Zone of Intrusion and Concrete Barrier Countermeasures

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Abstract

The concept of zone of intrusion is not yet widely documented in the highway geometric design industry. This paper extracts criteria from crash testing literature, to account for the critical offset behind the face of barrier - to prevent vehicles snagging on vertical fixed objects.

Reference tables are developed that provide zone of intrusion criteria for different design speeds, test levels (design vehicles), and barrier heights.

This information is useful to allow designers to optimize countermeasures; in particular beside: columns, bridge abutments, retaining walls, guide sign poles, and luminaires.

Examples are presented for:

- selectively pinning or buttressing free-standing barriers to eliminate sliding distance;

- applying short lengths of higher barrier adjacent to hazards;

- placing free-standing barrier beside retaining walls, instead of moment slab parapets;

- load distribution on structures, through the use of A-frame pole structures; and

- L-shaped foundations, to integrate with adjacent cut and fill slopes or avoid utilities.

1.0 Context

This paper extends the content of the Concrete Barrier Criteria report that was developed for the Port Mann Bridge/Highway 1 Project (PMH1). This project is a 37 kilometre design build freeway reconstruction through the Vancouver Lower Mainland, including 16 interchanges and a major bridge crossing of the Fraser River.

McElhanney is a civil engineering participant within H5M – which is a design joint venture partnership, lead by Hatch Mott MacDonald and Marshall Macklin and Monaghan. The Contractor is Kiewit Flatiron. The Owner is the Transportation Investment Corporation of British Columbia.

The barrier designs presented are therefore within the context of the British Columbia Ministry of Transportation and Infrastructure design guidelines. The designs also draw upon the experience and crash testing conducted by other North American highway jurisdictions and researchers.

2.0 Introduction

This document focuses on some of the unique situations that are not always rigorously dealt within highway design guidelines. It is intended to broaden the perspective of practitioners and provide guidance in the selection of barrier types and offsets for various situations.

The application of barriers as countermeasures on highway projects often involves unique situations. For example, the barriers are often located at the top of slope or wall. Often, there are columns or other hazards close to the barrier, i.e. within the zone of intrusion. These situations require the designer to consider a variety of barrier configuration options to achieve the required performance.

Roadside design is a process of removing or protecting obstacles to create a clear zone beside highways. The first preferred forms of treatment are to flatten the adjacent slopes, to make them recoverable, and to remove fixed objects.

Some obstacles, such as lamp standards and other roadside poles, cannot practically be removed; however, they can be made breakaway. Barriers are applied to protect vehicle occupants from leaving the road or crossing into oncoming traffic.

In British Columbia, roadside barriers generally take the form of:

- concrete barriers,
- steel beam on posts, or
- wire rope on posts

Section 3 develops the geometric limits of zone of intrusion for crash test levels with respect to a range of potential barrier heights.

Section 4 provides a summary of the test levels and overview background.

Sections 5 and 6 provide example barrier applications.

3.0 Zone of Intrusion

Zone of intrusion (ZOI) is an area behind the barrier, which is to be free of fixed objects that a vehicle could impact. This key parameter has been recently further understood through research for the preparation of guidelines for attachments to bridge railings.

The zone of intrusion concept is starting to be adopted by jurisdictions within design guides. Alberta Transportation requires ZOI clearances and the new Transportation Association of Canada Guide to Bridge Traffic and Combination Barriers provides some guidance. ZOI is now finding its way into our road design safety audits in British Columbia and has been adopted for the PMH1 Project.

Past roadside barrier designs did not always fully account for the zone of intrusion. This offset needs to be considered more consistently, in particular for retained bridge abutments, bridge columns, and roadside poles.

Table 1 lists zones of intrusion to consider when offsetting fixed objects or when selecting the type of barrier to apply.

As shown in the table, designers should generally use an 810 or higher barrier with appropriate intrusion distance in high risk areas, because of the better re-direction performance of the higher barriers. Examples of higher risk include: medians, on top of retaining walls, or beside columns.

As the barrier height is increased, the zone of intrusion is reduced, for a given test level. For example, the 1070 height barrier is effective at almost eliminating the zone of intrusion for Test Level 3 (TL-3) and, similarly, a 1420 height barrier would completely eliminate the need for TL-3 zone of intrusion.

As the design speed increases, so does the zone of intrusion. This is exhibited by the first three rows in the table: where test levels 1, 2, and 3; represent speeds of 50 kph, 60 to 70 kph and 80 to 100 kph. For an 810 high barrier, the zone of intrusion at these speeds increases from 178 mm to 610 mm.

Also, as the size of the vehicle increases so does their intrusion over barriers. This is clear in the table for TL-3, TL-4, and TL-5, whose largest test vehicle represents: pickups, single-unit box trucks, and semi-trailer trucks respectively. As the mix of vehicles in traffic becomes larger, so does the required allowance for zone of intrusion.

810 is a very common barrier height. 1070 is the newer tall wall height; required to effectively redirect vehicles at TL-5 (semi-trailers). The 1420 height barrier is shown in the table for a situation where the zone of intrusion cannot be economically achieved with a lower barrier. Raising the barrier height may be a more practical solution than moving the obstacle further away.

Table 1   Zone of Intrusion with Concrete Barrier

Test Level	Height of Concrete Barrier (mm)	Cab Width of Intrusion (mm), (i)	Truck Box Width of Intrusion (mm), (i)
TL-1	508	550	no box
TL-1	810	178 (1)	no box
TL-2	508	711 (1)	no box
TL-2	690	457 (1)	no box
TL-2	810	305 (1)	no box
TL-2	1070	178 (1)	no box
TL-3	690	762 (1)	no box
TL-3	810	610 (1)(7)	no box
TL-3	1070	254 (1) (interpolated)	no box
TL-3	1420	100 (interpolated)	no box
TL-4	810	864 (1)(7)	2032 (1)(7)
TL-4	1070	610 (1)	610 (1)
TL-4	1420	230 (interpolated)	457 (interpolated)
TL-5	810	TL-5 not achievable with 810 high barrier	
TL-5	1070	1220 (1)	2200 (1)
TL-5	1370	457 (1)	1140 (1)
TL-6	2286	0 (1)	100 (1)

Note:

(i)   Intrusion widths shown are for safety shaped (F-shaped or New Jersey) or constant sloped (California or Texas) concrete barrier. There is an inverse correlation between barrier height and intrusion width. For a specific result for another type of barrier and crash test level, refer to the appendix of reference (1). Alternately review video or high speed photos of the specific device crash tests to measure or estimate widths needed.

Table 1 above is generalized from, and relies heavily upon, the February 26, 2003, paper and crash testing conducted by Keller, Sicking, Faller, Polivka & Rohde, "Guidelines for Attachments to Bridge Rails and Median Barriers". This work documents the zones of intrusion for crash tests of various vehicles with a variety of barrier types and barrier heights.
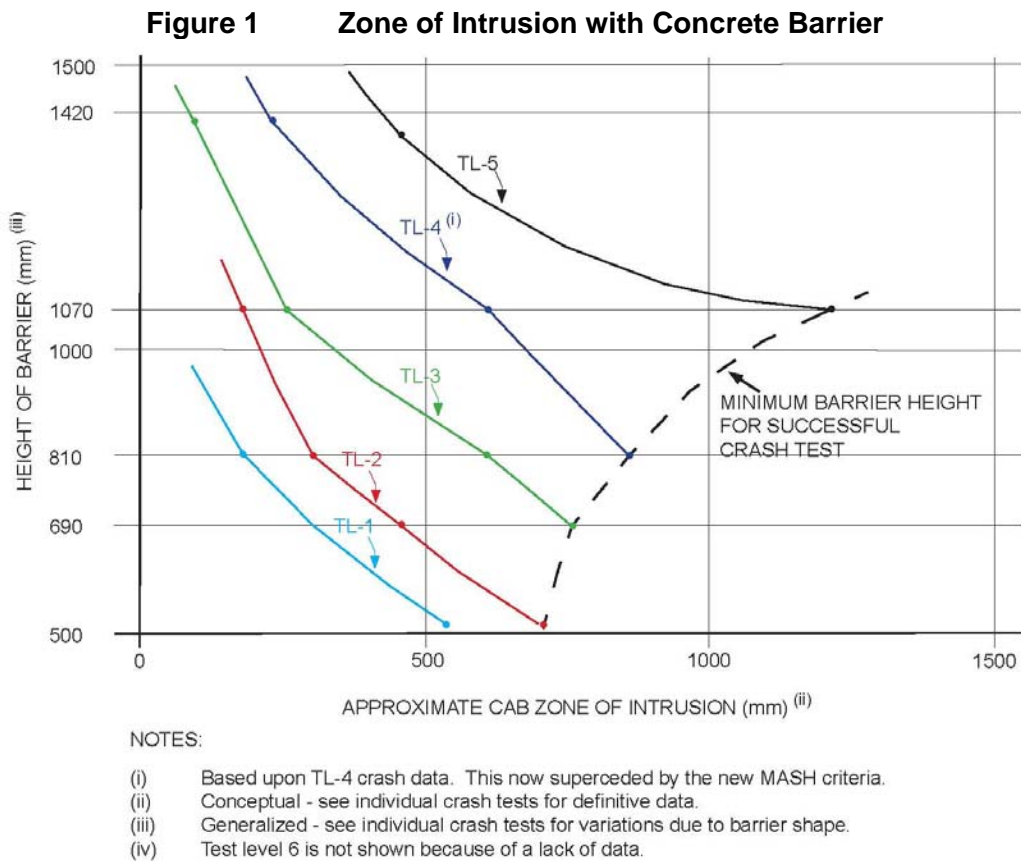
Two columns are shown for zone of intrusion: cab intrusion width and truck box intrusion width. This provides two options to design for. Where the location is constrained, the designer may wish to only provide for the width of the intruding cab. The concept in these cases may be to not snag the cab (to protect the driver); but to allow a truck box to be snagged. This assumes that the truck box is of light construction and will be crumpled. The object being hit must be either

strong enough or expendable enough to take the truck box impact. The choice to use the narrower zone will be influenced by the situation and the number of trucks at risk.

Figure 1 (below) is a graphical version of Table 1. This diagram is conceptual only. The purpose is to illustrate that:

- the ZOI increases with the higher test levels, and

- the ZOI decreases as the barrier height is raised.

For a specific application, consult the crash test results for the actual barriers being considered.

Figure 1   Zone of Intrusion with Concrete Barrier

NOTES:

(i)   Based upon TL-4 crash data. This now superceded by the new MASH criteria.
(ii)   Conceptual - see individual crash tests for definitive data.
(iii)   Generalized - see individual crash tests for variations due to barrier shape.
(iv)   Test level 6 is not shown because of a lack of data.

The curves in the graph can be used by designers, when examining a constrained location, to decide how to provide zone of intrusion for a particular mix of traffic or test level. Typical choices facing the designer are whether to move the obstruction or alignment further apart, to raise the height of the barrier, or to change the design performance level objective.

Where there are significant volumes of trucks next to crash intolerant obstructions or where accident costs are high, those wider cargo box zones may be the controlling criteria. The following graph shows approximate zones of intrusion for truck boxes. Care is needed in interpretation due to limited data. However, the points plotted are the larger observed values from reference (1).

If control of the truck box rolling is required, then taller barriers are needed:

- The 810 high barrier has large amounts of intrusion for TL-4 (1070 height is therefore preferred); and
- at least 1070 high barrier is needed for TL-5 (with higher being more effective).

**Figure 2   Truck Box Intrusion**
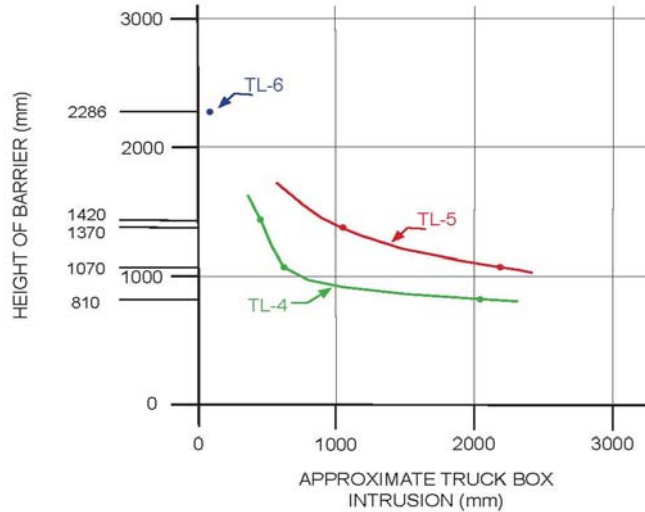
4.0   Concrete Barrier Geometric Criteria

Given a test level to design for, the application of concrete barrier has a number of considerations. There are three geometric parameters for the designer to apply:

- Height of barrier: which is largely driven by the design case (test level) and the severity of hazard;
- Sliding distance: which applies to precast free-standing segmentally-joined barriers;
- Zone of intrusion: which is an offset behind the barrier to fixed vertical objects. Keeping this area clear is intended to prevent vehicles from snagging on objects behind the barrier.

These geometric parameters are illustrated in Figure 1. Note that barriers can be rigid or segmental-free standing (sliding type).

Figure 3   Geometric Parameters
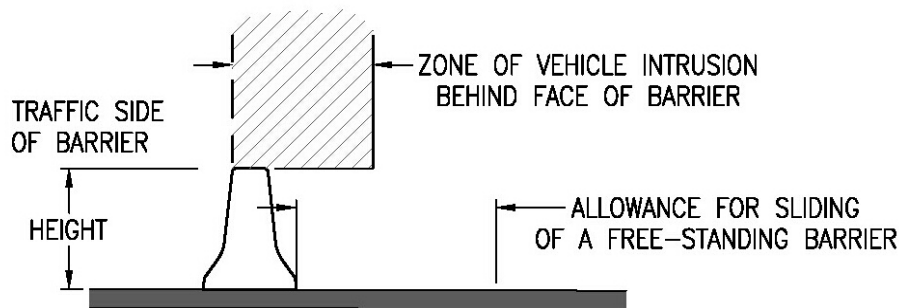
Where the barrier is of the sliding type, then total offset required is additive: offset required = zone of intrusion + sliding distance. A point often overlooked by designers.

These parameters vary by a number of factors which are location specific. The following subsections provide guidance for the geometry of barrier placement.

4.1   Height of Barrier

There are various heights of concrete barrier being considered on the PMH1 project. These are listed in Table 2.

Three concrete barrier heights are well defined in BC MoT Highway design documentation. They are CLB, CRB, and CMB/CPB; with heights of 460, 690, and 810 respectively.

The height of 1070 (42 inches) is generally being applied by the structural group on bridge parapets. This 1070 height is also referred to as the "tall SAFETY Shape" by other highway jurisdictions. In the free-standing version; the purpose of the taller barrier is to reduce the zone of intrusion, reduce sliding distance and/or accommodate larger vehicles.

The barrier height of 1420 is occasionally used for deflecting trucks or for shielding approaching headlights at the median. This height will intercept the deck of a truck, reducing rolling of the box. For lighter vehicles, the zone of intrusion can be eliminated with this barrier height.

Table 2   Height of Concrete Barriers

Designation (i)	Application	Height	Source Specification
CRB	Free-standing at roadside	690	BC MoT SP941-01.02.02
PL-1	Steel two-rail bridge railing	760	BC MoT Supplement to CHBDC S6-06 figure 12.4.3.2.1.d
CMB	Freestanding at median	810	BC MoT SP941-02.01.02,
CPB	Beside vertical wall	810	BC MoT SP941-02.01.05
PL-2	On top of retaining wall, or a bridge parapet	810	BC MoT Supplement to CHBDC S6-06 2784-1
PL-2 with combination rail,	Where pedestrians could be present on structure	1070	BC MoT Supplement to CHBDC S6-06 figure 12.4.3.2.1.i and 12.4.5.1.a.
PL-3	When warranted by bridge code	1070	
Tall Wall	Semi-trailer truck re-direction	1070	FHWA SGM-12
60G	For truck box ZOI reduction and for glare screen	1420	Caltrans Plan No. A76D
PL-2 with combination bridge rail	On a structure where bicycles are present	1400	BC MoT Supplement to CHBDC S6-06 figure 12.4.6.1.e

Note:

(i)   The BC Bridge guidelines classify barriers in the series PL-1, PL-2 and PL-3, while the BC Highway guidelines label concrete barrier components with a three letter acronym CRB, CMB and CPB. The design of taller concrete barriers is from other jurisdictions.

4.2 Test Levels

Roadside safety design is based upon crash testing of roadside devices. Barriers are rated for their performance in deflecting vehicles. The procedure for testing barriers was defined by: NCHRP Report 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features, Transportation Research Board, National Research Council; Ross, Sicking, Zimmer and Michie, National Academy Press, 1993 (4). This document was in effect at the time of the PMH1 project contract start, and for future projects has now been updated by MASH (9)

A very brief summary of the Test Levels within NCHRP 350 and MASH is contained within Table 3. These test levels are generic for North America. This presentation concept is similar to that presented in a paper by Susan Barlow of the Queensland Department of Main Roads (10). Variants (shown in brackets) between NCHRP 350 and MASH are from John Morrall's lecture notes, University of Calgary (8). Note the range of test/design vehicles that are accounted for at each test level.

Table 3   Summary of Test Levels Within NCHRP 350 and MASH

Test Level	Vehicle Mass	Speed (kph)	Impact Angle (degrees)
TL-1	820 (1100 MASH) kg car	50	20 (25 MASH)
	700 kg car		20 (25 MASH)
	2000 (2270 MASH) kg pickup truck		25
TL-2	820 (1100 MASH) kg car	70	20 (25 MASH)
	700 kg car		20(25 MASH)
	2000 (2270 MASH) kg pickup truck		25
TL-3	820 (1100 MASH) kg car	100	20 (25 MASH)
	700 kg car		20 (25 MASH)
	2000 (2270 MASH) kg pickup truck		25
TL-4	820 (1100 MASH) kg car	100	20 (25 MASH)
	700 kg car		20 (25 MASH)
	2000 (2270 MASH) kg pickup truck		25
	8000 (10000 MASH) kg single-unit truck	80 (90 MASH)	15
TL-5	820 (1100 MASH) kg car	100	20 (25 MASH)
	700 kg car		20 (25 MASH)
	2000 (2270 MASH) kg pickup truck		25
	36000 kg tractor trailer	80	15
TL-6	820 (1100 MASH) kg car	100	20 (25 MASH)
	700 kg car		20 (25 MASH)
	2000 (2270 MASH) kg pickup truck		25
	36000 kg tanker truck	80	15

<u>Selecting the Test Level</u>

Different test levels often apply at different locations. They could be applied as follows; but this does depend on the assigned project design criteria:

TL-1   Side roads, where the design speed is 50 kph or less.

TL-2   Side roads, where the design speed is 60 kph to 70 kph.

TL-3   Where there are not many trucks and where the design speed is generally 80 kph or higher.

TL-4   Where there are significant numbers of buses or delivery trucks, and where the design speed is generally 80 kph or higher.

TL-5   Where there are many semi-trailer trucks and the design speed is 80 kph or higher.

Where there are few trucks, the first three test levels are generally adequate: TL-1, TL-2, or TL-3. In these cases, the vehicle speeds will often determine which test level to use. However, at high risk locations like drop offs or bridges, TL-4 is often the minimum applied.

Where truck volumes are significant, then TL-4, TL-5, and TL-6 levels address progressively larger trucks. These test levels represent: cargo box trucks, semi-trailer trucks, and tanker trucks (plus a compliment of smaller vehicles).

For a more rigorous determination, a cost benefit assessment will indicate which level to use. Note that, any theoretical test level selection will be over-ridden if there is a history of truck accidents. In which case, the accident history will determine the level of counter-measure that is appropriate.

4.3   Sliding Distance

In many British Columbia applications, the roadside barrier is pre-cast free-standing on asphalt. These segmentally linked barriers are intended to slide to reduce the deceleration stress on the vehicle occupants; as well as being easy to install for temporary applications. Therefore, it is necessary to allow for the deflection of these barriers.

Where sliding barrier is installed on the top of a retaining wall, a paved sliding distance behind the barrier is required to support the barrier during impact. At roadside, a rounded gravel shoulder is considered adequate.

Note that sliding distance is also analogous to the deflection of steel guardrail. In that case the movement of the rail, as well as the zone of intrusion need to be added to achieve a suitable offset to a fixed vertical object.

Based upon prior crash test results (5) (6), we chose, for the PMH1 project, two sliding distances as indicated in Table 4.

The sliding distances selected are 100 to 200 wider than most crash test results that were obtained for BC MoT segmental pre-cast concrete barrier.

Table 4   Sliding Distances Interpolated for BC MoT Free Standing Barriers

Application	Sliding Offset Behind Barrier (i) (ii)
High Speed > 80 kph	1000 (5) (6)
Low Speed ≤ 80 kph	500 (5)

Notes:

(i)   In addition to the sliding distance, zone of intrusion to also be added where barrier is placed beside vertical obstructions.

(ii)   Many jurisdictions have segmental barriers that have more of a hinge at the join between pre-cast segments. These types have large sliding distances.

The segment lengths, type of joint and amount of torsion that the joint transmits will significantly affect the segmented barrier's deflection. Refer to crash tests of your particular jurisdiction's pre-cast barrier to determine barrier specific deflections to allow for.

Sliding distance does not apply if the barrier is rigid. Types of rigid barrier include the following:

- Cast-in-place reinforced barrier with a foundation (for example with moment slab).
- Extruded or cast-in-place continuous barrier, for example Alberta CB6-4.3M3.
- Reinforced bridge parapet.
- Segmental concrete barrier that is pinned to the underlying pavement structure.
- Filling or buttressing behind the barrier, for example with gravel.

Converting to a rigid barrier, instead of a sliding barrier, is one way to address ZOI or limited space requirements.

5.0   Applications

The application of the preceding criteria is dependent upon the situation. The barrier criteria selected is affected by: the design speed, the types and frequencies of vehicles in the traffic mix, the exposure or hazard risk, and the proximity of fixed objects. Primarily, the designer is to select: the height of barrier, whether it is to be rigid, and consider the site specific requirements for a safe offset from fixed objects.

Note that abrupt changes in terrain, such as steep side slopes, creek banks, cross ditches and headwalls are also high risk locations which normally require protection.

5.1   Decision Process

As an example of a site specific barrier offset decision process, the following may be the sequence of treatments considered, in order of preference:

1)   Offset object and specify side slope, such that clear zone is achieved.

2)   Reshape the ground or the object; so that it will not snag a vehicle. An example includes extending and bevelling the end of a culvert with wheel bars.

3)   Make an object breakaway, if not too heavy. The typical examples are luminaires or signs on post(s).

4)   Apply sand barrels or an attenuator to protect an isolated object.

5) Provide a barrier flare with concrete roadside barrier.

6) Where risk is higher (for example at vertical drop or at median), provide a taller concrete barrier.

7) Where both zone of intrusion plus sliding distance cannot be achieved practically – pin pre-cast barrier in the vicinity of the object, providing the appropriate zone of intrusion.

8) Make the barrier continuously poured (rigid with end anchors), to eliminate sliding.

9) On a bridge or retaining wall, cast-in-place reinforced parapet connected to deck or moment slab.

10) With a pole in a narrow median, raise a fixed pedestal to the appropriate height to achieve a smaller zone of intrusion, transitioning up and down from median barrier.

11) At high volume locations with trucks, consider tall wall concrete barrier, 1070 high.

12) Where there are high volumes of trucks, bridge columns, or the corner of an abutment wall - close to the roadside or at median driving lanes - raise the concrete barrier further to 1420 height to achieve the required narrow zone of intrusion.

5.2   Cost Benefit

To justify substantial barrier upgrading costs, it is useful to conduct a cost benefit analysis. This can be achieved with a spreadsheet containing traffic volumes, traffic mix, frequencies of relevant accidents, accident costs and barrier costs.

Example of Simplified Calculation

Given a countermeasure which would protect for trucks, in addition to cars:

- With 120,000 AADT, then 60,000 AADT in one direction.
- With 8% trucks, then 1,752,000 trucks will pass the hazard each year.
- With a 20 year design life of the project then 35 million trucks will pass by.
- Length of hazard of 3 m plus say 20 m crash zone = 23 m protection zone.
- Using an accident rate of 1 per 650,000 km, then the accident rate per meter is 2×10^{-9}.
- Number of trucks X Hazard zone length X accident rate per meter = 1.2 accidents at the site, over the life of the project (all types of accidents).
- Using 12% off road right accidents, then 0.15 collisions will occur with hazard over the design life of the project.

Apply the cost of the accident, from your jurisdictions actuarial values. Note that since the accident would occur with or without the countermeasure, one must estimate the accident cost reduction: if the countermeasure would prevent the cab of a truck from snagging on a column, for example. Then, the accident cost savings would be equivalent to the cost of a fatal accident minus the cost of the average accident times the frequency.

So, using BC's ($5.6 million for the fatal accident cost - $650,000 for the average accident cost) X 0.15, gives a $740,000 accident cost savings.

In this example the calculated accident cost would easily justify increasing the height of a barrier and making it rigid to put the hazard outside of a truck cab zone of intrusion.

This approach does not discount future accident costs. So, one can consider this approach conservative and humanistic

For a more rigorous approach, consider applying the Roadside Safety Analysis Program (RSAP) software (11).

5.3   Example Concrete Barrier Applications

Generally all hazards within clear zone require protection from vehicles snagging on them; except for low volume and/or low speed roads where the clear zone will be explicitly narrower. Most jurisdictions have standardized roadside barriers to apply. However, there are many cases where the designer must apply the concepts of zone of intrusion, select an appropriate barrier height and determine whether to make a barrier rigid.

To assist in visualizing the design options, the following figures show examples of typical applications:

a)   Apply free-standing Concrete Roadside Barrier (CRB) at the roadside where clear zone is not available. Allow for sliding distance based on design speed. Select zone of intrusion based upon test level. This is a BC MoT conventional barriered right side shoulder treatment.

**Figure 4   Precast Concrete Roadside Barrier**
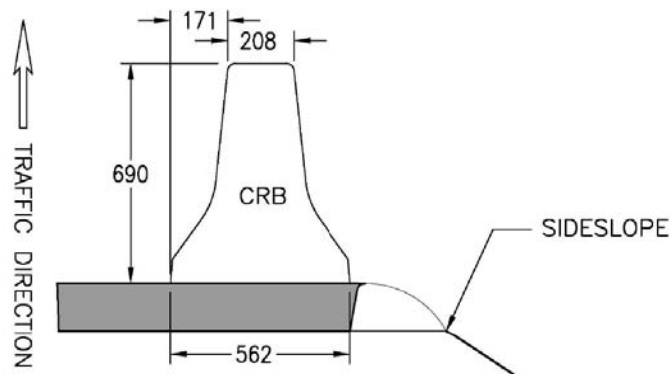
b)   Apply free-standing Concrete Median Barrier (CMB) at paved medians with median shoulders on both sides. In British Columbia, this is the conventional narrow median treatment. For other jurisdictions and higher volume situations a tall wall may be more appropriate.

**Figure 5   Precast Concrete Median Barrier**
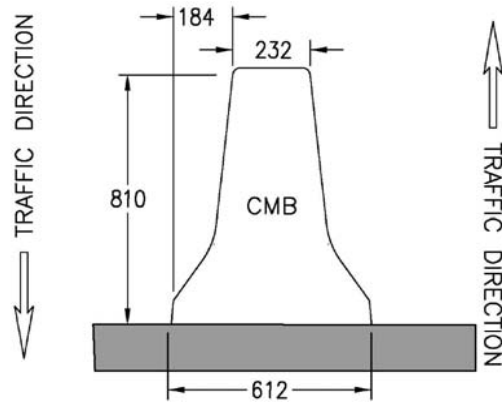
c)   Apply free-standing CMB to the roadside where there are higher risks, such as vertical obstructions or drop offs. Allow for sliding distance based upon design speed. Select zone of intrusion based upon test level. Common examples of this are on top of retaining walls. The sliding zone to apply depends upon the design speed.

**Figure 6   Precast Concrete Barrier at Retaining Wall**
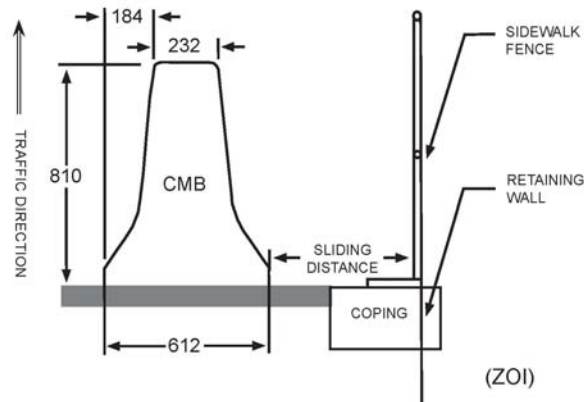
d)   Make CMB rigid where sliding zone is not available, but the zone of intrusion (ZOI) can be made available. Guide sign columns close behind the barrier are an example of this. See Section 4.3 for methods of making barriers rigid.

**Figure 7   Pinned Concrete Barrier**
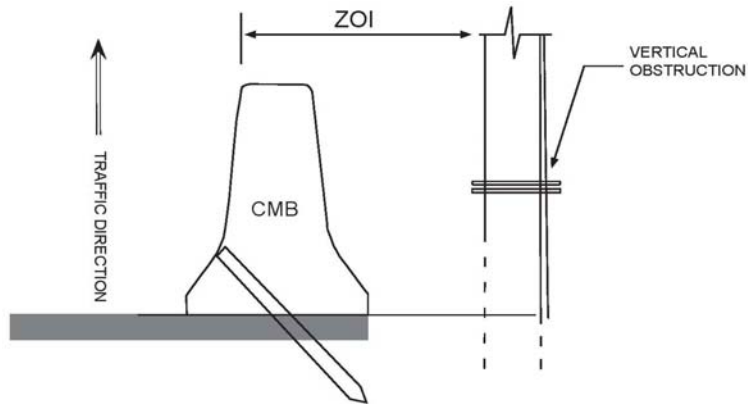
e)   Apply CPB against vertical walls. Ensure that the starts of the walls are appropriately treated to prevent vehicles snagging. The vertical wall above CPB, if smooth, may be within the ZOI, if the beginning of the wall is appropriately transitioned.

**Figure 8   Precast Concrete Pier Barrier**
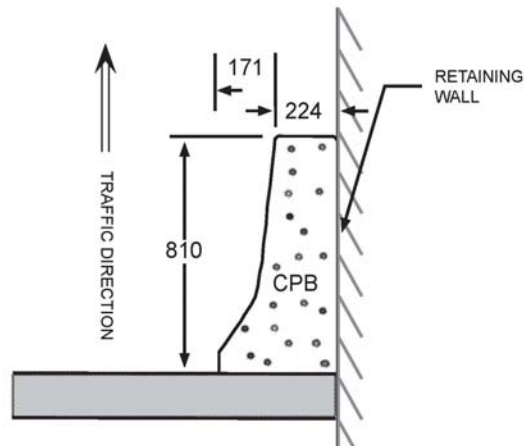
f)   Where there are trucks with limited space and a conventional moment slab parapet is not desired, consider a continuous (extruded or cast-in-place) barrier to eliminate sliding distance.

Figure 9   Rigid Continuous Barrier
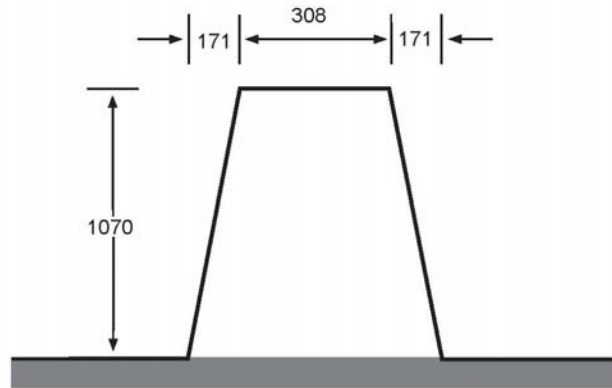
g)   Apply rigid CMB at median bridge columns with adjacent HOV lanes (where there are few trucks). Allow for an appropriate zone of intrusion, depending upon design speed. Buttressing pre-cast barrier with gravel and an asphalt cap behind will prevent sliding and reduce the offset required.

Figure 10   HOV Lane Median Barrier at Column
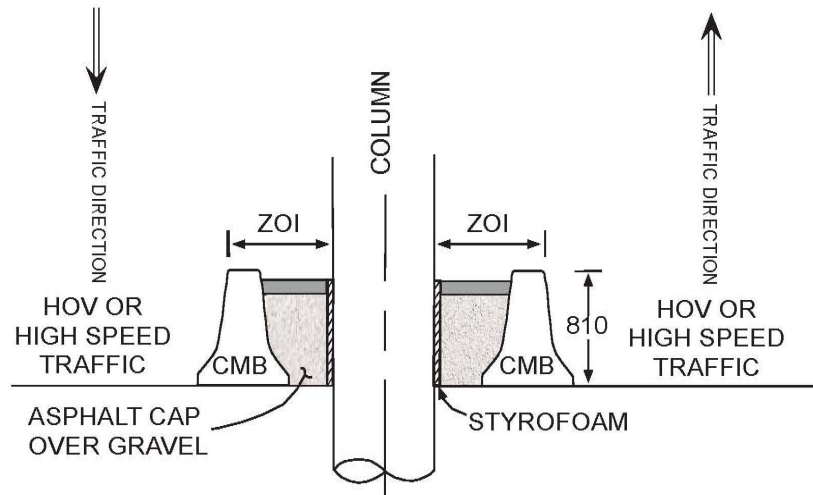
h)   Apply 1420 rigid barrier adjacent to General Purpose lanes, where there are obstructions close behind, sliding distance is not available, and control of truck box zone of intrusion is desired. The gravel buttressing behind is optional; since the continuous barrier is rigid (fixed/reinforced end termini required). On the PMH1 project this more substantial treatment is due to the high volume of trucks on the mainline outside lanes. This barrier, developed by Caltrans, can also be used as a glare screen at medians.

Figure 11　　General Purpose Lane Barrier at Column
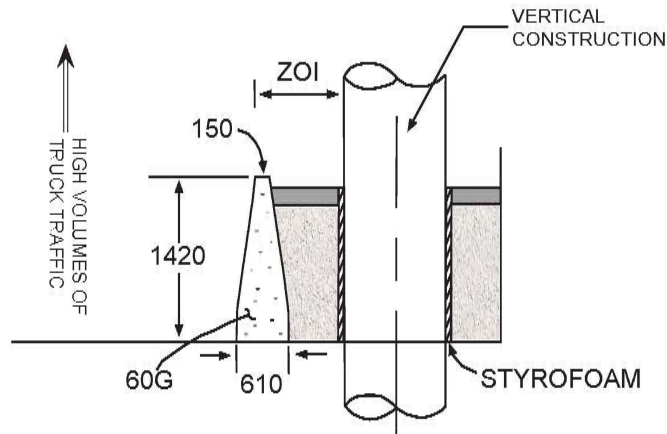
i)　　If a concrete barrier is integral with a structure it falls within the bridge code S6-06 and the BC Supplement Chapter 12.

The BC Bridge Code has three performance levels: PL-1, PL-2, and PL-3, with an allowance for 1370 high barrier as well. Examples of typical parapets for the three performance levels follow.

Figure 12　　PL-1 Steel Two-Rail, PL-2 Concrete Parapet, PL-3 Concrete Parapet
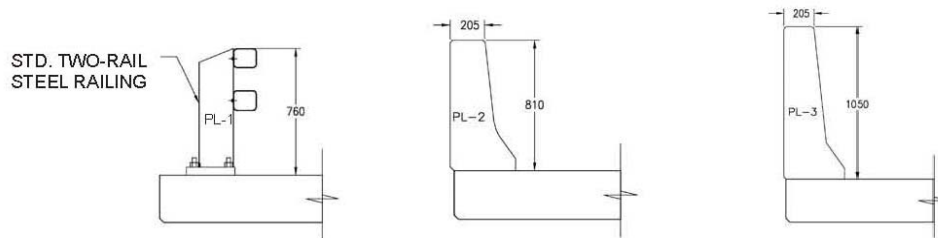
Equivalencies between bridge barrier and highway roadside barrier terminology are as follows:

Table 5　　Railing Level Equivalency Table (12)

| Bridge Parapet Performance Level (AASHTO Guide Specifications)	Equivalent Roadside Barrier Test Level (NCHRP Report 350)
PL-1	TL-2
PL-2	TL-4 (i)
PL-3	TL-5

Note:

(i)　　MASH, changed the crash test for the single unit truck (TL-4) from an 8000 kg vehicle to 10,000 kg and from 80 kph to 90 kph. This is a substantial increase in energy; so results from past crash tests may not be the same if tested today.

Chapter 12 of the BC Supplement to S6-06 (national bridge code) provides a series of tables to calculate which performance level to apply. The indexes are based upon: average annual daily traffic, type of highway, horizontal alignment curvature, grade, height of structure, shoulder width, and percentage of trucks. The structural engineer will determine which performance level to apply on an individual structure basis. In general, the majority of structures require PL-2, and some require PL-3.

Add bicycle or pedestrian rail on top of bridge parapets, where there is a drop off hazard and these users are present. Alternately, in well lit areas extend the concrete barrier to the equivalent combination barrier height, or add a sidewalk fence behind. The fence height for pedestrians is 1.05. The fence height for bicycles is 1.40.

j) To transition from the PL-3 (1070) height to the PL-2 (810) height a vertical transition is introduced at the end of the structure. This same type of treatment is often used where different heights of barriers are to be introduced. As a guideline, approximately a 1:10 rate of vertical transition is often used.

**Figure 13   Concrete Barrier Profile Transition**
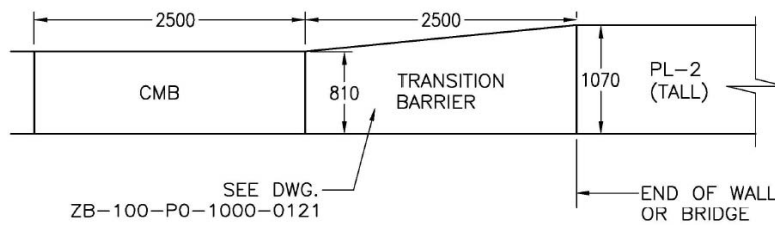
6.0   Foundations

6.1   Customized Shoulder Foundations

The most common obstacle to protect for is a guide sign pole structure or a heavy luminaire. Standard footings for these are trapezoidal (requiring a significant width of soil buttressing) or inverted tee shaped (with minimum cover requirements). However, ditches or fill slopes are the predominate treatment along the edge of highways and conflict with these standard types of foundations. To solve this common dilemma, an L-shaped foundation is effective.

Figure 14   L-Shaped Foundation

17
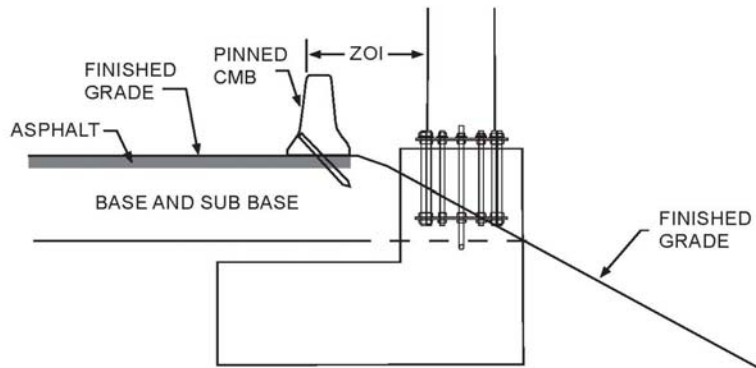
6.2   Median Transition to Higher Pedestal

At narrow medians, which are widely used in mountainous jurisdictions, there is often limited ability to provide zone of intrusion for median poles. For lighting, the preferred solution is high-mast lighting that does not require median poles, but this is often not practical between interchanges and roadside luminaires will not always reach a wide pavement. For sign bridges, there is often no alternative to placing a pole at the median and on top of a concrete barrier.

One solution may be to raise the pole pedestal to a height where the zone of intrusion can be minimized. Heights to consider raising the median to are 1070 or 1420. Figure 15, shows one design for a raised median pedestal. Note that without a wider median barrier, it is generally not possible to fully provide for zone of intrusion. However, the higher pedestal will reduce the risk of snagging at Test Level 3 or lower.

**Figure 15   Raised Median Pedestal**
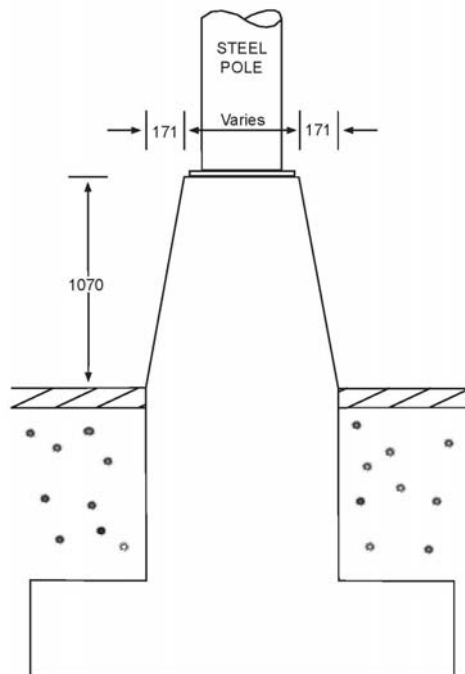
6.3   A-Frame Supports

Where larger guide signs are to be supported on bridge decks, or on light weight fills; it is necessary to distribute the resultant loads over a broader area. To achieve this, A-Frame pole structures at each end of the sign bridge are effective.

Legs of the A-Frame are then supported on single vertical piles with flange plates (eliminating the need for a pile cap), or in the case of a structure, supported on pairs of corbels.

Figure 16   A-Frame Pole Supports
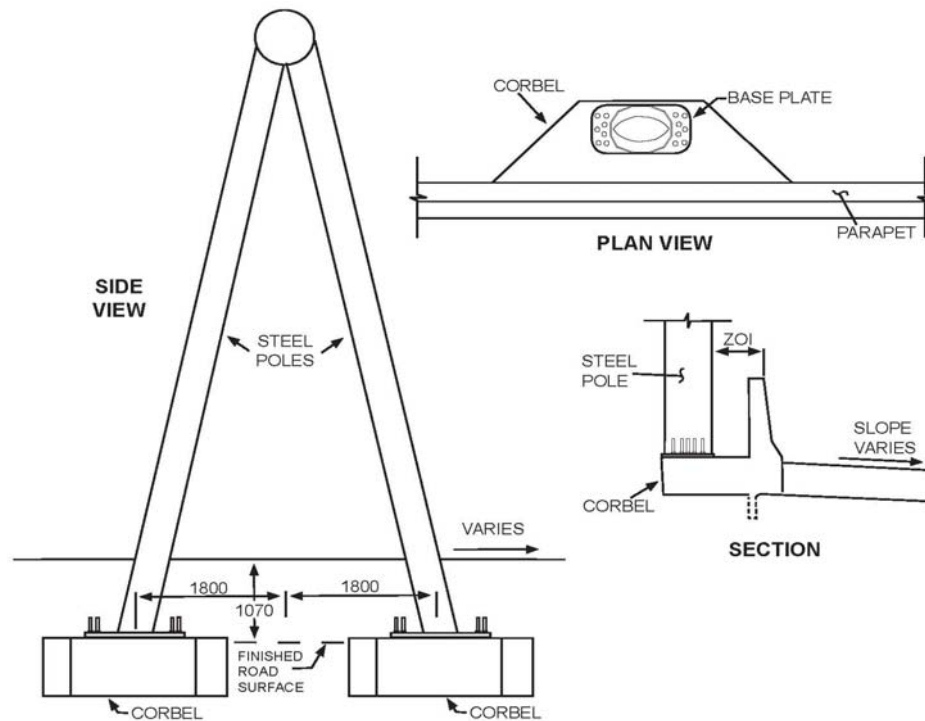
7.0   Conclusion

Highway design requires consideration of a number of factors when selecting a barrier countermeasure to protect for a roadside hazard; in particular:

- Test Level or Performance Level to use (at the specific location);
- Height of barrier to use (barriers considered must have had successful crash tests for that level)
- Zone of intrusion to allow for (for the largest vehicle in the test level);
- Sliding zone (where segmental free-standing barrier is applied); and
- Various methods of preventing a sliding barrier from moving, where lateral space is constrained.

The performance of barriers with different vehicles is strongly correlated with the height of the barrier chosen. A useful approach is to raise the height of the barrier in the vicinity of the hazard in order to reduce the zone of intrusion.

There are a number of methods to fix barriers where barrier sliding is not possible or desired. These range from pinning and continuous extruding, to buttressing and full foundations.

Although the standardized barriers vary by jurisdiction, the examples provided can be used to adapt to unique situations.

8.0   References

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