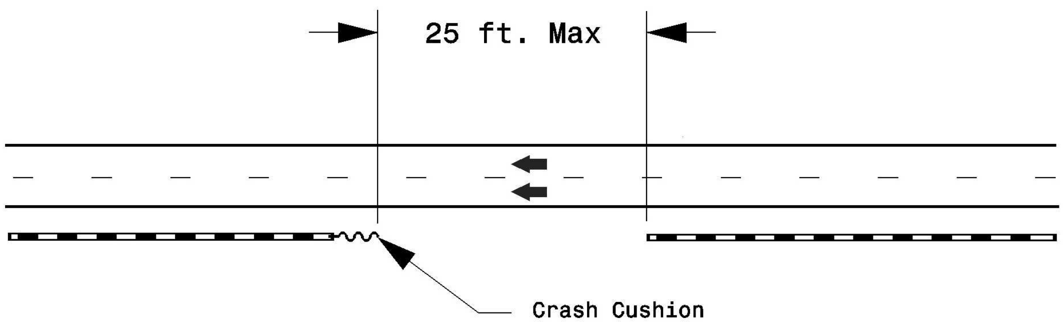


Figure 12 – Parallel Installation

5.8.7 Two-Way Traffic

When barrier is warranted for separation of two-way traffic, its selection will depend directly on the amount of allowable deflection. Barrier selection and placement should be designed so that upon impact, the barrier does not deflect into an opposing lane. Factors that will affect the deflection of the barrier are:

- The number of lanes adjacent to barrier can increase impact angle
- Posted speed limit
- Barrier type
- Type of traffic, e.g., heavy truck traffic

Once the number of lanes is determined, the impact angle and impact severity can be selected. Refer to Section 5.5 Performance Attributes to determine deflection. If there is not enough offset available to keep the barrier from deflecting into the traveled way, then the following alternatives should be considered:

- Anchor the barrier
- Another type of barrier may be selected that can accommodate the estimated deflection
- Or, other traffic control methods may be considered so that the offset from the barrier to the edge lines is equal to or greater than the estimated deflection. Other traffic control methods may include reducing lane widths or shifting lanes onto shoulders.

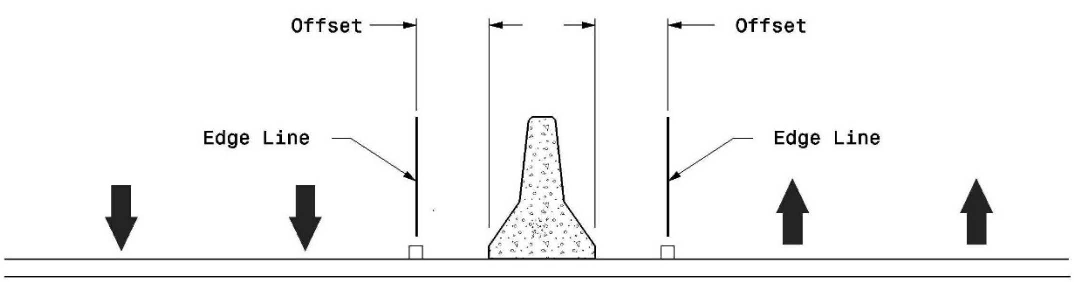


Figure 13 – Two-Way Traffic

5.8.8 Transitions

Transition sections of barrier are necessary to provide continuity of protection when two different barriers are joined, or when a barrier is attached to a rigid object such as a bridge pier. Transition sections are needed between adjoining barriers with different deflection characteristics, such as between guardrail and concrete barrier. A transition section provides for a uniform deflection to occur when a more flexible system attaches to a more rigid system. This will reduce the possibility of the vehicle pocketing, snagging, or penetrating. There are a number of methods to transition barrier depending on the two systems involved. Increased post spacing on guardrail, use of transition panel end shoes, rubrails, and larger size or stronger posts are some examples.

Various Roadway Standard Drawings and special details show methods for transitioning guardrail to bridge rail and guardrail to concrete barrier for pier protection. Contact the Plans and Standards Management Section of the Project Services Unit to have the proper detail sheet designed and included in the Roadway Plans.

5.8.9 Anchored Barrier

Anchored PCB is used in locations where the required deflection distance cannot be obtained. There are three approved methods of anchoring concrete barrier depending on the type of surface the barrier is going to be installed on, but one common factor between the different methods is that the barriers have to be anchored to asphalt or concrete pavement. There is no approved method of anchoring concrete barrier to soil (Refer to Roadway Standard Drawing 1170.01 for detailed information relating to the methods of anchored barrier installation).

Note: Water-filled barrier does not have an anchoring system.

5.8.10 Drainage Barrier

Drainage PCB is used in locations where surface water runoff could cause a hazardous accumulation of water on the traveled way. Drainage PCB is designed with a drainage slot at the base of the barrier that permits water to flow through the bottom of barrier. Refer to Roadway Standard Drawing 1170.01 for more information regarding the drainage slot on the barrier.

Below are guidelines of where and where not to use concrete drainage barrier after the decision has been made to use some type of concrete barrier:

- Drainage PCB should be used on the low side of a horizontal curve, because any water on the roadway will flow downward toward the barrier and can escape through the drainage slot.
- Unless there is a drainage system behind the barrier, drainage PCB **should not** be used on the high side of a horizontal curve because any water on the backside of the barrier may run through the barrier and onto the roadway creating a potential for hydroplaning.
- Drainage PCB should be used at the low point of a sag vertical curve because any water on the roadway will run to the low point on the roadway. Once the water reaches the low point on the curve, it can escape through the drainage slot.

5.9 Required Length of Need

This section covers the design procedure for determining the Length of Need (X) for temporary barriers. The following variables are considered when placing temporary barrier to effectively shield an area of concern:

- Clear Zone (L_C)
- Run-out Length (L_R)
- Flare Rate (a:b)
- Lateral extent of Area of Concern (L_A)
- Tangent Length upstream from Area of Concern (L_1)
- Lateral Offset of barrier from traveled way (L_2)
- Lateral Offset from traveled way to beginning of need (Y)

5.9.1 Length

The following figures show the relationship of the variables when calculating the Length of Need:

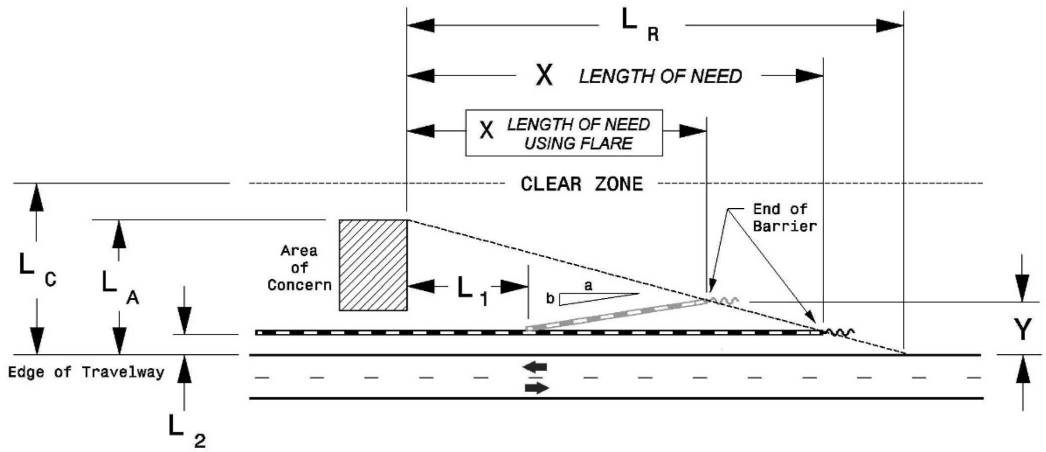


Figure 14 – Layout for "Adjacent Traffic"

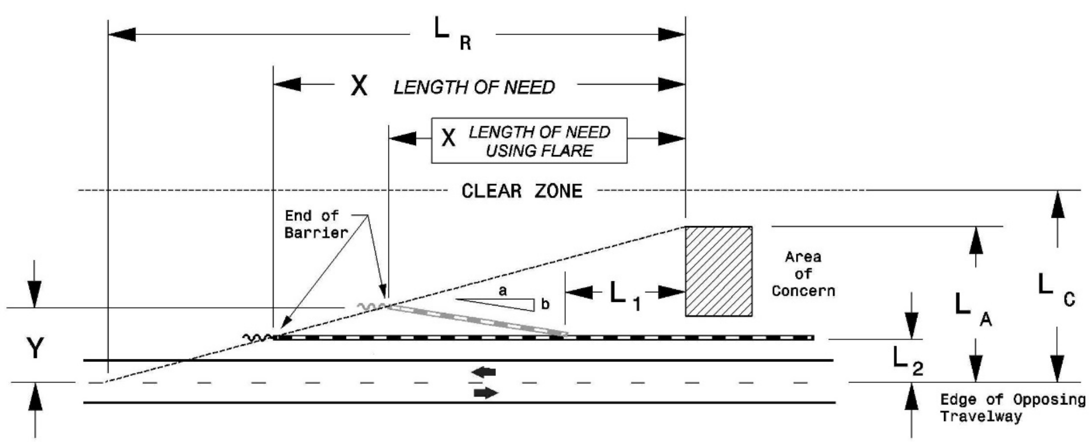


Figure 15 – Layout for "Opposing Traffic"

5.9.1.1 Length of Need (X)

The Length of Need (X) is the total length of longitudinal barrier needed to shield an area of concern. The Length of Need can be calculated by inputting the variables into the following formulas:

$$\text{Without Flare } X = \frac{L_A - L_2}{L_A / L_R} \qquad \text{With Flare } X = \frac{(L_A - L_2) + (b/a)(L_1)}{b/a + (L_A / L_R)}$$

5.9.1.2 Clear Zone (L_C)

The Clear Zone (L_C) is the total roadside border area, starting at the edge of the shoulder and including a recoverable slope, a non-recoverable slope, and/or a clear run-out area. Barrier ends that are within the clear zone will need a crashworthy end treatment. In addition, there are three ranges of Clear Zone width, L_C, that deserve special attention for an approach barrier for “Opposing Traffic”:

- If the barrier is located beyond the “Opposing Traffic” Clear Zone (L_C), no additional barrier is required. However, a crashworthy end treatment should be considered based on ADT, distance beyond the clear zone and roadway geometrics.
- If the barrier is located within the “Opposing Traffic” Clear Zone (L_C), but the area of concern is beyond it, no additional barrier is required, but a crashworthy end treatment should be used.
- If the area of concern extends well beyond the “Opposing Traffic” Clear Zone (L_C), the designer may choose to shield only that portion which lies within the clear zone by setting L_A equal to L_C

The Roadside Design Guide discusses in Chapter 9 how the work zone “clear zone” differs from the before-construction “clear zone” and it states - “Engineering judgment must be used in applying the “clear zone” to work zones”. Because the manual does not publish clear guidance for work zone “clear zone” ranges, it is suggested to use the following chart from the Roadside Design Guide which shows the appropriate “clear zone” ranges used for permanent construction:

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 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
40-50	Under 750	10 – 12	12 – 14	*	8 – 10	10 – 12	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	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	Under 750	16 – 18	20 – 24	*	10 – 12	12 – 14	14 – 16
	750-1500	26 – 30	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	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	22 – 24
	Over 6000	30 – 34	38 – 46	*	22 – 24	26 – 30	28 – 30

* The width of the clear zone has to be extended to an equal width of the non-recoverable slope width.

Figure 16 – Suggested Clear Zone Widths (ft.)

5.9.1.3 Run-out Length (L_R)

The Run-out Length (L_R) is the theoretical distance needed for a vehicle that has left the roadway to come to a stop.

Design Speed (mph)	Traffic Volume (ADT)			
	Over 6000 vpd	2000 - 6000 vpd	800 - 2000 vpd	Under 800 vpd
	L_R (ft)	L_R (ft)	L_R (ft)	L_R (ft)
70	475	445	395	360
60	425	400	345	330
55	360	345	315	280
50	330	300	260	245
45	260	245	215	200
40	230	200	180	165
30	165	165	150	130

Figure 17 – Suggested Run-out Lengths for Barrier Design

5.9.1.4 Flare Rate (a:b)

Flare is defined as the variable offset distance of a barrier to move it farther from the traveled way. The flare rate is the rate of diversion that the barrier moves away from the traveled way.

Design Speed (mph)	Flare Rate for Barrier	
	Anchored	Un-Anchored
70	20:1	15:1
60	18:1	14:1
55	16:1	12:1
50	14:1	11:1
45	12:1	10:1
40	10:1	8:1
30	8:1	7:1

Figure 18 – Suggested Flare Rates for Barrier Design

5.9.1.5 Lateral Extent of Area of Concern (L_A)

The Lateral Extent (L_A) is the distance from the edge of the traveled way to the far side of the hazard or work area, or to the edge of the Clear Zone (L_C). The distance L_A controls the temporary barrier Length of Need (X), and therefore, is important that this area be properly identified.

5.9.1.6 Tangent Length upstream from Area of Concern (L_1)

The Tangent length (L_1) is the length of barrier upstream from the Area of Concern to the beginning of the flare. This is a variable length selected by the designer when the barrier cannot be flared, such as a transition when barriers of different flexibility are tied together, i.e., when concrete barrier ties to guardrail.

The designer may need to define the Lateral Offset (Y) to insure that barrier with flare will be positioned on a paved surface, i.e., barrier placed on a narrow shoulder. In this situation, the governing factor will be the distance for L_1. To calculate for L_1, first solve for Length of Need (X) with the first equation and use that result in the second equation:

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

5.9.1.7 Lateral Offsets of Barrier from Travel Way (L_2)

The Lateral Offset (L_2) of barrier from traveled way is the distance from the edge of the traveled way to the face of the temporary barrier. Refer to Section 2.5.8.1.3 Minimum Lateral Offsets from Traffic for minimum offset requirements.

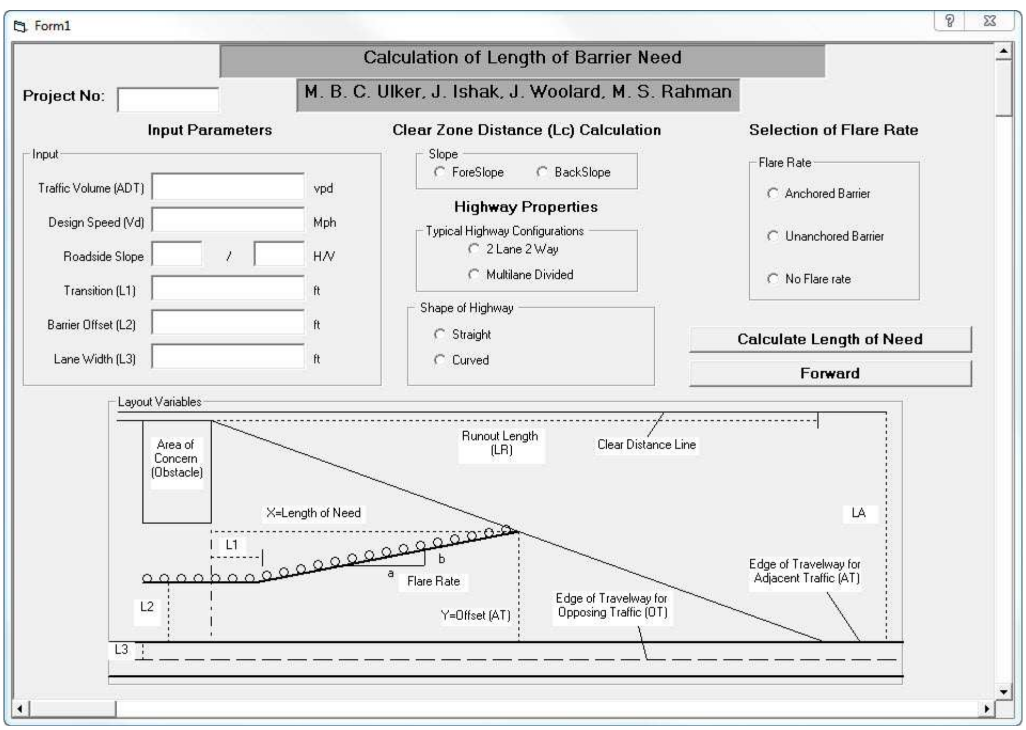
5.9.1.8 Lateral Offsets from Travel Way to Beginning of Need (Y)

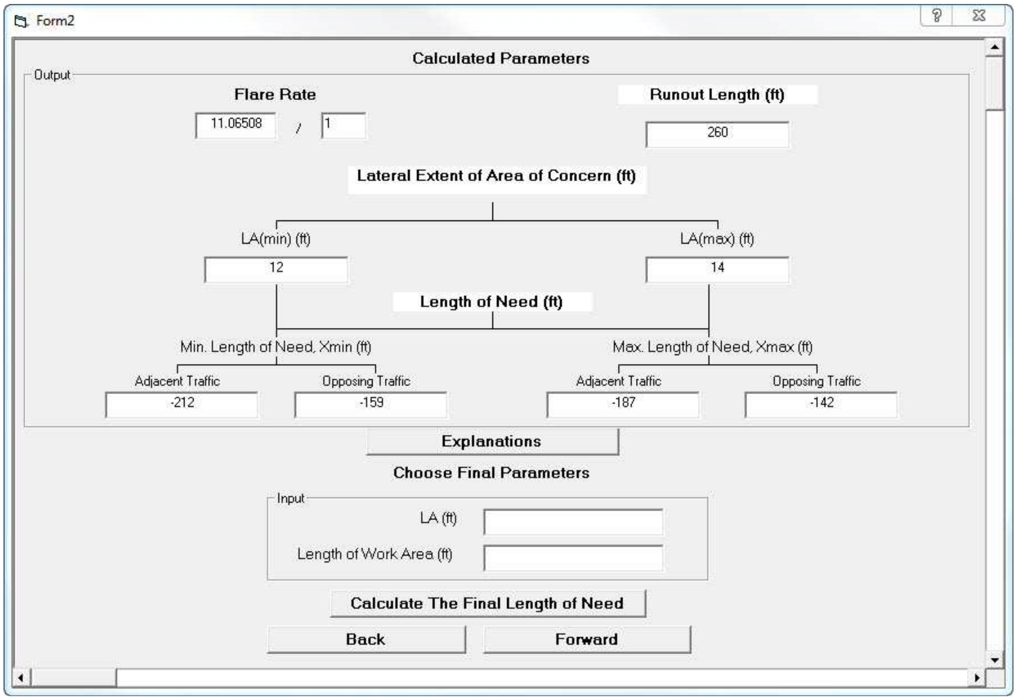
The Lateral Offset (Y) from the edge of the traveled way to the beginning of the Length of Need (X) when barrier is flared can be calculated by using the following equation:

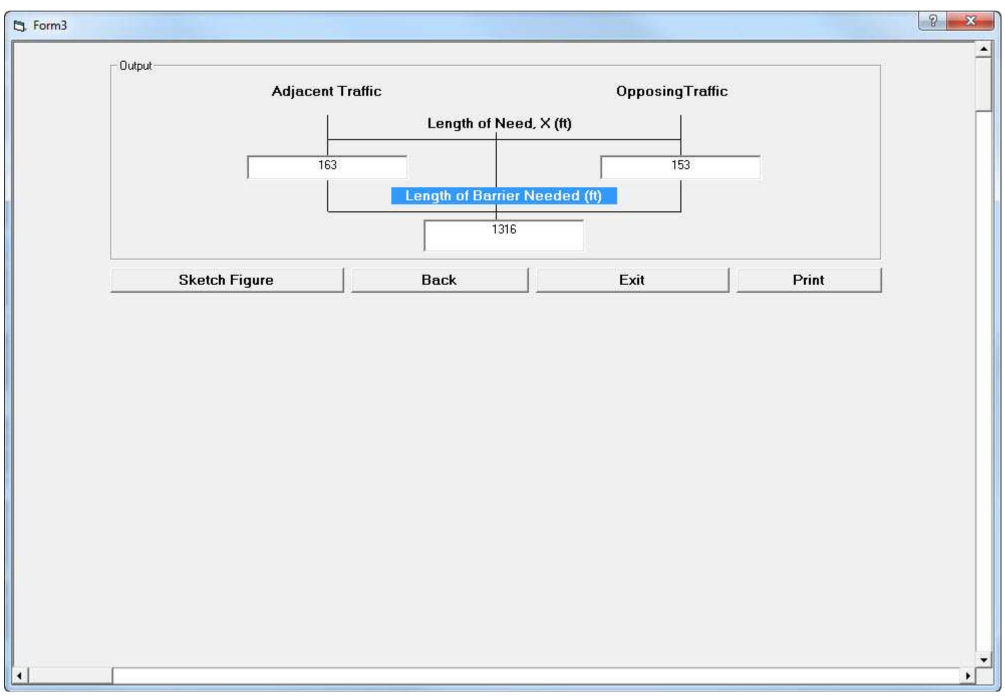
$$Y = L_A - \frac{L_A}{L_R} X$$

5.9.1.9 Length of Need Program

The WZTCS has a computer program that will calculate the results for all the equations discussed. The Length of Need program was developed for the WZTCS by NC State University. The following are examples of the input and output screens for the program:




Form2
Calculated Parameters
Output
Flare Rate
11.06508 / 1
Runout Length (ft)
260
Lateral Extent of Area of Concern (ft)
LA(min) (ft)
12
LA(max) (ft)
14
Length of Need (ft)
Min. Length of Need, Xmin (ft)
Adjacent Traffic
-212
Opposing Traffic
-159
Max. Length of Need, Xmax (ft)
Adjacent Traffic
-187
Opposing Traffic
-142
Explanations
Choose Final Parameters
Input
LA (ft)
Length of Work Area (ft)
Calculate The Final Length of Need
Back
Forward


Form3
Output
Adjacent Traffic
OpposingTraffic
Length of Need, X (ft)
163
153
Length of Barrier Needed (ft)
1316
Sketch Figure
Back
Exit
Print

5.9.2 Area of Concern on a Horizontal Curve

The Length of Need equation discussed above is applicable to straight highway alignment **only**. A vehicle leaving the road on the outside of a curve will generally follow a tangential runout path. Therefore, rather than using the theoretical L_R distance to calculate the Length of Need (X), use the tangent line from the curve to the outside edge of the hazard (or Clear Zone distance if the hazard extends past the Clear zone). The barrier Length of Need then becomes a function of the barrier offset from the traveled way edge and can be obtained graphically by scaling. A flare should not be used along horizontal curves 3 degrees or greater. A crashworthy end treatment is required if the barrier approach end is within the Clear Zone.

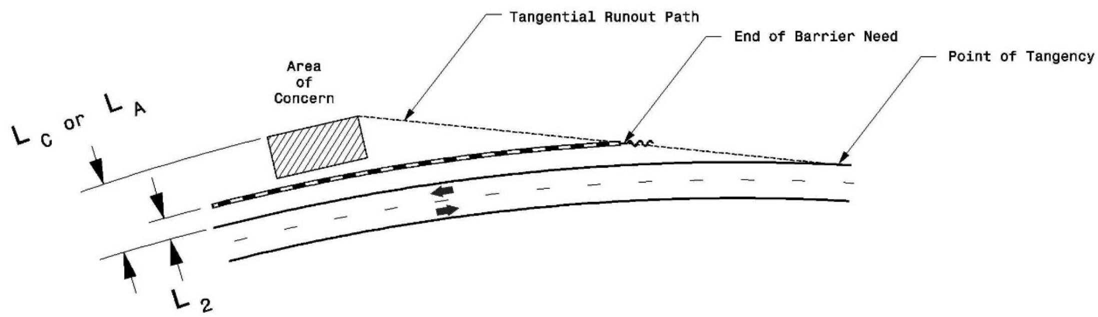


Figure 22 – Area of Concern on a Horizontal Curve

5.9.1 Appendix A Graphs & Charts

Table 3-1 Clear-zone distance in feet from edge of through traveled way
***Roadside Design Guide* p. 3-3**

[U.S. Customary Units]

DESIGN SPEED	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 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 3D II for practicality and to provide a constant roadway template if previous experience with similar projects or designs indicates satisfactory performance.

* Since recovery is best likely on the unshielded, traversable 1V:3H slopes, fixed objects should not be present in the vicinity of the toe of these slopes. Recovery of high-speed vehicles that encroach beyond the edge of the shoulder may be expected to occur beyond the toe of slope. Determination of the width of the recovery area at the toe of slope should take into consideration right-of-way availability, environmental concern, economic factors, safety needs, and crash histories. Also, the distance between the edges of the shoulder traveled lane and the beginning of the 1V:3H slope should influence the recovery area provided at the toe of slope. While the application may be limited by several factors, the foreslope parameters which may enter info determining a maximum desirable recovery area are illustrated in Figure 3.2.

Table 3-2 Horizontal Curve Adjustments
***Roadside Design Guide* p. 3-4**

K_{CZ} (Curve Correction Factor) [U.S. Customary Units]

RADIUS [ft]	DESIGN SPEED [mph]						
	40	45	50	55	60	65	70
2860	1.1	1.1	1.1	1.2	1.2	1.2	1.3
2290	1.1	1.1	1.2	1.2	1.2	1.3	1.3
1910	1.1	1.2	1.2	1.2	1.3	1.3	1.4
1640	1.1	1.2	1.2	1.3	1.3	1.4	1.5
1430	1.2	1.2	1.3	1.3	1.4	1.4	--
1270	1.2	1.2	1.3	1.3	1.4	1.5	--
1150	1.2	1.2	1.3	1.4	1.5	--	--
950	1.2	1.3	1.4	1.5	1.5	--	--
820	1.3	1.3	1.4	1.5	--	--	--
720	1.3	1.4	1.5	--	--	--	--
640	1.3	1.4	1.5	--	--	--	--
570	1.4	1.5	--	--	--	--	--
380	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] (Figure 3.1 or Table 3.1)
K_{CZ} = curve correction factor

Note: The clear-zone correction factor is applied to the outside of curves only. Curves flatter than 900 m [2860 ft] do not require an adjusted clear zone.

Table 9-1 Example of clear-zone widths for work zones
***Roadside Design Guide* p. 9-2**

Speed (km/h)	Widths (m)	Speed [mph]	Widths [ft]
100 - 110	9	[60 - 70]	[30]
90	7	[55]	[23]
70 - 80	5	[45 - 50]	[16]
50 - 60	4	[30 - 40]	[13]

Figure 5-1b Comparative risk warrants for embankments
***Roadside Design Guide* p. 5-6**

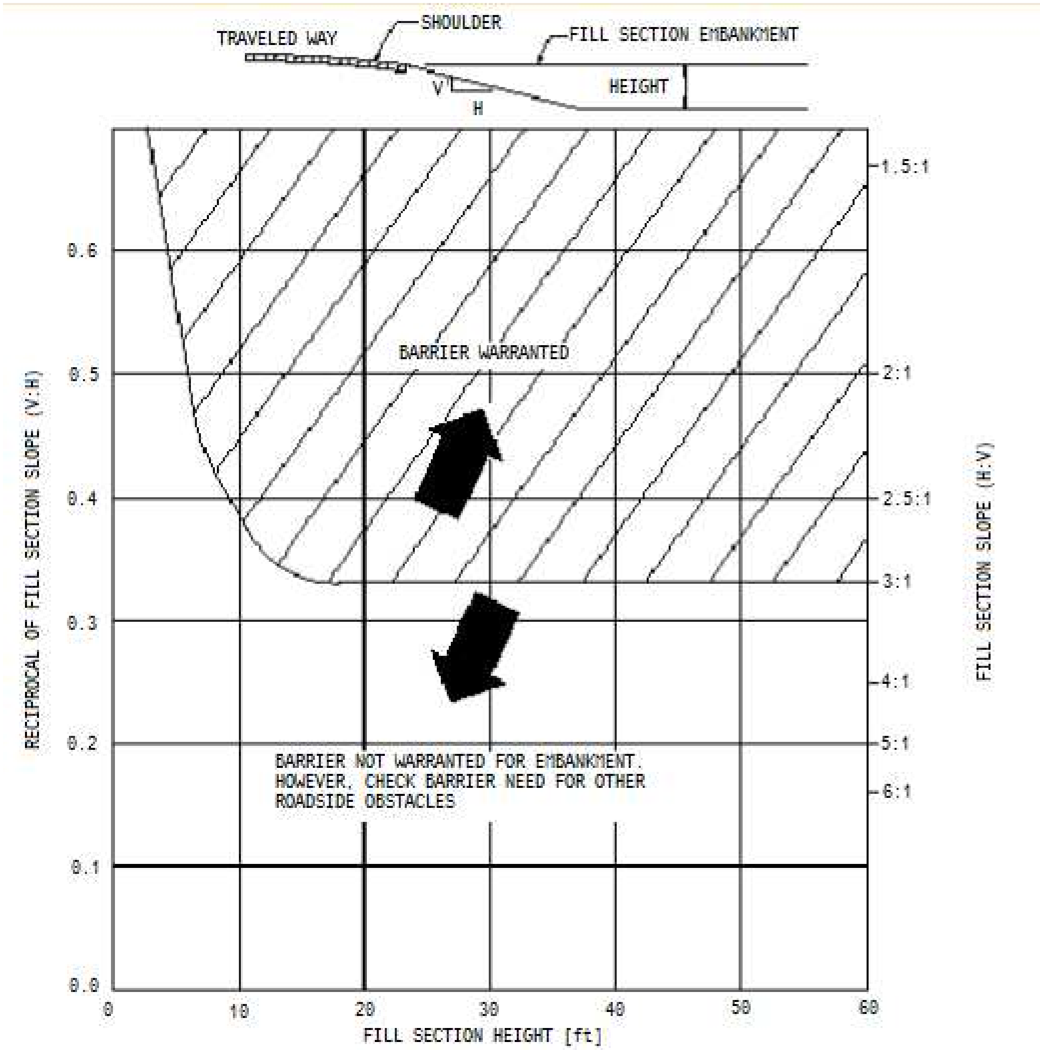


Figure 5-2b Example design chart for embankment warrants based on fill height, slope, and traffic volume
***Roadside Design Guide* p. 5-7**

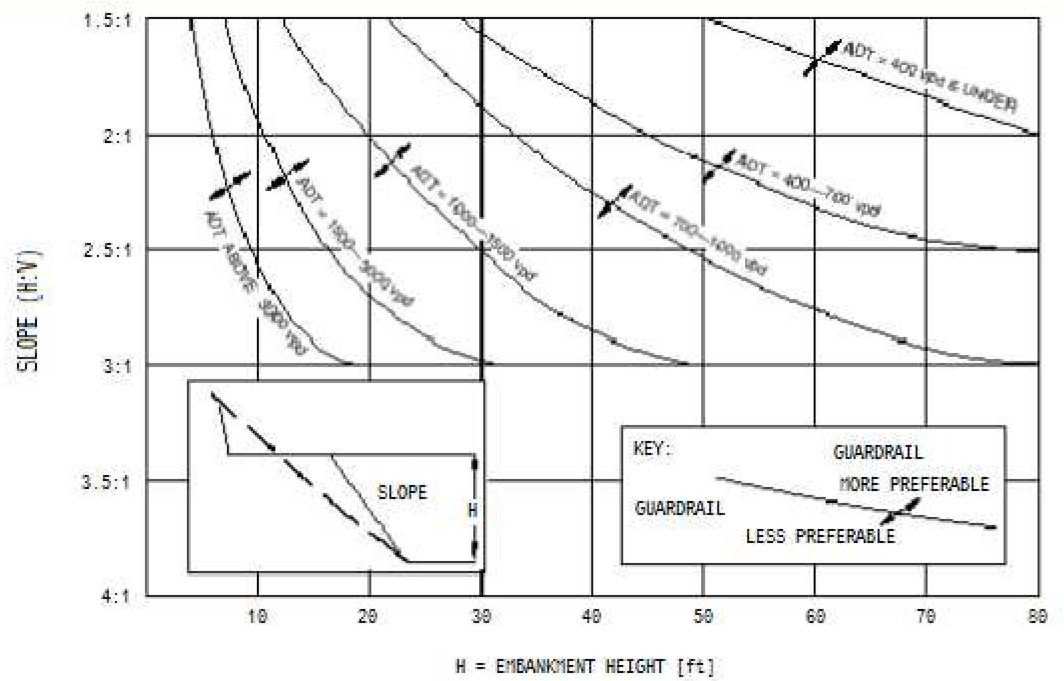
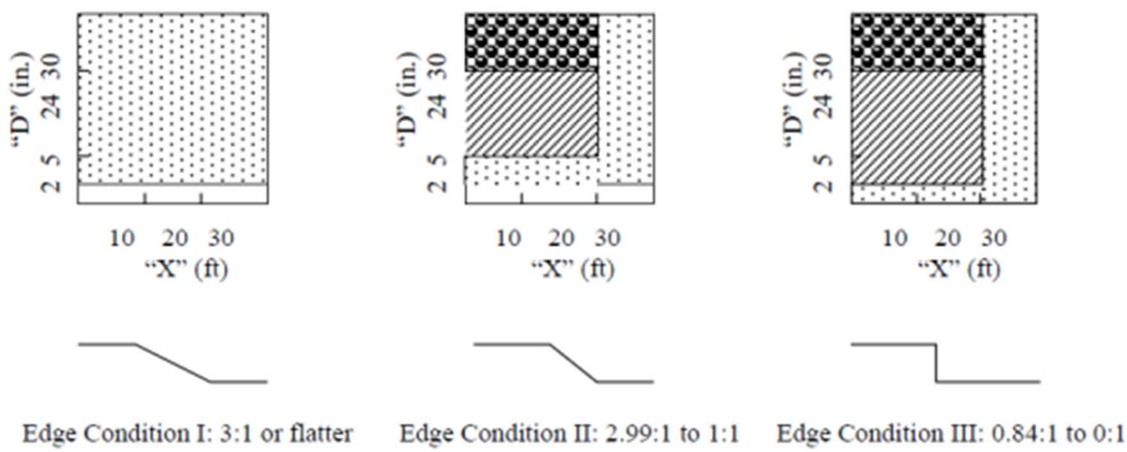
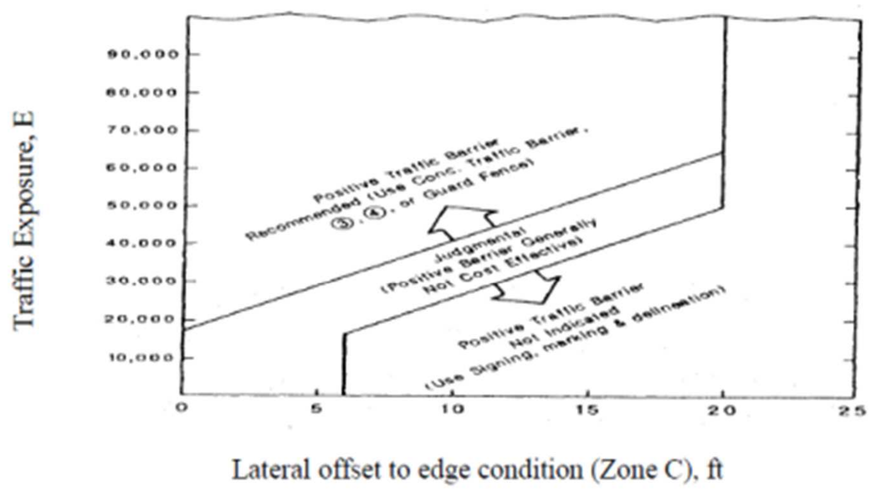


Figure 16 Definition of Treatment Zones and Treatment Selection Guidelines for Various Edge Conditions
CTRE Iowa State University: *Traffic Control Strategies in Work Zones with Edge Drop-offs* p. 38



Zone	Usual Treatment
A	SHOULDER DROP-OFF or UNEVEN LANES signs plus vertical panels.
B	SHOULDER DROP-OFF or UNEVEN LANES signs plus drums with steady burn lights. Where restricted space precludes the use of drums, use vertical panels. An edge fill may be provided to change the edge slope to that of the preferable Edge Condition I.
C	Check indications for positive barrier. Where positive barrier is not indicated, the treatment shown above for zone B may be used after consideration of all other applicable factors.

Figure 17 Conditions Indicating Use of Positive Protection
CTRE Iowa State University: *Traffic Control Strategies in Work Zones with Edge Drop-offs* p. 39



Notes:

1) E = ADT * T, Where ADT is that portion of the average daily traffic volume traveling within 20 feet (generally two adjacent lanes) of the edge dropoff condition and, T is the duration time in years of the dropoff condition.
2) Primarily applicable to high speed conditions only.
3) Barrel Mounted Guard Fence may be used in lieu of CTB where speeds of 45 mph or less and impacting angles of 15 degrees or less are anticipated.
4) An approved end treatment should be provided for any positive barrier end located within a lateral offset of 20' from the edge of the travel lane.

Table 17 Typical Criteria for Consideration for Temporary Traffic Positive Protection CTRE Iowa State University: *Traffic Control Strategies in Work Zones with Edge Drop-offs* p. 76

State	Criteria
Iowa	Drop-off depth > 10 inches, located within 10 feet of travel way (informal)
Arkansas	Drop-off depth > 5 feet
California	Drop-off depth > 6 inches, located within 8 feet of travel way; special engineering consideration for all drop-offs > 2.5 feet
Florida	Drop-off depth > 3 inches, located within 12 feet, project duration > 1 day
Minnesota	Optional for drop-off depth > 4 inches, if no wedge, located adjacent to travel way, speed > 30 mph, project duration > 3 days, length < 50 feet; if 12 inches, recommended
Missouri	Alternative for use with lane closures when drop-off depth > 2 inches
Montana	Drop-off located within 30 feet of travel way, if no wedge provided, exposures exceeding 48 hours, spacing factor < 20 feet by formula)
New York	Drop-off depth > 2 feet, speed limit > 45 mph, AADT ≥ 7500, project duration ≥ 60 days
North Dakota	Drop-off depth > 5 inches located between travel lanes, drop-offs depth > 12 inches, located adjacent to travel way, speed limit> 30 mph, project duration > 7 days, project length > 50 feet.
Ohio	Drop-off depth > 5 inches located between travel lanes, drop-off depth > 2 feet located within 30 feet of travel way, overnight exposure
Texas	Drop-off depth > 2 feet, speed limit > 40 mph
West Virginia	Drop-off depth > 3 inches, project duration > 48 hours, speed limit > 45 mph, located within 30 feet of travel way on multilane highways, located within 20 feet of travel way on undivided highways

NC Drop-off Guidelines Criteria
Drop-off depth < 2 inches, located within 10 feet or less of travel way
Drop-off depth within 2 - 3 inches, located within 10 feet or less of travel way
Drop-off depth > 3 inches, located within 8 feet of travel way
Drop-off depth within 3 – 12 inches, located within 10 feet or less of travel way
Drop-off depth > 12 inches, located within 10 feet or less of travel way
Drop-off depth within 2 – 30 inches, located within 10 to 30 feet of travel way
Drop-off depth > 30 inches, located within 10 to 30 feet of travel way

***Refer to NC Drop-off Guidelines in WZTC Design Manual**

5.9.2 Appendix B Examples

<u>Engineering Study to determine if Positive Protection is warranted</u>

<u>Problem:</u>
Culvert extension to one side of a 2L2W. Shoring is required to hold back existing fill slope once existing wings and headwall removed. Shoring location is approximately 15' right of the travelway. Several drives are within the possible barrier length of need.

<u>Exposure Control Measures investigated:</u>
1. No available detour routes.
2. Using temporary pavement or on-site detour not practical due to stream/environmental impacts on the opposite side of the road.

<u>Clear Zone:</u>
Per Roadside Design Guide, the clear zone is 20 - 24' based on 60 mph speed and ADT of 6000. Since this is a work zone, assume the low end of this range.

The hazard is inside this range.

<u>Traffic Speeds:</u>
Posted speed is 55 mph but 85% is probably around 60 as this is a rural route; not heavily congested.

<u>Roadway Geometry:</u>
Favorable; relatively flat and straight.

<u>Duration:</u>
Traffic expected to be exposed to the hazard for 1 month or less based on input from the Resident.

<u>Impacts on project cost:</u>
Significant. If PCB was used, as many as 4 crash cushions would be necessary due to breaks in the PCB for the driveways.

<u>Conclusion:</u>
The hazard is within the clear zone for a final design, however it is fairly close to the limit. It should be expected that motorist would have a heightened sense of awareness due to advance warning signage and delineation. With this said, whether or not the hazard is within the clear zone in a work zone application is debatable.

It could be argued that the severity of crash would be worse striking PCB here and then redirected into the path of oncoming traffic.

Multiple crash cushions due to the drives significantly raises costs and the breaks in the PCB over a short length would lessen the effectiveness of PCB.

Based on this, in combination with the relatively short duration, the recommendation was not to use PCB at this site. However, we did recommend increasing the level of delineation at the site by using water-filled barrier, not as positive protection, but as a superior delineator to drums or cones. This would also add a minor degree of positive protection that is much more forgiving than PCB.

Engineering Study to determine if positive protection is warranted

Problem:
End Bent #2 shall be constructed during a full road closure under a 60 day ICT. Upon completion, the road will be reopened to traffic on the existing alignment with the exposed EB about 10 ft from the SB travel lane.

Exposure Control Measures investigated:

1. There is an available detour. However, three schools are located within 1 mile of the project and the Division as well as the School Board will only support an offsite detour during the summer months. This period will be used to construct the end bent.
2. Using temporary pavement or an on-site detour is impossible due to the proximity of the existing structure, environmental impacts to the existing stream, and possible impacts to a historic property within the project limits.

Clear Zone:
Per the RDG, Table 3-1, the clear zone is 16 to 20 ft. based on a posted speed of 50 mph and a construction year ADT of 1300 vpd. Since this is a work zone and there are 30 mph design exceptions in the roadway plan, we went with the low end of this range.

The hazard is 10 ft from the travel way; clearly within the clear zone even if a 30 mph speed is used for clear zone analysis.

Roadside Geometry
The geometry was quite adverse based on horizontal curvature of 15 degrees and a slope of 8%.

Duration:
The traffic was expected to be exposed to the hazard for 1 to 3 months. Hazards associated with installation of PCB are a non-issue because the PCB can be installed while the detour is in place.

Conclusion:
Positive Protection was warranted due to the long term presence of a rigid object clearly within the clear zone. Roadside geometrics were also clearly adverse. It was reasonable to assume a higher than normal percentage of drivers would be inexperienced due to the proximity of a high school. Offsite and onsite detours were investigated as a means to lessen the exposure of motorist. Neither was determined to be practical or feasible.

5.10 Design Resources

"Manual on Uniform Traffic Control Devices", *Federal Highway Administration,* Washington, DC, November 2009

"Roadside Design Guide", *American Association of State Highway and Transportation Officials*, Washington, DC, 2002

"NCHRP Report 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features," *Transportation Research Board*, Washington, DC, 1993.

NCHRP Report 350 Test 3-11 of the North Carolina Department of Transportation, Design Portable Concrete Barrier for FHWA Approval Test #2, Test No.:020104

Precast Concrete Barrier Crash Testing, Final Report SPR 330, December 2001, Oregon Department of Transportation.

Energy Absorption Systems, Inc., One East Wacker Drive, Chicago, IL, 60601.

Barrier Systems Inc., 180 River Road Rio Vista, CA. 94571

American Association of State Highway and Transportation Officials. Roadside Design Guide.

Ivey, Don L., King K. Mak, Harold D. Cooner, and Mark A. Marek. "Safety in Construction Zones Where Pavement Edges and Drop-Offs Exist." Transportation Research Record 1163, 1988, pp. 43-62.

Center for Transportation Research and Education, Department of Civil and Construction Engineering, Iowa State University, "Traffic Control Strategies in Work Zones with Edge Drop-Offs", August 2002 p. 76.

Federal Highway Administration. Manual on Uniform Traffic Control Devices (MUTCD). U.S. Department of Transportation, Washington, D.C.

Bryden, James and Mace, Douglas (2002). Guidelines for Design and Operation of Nighttime Traffic *Control for Highway Maintenance and Construction,* National Cooperative Highway Research Program Report NCHRP-476, Transportation Research Board of the National Academies, Washington, D.C.