Alberta Guidelines for Upgrading Bridgerails and Approach Guardrail Transitions

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Abstract

Experimental crash testing has demonstrated that static design procedures are inadequate to predict the complex interaction that occurs when an errant vehicle strikes a bridgerail system. As a result of this deficiency, bridgerail systems designed to old standards do not provide the optimum protection to the occupants of the vehicle in terms of personal safety, or of helping to ensure that the driver of the vehicle is able to maintain control after impact. Following the publication and adoption of the Canadian Highway Bridge Design Code (CAN/CSA-S6-00) by Alberta Transportation (AT), a series of standard drawings incorporating the new safety concepts were developed by AT for use on new construction projects.

It was also decided that in addition to applying the improved standards for new construction, it would be prudent to apply the same safety concepts to the upgrading of existing bridgerail systems whenever practical. However, since it is not practical to crash test existing installations, and that there are limitations on the amount of funding available in the construction program for rehabilitation, it was recognized that guidelines on 'when and how to rehabilitate' would need to be developed. It was also recognized that in addition to engineering issues, the Guidelines would have to include features that would enable priorities for rehabilitation to be established, and from these priorities a program for upgrading the existing rail systems could be developed, as and when funds became available.

This paper will give an overview of the development of the Guidelines, and the discussion will include the evaluation of existing AT bridgerail systems and approach guardrail transitions, and the needs to upgrade with respect to safety. The paper will also discuss prioritizing projects using cost-benefit analysis, based on encroachment rates, severity indices, present value costs, etc.

The Guidelines are a joint effort between Alberta Transportation and UMA Engineering Ltd.

1. Introduction

Bridgerails are a safety feature provided to prevent errant vehicles from penetrating and falling off bridges. Similarly approach guardrails are provided to prevent vehicles from hitting the ends of the bridgerail and from going off the approach pavement into streams or other roadways passing under the bridge. Apart from having adequate strength, bridgerails and guardrails must also be able to smoothly re-direct the accident vehicle back onto the roadway, to reduce the probability of occupant injuries and further involvement of other vehicles in the accident.

As a result of crash testing experiences in the United States over the last twenty years, much was learned on the interaction between vehicles and different kinds of roadside barriers. The AASHTO "Guide Specifications for Bridge Railings[1]" was published in 1989, and introduced the concepts of crashworthy bridgerail assemblies, and multiple performance levels for different traffic and bridge site conditions. The Canadian Standards Association published the new "CAN/CSA-S6-00 Canadian Highway Bridge Design Code (CHBDC)[2]" in the year 2000, and Section 12 of the new code brought the bridgerail design in line with the AASHTO requirements.

Alberta Transportation (AT) was fully aware of the developing requirements of the CHBDC and the safety improvements in bridgerail features. In 1998, AT engaged UMA to examine a total of 22 crash-tested bridgerail designs. As a result of the investigation, two Performance Level 1 and three Performance Level 2 designs were adopted as AT standards for new construction.

Subsequently, AT turned its attention to what needed to be done with the existing inventory of older bridgerails. UMA was again engaged to assist AT to formulate a set of rational, documented guidelines for determining when an existing bridgerail and/or guardrail transition should be upgraded.

2. Current practice for bridgerail rehabilitation

Currently, bridgerail and approach guardrail rehabilitation are usually triggered by:

- Bridge rehabilitation projects, where contractor mobilization and traffic accommodation costs are paid for in conjunction with other rehabilitation work.
- Past accident history, skid marks, damage to bridgerail or guardrail and concerns from the regional office, local residents or police.
- Highway/bridge twinning projects – approach guardrail on existing structure may be upgraded where new bridgerail will be provided on the new twin structure .
- 3R/4R projects on approach highway.
- Guardrail upgrade on approach highway.

Factors that are considered in the decision making process are:

- Structure age, condition and remaining life.
- Life cycle cost analysis of rehabilitation alternatives.
- Future plans for bridge widening or replacement.
- Recurring accidents that cannot be mitigated by improving pavement conditions, e.g. improving skid resistance by chip-seal or new overlay.
- Existing deck and curb conditions.
- Shoulder width.

The problem with this is that it often relies heavily on personal judgement and is reactive rather than pro-active. The potential exists that unwarranted bridgerail improvements may be carried out and funds expended without appropriate beneficial returns, while other bridge sites with more critical conditions may be missed.

3. Benefit/cost analysis

For the existing bridge inventory, there is a considerable mileage of existing bridgerails and approach guardrails that does not meet all the new design requirements. However, these existing bridgerails represent a significant capital expenditure that was invested with the expectations of a long service life. It is not reasonable to render all of them obsolete without justification from the potential to realize significant benefits. Transportation is only one of many competing societal needs that demand a share of government funding. Therefore a decision to upgrade or replace an existing bridgerail should be based on cost-benefit considerations to ensure the efficient use of limited funds. For example, if the traffic is of very low volume and the potential of a collision with the bridgerail is nearly non-existent, then there will be no benefit to spending the money on upgrading a bridgerail.

In 2001, a report entitled "Roadside Design – A Review of Practices and Guidelines for Clear zones, Barriers, etc.[3]" was prepared for AT by Stantec Consulting Ltd. This report identified, at the planning level of accuracy, the number of bridgerails/approach rail transitions in Alberta that do not meet the new CSA-S6-00 standards. Subsequently in March 2003, a report entitled 'Guidelines for Upgrading of Existing Bridgerails/Approach Rail Transitions[4]', was completed by UMA Engineering, to provide guidance for detailed site-specific analysis.

The report presents an easy to use life cycle cost-benefit analysis procedure for determining the need to upgrade an existing bridgerail/approach rail transition. It is primarily based on analysis modules contained in Appendix A of the 1996 AASHTO Roadside Design Guide[5], the 2002 AASHTO Roadside Design Guide[6], the 1989 AASHTO Guide Specifications for Bridge Railings and the 2000 CHBCD.

In Alberta, there are no inventory and accident database of sufficient detail, accuracy and precision that one could use to evaluate the field performance of specific bridgerail designs. To create such a database would be extremely time consuming and costly. Therefore the modules used in the formulation of the analysis procedure are necessarily based on theoretical models and assumptions. Nevertheless, the models used are fairly complex and account for many different factors in an attempt to reflect the real life variations in operating speed, traffic mix, vehicle characteristics, encroachment angle, etc. and a range of accident severity ranging from minor property damage to fatality. The resulting guidelines are calibrated based on engineering judgement and practicality, and are not intended to be academically rigorous.

The main factors considered in the development of the cost-benefit procedure include:

- the frequency of a bridgerail or approach rail transition collision;
- the severity (societal cost) of a bridgerail or approach rail transition collision; and
- the life cycle costs of bridgerail and/or approach rail transition upgrading.

3.1 Frequency of collisions

The frequency of collisions is given by:

$$F = R * P * k_c * k_g * k_m \text{ collisions /km/year}$$

where:

F = frequency of bridgerail or approach rail transition collisions
R = basic encroachment rate for ADT of highway section under consideration (Table 3.1.1)
P = lateral encroachment probabilities (Table 3.1.2)
k_c = highway curvature factor (Table 3.1.3)
k_g = highway grade factor (Table 3.1.4)
k_m = highway multilane factor (Table 3.1.5)

Table 3.1.1 Basic Encroachment Rate (R)

Traffic Volume (AADT)	**Basic Encroachment Rate – Undivided Highways (encroachments/km/yr)**	**Basic Encroachment Rate – Divided Highways (encroachments/km/yr)**
0	0.00	0.00
1000	0.34	0.13
2000	0.61	0.23
3000	0.80	0.30
4000	0.91	0.36
5000	0.97	0.38
6000	0.92	0.38
7000	0.76	0.41
8000	0.88	0.43
9000	0.66	0.45
10,000	0.67	0.48
11,000	0.70	0.50
12,000	0.72	0.53
13,000	0.74	0.56
14,000	0.76	0.59
15,000	0.79	0.62
16,000	0.81	0.66
17,000	0.83	0.69
18,000	0.86	0.72
19,000	0.88	0.75
20,000	0.91	0.79
21,000	0.93	0.83
22,000	0.95	0.87
23,000	0.98	0.91
24,000	1.00	0.95
25,000	1.02	0.99

Table 3.1.2 Lateral Encroachment Probabilities (P)

Shoulder Width (m)	Design Speed (kph)					
	50	60	80	100	110	120
0.00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.50	0.6798	0.7393	0.8242	0.8901	0.9102	0.9213
1.00	0.5203	0.5919	0.6877	0.7731	0.8073	0.8397
1.50	0.4132	0.4921	0.5956	0.6794	0.7192	0.7542
2.00	0.3319	0.4135	0.5283	0.6056	0.6454	0.6842
2.50	0.2698	0.3497	0.4720	0.5472	0.5849	0.6233
3.00	0.2209	0.2973	0.4217	0.4983	0.5344	0.5723
3.50	0.1822	0.2544	0.3766	0.4555	0.4906	0.5274
4.00	0.1506	0.2179	0.3367	0.4174	0.4515	0.4881
4.50	0.1248	0.1874	0.3012	0.3828	0.4158	0.4520
5.00	0.1035	0.1613	0.2700	0.3516	0.3834	0.4189

Table 3.1.3 Highway Curvature Factor (k_c)

Radius of Curve (m)	Bridgerail/Approach Rail Transition on Outside of Curve	Bridgerail/Approach Rail Transition on Inside of Curve
<300	4.00	2.00
350	3.00	1.65
400	2.40	1.45
450	1.90	1.30
500	1.50	1.15
550	1.20	1.05
>600	1.00	1.00

Table 3.1.4 Highway Grade Factor (k_g)

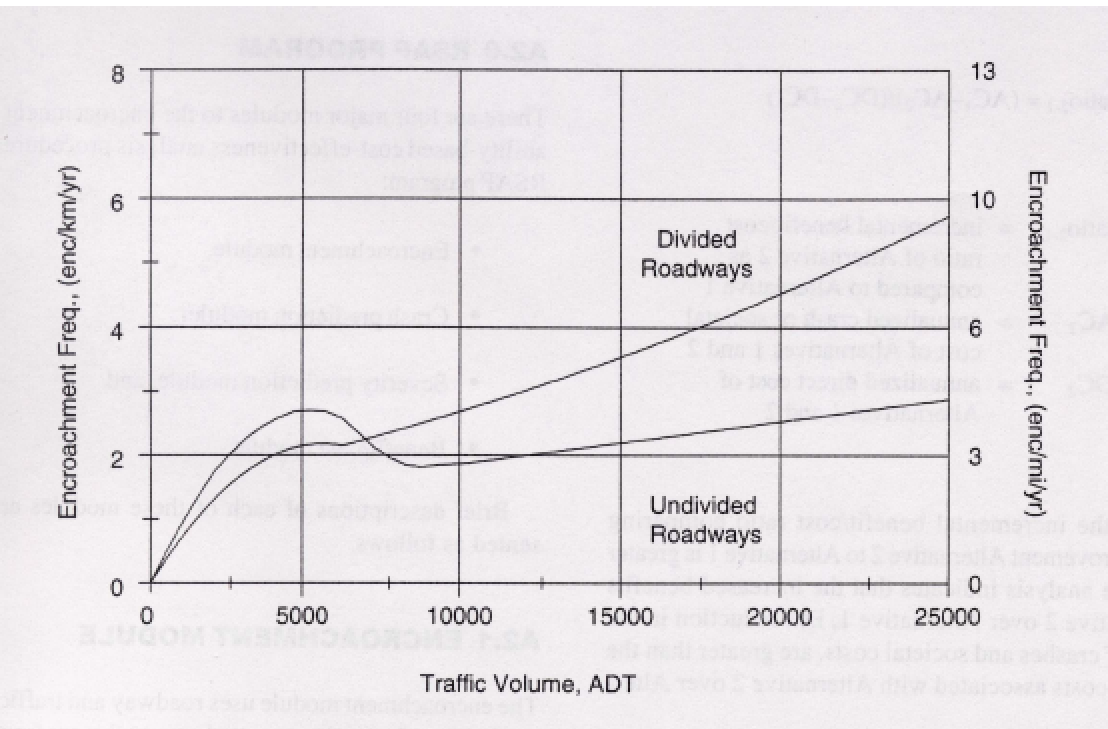
Grade*	Highway Grade Factor
>-2	1.00
-3	1.25
-4	1.50
-5	1.75
<-6	2.00

Table 3.1.5 Highway Multi-lane Factor (k_m)

Design Speed (kph)	Highway Multi-Lane Factor
50	1.20
60	1.30
80	1.45
100	1.60
110	1.65
120	1.70

The basic or average encroachment rate shown in Table 3.1.1 is based on Figure A.1 of the 2002 AASHTO Roadside Design Guide. This represents the frequency of vehicles leaving their travel lane and is based on encroachment data from the Cooper[7] study in the late 1970s in five Provinces. The basic encroachment rate is a function of ADT and is broken down by two-lane undivided and four-lane divided highways.

Figure A.1 AASHTO Roadside Design Guide 2002 Edition



An errant vehicle will encroach only a finite distance outside its travel lane and the farther the bridgerail or guardrail is from a travel lane the less likely it is to be struck by the encroaching vehicle. The lateral encroachment probability, shown in Table 3.1.2, is based on Table A1.1 to A1.8 of the 1996 AASHTO Roadside Design Guide, and is given as a function of the lateral offset and the design speed. For example, from Table 3.1.2, with a bridgerail offset of 2 m from the edge of the travel lane, the lateral encroachment probability is 33.2% at a speed of 50 kph and 64.5% at a speed of 110 kph. To develop the lateral extent of probability curves, the Roadside Design Guide employs a computer program to integrate the lateral extent of encroachment for a combination of 13 different vehicles, encroaching on the roadside at 12 speeds and up to 13 angles for each of the 12 speeds, in eight traffic mixes defined by percentage of trucks. It should be noted that the assumed design speed probability density curve made allowances for vehicles travelling above and below the design speed, and the traffic mixes assumed were dominated by automobiles and light trucks.

The product of P and R represents the basic collision rate. It is then modified to account for specific highway characteristics by factors such as highway curvature, grade and multilane effects.

An adjustment factor of less than 1.0 may be added for highway sections with special safety counter-measures such as rumble strips or increased law enforcement.

3.2 Severity of collisions

Currently, AT attaches the following societal costs to vehicle collisions:

Property damage only…………………………………………………………… $12,000
Injury………………………………………………………………………… $100,000
Fatal………………………………………………………………………. . $1,340,000

In the benefit-cost analysis, the average severity of a collision is represented by a severity index of 1 to 10, each of which has an assigned dollar value. Each severity index is assigned a combination of accidents with increasing severity in accordance with Table A.6a 1996 AASHTO Roadside Design Guide. Then the severity/cost relationship as shown in Table 3.2.1 is developed using the Alberta collision costs.

Table A.6a AASHTO Roadside Design Guide 1996 Edition

Accident Severity Level	Proportion of Accident Severity Level (%)											
	SI Level											
	0	0.5	1	2	3	4	5	6	7	8	9	10
PD01	0.0	100	66.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PD02	0.0	0.0	23.7	71.0	43.0	30.0	15.0	7.0	2.0	0.0	0.0	0.0
Slight Injury	0.0	0.0	2.3	7.0	21.0	32.0	45.0	39.0	28.0	19.0	7.0	0.0
Moderate Injury	0.0	0.0	2.3	7.0	21.0	32.0	45.0	39.0	28.0	19.0	7.0	0.0
Severe Injury	0.0	0.0	0.0	0.0	1.0	5.0	10.0	20.0	30.0	27.0	18.0	0.0
Fatal	0.0	0.0	0.0	0.0	1.0	3.0	8.0	18.0	30.0	50.0	75.0	100

Table 3.2.1 Severity Index – Cost per Collision

Severity Index	Cost
1	$20,448
2	$37,520
3	$74,560
4	$110,800
5	$186,000
6	$317,040
7	$470,240
8	$720,000
9	$1,030,000
10	$1,340,000

Benchmark severity indices for standard barriers, fixed objects, railing penetration, rollover, etc. were obtained from Table A.13.8 & 13.9 - 1996 AASHTO Roadside Design Guide and Appendix A – 1989 AASHTO Guide Specifications for Bridge Railings. The benchmark barrier indices were then adjusted for vehicle penetration, rollover and snagging, caused by the presence of undesirable features in the older bridgerail/guardrail transition designs, to obtain appropriate severity indices for the specific railing/transition types under consideration. Table 3.2.2 summarizes the percentages for different designs speeds and bridgerail performance characteristics.

Table 3.2.2 Assigned Percentage of Vehicles for which Bridgerail Under-performs

Bridge Performance Criteria	Design Speed (kph)					
	50	60	80	100	110	120
Vehicle Penetration of Bridgerail (Bridgerail Meets PL-2 Strength Criteria)	0.25	0.5	1.5	2.5	3.0	3.5
Vehicle Penetration of Bridgerail (Bridgerail Meets PL-1 Strength Criteria)	0.5	1.0	3.0	5.0	6.0	7.0
Vehicle Penetration of Bridgerail (Bridgerail on Safety Curb has Inadequate Height)	1.0	2.0	6.0	10.0	12.0	14.0
Vehicle Rollover with Safety Curb	1.0	2.0	6.0	10.0	12.0	14.0
Excessive Vehicle Deceleration	1.5	3.0	9.0	15.0	18.0	21.0

3.3 Economic analysis

The proposed life cycle benefit-cost analysis procedure is based on the present worth method using a discount rate of 4% to 6% and a traffic growth rate of 2 %. The project life is assumed to be the length of time until the bridge, deck or curb replacement is expected. A project life not exceeding 20 years is recommended.

The present worth of collision costs for each upgrading alternative is determined as:

$$PWAC = F * AC * k_s * L * KC / 1000$$

where:

PWAC = present worth of accident costs

F = frequency of bridgerail or approach rail transition collisions as defined in Section 3.1

AC = cost per collision for severity index of design alternative

k_s = bridge height and occupancy factor (Table 3.3.1)

L = length of bridgerail or approach guardrail transition

KC = factor calculated to convert annual accident costs to present worth for selected discount rate

Table 3.3.1 Bridge Height and Occupancy Factor (k_s)

Bridge Height Above Ground (m)	Bridge Height and Occupancy Factor		Bridge Above Ground (m)	Bridge Height and Occupancy Factor	
	Low Occupancy Land Use	High Occupancy Land Use		Low Occupancy Land Use	High Occupancy Land Use
<5	0.70	0.70	14	1.45	1.70
6	0.70	0.80	15	1.55	1.85
7	0.70	0.90	16	1.70	1.95
8	0.70	1.00	17	1.80	2.05
9	0.80	1.15	18	1.95	2.20
10	0.95	1.25	19	2.05	2.30
11	1.05	1.35	20	2.20	2.40
12	1.20	1.50	>24	2.70	2.85
13	1.30	1.60			

The most effective upgrading alternative, including the do nothing option, can be determined by comparing the summation of PWAC and the present worth of different upgrading alternatives. The alternative with the lowest total present worth will be the best alternative.

The analysis can also be used for prioritizing different bridge sites eligible for upgrading by ranking their benefit/cost ratios. The benefit will be the reduction in PWAC effected by the upgrade and the cost will be the cost of the selected upgrading alternative. When determining the upgrading costs, considerations should be given to other associated costs such as traffic accommodation, curb and deck repair, approach guardrail lengthening, side-slope improvements, additional right of way, etc.

4. Assessment of existing Alberta Bridgerails and Approach Guardrail Transitions

Figure 4.1 and 4.2 shows the major bridgerail types in Alberta prior to the adoption of crash-tested designs in 2000. Each railing type has been assessed and assigned appropriate severity indices for different design speeds.

Figure 4.1 Alberta Bridgerail Types prior to 2000

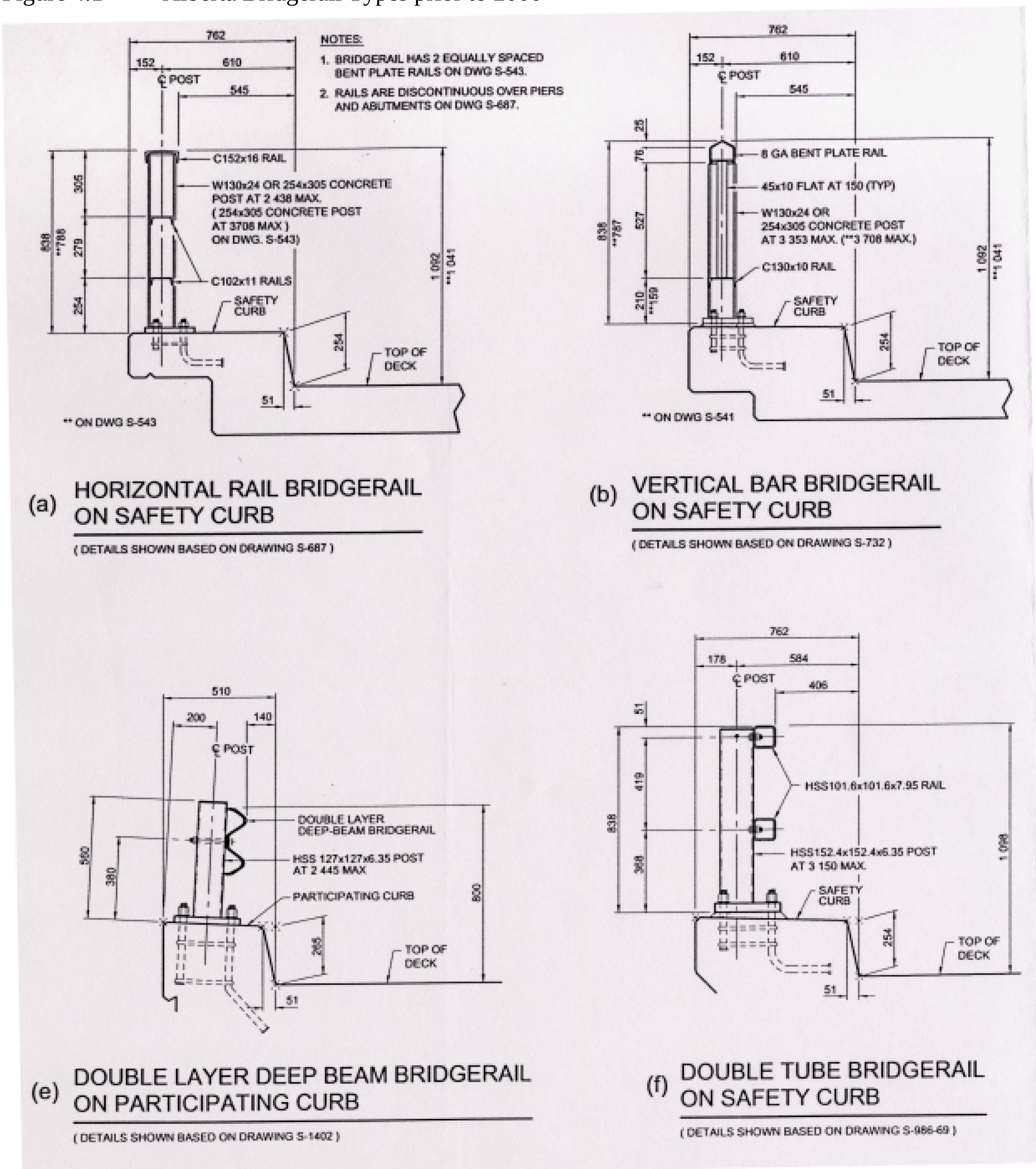


Figure 4.2 Alberta Bridgerail Types prior to 2000

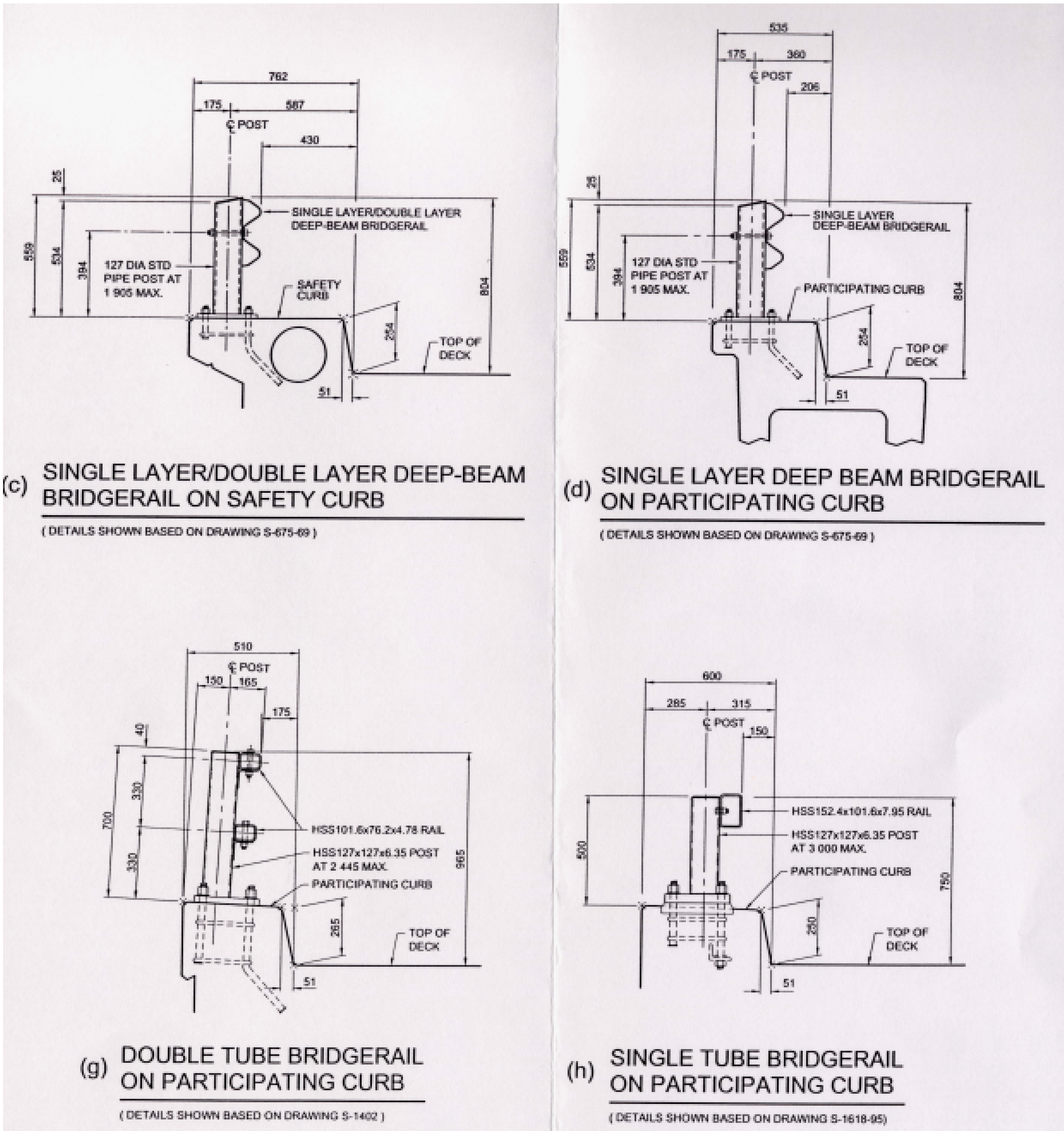


Table 4.1 summarizes the bridgerail types and their deficiencies. Table 4.2 presents the severity indices after the bridgerail is upgraded and Table 4.3 presents a summary of the severity indices assigned to each bridgerail type and their associated approach guardrail transitions prior to upgrading.

Table 4.1 Existing Bridgerail Assessment

Bridgerail Type	**Strength**	**Inadequate Height for PL2**	**Snagging Potential**	**Lack of Continuity**	**Safety curb**	**Transition connected**	**Weak Transition**
Horizontal Rail on safety Curb	< PL1 < PL2	<PL2 Dwg S543 only	Posts & abutments	@ piers & abutments	Yes	No	Yes
Vertical Bar Bridgerail on Safety Curb	< PL1 < PL2	<PL2 Dwg S541 only	Posts & abutments		Yes	No	Yes
Single Layer Deep-beam Bridgerail on Safety Curb	< PL1 < PL2	< PL1 < PL2			Yes	No	Yes
Double Layer Deep-beam Bridgerail on Safety Curb	< PL2	< PL1 < PL2			Yes	No	Yes
Single Layer Deep-beam Bridgerail on Participating Curb	< PL2					No	Yes
Double Layer Deep-beam Bridgerail on Participating Curb	< PL2					Yes	Yes
850 mm Double Tube Bridgerail on Safety Curb			Posts		Yes	Yes	Yes
700 mm Double Tube Bridgerail on Participating Curb			Posts			Yes	Yes
500 mm Single tube on Participating Curb		< PL2	Posts			Yes	Yes

Table 4.2 Severity Indices for Upgraded Bridgerails

Bridgerail Upgrade	**Design speed (kph)**					
	50	**60**	**80**	**100**	**110**	**120**
PL1 upgrade	2.0	2.1	2.6	3.3	3.6	4.0
PL2 upgrade	2.0	2.1	2.5	3.0	3.3	3.7

Table 4.3 Severity indices for Existing Bridgerails and Transitions

Bridgerail Type	**Design speed (kph)**					
	50	**60**	**80**	**100**	**110**	**120**
Horizontal Rail on safety Curb	2.0	2.2	2.8	3.6	4.1	4.4
Transition for above	5.4 m @ 2.2	5.8 m @ 2.6	6.8 m @4.6	8.5M @5.6	9.9 m @ 6.0	11.4 m @6.6
Vertical Bar Bridgerail on Safety Curb	2.0	2.2	2.8	3.6	4.1	4.4
Transition for above	5.4 m @ 2.2	5.8 m @ 2.6	6.8 m @4.6	8.5M @5.6	9.9 m @ 6.0	11.4 m @6.6
Single Layer Deep-beam Bridgerail on Safety Curb	2.1	2.2	3.0	3.8	4.1	4.4
Transition for above	5.4 m @ 2.2	5.8 m @ 2.6	6.8 m @4.6	8.5M @5.6	9.9 m @ 6.0	11.4 m @6.6
Double Layer Deep-beam Bridgerail on Safety Curb	2.1	2.2	3.0	3.8	4.1	4.4
Transition for above	5.4 m @ 2.2	5.8 m @ 2.6	6.8 m @4.6	8.5M @5.6	9.9 m @ 6.0	11.4 m @6.6
Single Layer Deep-beam Bridgerail on Participating Curb	2.0	2.1	2.6	3.3	3.6	4.0
Transition for above	2.4 m @ 2.2	2.8 m @2.6	3.8 m @ 4.6	5.5 m @ 5.6	6.9 m @ 6.0	8.4 m @ 6.6
Double Layer Deep-beam Bridgerail on Participating Curb	2.0	2.1	2.6	3.3	3.6	4.0
Transition for above	0.4 m @ 2.0	0.7 m @2.2	1.5 m @ 3.2	2.7 m @ 4.5	3.5 m @ 5.0	4.2 m @ 5.6
850 mm Double Tube Bridgerail on Safety Curb	2.0	2.1	2.7	3.4	4.0	4.3
Transition for above	1.9 m @ 2.0	2.2 m @2.2	3.0 m @ 3.2	4.2 m @ 4.5	5.0 m @ 5.0	5.7 m @ 5.6
700 mm Double Tube Bridgerail on Participating Curb	2.0	2.1	2.6	3.3	3.9	4.2
Transition for above	0.4 m @ 2.0	0.7 m @2.1	1.5 m @ 3.2	2.7 m @ 4.5	3.5 m @ 5.0	4.2 m @ 5.6
500 mm Single tube on Participating Curb	2.0	2.1	2.6	3.3	3.9	4.2
Transition for above	0.4 m @ 2.0	0.7 m @2.2	1.5 m @ 3.2	2.7 m @ 4.5	3.5 m @ 5.0	4.2 m @ 5.6

The term ‘safety curb’ came from the old times when the curb portion projecting in front of the bridgerail was thought to offer a safe protected space for inspection personnel. It is a misnomer because the projecting curb can actually become an unsafe feature for high speed traffic. Depending on the speed and angle of impact, the curb can potentially cause an impacting vehicle to climb or jump the curb and hit the bridgerail at an undesirable height, or cause instability and rollover. A curb is deemed to be a safety curb if it measures more than 230 mm from the gutter line to the face of the bridgerail.

The weak approach guardrail transitions prior to 2000 typically do not possess sufficient stiffness to meet the new NCHRP 350 requirements. The risks involved are snagging of the bridgerail end or curb end, or pocketing of the guardrail, which can result in sharp re-direction of the vehicle into adjacent traffic. The severity indices for the transitions are assigned finite lengths.

5. Upgrading conceptual designs

With the many variations of existing bridgerails and bridgerail end details, it is not practical and too expensive to crash test each different situation. The rehabilitation schemes are therefore developed without crash-testing, but incorporate guidance provided in the AASHTO LRFD code and also information available from many crash test reports.

The primary goals for improvement designs are to provide smooth redirection of an accident vehicle, and minimize snagging or pocketing potential. Due to the wide variety of existing installations and site conditions, it should be recognized that sometimes the available options are limited. Vehicle impacts generate significant forces. Good understanding of crash-tested features, flexibility and sound engineering judgement are required in developing a successful design.

Figures 5.1 and 5.2 show the bridgerail upgrading alternatives. Figure 5.3 shows a PL1 transition upgrade. Figure 5.4 shows a PL2 transition upgrade.

Figure 5.1 Bridgerail upgrading alternatives

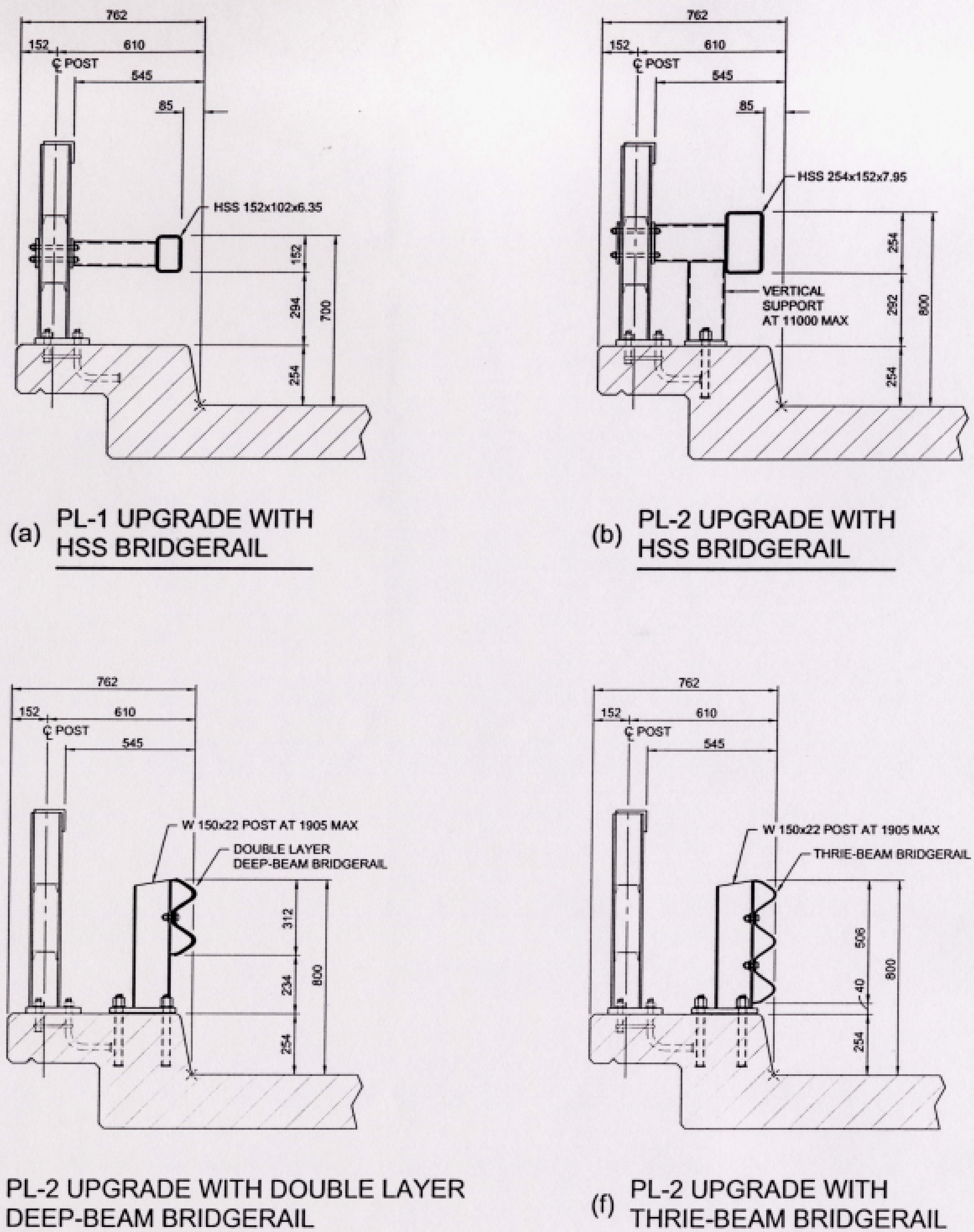


Figure 5.2 Bridgerail upgrading alternatives

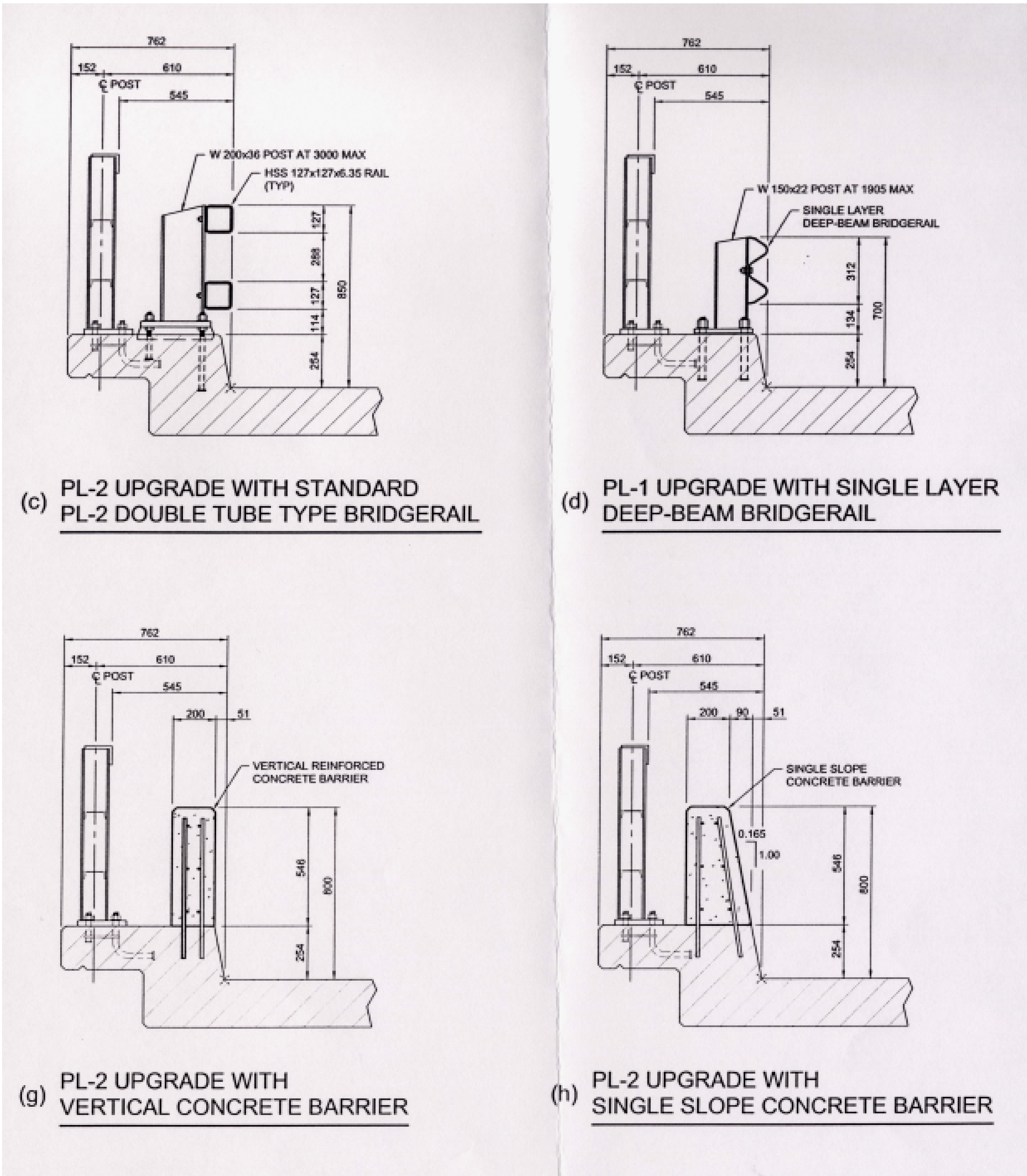


Figure 5.3 PL1 Approach Guardrail Transition Upgrade

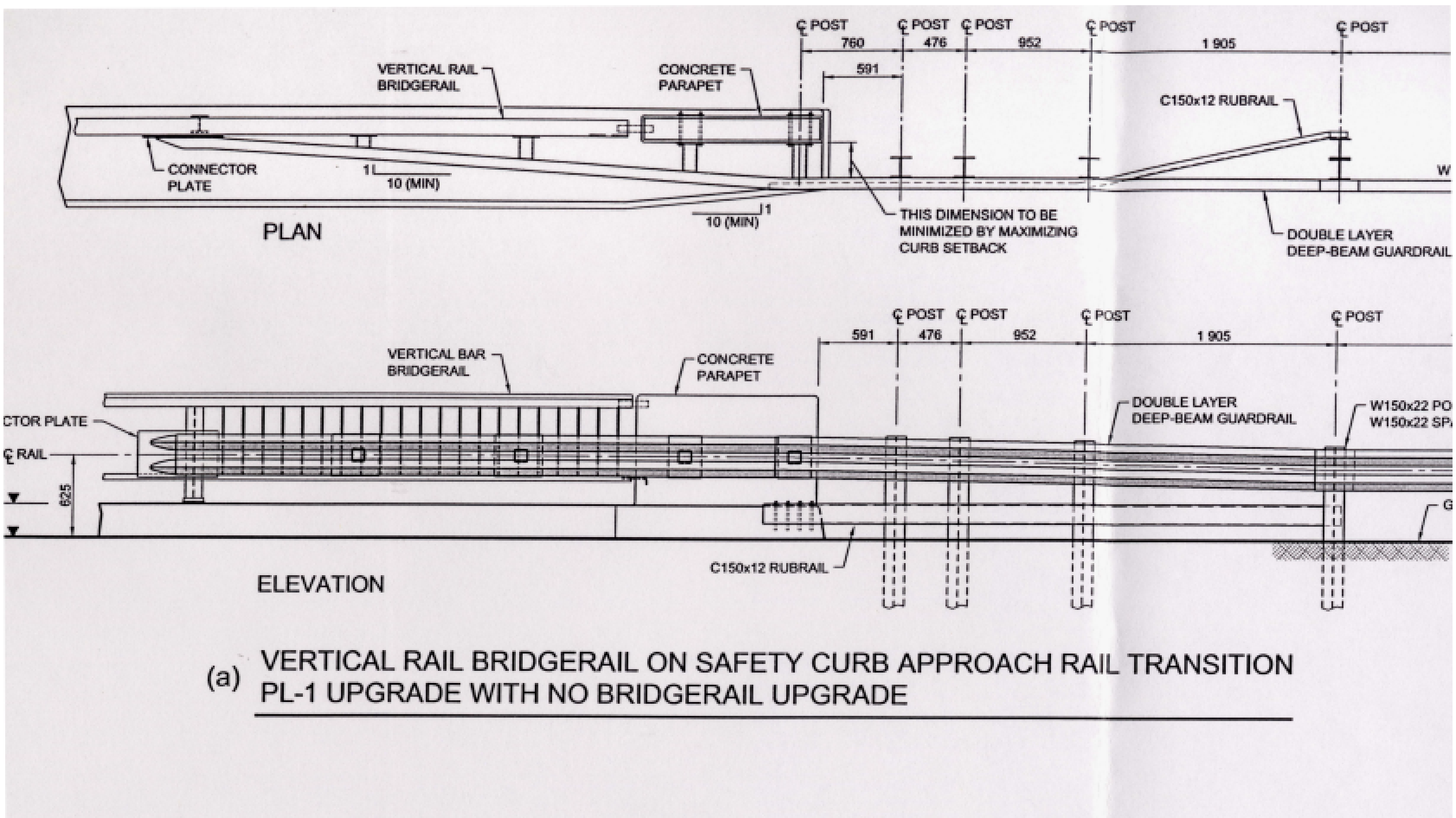
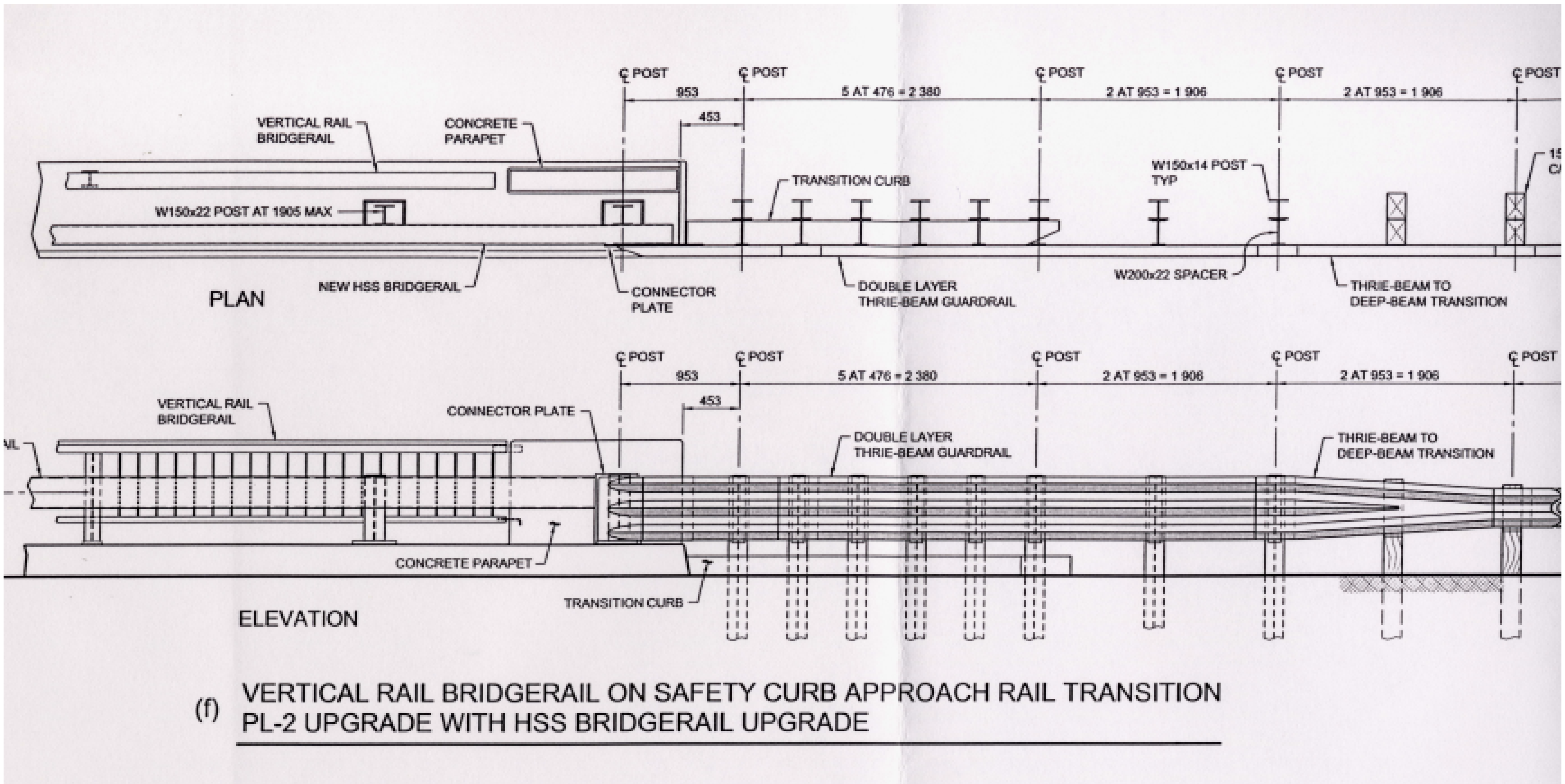


Figure 5.4 PL2 Approach Guardrail Transition Upgrade



6. Observations and discussions

The following tables show the upgrading ADT threshold for the assumed sets of criteria shown.

Table 6.1 Typical AADTs for Bridgerail Upgrading on Undivided Highways V = 100 kph

Bridgerail Type	Bridgerail Upgrading Cost	AADT Required for Bridgerail Upgrading
Horizontal Rail on Safety Curb (PL-1 Upgrade)	$250/m	>25,000
Horizontal Rail on Safety Curb (PL-2 Upgrade)	$400/m	4,000
Vertical Bar on Safety Curb (PL-1 Upgrade)	$250/m	>25,000
Vertical Bar on Safety Curb (PL-2 Upgrade)	$400/m	4,000
Single Layer/Double Layer Deep-Beam on Safety Curb (PL-1 Upgrade)	$250/m	2,500
Single Layer/Double Layer Deep-Beam on Safety Curb (PL-2 Upgrade)	$400/m	2,500
Single Layer Deep-Beam on Participating Curb (PL-2 Upgrade)	$250/m	>25,000
Double Layer Deep-Beam on Participating Curb (PL-2 Upgrade)	$250/m	>25,000
Double Tube on Safety Curb (PL-2 Upgrade)	$300/m	>25,000
Double Tube on Participating Curb (PL-2 Upgrade)	$300/m	>25,000
Single Tube on Participating Curb (PL-2 Upgrade)	$250/m	>25,000

k_c = 1.0, k_g = 1.0, V = 100 kph, P = 0.7731 (1.0 m shoulder width), k_m = 1.60, ks = 1.0, KC = 16.252 (4% discount rate and 20 year project life)

Table 6.2 Typical AADTs for Bridgerail Upgrading on Divided Highways V = 110 kph

Bridgerail Type	Bridgerail Upgrading Cost	AADT Required for Bridgerail Upgrading
Horizontal Rail on Safety Curb (PL-1 Upgrade)	$250/m	16,000
Horizontal Rail on Safety Curb (PL-2 Upgrade)	$400/m	17,000
Vertical Bar on Safety Curb (PL-1 Upgrade)	$250/m	16,000
Vertical Bar on Safety Curb (PL-2 Upgrade)	$400/m	17,000
Single Layer/Double Layer Deep-Beam on Safety Curb (PL-1 Upgrade)	$250/m	16,000
Single Layer/Double Layer Deep-Beam on Safety Curb (PL-2 Upgrade)	$400/m	17,000
Single Layer Deep-Beam on Participating Curb (PL-2 Upgrade)	$250/m	>25,000
Double Layer Deep-Beam on Participating Curb (PL-2 Upgrade)	$250/m	>25,000
Double Tube on Safety Curb (PL-2 Upgrade)	$300/m	17,000
Double Tube on Participating Curb (PL-2 Upgrade)	$300/m	20,000
Single Tube on Participating Curb (PL-2 Upgrade)	$250/m	16,000

k_c = 1.0, k_g = 1.0, V = 110 kph, P = 0.6454 (2.0 m shoulder width), k_m = 1.65, ks = 1.0, KC = 16.252 (4% discount rate and 20 year project life)

Table 6.3 Typical AADTs for Transition Upgrading on Undivided Highways V = 100 kph

Bridgerail Type	**Approach Rail Transition Upgrading Cost**	**AADT Required for Approach Rail Transition Upgrading**
Horizontal Rail on Safety Curb (PL-1 Upgrade)	$8,000/corner	800
Horizontal Rail on Safety Curb (PL-2 Upgrade)	$12,000/corner	1,100
Vertical Bar on Safety Curb (PL-1 Upgrade)	$8,000/corner	800
Vertical Bar on Safety Curb (PL-2 Upgrade)	$12,000/corner	1,100
Single Layer Deep-Beam on Safety Curb (PL-1 Upgrade)	$8,000/corner	800
Single Layer Deep-Beam on Safety Curb (PL-2 Upgrade)	$12,000/corner	1,100
Single Layer Deep-Beam on Participating Curb (PL-1 Upgrade)	$6,000/corner	900
Single Layer Deep-Beam on Participating Curb (PL-2 Upgrade)	$10,000/corner	1,500
Double Layer Deep-Beam on Participating Curb (PL-1 Upgrade)	$6,000/corner	>25,000
Double Layer Deep-Beam on Participating Curb (PL-2 Upgrade)	$10,000/corner	>25,000
Double Tube on Safety Curb (PL-1 Upgrade)	$6,000/corner	>25,000
Double Tube on Safety Curb (PL-2 Upgrade)	$10,000/corner	>25,000
Double Tube on Participating Curb (PL-1 Upgrade)	$6,000/corner	>25,000
Double Tube on Participating Curb (PL-2 Upgrade)	$10,000/corner	>25,000
Single Tube on Participating Curb (PL-1 Upgrade)	$6,000/corner	>25,000
Single Tube on Participating Curb (PL-2 Upgrade)	$10,000/corner	>25,000

k_c = 1.0, k_g = 1.0, V = 100 kph, P = 0.7731 (1.0 m shoulder width), k_m = 1.60, ks = 1.0, KC = 16.252 (4% discount rate and 20 year project life)

Table 6.4 Typical AADTs for Transition Upgrading on Divided Highways V = 110 kph

Bridgerail Type	Approach Rail Transition Upgrading Cost	AADT Required for Approach Rail Transition Upgrading
Horizontal Rail on Safety Curb (PL-1 Upgrade)	$8,000/corner	1,700
Horizontal Rail on Safety Curb (PL-2 Upgrade)	$12,000/corner	3,000
Vertical Bar on Safety Curb (PL-1 Upgrade)	$8,000/corner	1,700
Vertical Bar on Safety Curb (PL02 Upgrade)	$12,000/corner	3,000
Single Layer Deep-Beam on Safety Curb (PL-1 Upgrade)	$8,000/corner	1,700
Single Layer Deep-Beam on Safety Curb PL-2 Upgrade)	$12,000/corner	3,000
Single Layer Deep-Beam on Participating Curb (PL-1 Upgrade)	$6,000/corner	2,000
Single Layer Deep-Beam on Participating Curb (PL-2 Upgrade)	$10,000/corner	4,000
Double Layer Deep-Beam on Participating Curb (PL-1 Upgrade)	$6,000/corner	>25,000
Double Layer Deep-Beam on Participating Curb (PL-2 Upgrade)	$10,000/corner	>25,000
Double Tube on Safety Curb (PL-1 Upgrade)	$6,000/corner	19,000
Double Tube on Safety Curb (PL-2 Upgrade)	$10,000/corner	>25,000
Double Tube on Participating Curb (PL-1 Upgrade)	$6,000/corner	>25,000
Double Tube on Participating Curb (PL-2 Upgrade)	$10,000/corner	>25,000
Single Tube on Participating Curb (PL-1 Upgrade)	$6,000/corner	>25,000
Single Tube on Participating Curb (PL-2 Upgrade)	$10,000/corner	>25,000

k_c = 1.0, k_g = 1.0, V = 110 kph, P = 0.6454 (2.0 m shoulder width), k_m = 1.65, ks = 1.0, KC = 16.252 (4% discount rate and 20 year project life)

Based on the limited analysis performed, the following general observations can be made:

- There is little justification for upgrading an existing bridgerail to PL1, probably because the benefits gained are insignificant.
- For undivided 2 lane highways, upgrading to PL2 may be required starting at ADT of 2500 to 4000.
- For divided 4 lane highways, upgrading to PL2 may be required starting at ADT of approximately 16,000.
- Because of their finite lengths, approach guardrail transitions are similar to isolated fixed objects. Although the frequency of collisions with transitions predicted by this procedure is low, the severity and hence the collision costs are high. This is reflected in the low ADTs that justify end transition upgrade. This may also be contrary to real life observations that many bridge related collisions involve the bridge ends.
- The severity indices and hence the analysis results are very sensitive to design speeds.
- These guidelines will be tested and further developed by using them to develop priority lists for future bridgerail upgrade.

7. References

1 AASHTO *Guide Specifications for Bridge Railings*, 1989
2 *CAN/CSA-S6-00 Canadian Highway Bridge Design Code*, December 2000
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4 UMA Engineering, *Guidelines for Upgrading of Existing Bridgerails/Approach Rail Transitions*, Technical Standards Branch, Alberta Transportation, March 2003
5 AASHTO *Roadside Design Guide,* 1996 Edition
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7 Cooper, P., *Analysis of roadside Encroachments – Single Vehicle Run-Off-Road Accident Data Analysis for five Provinces,* B. C. Research. Vancouver, British Columbia, Canada, March 1980