3. Roadside Design Process

3.1 Introduction

This chapter describes the roadside design process to be used for design of the roadside environment on provincial highway projects. The process integrates the policies from chapter 2 with the design treatments from chapter 4 to provide a traceable and repeatable design methodology.

3.1.1 Design Process

The primary objective of roadside design is to select the appropriate features and dimensions that will provide a cost beneficial design that provides a balance between safety performance, durability and operating functions for a particular highway corridor or highway segment. This is sometimes difficult to achieve because optimizing one set of functions may diminish the effectiveness of other functions. For example, a drainage ditch typically performs more efficiently if it is deep and has relatively steep sides to increase the flow depth. However, as roadside ditches are generally required adjacent to the roadway to provide positive drainage of the pavement structure and to convey surface runoff from the roadway, flatter traversable foreslopes and ditch cross-sections are desirable for roadside safety. This creates a potential conflict with the hydraulic design requirements for the ditch. The roadside design activity needs to resolve design choices such as these in a cost beneficial, clear, and consistent manner.

Factors to consider during the roadside design process include:

- Topography;
- Drainage;
- Environmental features;
- Operational and safety considerations;
- Property impacts;
- Political and financial commitments;
- Landscaping requirements, and
- Utility conflicts.

The Desirable Clear Zone (DCZ) distances from Table 2-2 are intended to achieve a balance between the safety benefit of providing a flat, smooth, firm surface with no protruding obstacles versus the possible constraints that limit the width adjacent to the travelled way. The DCZ distance is a function of design speed, Annual Average Daily Traffic (AADT), and either the foreslope or backslope of the roadside, on a tangential roadway. The DCZ distance is the width that the designer should review and try to provide or exceed in the corridor. The DCZ may vary along the highway depending upon whether the highway segment is on tangent or on a curve. The presence of a horizontal curve may influence the DCZ distance on the outside of the curve dependent on radius and design speed.

The designer should attempt to address the constraints first, whether it be the space available, environmental commitments, property restrictions, or funding, to provide the DCZ. Section 3.2.3 highlights several roadside mitigation strategies that might be considered.

In some cases, it may become apparent that the DCZ is not achievable within the corridor, or within localized segments of the corridor, even after considering a significant level of mitigation. The designer may consider an adjustment to the DCZ. This adjustment to the DCZ, should be documented in accordance with the policy in Section 2.1.2.

As design progresses, the information that is available to the designer becomes more certain and this permits further refinement of the roadside design strategy. For example, during corridor planning, the designer might only be able to determine the DCZ width for the corridor, whereas during preliminary design the designer would typically deal with the DCZ width, possible mitigation strategies, and may have determined preliminary adjustments to the DCZ width, if required.

The overall roadside design process is comprised of five basic steps:

1. Select the appropriate DCZ value from Table 2-2;
2. Identify the obstacles that exist within or just beyond the DCZ;
3. Select a mitigation strategy;
4. Document whether DCZ is available throughout project, or identify areas where it was not practical or cost beneficial to provide DCZ; and
5. Design the roadside feature(s).

Figure 3-1 illustrates the overall roadside design process.

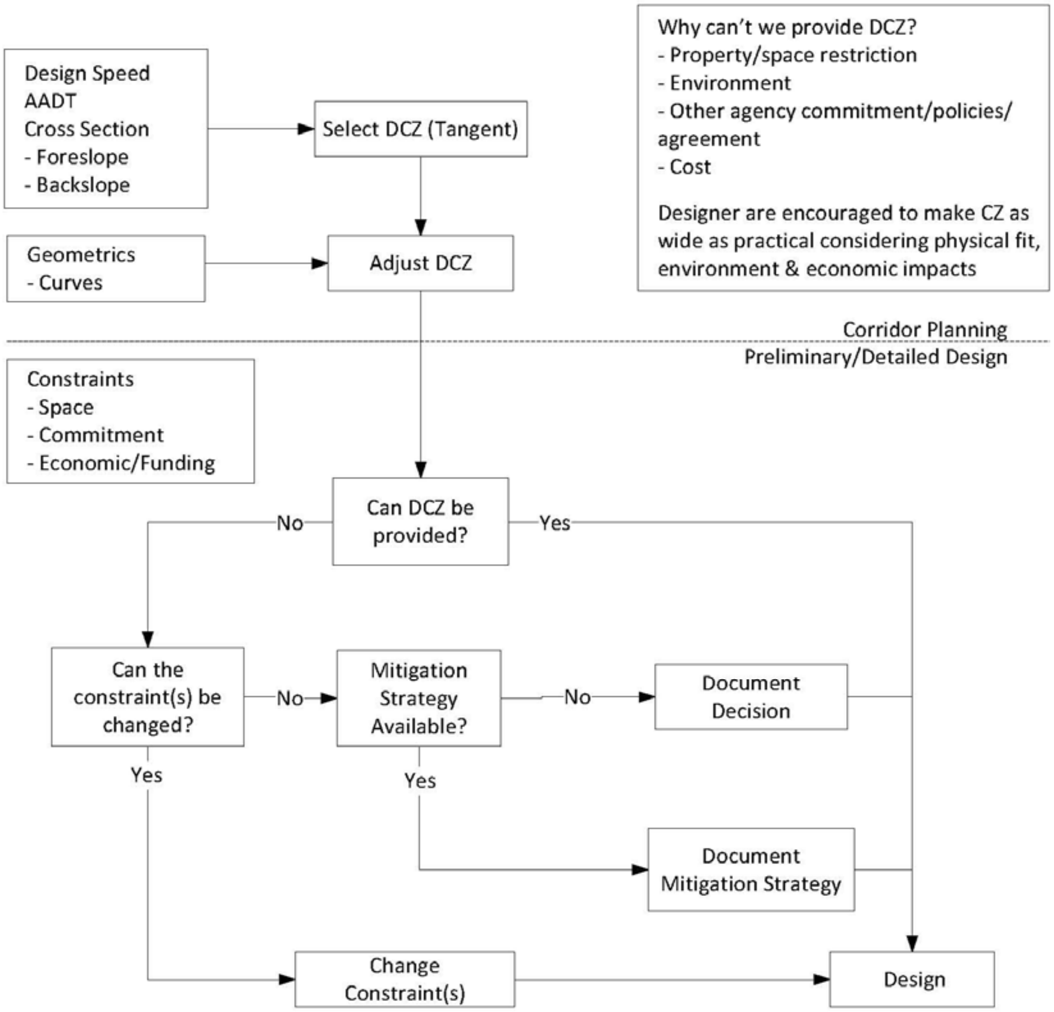


Figure 3-1: Roadside Design Process

3.1.2 Desirable Clear Zone

DCZ values from Table 2-2 are the recommended traversable obstacle free area located adjacent to the travelled way that is available for use by an errant vehicle. This border area includes paved or unpaved shoulders, bike lanes, shoulder rounding, recoverable or non-recoverable slopes, traversable features, and/or a clear runout area. The border area may be located on the outside (i.e. right side) of the highway or within the median (i.e. left side) of divided highways.

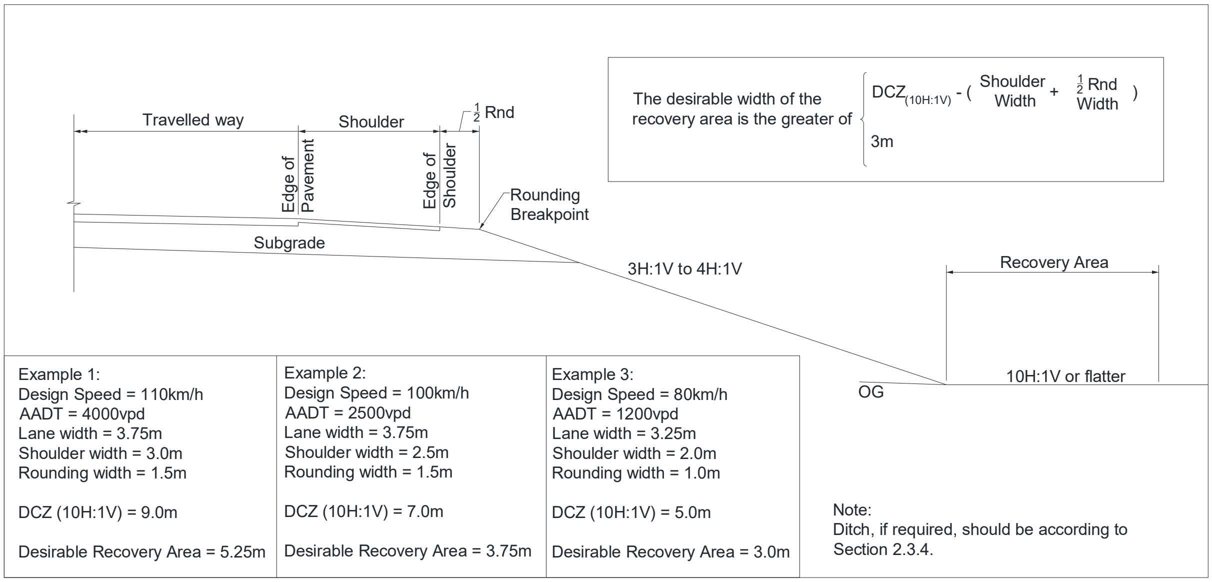
The surface within the DCZ should be relatively smooth, firm, and free of obstacles (eg., protrusions should not be greater than 100mm in size) and abrupt surface transitions to minimize negative influences on vehicle stability.

The Ministry uses a modified version of the suggested clear zone distance table from AASHTO's Roadside Design Guide (RDG). The AASHTO clear zone distance table was modified to provide a specific value, rather than a range of suggested values for each combination of the design and traffic variables, and were rearranged to illustrate the effect of slope on DCZ.

It is important for the designer to recognize that these values should only be considered as a guide when considering roadside design improvements. The DCZ does not define an absolute limit of safety. The original GM Proving Ground testing program suggested that the clear zone distance provided should be greater than the distance that most errant vehicles will likely travel off of the road. AASHTO notes that their clear zone distance values are based on limited empirical data and were extrapolated to provide only a general approximation of the needed clear zone distance for a broad range of design and traffic conditions. Recall from Figure 1-3 that a clear zone distance of 9.1 m or more on a high-speed highway with relatively flat slopes would permit about 80% of the vehicles leaving the roadway to recover. However, this also means that about 20% of the vehicles leaving the roadway will not be accommodated within the desirable clear zone (e.g., will travel beyond the DCZ). Designers should consider the safety consequences of vehicles that will travel beyond the DCZ provided, and when easily achieved and cost beneficial, exceed the DCZ.

The measurement of the DCZ distance is only applicable over recoverable surfaces (firm; 4H:1V or flatter). Non-recoverable surfaces (considered to have a falling slope between 3H:1V and 4H:1V) encountered within the roadside are traversable but generally preclude the driver from returning to the roadway. An errant vehicle will not likely stop on the steeper slope and should be expected to travel to the bottom of the slope or beyond. As such, the limit of the DCZ should be extended to compensate for the longer travel distance anticipated beyond the toe of slope. The extension of the DCZ beyond the toe of slope should be the applicable DCZ value for a

10H:1V or flatter slope, minus the sum of the width of the shoulder and half the width of the rounding; and should not be less than 3 m as illustrated in Figure 3-2.



The desirable width of the recovery area is the greater of
$\mathrm{DCZ}_{(10H:1V)} - (\text{Shoulder Width} + \frac{1}{2}\,\text{Rnd Width})$
3m

Example 1:
Design Speed = 110km/h
AADT = 4000vpd
Lane width = 3.75m
Shoulder width = 3.0m
Rounding width = 1.5m

DCZ (10H:1V) = 9.0m

Desirable Recovery Area = 5.25m

Example 2:
Design Speed = 100km/h
AADT = 2500vpd
Lane width = 3.75m
Shoulder width = 2.5m
Rounding width = 1.5m

DCZ (10H:1V) = 7.0m

Desirable Recovery Area = 3.75m

Example 3:
Design Speed = 80km/h
AADT = 1200vpd
Lane width = 3.25m
Shoulder width = 2.0m
Rounding width = 1.0m

DCZ (10H:1V) = 5.0m

Desirable Recovery Area = 3.0m

Note:
Ditch, if required, should be according to Section 2.3.4.

Figure 3-2: DCZ Distance on Recoverable vs Non-Recoverable Slopes

Along the outside of horizontal curves, dependent on design speed and radii, an adjustment factor to adjust the desirable clear zone distance should be applied. The DCZ for a horizontal curve is adjusted upward by multiplying the DCZ on tangent by the appropriate curve correlation factor from Table 2-3, and rounding to the nearest 0.5 m. This may or may not influence the right-of-way width.

The adjusted DCZ should be tapered from the DCZ on tangent sections to the wider adjusted DCZ on the outside of curves before and after the curve segment. The taper should be smoothly transitioned:

- Over the length of the spiral, for curves with spirals; and
- Over a 20:1 transition (with the taper length located ⅓ on curve, ⅔ on tangent), for curves without spirals.

Figures 3-3 and 3-4 illustrate how to transition the DCZ width on the outside of horizontal curves is applied.

Designers are encouraged to locate non-traversable design features beyond the DCZ and adjusted DCZ on outside of horizontal curves. Recognizing that some vehicles will likely travel beyond the DCZ, if the opportunity exists to cost beneficially locate obstacles well beyond the DCZ and adjusted DCZ, it should be considered and evaluated. For example, locating a line of hydro poles or a ditch farther away from the travelled way closer to edge of right-of-way to further reduce the probability of errant vehicle impacts can usually be accommodated. A small change like this may improve the safety of the roadway with minimal increase in cost dependent on local conditions.

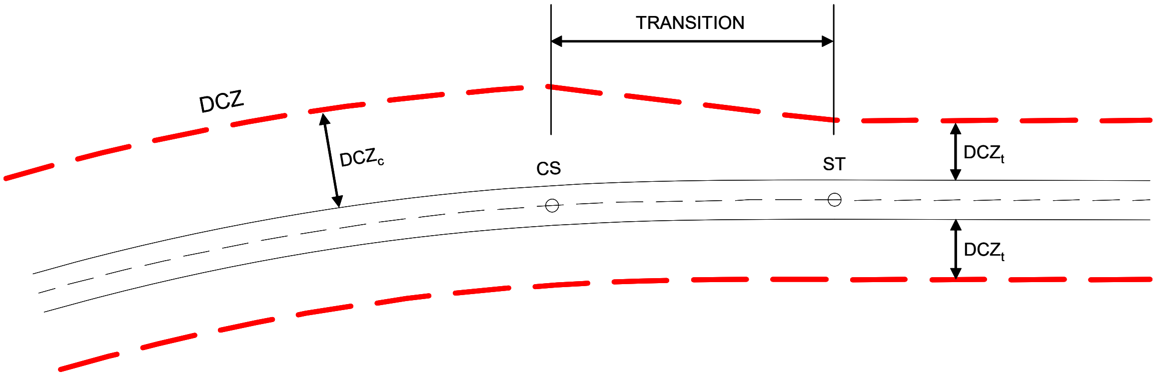


Figure 3-3: DCZ Distance Transition with Spiral

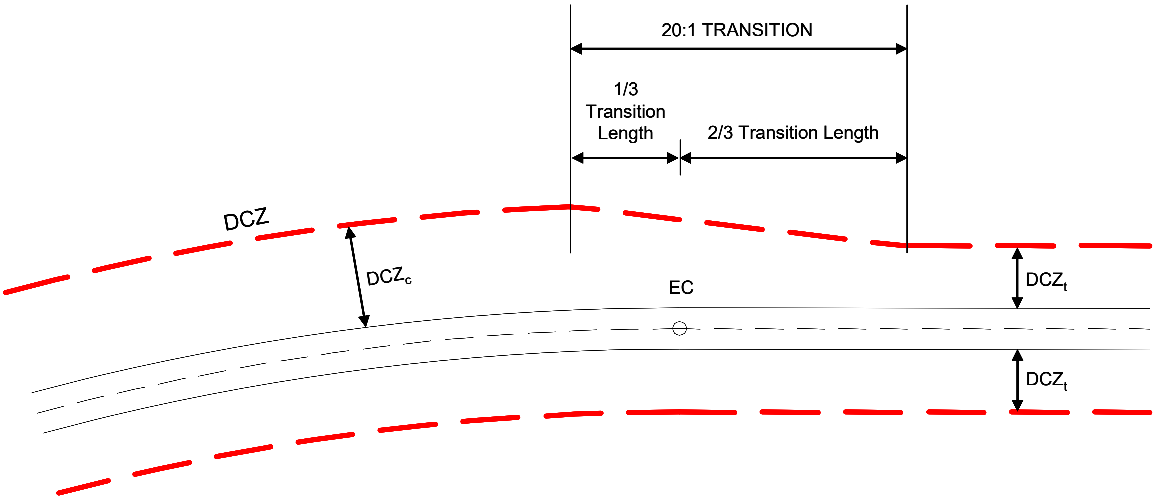


Figure 3-4: DCZ Distance Transition without Spiral

3.1.3 Identifying Areas of Concern

The next step in the roadside design process is to identify areas of concern and obstacles within or near the DCZ. An area of concern is defined as an obstacle or roadside configuration such as critical slopes that can increase the potential for personal injury and/or vehicle damage when traversed or impacted by an errant vehicle leaving the travelled portion of the roadway. Obstacles include any non-breakaway or non-traversable roadside feature typically greater than 100 mm in diameter or protrusion greater than 100mm in height located within the roadside.

The DCZ limit is plotted on the highway base plans in order to identify all of the areas of concern located within the DCZ. Figure 3-5 illustrates this process.

Potential obstacles that should be identified within the DCZ include:

- Boulders;
- Rock face/cut;
- Steep backslopes;
- Transverse slopes (including embankments and drainage ditches or channels);
- Structures including bridge abutments and piers;
- Permanent and temporary changeable message signs;
- Utility poles with non-breakaway posts;
- Traffic signs with non-breakaway supports;
- Foreslopes steeper than a 3H:1V;
- Watercourses and water bodies with a depth of 1m or more;
- Deep ‘V’ ditches;
- High fill embankments;
- Non-traversable culvert ends;
- Vegetation with 100 mm diameter and greater; and
- Non-yielding mail boxes.

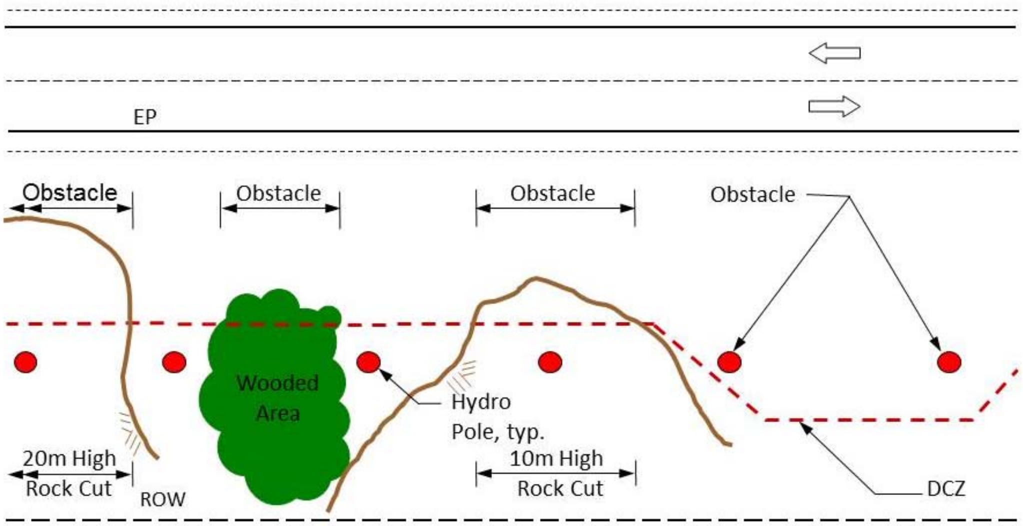


Figure 3-5: Identifying Areas of Concern and Obstacles

3.1.4 Risk Mitigation Strategies

It is recognized that the province is not always able to incorporate safety opportunities into its work program, due to physical, environmental, and/or fiscal priorities and constraints. However, the designer is encouraged to be proactive in improving safety where practical and cost beneficial. The intent of providing a desirable clear zone adjacent to the travelled way is to minimize the potential of collisions with obstacles in the roadside environment.

The designer’s initial focus should be on ways to provide the full DCZ distance, fully considering physical and economic constraints, and stakeholder expectations. However, as it is not always practical and cost beneficial to provide the full DCZ distance, therefore a mitigation strategy should be employed to reduce the severity potential of impacts with roadside obstacles.

For each obstacle identified, the following strategies initially presented in Section 1.6, listed in priority of preference, should be considered to determine the appropriate roadside mitigation:

1. Remove the obstacle;
2. Relocate the obstacle to reduce the probability of it being impacted;
3. Redesign the obstacle so that it can be safely traversed;
4. Reduce the impact severity of the obstacle by using an appropriate breakaway design;
5. Shield the obstacle with a barrier system or crash cushion;
6. Delineate the obstacle, and if the above mitigation measures are not appropriate;
7. Reduce the posted speed.

Strategies to redesign, relocate, and reduce the severity of obstacles can be accomplished using the design treatments presented in Chapter 4 of this manual.

The mitigation strategy involving shielding is unique among other strategies because it adds additional design features (i.e. roadside safety hardware) to the right-of-way, rather than modifying the feature (location, and severity, delineation). The design of roadside safety hardware is a significant aspect of the roadside design process and requires special attention. Section 3.1.7 presents the design processes for roadside hardware.

3.1.5 Shielding Obstacles with Roadside Hardware

Shielding is typically accomplished by placing roadside safety hardware (barrier systems, end treatments, or crash cushions) between the travelled way and the obstacle or area of concern. The designer should recognize that the roadside safety hardware is also considered to be an obstacle. The expectation is that a collision with roadside safety hardware will be less severe, in terms of injury and damage to a vehicle, than a collision with the obstacle being shielded. This assumes that the roadside safety hardware is designed, constructed, and maintained properly.

There are several steps in the design of roadside hardware:

1. Determine the shielding requirements (Length of Need – see Sections 2.4.3 and 3.1.6);
2. Identify potential barrier system alternatives (based on location, traffic, working width – see Section 3.1.7) and select preferred hardware; and
3. Identify potential end treatment or crash cushion alternatives for the barrier system selected (based on location, traffic, working width – see Section 3.1.8) and select preferred hardware.

3.1.6 Barrier System Length of Need

The Length of Need (LON) is defined as the length of barrier system required to shield an obstacle. This length may include some or all of the length of end terminal used on the barrier system. The length of end terminal that can be used as part of the LON is dependent on where on the terminal it can start to redirect errant vehicles during an impact. The components for LON for divided highways and undivided highways are illustrated and defined in Figures 2-15 and 2-16 respectively.

The LON is the summation of the lengths of three components:

- Approach length to the obstacle;
- Length of the obstacle; and
- Leaving length after the obstacle (also considered to be the approach length for opposing traffic, where applicable).

The LON is influenced by the:

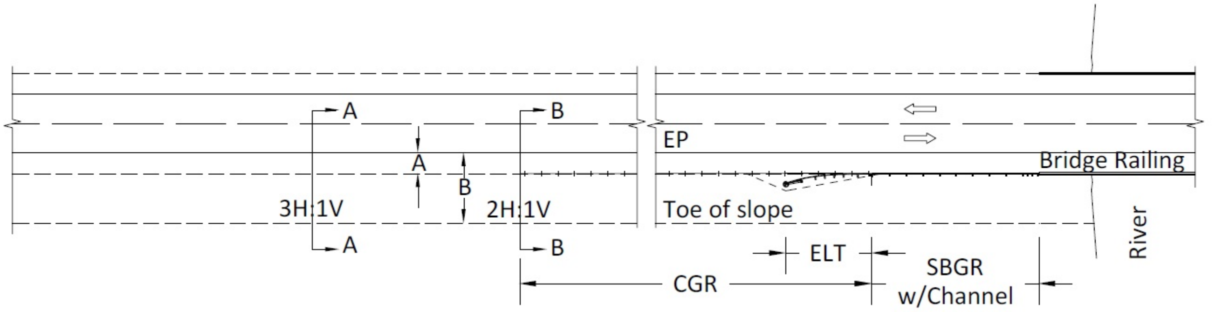
- Encroachment length that an errant vehicle is expected to travel once it has departed the travelled way;
- Distance between the back of obstacle and the travelled lanes; and
- Offset of the barrier system to the obstacle and to the travelled lanes.

The encroachment length values recommended for LON calculations are provided in Table 2-16.

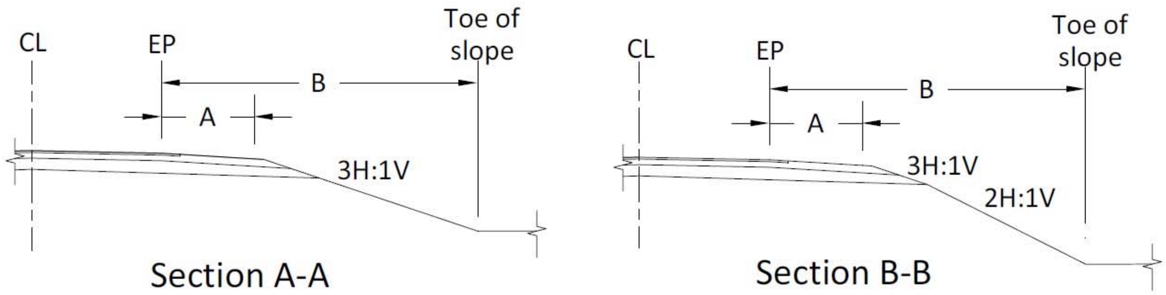
For areas of concern, such as a critical fill foreslope (steeper than 3H:1V) on the approach to a bridge, Figure 3-6 shows an existing condition on a two-lane high speed provincial highway with cable guide rail and SBGR. In this example, the existing cable guide rail is being replaced in accordance with the guidance in Section 3.3.4. The existing SBGR, structure connection and Eccentric Loader Terminal transition were in acceptable condition. As part of the evaluation, existing cross-sections taken at 25m intervals indicated that the approach end of the existing cable guide rail was located where the existing fill was 2.5m high with a 2H:1V foreslope (Section B-B). The adjacent fill section (Section A-A) 25m to the west (left) was also 2.5m high but with a 3H:1V slope.

Based on severity indices for a design speed of 100 km/h for a 2.5m high 2H:1V foreslope, a 2.5m high 3H:1V foreslope, and a roadside barrier system, the start of the area of concern is located at section B-B where the severity index for the critical 2H:1V is higher than the severity index for the barrier system. For the length of need calculation, B is equal to the horizontal distance from the edge of travelled lane to the toe of slope.

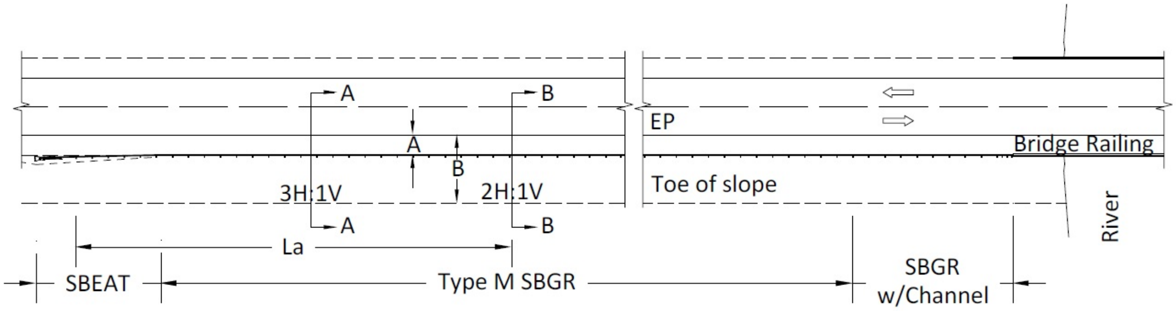
As there is currently no acceptable transition from high tension 3 cable guide rail to SBGR, the existing cable guide rail system and Eccentric Loader Terminal transition needs to be removed and replaced with Type M SBGR with an SBEAT as shown in the bottom sketch in Figure 3-6. Widening of the fill at the proposed location of the SBEAT will be required in accordance with the current standards.



Existing Condition with Existing Cable Guide Rail and SBGR on Approach to Bridge



Existing Fill Cross Sections



Proposed SBGR and LON on Approach to Critical Fill Foreslope and Bridge

Figure 3-6: Protection to Back or Bottom of Area of Concern

Obstacles located in the vicinity of interchange ramps or other adjacent roadways require special attention. The encroachment requirements for the obstacle associated with each facility should be checked to confirm the extent of mitigation required.

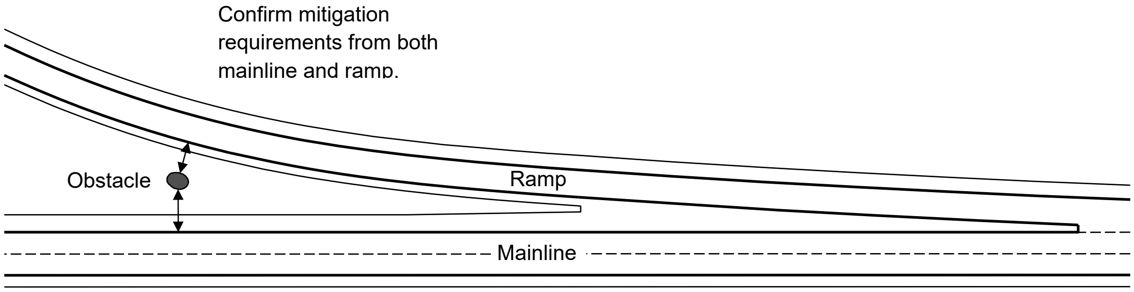


Figure 3-7: Mitigation Requirements at Exit Ramps

When multiple obstacles exist within close proximity to each other, it may be necessary to consider these obstacles as a combined obstacle because the individual LON for the obstacles may overlap or result in a small separation between the two obstacle lengths. Consider combining roadside hardware shielding applications when the:

- LON for adjacent obstacles overlap; or
- Gap between barrier systems is less than or equal to 50m.

An exception to this would be when a gap is required between adjacent barrier systems to accommodate an entrance to a property or to access a stormwater management pond. The designer should attempt to minimize the severity of an errant vehicle striking an obstacle or the ends of the barrier system after the gap by specifying an applicable end terminal active in CPS. In many cases, the need for a gap in the barrier system to accommodate entrance or access roads can be avoided by relocating the access points to the far side of the obstacle, especially on divided highways.

The encroachment length (E) for the approach end is measured from the obstacle to the:

- Edge of the through travel lane (eg., edge of pavement between the right traffic lane or ramp and shoulder); or
- Edge of auxiliary lane (eg., speed change or passing lane), where applicable.

The final component of the LON is the leaving end of the barrier system. On undivided highways, an encroachment length (E) for the opposite-direction traffic is required to shield the obstacle. The same encroachment length (E) are used for calculations, but are measured from the edge of lane for opposing direction of travel:

- Centerline of two-lane highways and multilane highways (without flush or raised medians);
- Edge of passing lanes (eg., between opposing traffic lanes), where applicable; and
- Edge of median for multilane highways (with flush or depressed medians).

Barrier systems on divided highways are generally not intended to shield obstacles from opposite-direction traffic, but this is somewhat dependent on how wide the median is and what, if any, cross-median shielding has been provided. Barrier systems located in a narrow median are more susceptible to opposite-direction hits and should have end treatments if they are located within the DCZ for opposing traffic and not shielded by an appropriate length of barrier.

Shy Line Offset and Barrier Flare Rates

The shy line is defined as the distance between the edge of the driving lane to the inside edge of a barrier system. Barriers placed in close proximity to the travel lane may cause drivers to feel uncomfortable, causing them to slow down and / or change positions. This can cause a reduction in capacity on high speed, high volume roadways. It is desirable that barriers be placed at or beyond the shy line offsets according to the AASHTO Roadside Design Guide, 2011 in table 3-1 below, however barriers may be placed at offsets equal to the recommended shoulder width required for the design speed and traffic volume. Barrier offset should not result in increased impact angles and barriers should always be constructed with appropriate grading requirements.

Design Speed (km/h)	Shy line offset (m)
130	3.7
120	3.2
110	2.8
100	2.4
90	2.2
80	2.0
70	1.7
60	1.4
50	1.1

Table 3-1: Recommended Minimum Shy Line Offsets

The AASHTO Roadside Design Guide recommends maximum flare rates for new permanent barriers inside and beyond the shy line. These values are presented in Table 3-2 Below:

Design Speed (km/h)	Maximum Flare Rate for Barrier Inside Shy Line	Maximum Flare Rate for Rigid Barrier Beyond Shy Line	Maximum Flare Rate for Semi-rigid Barrier Beyond Shy Line
≥ 110	30:1	20:1	15:1
100	26:1	18:1	14:1
90	24:1	16:1	12:1
80	21:1	14:1	11:1
70	18:1	12:1	10:1
60	16:1	10:1	8:1
50	13:1	8:1	7:1

Table 3-2: Recommended Maximum Barrier Flare Rates

3.1.7 Barrier System Selection

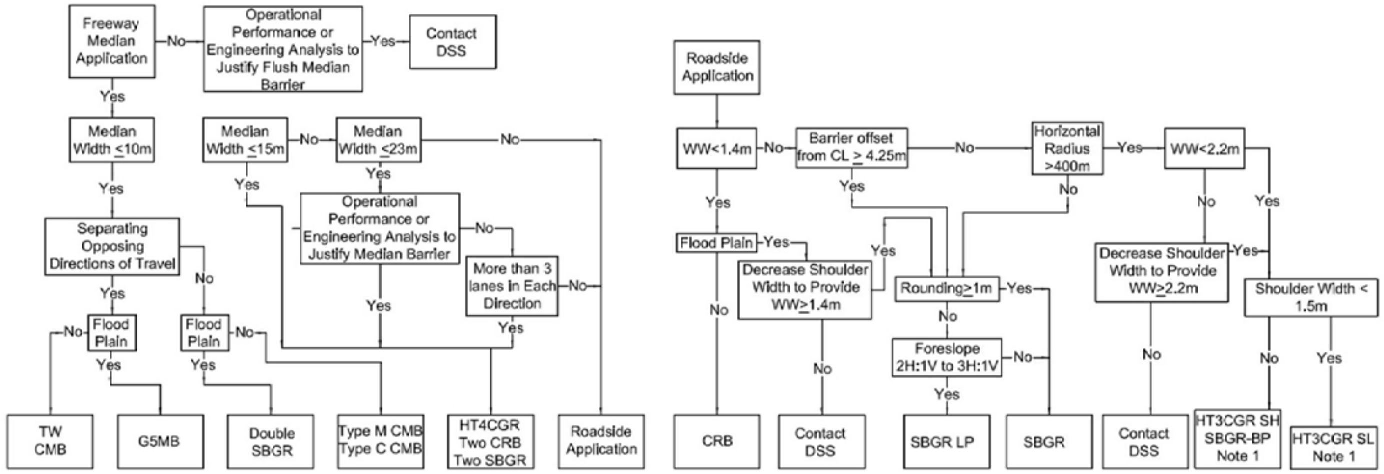
The selection of a barrier system is influenced by the type of facility, location of the system, topography, geometrics, and traffic and operational characteristics. The selection of the barrier system is based on the working width, location (median/roadside/gore), median width, offset distance from edge of travelled way to the barrier system, geometrics (tangent/curve), and the radius of curve.

Barrier systems should be used to separate opposing traffic flows where a significant risk of a cross median collision exists. Experience has shown that the risk of cross median collisions increases as the median width decreases. The Ministry’s policy for freeway medians and median barriers are provided in Section 2.3.6.

The selection of an appropriate barrier system when barriers are recommended in a median should be made using the process presented in Figure 3-8.

The working width of a barrier system governs the minimum offset between the barrier system and the obstacle that is being shielded. If the system is placed too close to the obstacle, the impacting vehicle may deflect the system into the obstacle. This may allow the vehicle to interact with the obstacle and negate the purpose of the barrier system.

A closed drainage system will likely be required with all narrow median barrier systems when median shoulders and any adjacent lanes drain towards the median.



Legend:
CMB: Concrete Median Barrier
CRB: Concrete Roadside Barrier
TW: Tall Wall
G5MB: Guardian 5 Median Barrier
M MB: Type M Median Barrier
C MB: Type C Median Barrier
SBGR: Steel Beam Guide Rail Type M

Legend (cont.):
SBGR LP: Steel Beam Guide Rail Type M with Long Posts
CGR: Cable Guide Rail
HT4CGR: High Tension 4 Cable Guide Rail (median)
HT3CGR: High Tension 3 Cable Guide Rail (roadside)
CGR: Offset from edge of shoulder to obstacle
WW: Working Width
SBGR-BP: Steel Beam Guide Rail at Breakpoint

Notes:

1. Barrier selection must provide a minimum 4.25m from centreline to traffic face of barrier. Working width of 2.0m may be used for proprietary blockless SBGR at rounding breakpoint

A. Refer to the appropriate section of the RDM for specific design guidelines for a barrier under consideration, including minimum installation length, requirements for grading and drainage, availability of transitions, terminals and treatments.

Figure 3-8 – Selection of Appropriate Barrier Systems Active in CPS

3.1.8 End Terminal and Crash Cushion Selection

Selection of end terminal or crash cushion is influenced by the type of barrier system (if applicable), type of facility, location of the end treatment or crash cushion, topography, geometrics, and traffic and operational characteristics. The selection of the end terminal or crash cushion is based on facility type (divided/undivided), location (approach/leaving end, median/roadside/gore), median width, cut/fill section, grading restrictions, geometrics (tangent or curve and radius of curve) and the size of the obstacle.

Most end treatments and crash cushions are propriety products. Some end treatments and crash cushions have similar characteristics and more than one product from one or several manufacturers may be appropriate for the same situation. As such, only general guidance is provided in the selection of an approved end treatment and/or crash cushion.

Guidance regarding the selection of end treatments and crash cushions is provided in the following sections for:

- High Tension 3-Cable Guide Rail;
- High Tension 4-Cable Median Guide Rail;
- Steel Beam Guide Rail;
- Concrete Roadside Barrier;
- Concrete Median Barrier; and
- Single Fixed Object.

High Tension Three-Cable Guide Rail:

The only end treatment standard currently active in CPS for High Tension Three Cable Guide Rail is the Safence High Tension Cable Guide Rail Terminal.

Design treatment information is presented in Section 4.3.2.2 and on the applicable standards active in CPS.

High Tension Four Cable Median Guide Rail:

There are currently two end treatments available for High Tension 4 Cable Median Guide Rail: the Gregory Safence and the Trinity HARP. Both systems meet the requirements of NCHRP Report 350. Design treatment information is presented in Section 4.3.1.

Steel Beam Guide Rail:

Figure 3-9 provides guidance in the selection of appropriate end treatments and terminals for Steel Beam Guide Rail:

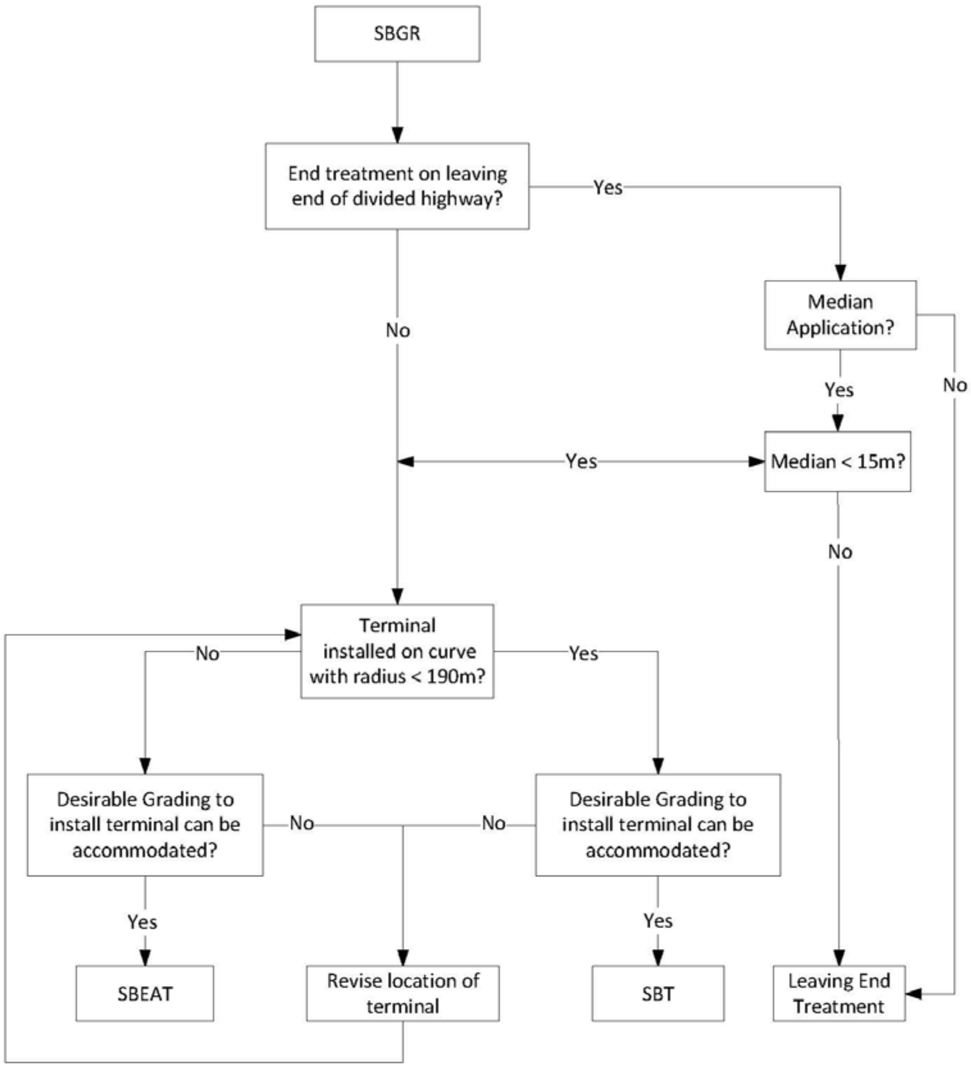


Figure 3-9 – Selection of End Treatment for Steel Beam Guide Rails

Design treatment information is presented in Chapter 4 and on the applicable standards active in CPS.

Concrete Roadside Barrier and Concrete Median Barrier:

Figure 3-10 provides guidance in the selection of end treatments and crash cushions for Concrete Roadside Barriers and Concrete Median Barriers:

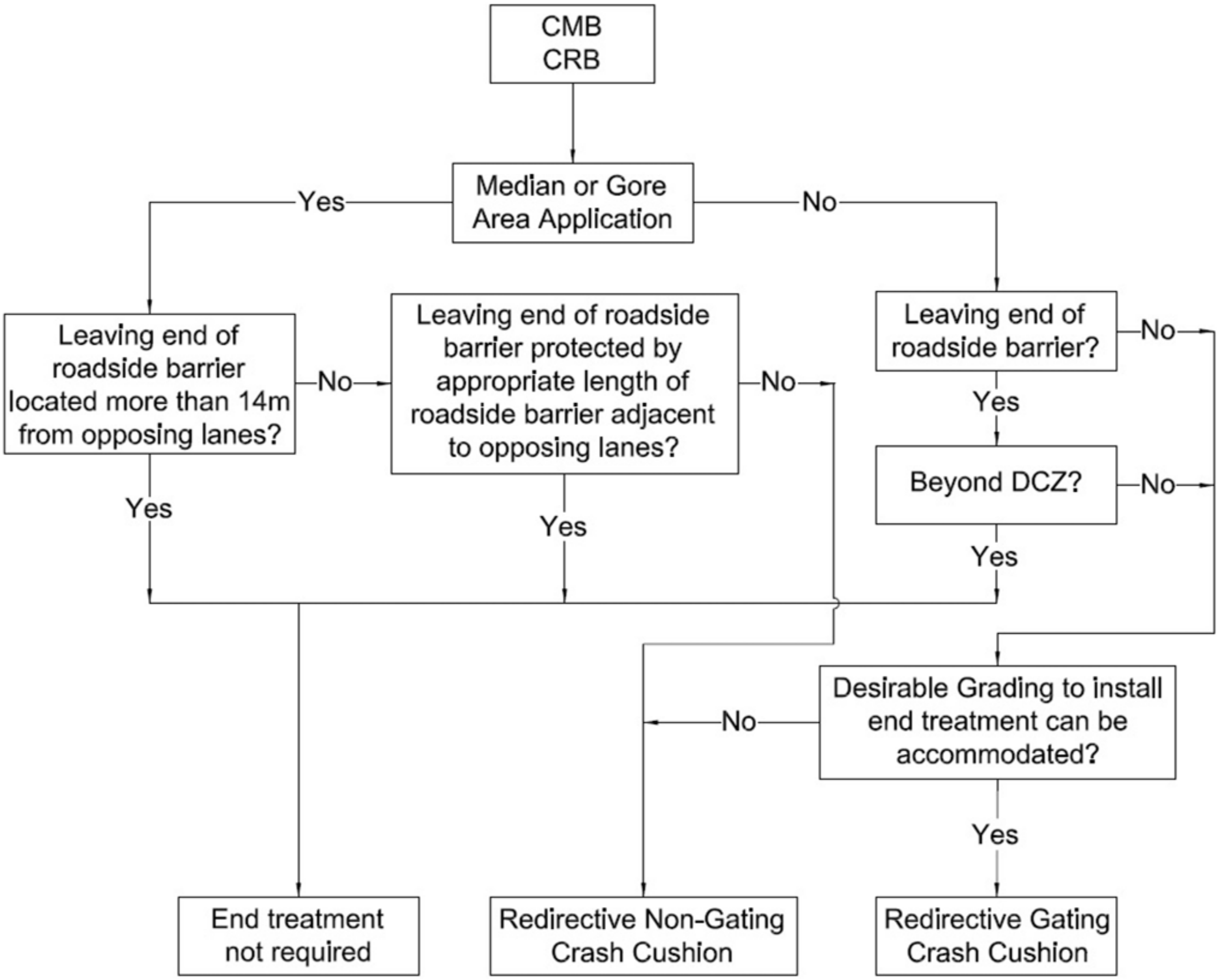


Figure 3-10 – Selection of End Treatment or Crash Cushion for Concrete Barriers

For Concrete Median Barrier, a transition section is required to properly terminate the barrier with a deeper end section and smaller end area to accommodate installation of a narrow crash cushion.

Design treatment information is presented in Chapter 4 and on the applicable standards active in CPS.

Single Fixed Obstacle:

Figures 3-11 provide guidance in the selection of crash cushions for a single fixed object located in a median, gore area, or on the roadside:

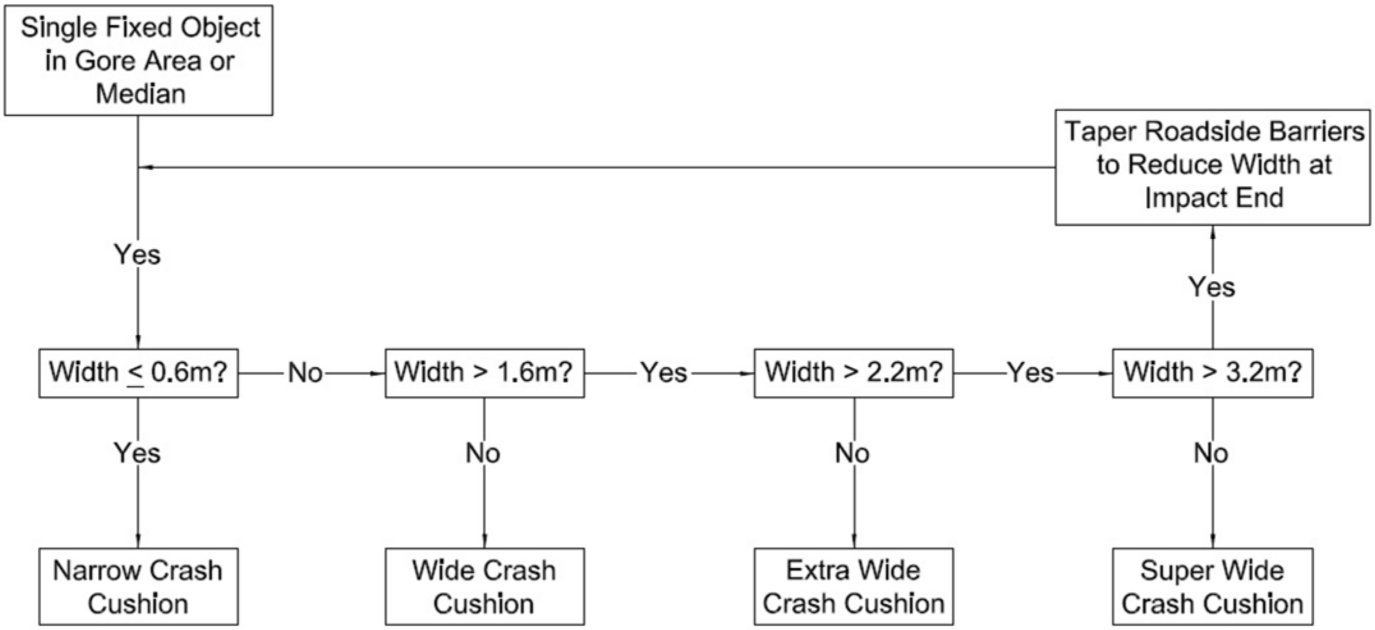


Figure 3-11: Selection of Crash Cushion for a Single Fixed Object in a Median, Gore or Roadside

Design treatment information is presented in Chapter 4 and on the applicable standards active in CPS.

3.1.9 Desirable Clear Zone

In some instances, the DCZ distance may not be available due to environmental, property, fiscal, and/or other constraints. In this situation, approval may be sought to adjust the clear zone distance for a specific segment of highway and documented accordingly in the Design Criteria. Adjusting the clear zone distance for a particular highway segment should be evaluated to ensure that it is the most appropriate strategy, and documented in accordance with the policy in Section 2.3.1.

The characteristics of the highway environment can influence the driver’s decision regarding travel speed, risk acceptance, and behaviour (passing, aggressive driving, inattention, for example). The driver takes cues from the level of consistency of how the roadway looks or feels to establish a personal level of comfort that guides driver action. Human factors studies on driver behaviour suggest that the drivers can more readily adapt to a change in the highway environment if they understand that a change will occur. This is the principle behind the use of advanced signs for major decision points to increase driver awareness, or even the tightening of successive interchange ramp curves to pre-condition a driver for the stop condition at the sideroad.

This can be extended to include the design consistency of the roadside. For example, some drivers who feel comfortable travelling at normal operating speeds on a highway with a wide and open roadside, may feel less inclined to do so on highways that have a long rock cut face in proximity to the travelled way. Changing the clear zone distance for a segment of highway will likely be perceived as a noticeable change by the driver that might influence driver comfort and action.

Major obstacles that prompt a localized reduction in the clear zone distance provided should be delineated to enhance the driver’s awareness of the possible changes in the roadside environment.

3.2 Benefit-Cost Evaluation

For roadside design on provincial highway projects, benefit cost evaluations should be completed using MTO’s Roadside Evaluation Manual and MTO’s Roadside.xlsx program.

The economic evaluation of roadside treatments is premised on a comparison of realized safety benefits and implementation costs. The avoided costs that would have been sustained by the community due to a collision associated with a particular roadside treatment are termed societal benefits. The implementation costs are the capital and maintenance expenditures required to provide and maintain the roadside treatment in a serviceable condition, generally over the service life of system or feature.

Societal benefits are calculated by estimating the anticipated cost that the community would have sustained if a collision had occurred.

Implementation costs are determined from one-time and annualized costs.

Economic factors, such as the life cycle period, discount rate, and escalation rate (if applicable), must be selected to perform the economic analysis.

3.2.1 Encroachment Rate and Probability

Obstacle modelling techniques have been in place for over 30 years. In 1974, Glennon introduced the encroachment probability model concept and this was presented in NCHRP Report 148 (Roadside Safety Improvement Programs on Freeways: A Cost-Effectiveness Priority Approach).

The encroachment probability model is built upon a series of conditional probabilities in the following form:

$$E(C) = V * P(E) * P(C/E) * P(I/C) * C(I)$$

where: $E(C)$ = estimated collision cost (\$CDN)

V = traffic volume (AADT)
$P(E)$ = probability of an encroachment (%)
$P(C/E)$ = probability of a collision given an encroachment (%)
$P(I/C)$ = probability of an injury given a collision (%)
$C(I)$ = cost of an injury (\$CDN – based on severity of collision)

3.2.2 Severity

The concept of severity was first introduced when cost-effectiveness selection procedures for roadside design were developed in the early 1970's. The principles of severity are:

- Collision severity, expressed in terms of a severity index (SI) is a surrogate measure of injury and property damage probability and severity;
- A severity index can range in value from 0 (no injury) to 10 (fatal injury); and
- Each design feature (such as a slope, bridge pier, ditch, roadside hardware, tree, or post) can be assigned an SI to reflect the relative differences in injury and property damage that would be sustained in similar collisions (speed, departure angle) between two or more features.

As an example, occupants in a vehicle that collides with a small tree or bush will likely sustain less injury than if the vehicle had hit a bridge pier. This is an intuitive result for this simple comparison, however, consider that a barrier may be installed in front of the tree and the bridge pier. Question: Is it cost-beneficial to install the barrier? The answer is determined through a benefit cost economic evaluation of design alternatives considering the installation cost of the barrier system versus the societal benefit (eg., the benefit to the community if the injuries were not sustained). This would require SI values to be assigned to the tree, the pier, and to the barrier system.

A set of severity tables that provides SI values for a broad range design features was included in Appendix A of AASHTO's 1996 Roadside Design Guide that is still in use by many road agencies today including MTO. The 1996 SI values have been modified with the addition of the 1991 FHWA SI values for rock cuts. The modified SI values used for provincial highway projects are included in Appendix A of this manual.

3.2.3 Implementation Costs

Implementation costs associated with roadside features typically consist of both construction and annual maintenance costs. However, it is sometimes difficult to determine the maintenance and repair costs of roadside features. As such, maintenance and repair costs are often ignored in the economic decisions even though they may result in significant costs. Rehabilitation costs are usually considered for roadside hardware. However, if reliable maintenance and repair information is available, it should be used for the evaluation.

Construction unit costs are available from the Ministry's HiCo estimating program. The program provides a wide range of unit costs using specific contract data, and District-wide, Region-wide, and Province-wide averages. Designers should use generalized construction cost information to determine the cost of the design alternatives. Cost comparisons can be made for specific design treatments or on a per unit length (e.g. per km) basis.

Rehabilitation costs for roadside features will generally equate to replacement costs or adjustment costs (e.g. adjustment to height of guide rail systems after pavement overlays) when future work is undertaken. Costs for rehabilitation should be obtained in the same manner as the construction costs.

3.2.4 Economic Factor Selection

The Ministry's Program Management Branch is responsible to provide the discount rate used in economic analyses. The discount rate varies by year but generally averages about 6%. For consistency, it is recommended that a discount rate of 4.5% be used for economic analysis of roadside features, unless otherwise directed.

The selection of a life cycle period is also required to perform the analysis. The life cycle period should be equal to or slightly exceed the greatest expected design life of the features being considered. This permits an opportunity to fully consider the cost of feature.

In general, the following life cycle periods should be used unless directed otherwise:

- Roadside hardware: 30 years
- Grading features: 30 years
- Structural features: 50 years

These return periods are suggested because:

The service life of roadside safety hardware can vary greatly from just a few hours to several decades. The Ministry's typical pavement rehabilitation cycle occurs about every 12 to 18 years, followed by reconstruction 10 to 20 years later. During pavement rehabilitation, only significantly damaged sections of roadside safety hardware will likely need to be replaced, and other sections may need to be adjusted to ensure acceptable system heights are maintained after pavement rehabilitation (eg., overlays). After 30 years, which often coincides with road reconstruction, steel roadside safety hardware systems will likely be rusted and near the end of their service life and are generally replaced.

The return period for grading features was selected as 30 years because major reconstruction work typically occurs at this interval. The premise is that major grading activities would likely be undertaken during reconstruction work.

The return period for the structural features was selected as 50 years to reflect the relatively longer service life expected (when compared to the other types of features considered). Recently built structural features will likely last much longer than the return period selected, but older bridges reaching the end of their service life could diminish the average service life of structural features to the period selected.

3.3 Documentation Requirements

An objective of the updated roadside design process is to ensure a consistent application of the policies and design treatments across the provincial highway system. Clear documentation promotes process consistency and this contributes to the quality of the design information generated.

It is expected that the designer will document the selection of the DCZ and the LON determined using the design process as part of a traceable design process, and for future reference, in accordance with the policy presented in Section 2.2.

Design processes, other than those presented in this manual for roadside design require authorization from the Highway Design Office, in accordance with the policy presented in Section 2.2. The documentation requirements of alternative design processes may be different from the documentation requirements listed in this section. The Highway Design Office should be contacted to confirm the documentation requirements for alternative design processes.

3.3.1 Clear Zone Documentation

Design decisions pertaining to clear zone should be documented for applicable projects in the project’s Design Criteria according to Section 2.3.1.

3.3.2 Contract Drawings

For new roadways and widened roadways, for new fill and cut sections, the specified foreslopes and backslope ratios and their respective limits should be shown on the contract drawings. For rock cut sections with rock faces, the desirable clear zone and rock fall catchment dimension, as well as ditch depth for rockfall catchment, should be shown on the contract drawings.

3.3.3 Length of Guide Rail System Documentation

Length of Need inputs and calculations for new barrier installations and barrier extension installations should be compiled into a roadside barrier design report. The simplest way to do this is to provide a sketch or part of a plan in letter size (8½” x11”) format to show the obstacle or area of concern that was evaluated for barrier. Each sheet should include the following information:

- Highway location (preferably station reference);
- Design speed and AADT;
- Lane width, shoulder width, and rounding width;
- Desirable Clear Zone limits;

- Obstacle or area of concern limit lines along with applicable severity indices;
- Barrier system location, length, and configuration;
- Expected number of yearly impacts with obstacle or area of concern without barrier vs expected number of yearly impacts with barrier system, along with expected benefit cost result from Roadside.xlsx.
- Encroachment lines (both directions if applicable); and
- Leaving end length (if applicable)

3.3.4 Existing Guide Rail Evaluations and Guide Rail Evaluation Reports

Existing runs of Steel Beam Guide Rail on high-speed roads with posted speed of 70 km/h or higher shall be replaced or converted to Type M. This involves removal of rail, offset blocks and mounting hardware, adjustment of posts and installation of new rail at Type M height and with mid-post splicing. Existing steel beam guide rail systems with wood posts on high-speed roads shall be replaced with Type M steel beam guide rail. Such existing runs of steel beam guide rail with steel posts should still be evaluated according to the procedure detailed herein as systems in poor condition may require complete replacement. Length of need should also be reviewed to determine whether an existing installation requires extension concurrent with its adjustment.

Existing runs of 3-cable guide rail shall be replaced with Type M steel beam guide rail on capital contracts.

Guide Rail Evaluation Reports are required during detailed design of reconstruction and rehabilitation provincial highway projects to justify new barrier installations, barrier replacement (including in-kind replacement), and/or barrier extensions. For existing steel beam guide rail and cable guide rail, existing installations should be reviewed and evaluated using the following criteria in the order that they are numbered as described below:

1. Mounting Height
2. System Condition
3. Operational History
4. Operational and Collision History
5. Severity of Obstacle or Area of Concern
6. Alternative Treatments

The Guide Rail Evaluation Report shall list all existing guide rail types, terminals, treatments, and transitions by station and length, and list the recommended action (Adjust, Remove, Replace, Extend) for each installation. The Evaluation Process for Steel Beam Guide Rail is provided in Figure 3-12. Runout Lengths are provided in Section 2.4.3 for calculation of Length of Need for new guide rail installations, guide rail replacement, and/or guide rail extensions. MTO Severity Index Tables for evaluation of roadside obstacles, roadside slopes, and guide rail systems are provided in Appendix A.

Steel Beam Guide Rail Criteria:

1. **Mounting Height:** When mounting heights for Type M Steel Beam Guide Rail (SBGR) are outside acceptable mounting height tolerances as specified in Table 3-3, and regrading/resurfacing of existing shoulders will not provide acceptable mounting heights at Completion of the Work, and the existing posts and rails are currently in acceptable condition, mounting heights shall be adjusted according to applicable standards active in the Contract Preparation System. When SBGR with steel posts and steel offset blocks needs to be adjusted for height, the existing steel offset blocks shall be replaced with wooden or plastic offset blocks.

System	Acceptable Mounting Height during Design and During Construction including Seasonal Shutdown – Top of Rail	Acceptable Mounting Height at Completion of the Work – Top of Rail
Type M SBGR	710 to 810 mm	760 to 810 mm
SBGR	680 to 760 mm	710 to 760 mm
SBGR with Channel	680 to 785 mm	735 to 785 mm

Notes:

a) Type M SBGR has rail splices located at every other post while SBGR has rail splices located halfway between every other post.

b) Minimum height of 660 mm is acceptable for existing non-Type M SBGR systems where posted speed limit is less than 70 km/h and system in good condition.

c) Heights measured vertically at the face of rail. Measurement to top of rail is accurate for existing installations when rail is not partially flattened from snowplows, graders, or minor vehicular impacts.

d) Where SBGR is adjacent to curb, mounting height shall be measured:
   - i. Vertically at face of guide rail when the face of guide rail is more than 300 mm beyond gutter line.
   - ii. Vertically at gutter line when face of guide rail is 300 mm or less beyond the gutter line.

Table 3-3: Acceptable SBGR Mounting Heights

2. **System Condition:** For review and evaluation of system condition, SBGR installations shall be divided into lots that are 100m in length, starting at the terminal on the approach end of the installation. Each lot consists of a maximum of 26 rail elements based on standard rail length of 3.81m each. When more than 50% of the posts and/or rail elements in a lot exhibit the following damage, replacement of the system within a lot is recommended. This damage criteria is only applicable for preparation of Guide Rail Evaluation Reports and is

not applicable to Maintenance Contracts.

a. Unsound wooden posts (e.g., broken or rotted).
b. Unsound steel posts (e.g., significant corrosion and section loss).
c. Significantly out of plumb wooden or steel posts (e.g., leaning by more than 10° transversely away from roadway: when using a 610mm (24”) carpenter level on back of post held vertically, horizontal distance to back of post at bottom of carpenter level exceeds 110mm).
d. Corroded rail elements (e.g., corrosion producing section loss or more than 50% of traffic face of rail is coated in rust).
e. Significantly dented rail elements (e.g., rail element is bent or dented with a lateral displacement from traffic face of more than 100mm). Standard depth of new rail element is 83mm in accordance with OPSD 912.125.
f. Significantly flattened rail elements (e.g. rail element height when measured on back of rail has a height greater than 400mm). Standard height of new rail element is 311mm in accordance with OPSD 912.125.

3. **Operational History:** Review with Maintenance to confirm if there are existing guide rail installations that are exhibiting poor safety performance (e.g., system failures involving vehicle penetrations, vaulting or rollovers) or there are locations involving injury or fatal collisions with roadside obstacles or features. If such locations are identified by Maintenance, a more detailed review and evaluation of the specific location(s) or guide rail installation shall be carried out in accordance with Criteria 4. If Maintenance identifies locations where guide rail could potentially be removed as an obstacle or area of concern has been removed, reconfigured, or relocated, resulting in a severity index being less than the severity index for the existing guide rail, the guide rail should be removed. MTO Severity Index Tables shall be used for evaluation of roadside obstacles, roadside slopes and guide rail systems.

4. **Operational and Collision History:** A 5 year collision summary from the Accident Information System shall be prepared for the project listing all injury and fatal collisions with existing guide rail installations (including terminals), or roadside obstacles (including rollovers on slopes). This summary shall be reviewed in the field with Traffic and Maintenance in conjunction with System Condition, and be included as an Excel file with the Guide Rail Evaluation Report. All of the injury and fatal collisions shall be highlighted yellow and red respectively. Additional information about injury and fatal collisions (e.g., road alignment, vehicle type, driver condition, weather conditions, guide rail condition, etc) from Accident Reports and field reviews or investigations shall be included in the Guide Rail Evaluation Report.

5. **Severity of Obstacle or Area of Concern:** When it has been determined that the existing guide rail mounting heights cannot be maintained or adjusted, and based on System Condition and/or Operational and Collision History, replacement of the guide rail system is recommended, the location and severity index of the obstacle or area of concern being shielded shall be reviewed and evaluated to justify continued shielding of the obstacle or

area of concern, and be included in the Guide Rail Evaluation Report. MTO Severity Index Tables shall be used for evaluation of roadside obstacles, roadside slopes and guide rail systems.

6. **Alternative Treatments:** Where continued shielding of obstacle(s) or area(s) of concern are recommended, cost effectiveness of alternative treatments such as removal or relocation/reconfiguration of obstacles or areas of concern should be considered and evaluated. When replacement of guide rail is recommended, Length of Need requirements shall be reviewed and determined in accordance with Runout Lengths MTO Severity Index Tables. For new guide rail installations, benefit cost evaluations shall be completed using the MTO’s Roadside Evaluation Manual and Roadside.xlsx program. Results of the evaluation shall be included in the Guide Rail Evaluation Report. Cost estimates for new guide rail installations and replacement of existing guide rail installation (removal and replacement) shall be included in the Guide Rail Evaluation Report.

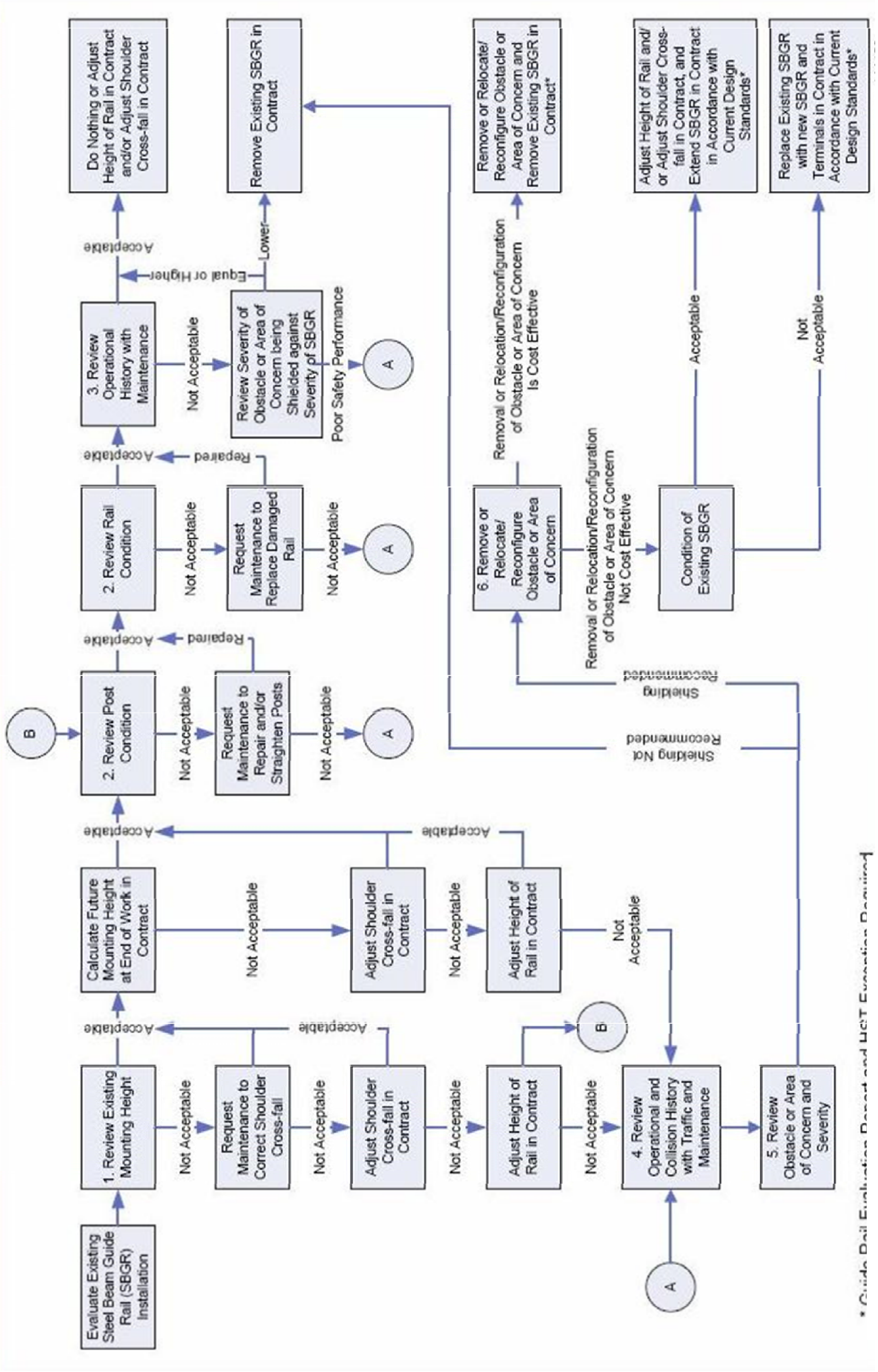


Figure 3-12: Steel Beam Guide Rail Evaluation Process for Rehabilitation and Reconstruction Projects on Low-Speed Roadways