

technical memorandum



road design series

Guidelines for Edge Protection and Medians on Dual Carriageway Roads, incorporating a Safe System Philosophy.

TM-2503

March 2013

Purpose

The launches of the Safer Journey's initiative and the Decade of Action for Road Safety have brought the way we design for safety into the limelight. The purpose of this memo is to define the interpretation of a Safe System philosophy for dual carriageway roads and how this may vary with context. In particular these guidelines are intended for use on all the Roads of National Significance (RoNS) projects.

Appendices to this memorandum provide examples of the rationale in practice, an analysis of the benefits and costs and also typical sections that illustrate these principles.

Background

Traditionally we have designed clear-zones along side our carriageways that, in order to limit cost and land-take, are traditionally accepted to have an operating efficacy of approximately 80% and a physical limit of 9.0m. With the safe system approach to road trauma, the risk profile associated with mitigating crash severity has shifted away from frequency towards severity. That is to say that we should no longer accept high severity crashes as unavoidable even if the likelihood is very low. However, to do this by applying the clear-zone principle, with its increasing width yielding diminishing returns, would precipitate huge swathes of gently sloped roadsides with little or no landscape features that would still not guarantee 100% success.

This is reinforced by research that shows that severe injury crashes occur at distances much greater than 9.0m. In fact, the most recent Austroads research has found that while run-off-road casualties decreased with increasing clear zone width, the greatest rate of decrease occurred over the first 4m. More importantly the research found that 30% of all run-off-road casualties occurred in clear zones >13m and that the decrease in 'hit objects' crashes in wide clear zones was accompanied by an increase in roll-over crashes. For medians the equivalent offset is moderated to 3m due largely to the prevailing cross-fall being away from the median.

The challenge is to provide a solution that attempts to cater for all outcomes in a pragmatic and affordable compromise that has the 'Safe System' balance of severity and exposure.

Discussion

In the absence of a wider need to provide or maintain corridor width, e.g. for future proofing, quantities balance, or other practical reasons, the most recent research now suggests wide berms, shoulders and medians are not necessarily beneficial. In particular when, concrete and other semi-rigid barriers are placed at greater distances from the carriageway, the collision angle of an errant vehicle increases. This results in higher perpendicular impact forces, and higher severity crash outcomes, unless they are placed such a distance away that the impact speed is significantly reduced (<30km/h).

Note that, while the Wire Rope Barrier (WRB) is generally preferred because of its energy absorbing qualities, there are contexts that prohibit its use e.g. low radius curves or sharp sag curves. The barrier type should be therefore be selected using a project specific 'fit for purpose' exercise. In addition there are scenarios where a barrier installation is not a preferred solution and a run-out area can be safely provided. In such cases, the slope on this run-out area should ideally be limited to a maximum of 1:6.

There is also a need to ensure that shy lines to barriers are appropriate and that the selection of median type and cross section in particular, will provide the best value for money on a 'whole of life' basis. Note that the 'whole of life' cost must take into account predicted crash outcome severity. The cost of maintenance will have a significant impact on this and the maintenance of narrow medians may well require more extensive traffic control and lane closures.

Current design guidelines for dual-carriageways require the left-hand 2.5m shoulder be increased to 3m adjacent to a barrier. This provides the additional space needed for a driver to stop and get out of the vehicle safely. Therefore, there already is a predominance of safety barrier systems positioned 3m from the edge-line and perpetuating this offset under a Safe System philosophy will provide network consistency. As the greatest safety benefit (rate of crash decrease) occurs over the first 4m from the edge-line, a barrier positioned at 3m offset would be subject to a theoretically greater number of incidental strikes. However, the construction and maintenance issues associated with the additional 1m offset probably outweigh the additional cost of barrier repairs.

A "towards a Safe System compliant" design would therefore install forgiving safety barriers as a default treatment, however there is evidence to suggest that this would increase 'property only' crashes and that this cost should be included in the 'whole of life' calculation. The cost of the barrier compared to the additional benefit it provides should be considered on a case by case (location specific) basis.

As dual carriageway roads are principally designed to provide improved travel times and reliability, traffic lanes should generally be available at all times and not subject to closures or speed restrictions during normal median maintenance. The exception to this being barrier repairs that may require a short term closure/speed restriction; however these should be undertaken at a time of day that minimises traffic delays.

Appendices

Appendix A is an example of the rationale applied to a live project when considering the implementation of the Safe System.

Appendix B is an example of a whole of life benefit calculation for the installation of a WRB using the safe system principles compared to the use of a 9m clear zone.

Appendix C uses the whole of life benefits calculated in App. B and calculates the BC ratio for a typical expressway project.

Appendix D contains illustrative typical cross-sections based on the criteria in sections 1 and 2 following.

Recommended practice

Designers should use the figures from the tables below, appropriate to the context, taking into account the following factors:

1. Roadside:

1. In all instances the starting point would be that of a wire-rope barrier at a 3m offset,
2. A 1.0m (0.6m min) maintenance strip shall be provided behind the barrier to facilitate the satisfactory installation of the posts and repair of the post and embankment. This additional width will also improve embankment integrity and reduce scour due to water run-off on the inside of curves.
3. The slope of any additional width (required for sight distance) should match the adjacent shoulder. This will eliminate the detrimental effects associated with any hinge point (change in crossfall) on barrier performance. However, where hinge points (slope changes) cannot be avoided in front of the barriers, the increased slope should desirably be limited to a value of 1:10 with a maximum of 1:6. See note #4 below.
4. Where hinge points (slope changes) cannot be avoided in front of the barriers, the barrier must be placed within 0.5m of the hinge or at a distance greater than 1.4m (+3% to -10% change), 2m (+6% to -10% change) or 2.4m (+3% and +6% to -1:6 change). These prohibited zones are illustrated in the typical sections shown in Appendix D of this memo.
5. Consideration should be given to the surface treatment of the additional width, particularly where the slope and therefore any water run-off, is towards the shoulder. The preference is that the whole of the width, as described above, would be surfaced to minimise maintenance issues (spraying) and assure the integrity of the embankment. However, this should be balanced with possible increase in repair or reinstatement costs associated with any barrier strikes.
6. Consideration may be given to increasing offset to the barrier, particularly for a WRB, in order to decrease the 'Length of Need' for a hazard. It is imperative that such an increase does not compromise performance or increase impact angles beyond acceptable limits. Note that, in this case, the slope in the vicinity of the barrier should be no greater than 1:10, in accordance with the manufacturer's recommendations. This may be particularly relevant on the outside of a lower radius curve, for example to allow additional slide space for motorcyclists or where there is a 'point hazard' some distance from the edge-line.
7. The option of setting the barrier at the hinge point of a slope change may be considered, although this may be difficult to construct and maintain or repair because of the foundation requirements of the posts.
8. Installation of a 'slope barrier' 1.2m beyond the hinge point of a 1:4 slope (0.9m beyond the hinge point of a 1:3 slope) requires the project specific approval of HNO Traffic and Safety Manager. It may only be considered for use in very highly constrained locations where the requirement to achieve a desirable barrier offset outweighs the potential compromise in barrier performance and more complex maintenance and repair.

Note:

The term 'slope barrier' refers to a WRB with a slightly different wire height and configuration, with longer posts than a standard WRB. **Currently, there is only one approved 'slope' WRB system in NZ, though it is not currently available through industry suppliers.**

9. In relatively flat terrain, where the terrain beyond the run-out area is equally forgiving, a 9m run-out width with a desirable slope of 1:10 (maximum slope of 1:6) may be considered as an appropriate roadside treatment.

10. Any planting introduced in front of the barrier as landscaping, or to reduce vehicle speeds, must not compromise the performance of the barrier.
11. Notwithstanding the above starting points, consideration should always be given to providing a cost-effective solution at all points along the route, providing that this does not lead to excessive variations in edge treatment over short distances.

The following table summarises the above points:

Roadside Treatment Summary Table

Roadside		
Shoulder	Boundary	Notes
2.5m	Barrier offset 3.0m; 1.0m (0.6m min) additional maintenance space	Preferred barrier offset consistent with current practice. Practical compromise between recovery, impact angle and footprint whilst minimising incidental strikes.
	Barrier offset increased; 0.5m additional maintenance space	May be appropriate in context (sight distance). Slope maintained to and 0.5m beyond barrier. May be increased to 1:10 (1:6 max) providing introduction of hinge point does not compromise barrier performance.
	Barrier offset 3.0m placed at hinge point	Minimum to be used only where footprint is critical. Issues with constructability. ¹
	‘Slope barrier’;² offset includes 0.75m @ 1:4	Barrier system placed on slope and spacing of ropes increased. Slope beyond barrier may increase to limit footprint. Requires HNO National Office approval. <i>Note that there is a slope barrier tested to NCHRP 350 TL4 that is not currently supplied in NZ and therefore is likely to be a cost-prohibitive option</i>
	Barrier installed close to hazard	Offset will vary – minimises length of need. Requires a slope no steeper than 1:10 in vicinity i.e. front of it and within the design deflection.
	>9m Run-out area	Run-out area 1:10 desirable slope (1:6 max). No severe hazards at limit of run-out area. Planting may be used as speed reduction measure. Surface must be traversable i.e. suitable, compacted material.

Notes:

1. Because of maintenance and construction integrity issues, preference should be given to providing 1.0m (0.6m min) behind the barrier and adjusting the earthworks slopes beyond, rather than placing the barrier at the hinge point or on the slope.
2. The use of a ‘Slope Barrier System’ should be a last resort. This type of system will have unique post lengths and wire spacing, thereby creating a potential maintenance issue. Although there is one tested system, its performance is less predictable than a conventional system. Every effort should be made to modify the road corridor to facilitate a conventional installation.

Delineation of Extended shoulder

In order to comply with the TCD manual, additional width to the barrier increases the 'shoulder' to a value that requires hatching so that motorists do not perceive and use it as an extra lane. Depending on the crossfall and surfacing used, this will apply to the median as well as the left shoulder. Extensive hatching, however, may be undesirable from a maintenance and amenity perspective, particularly where the shoulder on the left hand side could be used by cyclists.

Where the presence of a barrier is intermittent, the shoulder width may vary along the route, thereby requiring only intermittent hatching. In this case, it is important to rationalise and use a consistent treatment for significant lengths and preferably along the entire length of shoulder in order to create a constant environment for the driver.

The requirement to differentiate the shoulder may be satisfied by considering one or a combination of the following treatments depending on the context and usage:

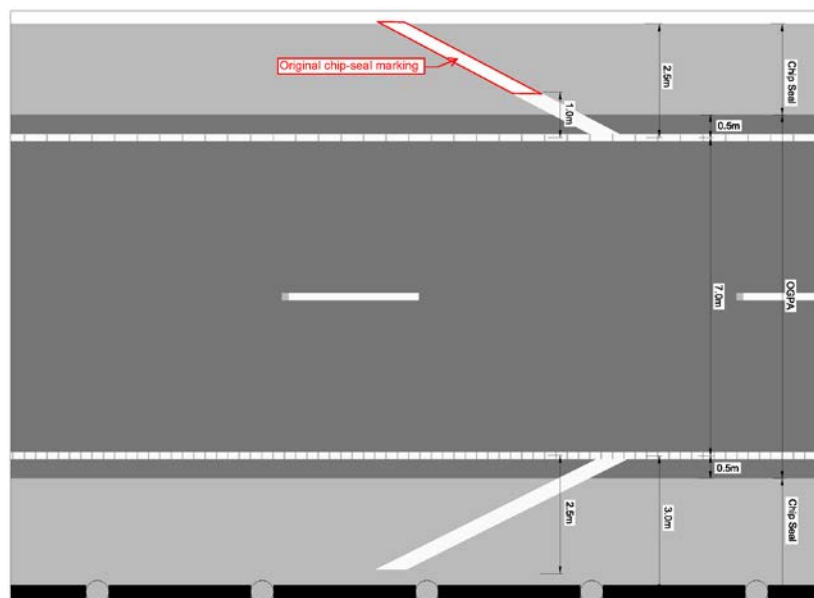
1. Full width shoulder hatching in accordance with the TCD manual
2. Use of audio-tactile pavement markings (ATPM) to better delineate the carriageway/shoulder interface. Placing the transverse markings outside the edge line will improve the differentiation.
3. An obvious change in surface between the lane and shoulder. This may occur some distance (0.5m with ATPM; 1.0m without ATPM) into the shoulder to facilitate the ATPM, safety and edge stability.
4. Limiting the hatching to the first 1m (closest to the running lane), thereby providing at least 1.5m of clear shoulder for cyclists.
5. Using clearly differentiated surfacing e.g. red chippings. (no cyclists)

Note that only option 1 is compliant with the current TCD Manual; the use of a combination of options 2, 3 and 4, or option 5 would require specific approval as a departure.

For example, the following shoulder treatment has been adopted for sections of the Waikato Expressway:

The road surface will have chip-seal laid for a year after opening before OGPA (Open Graded Porous Asphalt) is applied. It is important that the shoulder is clearly delineated at opening and therefore the hatching will be applied over its full width (2.5m or 3.0m) using standard water based marking.

When the OGPA is applied, this will be extend to 0.5m outside the lane line i.e. into the shoulder. P30 Specification compliant marking will be used to delineate the edge of the shoulder and running lane (ATPM) It will also be used to overlay the hatching to an offset of 1.0m from the lane line on the left shoulder (0.5m beyond the OGPA) and 2.5m on the right shoulder (2.0m beyond the OGPA). This will leave between 1.5m and 2.0m of chip-sealed shoulder on the left hand side that will still retain the original (pre-OGPA) hatching. Given that this will be only occasionally trafficked, the life of this marking will be significant. This will also provide a much smoother surface for cyclists than if the hatching had been remarked in P30 compliant paint.



2. Median:

Note that the median is defined as the distance between running lanes and therefore includes the carriageway shoulder. The following values assume a shoulder width of 1m.

1. The desirable median width is 6m with a centrally placed barrier.
 - i) This is wide enough to reduce incidental strikes by providing recovery width
 - ii) It maintains relatively low impact angles
 - iii) It does not impact significantly on driver behaviour as the corresponding 'shy distance' is greater than 2.8m (110km/h).
 - iv) It is ideally paved, but may be planted with low-maintenance ground-cover (not grass). Note that there will inevitably be some maintenance associated with plants becoming established.
2. Similar to the edge protection, the barrier must not be placed in a zone between 0.5m and 1.4m from a 'hinge point' produced by a change in slope from the back of the paved shoulder.
 - i) When the barrier is offset within the median, e.g. to achieve sightline requirements, then the minimum offset to the barrier from the edge-line on the non-widened side is 2.0m for a crowned median or 2.4m for a depressed median.
3. Consideration may be given to grassing part, if not all of the median if the width on either side of the barrier exceeds 3.5m. This will provide clear differentiation between the paved carriageway and the median.
4. If the median is to be grassed and therefore maintained, the minimum recommended width is 7m, with a centrally placed median barrier. i.e. 3.5 m either side of the barrier, assuming 2.5m of grass and 1m of shoulder.
5. For a grassed median, if the barrier is offset within the median, e.g. to achieve sightline requirements, then the minimum offset to the barrier on the non-widened side must be 3.5m.
6. The median width may be reduced to a minimum of 4m in constrained areas and areas where the cost is very sensitive to formation width.
 - i) 4m medians should be paved.
7. Median slopes should be appropriate for drainage requirements, however a slope less than or equal to 1:10 should be used wherever practicable.
8. For the same reason as #2 above, where the position of the barrier varies within the median, it must not be placed in a zone between 0.5m and 2.6m offset from the low point. It is preferable to move the median low point.
9. Ideally, 'V' profile medians are restricted to 1:10 maximum slope. The barrier must be placed within 0.5m of the low point to avoid adversely affecting the barrier performance.

The following table summarises the above points:

Median Treatment Summary Table

Median (including 1.0m shoulders)		
Width	Surface	Notes
6.0m	<ul style="list-style-type: none"> • Paved • Planted 	<p>Desirable; minimum width for compliant shy distance. Reduces likelihood of incidental strikes.</p> <p>Planting must be low height and require minimal maintenance</p>
7.0m	<ul style="list-style-type: none"> • Grassed 	<p>Minimum width required to facilitate maintenance.</p> <p>Where widened, 3.5m minimum offset to barrier.</p>
4.0m	<ul style="list-style-type: none"> • Paved 	<p>Minimum; may require specific treatment for drainage when depressed or on superelevated road.</p> <p>Offset to barrier does not satisfy shy-distance requirements.</p>

3. Sight Distance Issues

One of the key factors, governing the barrier offset is the need to provide horizontal forward sight distance. On *right hand curves*, this sight distance is very sensitive to the median width. To provide the required 260m sight distance, a 1.93m offset to a median barrier (2.0m to centre) requires a radius in the order of 2,300m. This offset has to increase with the use of lower horizontal radii. For example the same offset only provides around 190m of sightline on a 1,240m radius curve; to achieve a sightline of 260m this offset would become 5.08m. A balance must therefore be struck between a decrease in radius and an increase in offset to the barrier.

However, where the use of a lower radius curve is unavoidable, consideration may be given to reducing the sight distance in order to limit the median width or edge offset to a more practical value. For example, an 800m radius would require a barrier offset from the edge-line of about 8.85m to provide 260m sight distance, or about 5.1m to provide 209m.

Although there are cases where the vertical geometry requirements relating to sight distance may be relaxed (see below), there is less flexibility when it comes to horizontal constraints to sight distance. While the majority of vehicles may be visible over a barrier, the tail lights of such vehicles may not be. A TL4 barrier height is 810mm and the design height of car taillights is 800mm. There is, therefore, little margin to accommodate the effects of vertical profile and construction tolerance.

Specific departures for the vertical geometry relating to sight distance may be considered on a case by case basis, where there is a significant benefit to be gained by doing so. These will generally relate to reductions in crest curve K values. *Care must be taken not to combine such a reduction with minimum values of other parameters.*

Key issues that need to be considered are:

- For an anticipated operating speed of (110km/h), what is the deceleration rate and reaction time associated with proposed reduction?
- The sight distance that is provided to each of the standard object heights i.e. 0.2m, 0.8m
- The sight distance that would be required if the assumed deceleration rate is increased or the driver reaction time decreased.
- What deceleration rate and driver reaction time would be required for a vehicle travelling 10km/h above the anticipated operating speed (max 110km/h)

Addressing each of these components determines the level of erosion of the factor of safety associated with the departure.

4. Lighting Columns

The presence of a safety barrier at the edge of the shoulder will influence the position of lighting columns. The interaction of the safety barrier and lighting column, in the event of a crash, is unpredictable and remains largely un-tested. Therefore, to minimise this interaction, any lighting columns shall be placed outside the expected deflection of the barrier system.

All lighting columns behind a safety barrier system should be ground planted and satisfy the requirements of M26 in respect of being a passively safe object.

For example, a wire rope barrier system placed at the back of a 3m shoulder, with an expected deflection of 1.1m, would require a lighting column offset of 4.2m from the carriageway edge-line.

5. Cyclists

Applying the Safe System principles separates vulnerable users from the higher speed expressway traffic. Therefore off-road cycle facilities and alternative routes are to be provided and promoted wherever practicable, including the use of lengths of replaced or redundant state highway.

Cyclists are prohibited from using designated motorways and may be prohibited from using expressways by specific legislation, although the latter may be very difficult to enforce. Where not specifically prohibited, advice about the considerations relating to on-road cyclists is given in the 'Cycling Aspects of Austroads Guides' Section 4.8 and provision at grade separated interchanges should be in accordance with the advice in Section 5.6.

Discussion notes:

When combined with the 'widened shoulder delineation treatment' that uses limited (metre wide) hatching, as described earlier in this document, a 2.5m shoulder provides a 1.5m space for the cyclist separated by a 1m marked buffer.

The layout in the Austroads Guide to Road Design Part 4C is only advisory. Its use cannot be enforced, only encouraged. In reality, the cyclist may choose whether to cross at the continuity, at their own risk, or use the alternative prescribed 'safe crossing' route. If we don't provide the 'safe crossing', then we are not providing what is considered to be the safer alternative and, in effect, endorsing the additional risk.

The key safety issue is that, without it, the cyclist is required to leave the shoulder (approx 1.5m offset from the traffic lane), cross the ramp behind the continuity line and back onto the shoulder. Initially the cyclist would only appear in the peripheral vision of the motorist. The cyclist's offset from the traffic flow would compound the difficulty in predicting their behaviour. A motorist leaving the expressway at the ramp would be required to adjust their speed to avoid a cyclist choosing to take this course. While this may result in an acceptable outcome for the cyclist, it would result in unpredictable behaviour to other road users: adjusting speed, particularly decelerating (braking) on the main-line is undesirable.

By providing the layout in accordance with Part 4C, the whole situation is potentially much more predictable and in the cyclist's control as to when it is safe to cross. This would still be the safer option with higher volumes, when driver's behaviour is even more erratic (less predictable) at a diverge as they jostle for position. More vulnerable cyclists, who are intimidated by high traffic speed or volumes, are also unlikely to ride in this environment; if they are there however, then the facility is available for them.

For both on-road and off-road facilities, provision shall take into account any local and regional walking and cycling strategies.

Endorsed by: National Traffic & Safety Manager

Appendices

Appendix A

Project specific example of whole of life engineering considerations applied to create a Safe System compliant corridor. **This is not a definitive justification, rather an example of the engineering logic applied in context.**

Appendix B

Example calculation of whole of life Fatal and Serious Injury benefits – WRB vs 9m Clear-zone

Appendix C

Example calculation Benefit Cost Ratios – WRB vs 9m Clear-zone

Appendix D

Typical sections illustrating the Safe System principles

Appendix A

Project specific example of whole of life engineering considerations applied to create a Safe System compliant corridor. **This is not a definitive justification, rather an example of the engineering logic applied in context.**

The following is an extract from a paper presented to advise the way in which the Safe System philosophy and guidelines would be applied to a project.

Mid-block Section

*The mid-block cross-section has essentially been agreed – except confirmation of the 3m shy-line to WRB (from 4m) subject to confirming additional maintenance costs from barrier strike? The one exception for confirmation (and particularly relevant if the 3m shy-line is adopted) is **for a sealed surface to be provided to a nominal distance outside the WRB (nominally 0.5m).***

An aspect for consideration is that the sealed surface should only be to the width of the shoulder (of 2.5m). This would then leave a 0.5m unsealed surface between the carriageway and the WRB. The change in sealed surface on approach to the Wire Rope Barrier (WRB) and was considered less of an issue than sealing to a 3m width that would then require hatched pavement marking to show it is not a traffic lane. This is technically correct but is questionable in terms of ongoing practicality of maintenance requirements. The unsealed surface is likely to be prone to weed growth and sediment build-up, which will need ongoing spraying and debris trimming to ensure surface water flows do not pond within the carriageway (i.e. build-up may prevent water shed clear of the carriageway and shoulders).

The proposal is widening the chip seal surface to 0.5m outside the WRB – an additional 1m width over and above the preference expressed above. However, we suggest the OGPA surfacing would only extend to the edge of the LHS shoulder (i.e. 2.5m outside the carriageway). This would leave a 40mm high lip running 0.5m inside the WRB, but is considered preferable to ending the OGPA along the LHS edgeline, and considered reasonable to avoid OGPA surfacing through to the WRB. The additional chip seal cost is approximately \$100k.

It is considered that the ongoing maintenance requirements of an unsealed surface between the WRB's would outweigh the additional costs associated with an surfacing the 1m width of chip seal. Our asset management specialists estimate that the additional sealing would allow extension of timeframes between periodic spraying and substantial reduction in shoulder trimming to remove built-up debris. Both of these tasks would also remove the need to associated traffic management. Initial assessment suggests that the widened seal would save approximately \$10k/year for the network maintenance teams. Ignoring discount rates over time, the initial investment would be returned after 10 years of operation.

Expressway beneath underbridges

It is desirable to maintain a LHS shyline of 3m, to also allow for vehicles to park clear of the traffic lane beneath the bridge structure. Assuming adoption of the 3m LHS shyline along the mid-block length, this provides consistency of barrier protection along the LHS verge for the entire Expressway length.

We propose a short length variation to the RHS shyline requirements (from 2.8m to 1.5m) beneath bridges where central bridge piers are located within the median (at present this only affects two locations, with other bridges having their central pier removed, provided the recommended 3m LHS shyline requirements are adopted). This slight compromise in the RHS shyline will occur over a short distance (beneath the two affected underbridges), allows for consistency of the median width (of 6m) along the entire Expressway length, and minimises lengthening of affected bridges to span the additional median width. It is noted that some additional median widening (over 6m) will still be required at the northern interchange to maintain sight distance, however the additional median widening is minimised if 1.5m RHS shylines can be adopted.

The additional bridge costs associated with the 2.8m RHS shyline requirement are:

- Increase cost to Interchange bridge = \$110k
- Increased cost to Road bridge = \$156k

Appendix B

Example calculation of whole of life Fatal and Serious Injury benefits – WRB vs 9m Clear-zone

Base Data and Assumptions

- The project was split into three separate lengths based on traffic flows and corridor characteristics
- An average traffic flow for the three forecast years 2016, 2026, 2036 has been used based on the forecast AADT traffic flows
- The proportion of vehicles reaching a hazard is based on the 'No hazard struck' category in Fig.1.
- The severity ratio of hazards is derived from Austroads data. This is based on a variety of existing roadside environments and while it is considered appropriate for the individual hazards, the 'No hazard hit' category may potentially be of a lower severity for this assessment. This is due to comparison of the uniform and level embankment as per the design which will be the baseline for this assessment. To take this into account, two severity figures will be used, 0.38 and 0.30 as a 'High' and 'Low' respectively as a severity figure. The 'low' figure effectively being a 20% reduction in the Austroads figure.
- Where there are treatment/ attenuation ponds and swales these will be assumed to have the same severity ratio as for no hazard hit.
- All crashes in the assessment are based on ROR rate of 5 injury crashes/100mvkt
- For the purposes of this assessment, where any reduction in FSi crashes is calculated it is assumed that these will become minor injury crashes.
- The hazards which are protected by safety barrier such as bridge abutments and embankments in the design with the 9m clear zone, will remain in the same form for the WRB option.
- Social costs are based on NZTA Economic Evaluation Manual Tables A6.21 (e, f and g) for Loss of Control Crashes (off road) in 100km/h speed limit areas. Based on these values an average cost of fatal and serious has been used in this assessment.

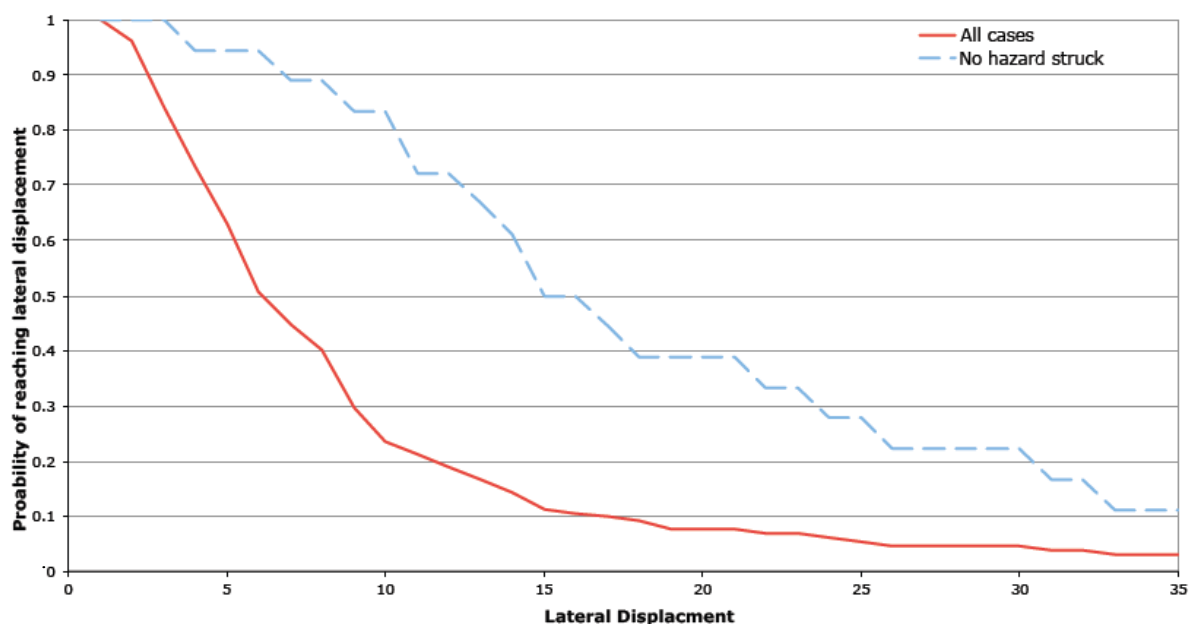


Fig. 1 Cumulative distribution of lateral displacement. Source: Centre for Automotive Safety Research

Table 1 – Forecast Traffic volumes

Direction	Forecast Traffic Flow (AADT)		
	2016	2026	2036
Increasing	18,300	22,000	23,600
Decreasing	17,700	21,600	24,200
Total	36,000	43,600	47,800
Increasing	18,400	22,000	24,500
Decreasing	18,900	23,200	25,600
Total	37,300	45,200	50,100
Increasing	8,800	11,900	16,300
Decreasing	9,100	12,200	16,400
Total	17,900	24,100	32,700

Table 2 - Severity ratio of roadside hazards: Source NZTA

Hazard type	Fatal or serious injuries per ROR casualty crash		
	100 and 110 km/h	80 km/h urban	60 km/h urban
Pole	0.55	0.57	0.50
Tree (shrub/scrub)	0.52	0.59	0.47
Rigid barrier	0.32	-	-
Semi-rigid barrier	0.40	-	-
Flexible barrier	0.23	-	-
No hazard hit	0.38	-	-

Results

Tables below present the overall summary of crash numbers and severity and their corresponding social cost¹ by the respective road sections in relation to;

- Current design with 9m clear zones and;
- WRB at 3m setback

In respect of the current design, two severity factors have been used for the clear zone based on; the Austroads data which is determined from existing roads and comprises a variety of roadsides (High) and; a factor reduced by 20% to take into account any benefits likely from the application of the new design (Low).

It can be seen that with the current design including 9m clear zones it is anticipated that there is likely to be a 'High' value of 4.4 FSi crashes per year (CPY) and a 'Low' value of 3.6 FSi CPY. The installation of WRB would reduce these crashes to 2.9FSi crashes per year representing a minimum likely saving of 0.7 FSi CPY. When considering this saving in FSi crashes and allowing for the migration of these to minor injury crashes this equates to a social cost saving of \$1.35Million annually.

It should be noted that this assessment has only taken into account a reduction in crash severity from, fatal and serious to minor injury. Anecdotal evidence suggests that many of these minor injury crashes may be reduced further to non-injury crashes.

Note - Social cost based on EEM (July 2006) figures for 100km/h Loss of control off road, Fatal \$3.55M, Serious \$0.375M and Minor \$22,000. Average KSi Social Cost of \$1.877M.

Table 3 - ROR crash assessment and social costs summary by design with clear zone treatment

	Total expected number of crashes per year in section based on 5/100mvkt	Number of Fsi crashes per year based on 'high' clear zone severity (0.38)	Number of Fsi crashes per year based on 'low' clear zone severity (0.3)	Minor crashes per year ('high' clear zone severity)	Minor crashes per year ('low' clear zone severity)	Social Cost Million \$* ('high')	Social Cost Million \$* ('low')
Crashes and social cost as per design with 9m clear zone	Section A - 1710m	1.33	0.50	0.43	0.84	0.90	0.827
	Section B - 4430m	3.55	1.34	1.13	2.22	2.43	2.174
	Section C - 14900m	6.77	2.58	2.08	4.21	4.89	4.01
	Total	11.65	4.39	3.64	7.27	8.02	7.009

Table 4 - ROR crash assessment and social costs summary with wire rope barrier treatment

	Total expected number of crashes per year in section based on 5/100mvkt	Number of Fsi crashes per year	Minor crashes per year	Social Cost Million \$*
Crashes and social cost with WRB	Section A - 1710m	1.33	0.37	0.96
	Section B - 4430m	3.55	0.94	1.822
	Section C - 14900m	6.77	1.60	3.117
	Total	11.65	2.91	5.655

Assuming the minimum 'Low' benefits only and a WRB design life of 20 years there is potential to save 18 Fatal and/or Serious crashes with an undiscounted social cost saving of \$24.3Million.

This assessment has also demonstrated that a significant proportion of crashes result in travel further than the 9m clear zones provided in the design. Although current hazards outside of the 9m clear zone have been taken into account, this assessment does not take into account any future changes to the land use. Changes outside of the designation such as tree growth, installation of fences and drainage ditches could occur increasing the crash risk further. The installation of WRB would remove these future risks.

Appendix C

Example calculation Benefit Cost Ratios – WRB vs 9m Clear-zone

The following example uses the benefits from Appendix B to calculate the Benefit/Cost ratio in accordance with the NZTA's Economic Evaluation Manual. The data used has been generalised from a real-world example. The lengths of the different sections were chosen for their typical road corridor character.

The following points should be noted:

- The difference between the High Severity and Low Severity Clear-zone benefits relates to the crash severity index associated with both. A hazard free roadside on a rural expressway may still cause an errant vehicle to roll, whereas a specifically designed clear-zone reduces this likelihood. The severity index therefore reduces from 0.38 to 0.30.
- For the purpose of a designed expressway, the High Severity Clear-zone may be ignored. This has not been included in the summary table
- This is based on an original design that had the clear-zone principle applied to its entire length. As part of the assessment, it has been assumed that all of the designed clear-zone has been replaced by WRB. In practice, there may be areas where the quality of the clear-zone could be improved to reduce the residual risk factor. Therefore increasing the value of the clear-zone as a solution.
- The predicted social costs for each 'option' have been calculated for the entire length of the section. These include the lengths of safety barrier required to protect hazards that cannot be removed to provide a clear-zone (e.g. steep batter slopes). These lengths are common to both social costs calculations.
- Allowance has not been made for:
 - the 'whole of life' Clear-zone costs.
 - Savings in land purchase
 - For the typical cross section of a new project, the saving in land purchase and maintenance costs is estimated to be 4m of corridor width, or 0.4ha per kilometre. Note that this is highly dependent on the drainage and earth slope detail and should be verified by the designers.

Clear Zone vs Wire Rope Barrier Benefit Cost Ratio Analysis - Section A

Details:

Average AADT 2016-2036 (westbound) =	21166 vpd
Average AADT 2016-2036 (eastbound) =	21300 vpd
Average AADT 2016-2036 (total) =	42466 vpd
Section Length =	1710 m
Length of Clear-zone replaced by Wire Rope Barrier in (both directions)	2020 m
No. of crashes per year	1.33
Crash rate = 5/100 million vehicle kms travelled	

Time Periods:

Base Date =	1/07/2011
Time Zero =	1/07/2014

Costs

Clear Zone Option Social Costs Based on Table 3 in Appendix B

"High" Social Cost per year
\$ 957,000.00 (based on NZTA EEM 2006 with Severity Factor of 0.38 and average Ksl \$1.877M and minor \$0.022M)

"Low" Social Cost per year
\$ 827,000.00 (based on reduced Severity Factor of 0.3 to take into account high standard of roadside design on proposed new road)

Following table determines the total High and Low Clear Zone crash Social Costs based on varying periods of analysis

Analysis Period	Uniform Series Present Worth Factor	Single Payment Present Worth Factor	Accident Trend Adjustment	Clear Zone Social Injury Cost		Total Cost over Analysis Period	
				"High"	"Low"	"High"	"Low"
20 years	10.2058	0.7938	0.95	\$ 957,000.00	\$ 827,000.00	\$ 7,365,000.00	\$ 6,365,000.00
25 years	11.0963	0.7938	0.95	\$ 957,000.00	\$ 827,000.00	\$ 8,008,000.00	\$ 6,920,000.00
30 years	11.7023	0.7938	0.95	\$ 957,000.00	\$ 827,000.00	\$ 8,445,000.00	\$ 7,298,000.00

Wire Rope Barrier Option Social Costs Based on Table 4 in Appendix B

\$716,000

Following table determines the total Wire Rope Barrier Social Costs for three periods of analysis

Analysis Period	Uniform Series Present Worth Factor	Single Payment Present Worth Factor	Accident Trend Adjustment	WRB Social Cost
20 years	10.2058	0.7938	0.95	\$ 5,511,000.00
25 years	11.0963	0.7938	0.95	\$ 5,991,000.00
30 years	11.7023	0.7938	0.95	\$ 6,319,000.00

Difference between Clear Zone and Wire Rope Option Crash Social Costs

Analysis Period	"High" Clear Zone Social Cost	"Low" Clear Zone Social Cost	WRB Social Cost	Net "High CZ" Social Cost	Net "Low CZ" Social Cost
20 years	\$ 7,365,000.00	\$ 6,365,000.00	\$ 5,511,000.00	\$ 1,854,000.00	\$ 854,000.00
25 years	\$ 8,008,000.00	\$ 6,920,000.00	\$ 5,991,000.00	\$ 2,017,000.00	\$ 929,000.00
30 years	\$ 8,445,000.00	\$ 7,298,000.00	\$ 6,319,000.00	\$ 2,126,000.00	\$ 979,000.00

Costs:

Wire Rope Construction Capital Cost Rate

Based on:			
Wire Rope Barrier including anchor blocks =	= 21,040m (total length) x \$75/m	= \$	1,578,000.00
Contractor Costs + overheads	plus 50%	= \$	789,000.00
		Total Base Estimate	\$ 2,367,000.00
			\$ 165,690.00
Contingency - assume 7%		Total Expected Estimate	\$ 2,532,690.00
Linear metre rate for 21,040 =		= \$	120.38
		Approx	\$ 125.00 /m

Length of Clear-zone replaced by Wire Rope Barrier in (both directions) **2020 m**

Length of WRB in Section A (m)	Wire Rope Construction Cost per m	Single Payment Present Worth Factor	Total Wire Rope Capital Construction Cost
2020	\$ 125.00	0.7938	\$ 200,400.00

Wire Rope Maintenance Costs:

21.04km length of edge protection wire rope barriers being installed - two barrier strikes per week at a repair cost of \$2,000/ strike
 Annual WRB Maintenance Cost = 2 strikes per month x \$2,000/strike x 12 months

\$ 48,000.00

Following table determines the total wire rope barrier maintenance costs based on varying periods of analysis

Analysis Period	Length of WRB (m)	Total Length of Edge WRB being Installed (m)	Proportion of Total WRB being Installed	Annual WRB Maintenance Costs	Uniform Series Present Worth Factor	Single Payment Present Worth Factor	Total WRB Maintenance Costs
20 years	2,020	21,040	0.0960	\$ 4,600.00	10.2058	0.7938	\$ 37,300.00
25 years	2,020	21,040	0.0960	\$ 4,600.00	11.0963	0.7938	\$ 40,500.00
30 years	2,020	21,040	0.0960	\$ 4,600.00	11.7023	0.7938	\$ 42,700.00

Benefit/Cost Ratio

Following table calculates the benefit/cost ratio for the additional "High" and "Low" Severity costs compared to installing a WRB

Analysis Period	Net "High CZ" Social Cost	Net "Low CZ" Social Cost	Total Wire Rope Capital Construction Cost	Total WRB Maintenance Costs	Total WRB Costs	"High CZ" Benefit Cost Ratio	"Low CZ" Benefit Cost Ratio
20 years	\$ 1,854,000.00	\$ 854,000.00	\$ 200,400.00	\$ 37,300.00	\$ 237,700.00	7.8	3.6
25 years	\$ 2,017,000.00	\$ 929,000.00	\$ 200,400.00	\$ 40,500.00	\$ 240,900.00	8.4	3.9
30 years	\$ 2,126,000.00	\$ 979,000.00	\$ 200,400.00	\$ 42,700.00	\$ 243,100.00	8.7	4.0

Clear Zone vs Wire Rope Barrier Benefit Cost Ratio Analysis - Section B

Details:

Average AADT 2016-2036 (westbound) =	22566 vpd
Average AADT 2016-2036 (eastbound) =	21633 vpd
Average AADT 2016-2036 (total) =	44199 vpd
Section Length =	4430 m
Length of Clear-zone replaced by Wire Rope Barrier in (both directions)	6289 m
No. of crashes per year	3.55
Crash rate = 5/100 million vehicle kms travelled	

Time Periods:

Base Date =	1/07/2011
Time Zero =	1/07/2014

Costs:

Clear Zone Option Social Costs Based on Table 3 in Appendix B

"High" Social Cost per year
\$ 2,560,000.00 (based on NZTA EEM 2006 with Severity Factor of 0.38 and average Ksi \$1.877M and minor \$0.022M)

"Low" Social Cost per year
\$ 2,174,000.00 (based on reduced Severity Factor of 0.3 to take into account high standard of roadside design on proposed new road)

Following table determines the total High and Low Clear Zone crash Social Costs based on varying periods of analysis

Analysis Period	Uniform Series Present Worth Factor	Single Payment Present Worth Factor	Accident Trend Adjustment	Clear Zone Social Injury Cost		Total Cost over Analysis Period	
				"High"	"Low"	"High"	"Low"
20 years	10.2058	0.7938	0.95	\$ 2,560,000.00	\$ 2,174,000.00	\$ 19,703,000.00	\$ 16,732,000.00
25 years	11.0963	0.7938	0.95	\$ 2,560,000.00	\$ 2,174,000.00	\$ 21,422,000.00	\$ 18,192,000.00
30 years	11.7023	0.7938	0.95	\$ 2,560,000.00	\$ 2,174,000.00	\$ 22,592,000.00	\$ 19,185,000.00

Wire Rope Barrier Option Social Costs Based on Table 4 in Appendix B

\$1,822,000

Following table determines the total Wire Rope Barrier Social Costs for three periods of analysis

Analysis Period	Uniform Series Present Worth Factor	Single Payment Present Worth Factor	Accident Trend Adjustment	WRB Social Cost
20 years	10.2058	0.7938	0.95	\$ 14,023,000.00
25 years	11.0963	0.7938	0.95	\$ 15,246,000.00
30 years	11.7023	0.7938	0.95	\$ 16,079,000.00

Difference between Clear Zone and Wire Rope Option Crash Social Costs

Analysis Period	"High" Clear Zone Social Cost	"Low" Clear Zone Social Cost	WRB Social Cost	Net "High CZ" Social Cost	Net "Low CZ" Social Cost
20 years	\$ 19,703,000.00	\$ 16,732,000.00	\$ 14,023,000.00	\$ 5,680,000.00	\$ 2,709,000.00
25 years	\$ 21,422,000.00	\$ 18,192,000.00	\$ 15,246,000.00	\$ 6,176,000.00	\$ 2,946,000.00
30 years	\$ 22,592,000.00	\$ 19,185,000.00	\$ 16,079,000.00	\$ 6,513,000.00	\$ 3,106,000.00

Costs:

Wire Rope Construction Capital Cost Rate

Based on:			
Wire Rope Barrier Including anchor blocks =	= 21,040m (total length) x \$75/m	=	\$ 1,578,000.00
Contractor Costs + overheads	plus 50%	=	\$ 789,000.00
		Total Base Estimate	\$ 2,367,000.00
Contingency - assume 7%			\$ 165,690.00
		Total Expected Estimate	\$ 2,532,690.00
Linear metre rate for 21,040 =		=	\$ 120.38
		Approx	\$ 125.00 /m

Length of Clear-zone replaced by Wire Rope Barrier in (both directions) **6289 m**

Length of WRB in Section B (m)	Wire Rope Construction Cost per m	Single Payment Present Worth Factor	Total Wire Rope Capital Construction Cost
6289	\$ 125.00	0.7938	\$ 624,000.00

Wire Rope Maintenance Costs:

21.04km length of edge protection wire rope barriers being installed - two barrier strikes per week at a repair cost of \$2,000/ strike
 Annual WRB Maintenance Cost = 2 strikes per month x \$2,000/strike x 12 months

\$ 48,000.00

Following table determines the total wire rope barrier maintenance costs based on varying periods of analysis

Analysis Period	Length of WRB (m)	Total Length of Edge WRB being Installed (m)	Proportion of Total WRB being Installed	Annual WRB Maintenance Costs	Uniform Series Present Worth Factor	Single Payment Present Worth Factor	Total WRB Maintenance Costs
20 years	6,289	21,040	0.2989	\$ 14,300.00	10.2058	0.7938	\$ 115,800.00
25 years	6,289	21,040	0.2989	\$ 14,300.00	11.0963	0.7938	\$ 126,000.00
30 years	6,289	21,040	0.2989	\$ 14,300.00	11.7023	0.7938	\$ 132,800.00

Benefit/Cost Ratio

Following table calculates the benefit/cost ratio for the additional "High" and "Low" Severity costs compared to installing a WRB

Analysis Period	Total "High CZ" Social Cost Benefit	Total "Low CZ" Social Cost Benefit	Total Wire Rope Capital Construction Cost	Total WRB Maintenance Costs	Total Costs	"High CZ" Benefit Cost Ratio	"Low CZ" Benefit Cost Ratio
20 years	\$ 5,680,000.00	\$ 2,709,000.00	\$ 624,000.00	\$ 115,800.00	\$ 739,800.00	7.7	3.7
25 years	\$ 6,176,000.00	\$ 2,946,000.00	\$ 624,000.00	\$ 126,000.00	\$ 750,000.00	8.2	3.9
30 years	\$ 6,513,000.00	\$ 3,106,000.00	\$ 624,000.00	\$ 132,800.00	\$ 756,800.00	8.6	4.1

Clear Zone vs Wire Rope Barrier Benefit Cost Ratio Analysis - Section C

Details:

Average AADT 2016-2036 (westbound) =	12566 vpd
Average AADT 2016-2036 (eastbound) =	12333 vpd
Average AADT 2016-2036 (total) =	24899 vpd
Section Length =	14900 m
Length of Clear-zone replaced by Wire Rope Barrier in (both directions)	12731 m
No. of crashes per year	6.77
Crash rate = 5/100 million vehicle kms travelled	

Time Periods:

Base Date =	1/07/2011
Time Zero =	1/07/2014

Costs:

Clear Zone Option Social Costs Based on Table 3 in Appendix B

"High" Social Cost per year
\$ 4,900,000.00 (based on NZTA EEM 2006 with Severity Factor of 0.38 and average Ksi \$1.877M and minor \$0.022M)

"Low" Social Cost per year
\$ 4,010,000.00 (based on reduced Severity Factor of 0.3 to take into account high standard of roadside design on proposed new road)

Following table determines the total High and Low Clear Zone crash Social Costs based on varying periods of analysis

Analysis Period	Uniform Series Present Worth Factor	Single Payment Present Worth Factor	Accident Trend Adjustment	Clear Zone Social Injury Cost		Total Cost over Analysis Period	
				"High"	"Low"	"High"	"Low"
20 years	10.2058	0.7938	0.95	\$ 4,900,000.00	\$ 4,010,000.00	\$ 37,712,000.00	\$ 30,862,000.00
25 years	11.0963	0.7938	0.95	\$ 4,900,000.00	\$ 4,010,000.00	\$ 41,002,000.00	\$ 33,555,000.00
30 years	11.7023	0.7938	0.95	\$ 4,900,000.00	\$ 4,010,000.00	\$ 43,242,000.00	\$ 35,388,000.00

Wire Rope Barrier Option Social Costs Based on Table 4 in Appendix B

\$3,117,000

Following table determines the total Wire Rope Barrier Social Costs for three periods of analysis

Analysis Period	Uniform Series Present Worth Factor	Single Payment Present Worth Factor	Accident Trend Adjustment	WRB Social Cost
20 years	10.2058	0.7938	0.95	\$ 23,989,000.00
25 years	11.0963	0.7938	0.95	\$ 26,083,000.00
30 years	11.7023	0.7938	0.95	\$ 27,507,000.00

Difference between Clear Zone and Wire Rope Option Crash Social Costs

Analysis Period	"High" Clear Zone Social Cost	"Low" Clear Zone Social Cost	WRB Social Cost	Net "High CZ" Social Cost	Net "Low CZ" Social Cost
20 years	\$ 37,712,000.00	\$ 30,862,000.00	\$ 23,989,000.00	\$ 13,723,000.00	\$ 6,873,000.00
25 years	\$ 41,002,000.00	\$ 33,555,000.00	\$ 26,083,000.00	\$ 14,919,000.00	\$ 7,472,000.00
30 years	\$ 43,242,000.00	\$ 35,388,000.00	\$ 27,507,000.00	\$ 15,735,000.00	\$ 7,881,000.00

Costs:

Wire Rope Construction Capital Cost Rate

Based on:			
Wire Rope Barrier including anchor blocks =	= 21,040m (total length) x \$75/m	= \$ 1,578,000.00	
Contractor Costs + overheads	plus 50%	= \$ 789,000.00	
		Total Base Estimate	\$ 2,367,000.00
Contingency - assume 7%			\$ 165,690.00
		Total Expected Estimate	\$ 2,532,690.00
Linear metre rate for 21,040 =		= \$	120.38
		Approx \$	125.00 /m

Length of Clear-zone replaced by Wire Rope Barrier in (both directions) **12731 m**

Length of WRB in Section C (m)	Wire Rope Construction Cost per m	Single Payment Present Worth Factor	Total Wire Rope Capital Construction Cost
12731	\$ 125.00	0.7938	\$ 1,263,200.00

Wire Rope Maintenance Costs:

21.04km length of edge protection wire rope barriers being installed - two barrier strikes per week at a repair cost of \$2,000/ strike
 Annual WRB Maintenance Cost = 2 strikes per month x \$2,000/strike x 12 months

\$ 48,000.00

Following table determines the total wire rope barrier maintenance costs based on varying periods of analysis

Analysis Period	Length of WRB (m)	Total Length of Edge WRB being Installed (m)	Proportion of Total WRB being installed	Annual WRB Maintenance Costs	Uniform Series Present Worth Factor	Single Payment Present Worth Factor	Total WRB Maintenance Costs
20 years	12,731	21,040	0.6051	\$ 29,000.00	10.2058	0.7938	\$ 234,900.00
25 years	12,731	21,040	0.6051	\$ 29,000.00	11.0963	0.7938	\$ 255,400.00
30 years	12,731	21,040	0.6051	\$ 29,000.00	11.7023	0.7938	\$ 269,400.00

Benefit/Cost Ratio

Following table calculates the benefit/cost ratio for the additional "High" and "Low" Severity costs compared to installing a WRB

Analysis Period	Total "High CZ" Social Cost Benefit	Total "Low CZ" Social Cost Benefit	Total Wire Rope Capital Construction Cost	Total WRB Maintenance Costs	Total Costs	"High CZ" Benefit Cost Ratio	"Low CZ" Benefit Cost Ratio
20 years	\$ 13,723,000.00	\$ 6,873,000.00	\$ 1,263,200.00	\$ 234,900.00	\$ 1,498,100.00	9.2	4.6
25 years	\$ 14,919,000.00	\$ 7,472,000.00	\$ 1,263,200.00	\$ 255,400.00	\$ 1,518,600.00	9.8	4.9
30 years	\$ 15,735,000.00	\$ 7,881,000.00	\$ 1,263,200.00	\$ 269,400.00	\$ 1,532,600.00	10.3	5.1

SUMMARY OF COST- BENEFIT ANALYSIS OF THE OPTIONS

Safe System Clear Zone vs Barrier Analysis

1 Project Options	Low Clear Zone Severity			Wire Rope Barrier			Low Clear Zone Severity -WRB		
	Section A:	Section B:	Section C:	Section A:	Section B:	Section C:	Section A:	Section B:	Section C:
COSTS:									
2 Capital Costs	-	-	-	0.200	0.624	1.263	0.200	0.624	1.263
3.1 Maintenance Costs 20 Year Analysis Period	-	-	-	0.037	0.116	0.235	0.037	0.116	0.235
3.2 Maintenance Costs 25 Year Analysis Period	-	-	-	0.041	0.126	0.255	0.041	0.126	0.255
3.3 Maintenance Costs 30 Year Analysis Period	-	-	-	0.043	0.133	0.269	0.043	0.133	0.269
4.1 Total Costs (2) + (3.1) 20 Year Analysis Period	-	-	-	0.238	0.740	1.498	0.238	0.740	1.498
4.2 Total Costs (2) + (3.2) 25 Year Analysis Period	-	-	-	0.241	0.750	1.519	0.241	0.750	1.519
4.3 Total Costs (2) + (3.3) 30 Analysis Period	-	-	-	0.243	0.757	1.533	0.243	0.757	1.533
BENEFITS:									
7.1 Accident Costs 20 Year Analysis Period	6.365	16.732	30.862	5.511	14.023	23.9890	0.8540	2.7090	6.8730
7.2 Accident Costs 25 Year Analysis Period	6.920	18.192	33.555	5.991	15.246	26.0830	0.9290	2.9460	7.4720
7.3 Accident Cost 30 Year Analysys Period	7.298	19.185	35.388	6.319	16.079	27.5070	0.9790	3.1060	7.8810
8 Seal Extn/Passing Lane	-	-	-	-	-	-	-	-	-
9 Carbon Dioxide	-	-	-	-	-	-	-	-	-
10 Tangible Benefits (5) to (8)									
11.1	20 Year Analysis Period Provisional B/C Ratio (7.1)/(4.1)						3.6	3.7	4.6
11.2	25 Year Analysis Period Provisional B/C Ratio (7.2)/(4.2)						3.9	3.9	4.9
11.3	30 Year Analysis Period Provisional B/C Ratio (7.3)/(4.3)						4.0	4.1	5.1

Appendix D

Typical sections illustrating the Safe System principles

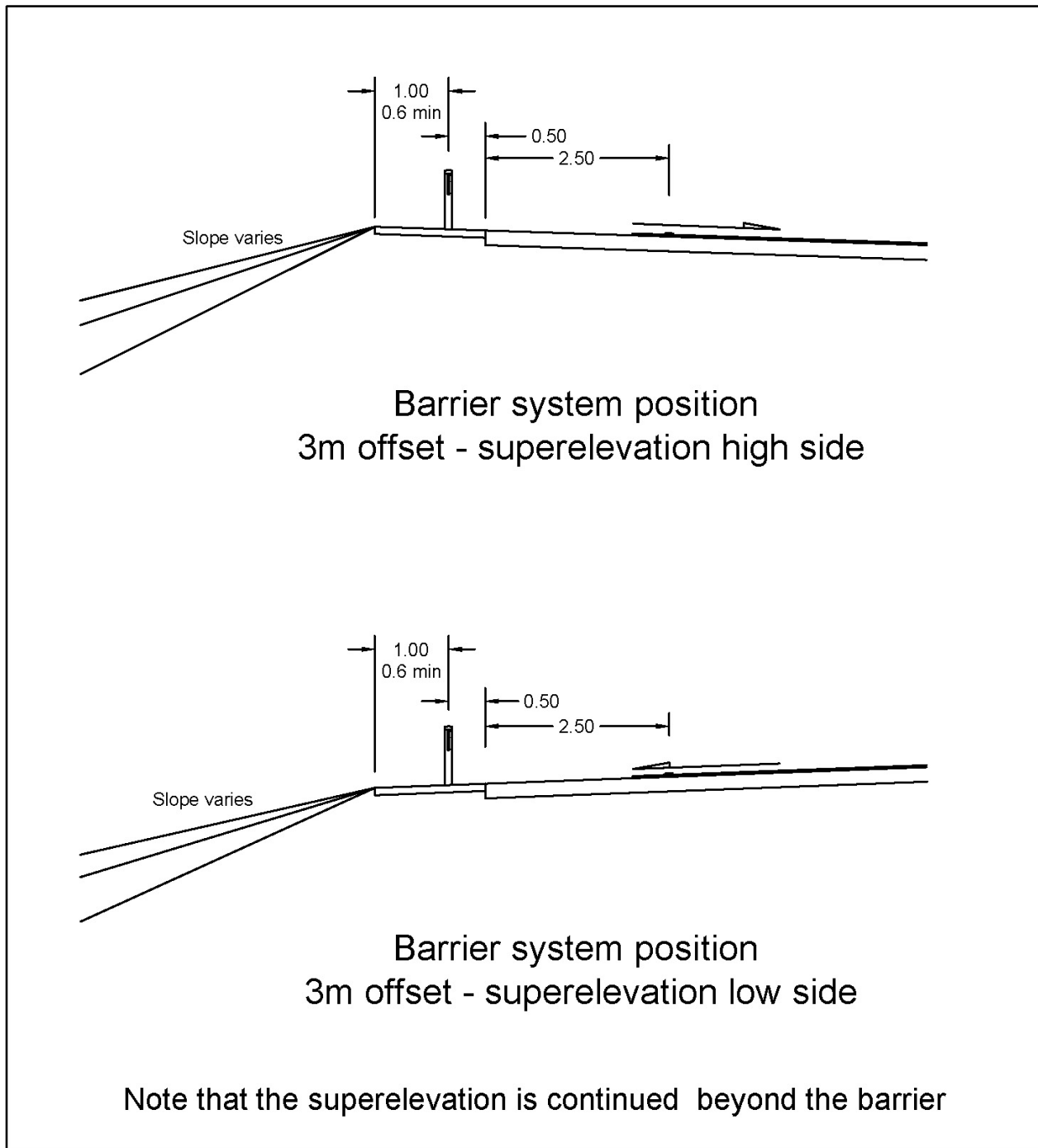


Figure D1 - Desirable barrier offset - continuous superelevation

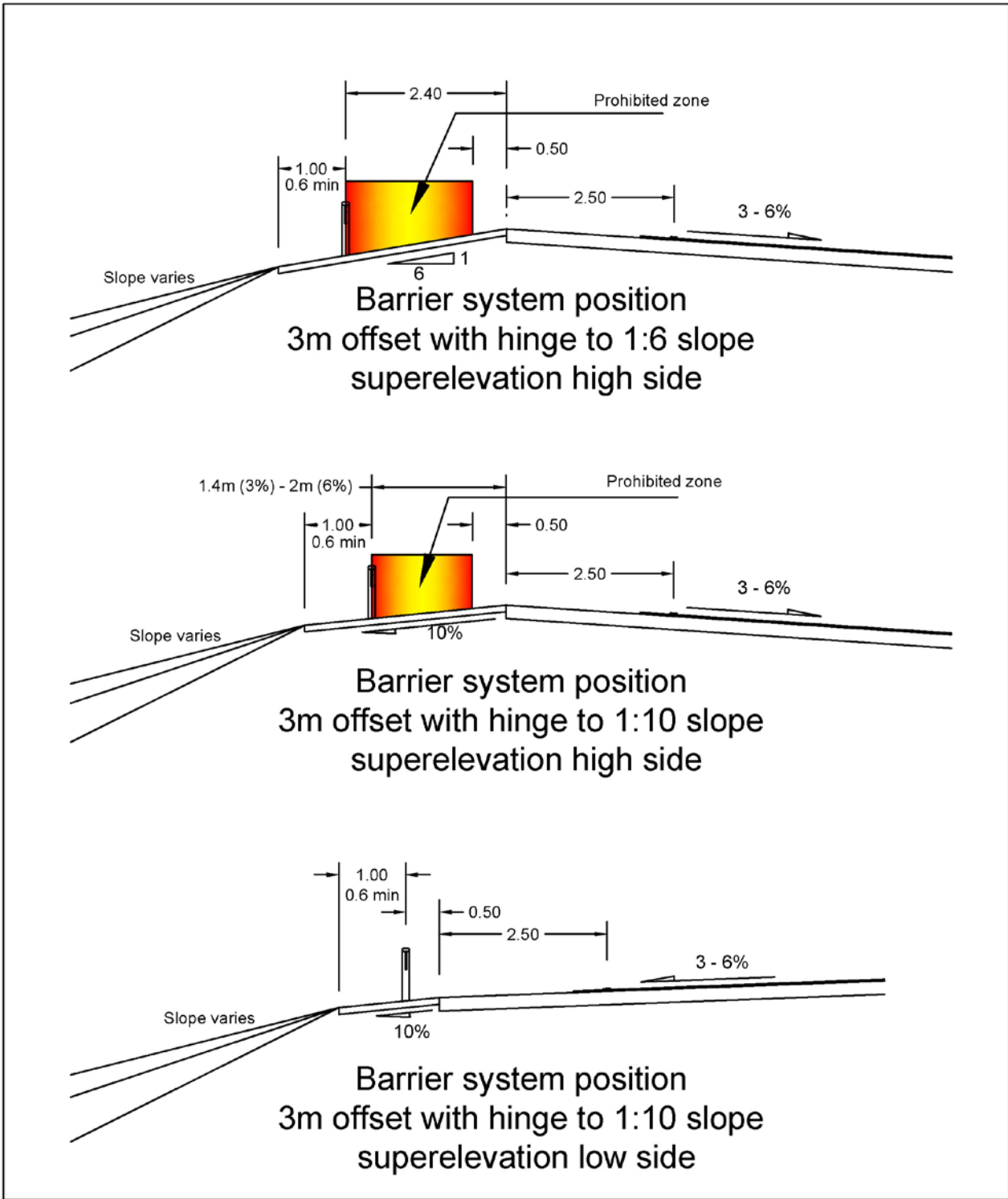


Figure D2 - Desirable barrier offset - hinge point at back of shoulder

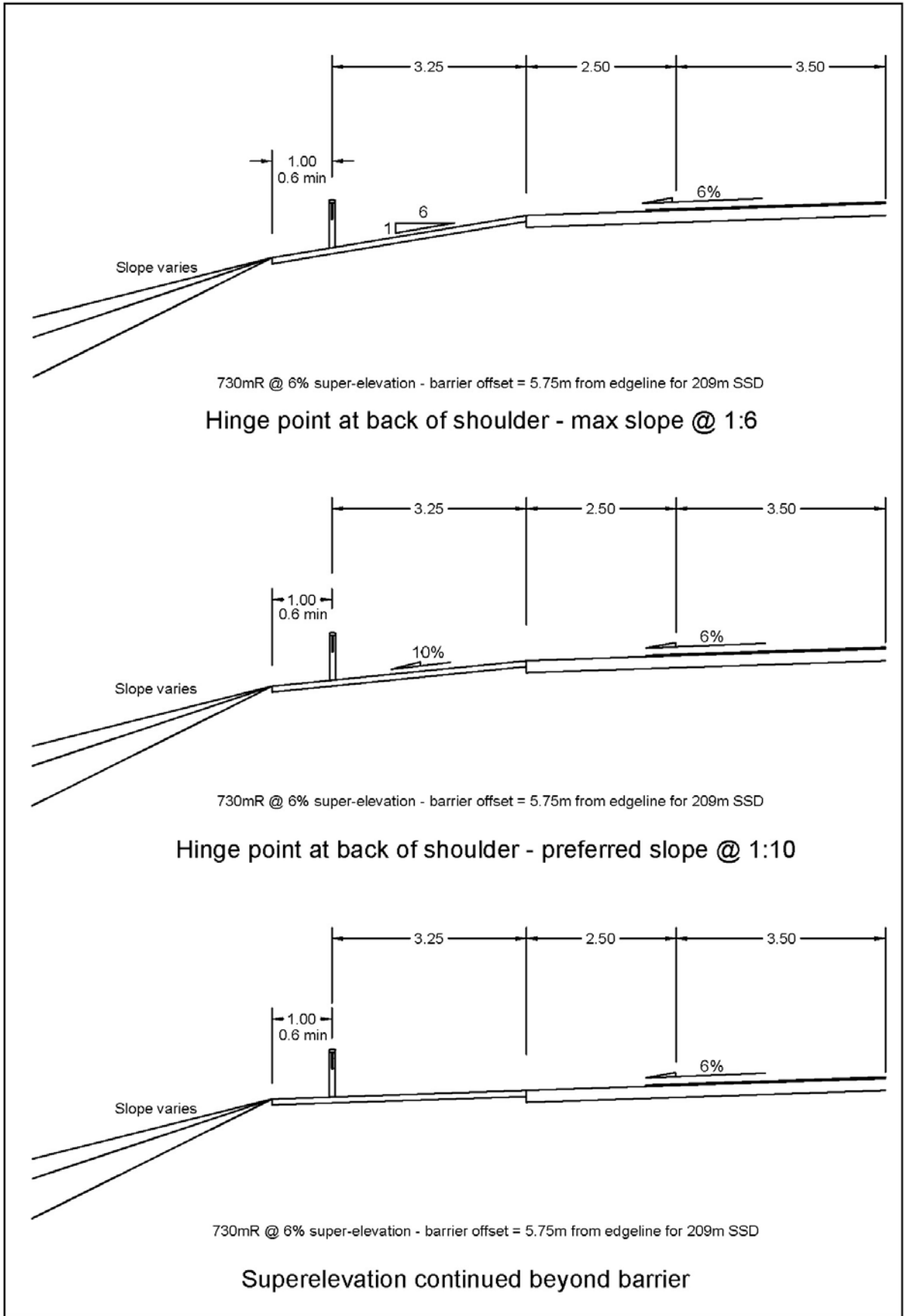


Figure D3 - Increased barrier offset for sight distance

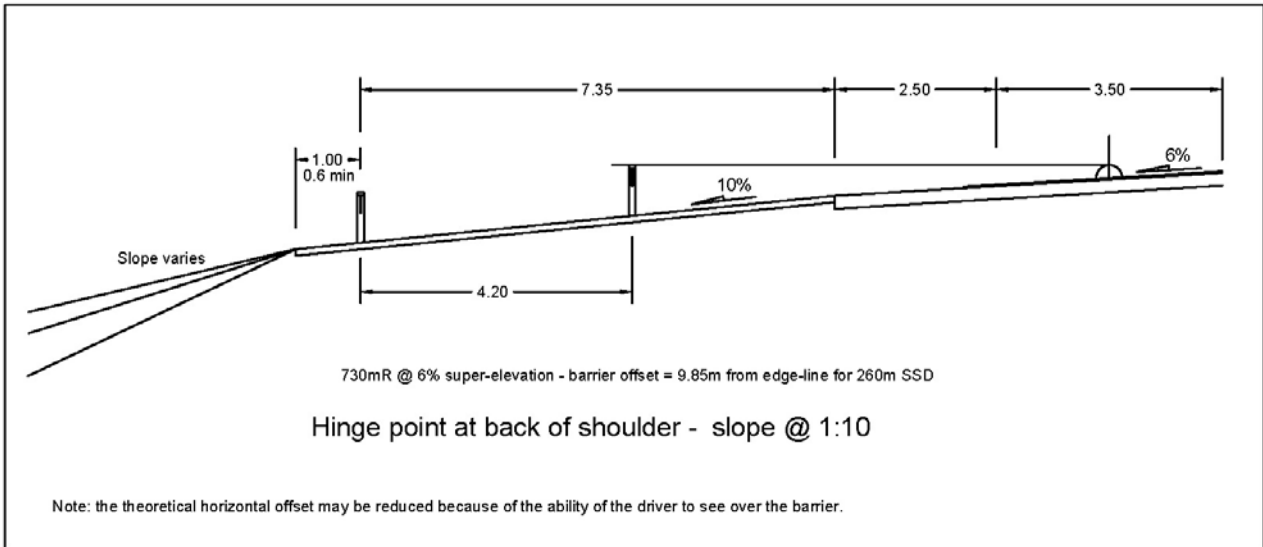


Figure D4 - Increased barrier offset for sight distance - hinge point at back of shoulder
 Note - ability to see over barrier is dependent on the vertical alignment

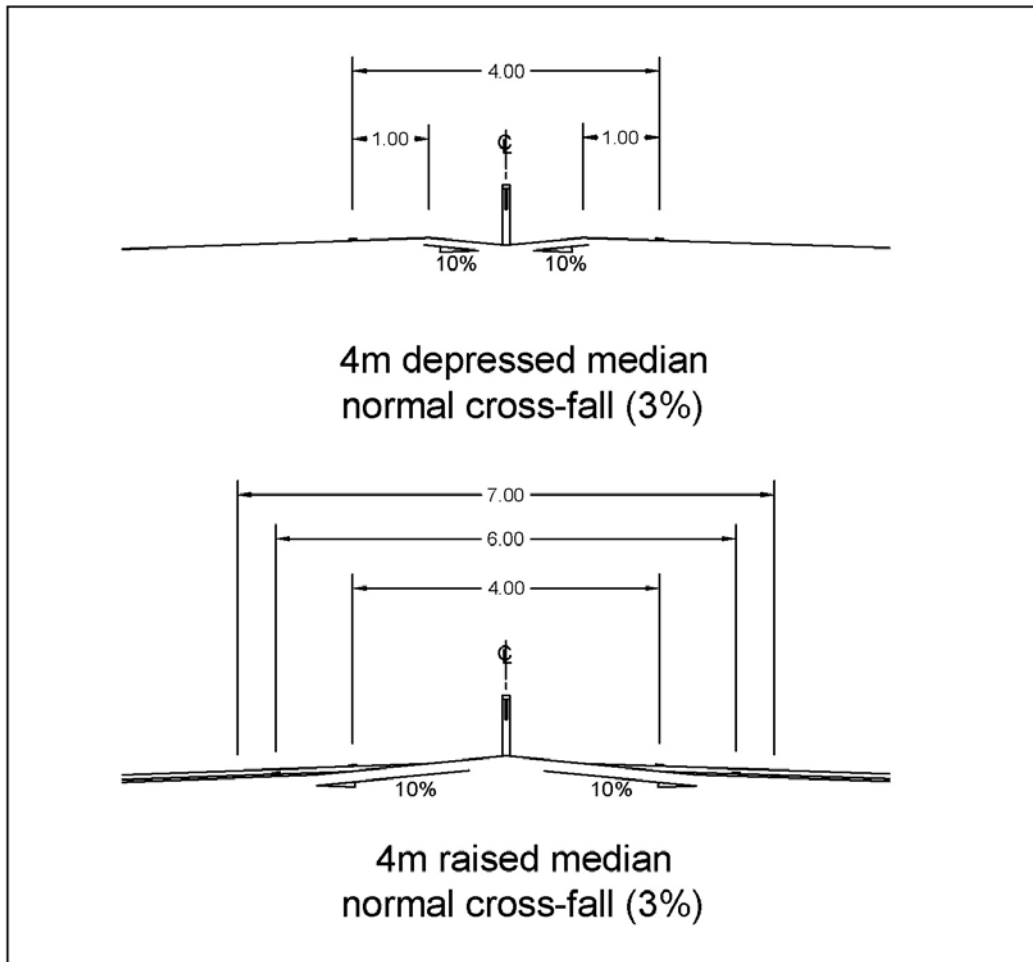


Figure D5 - Minimum 4m median

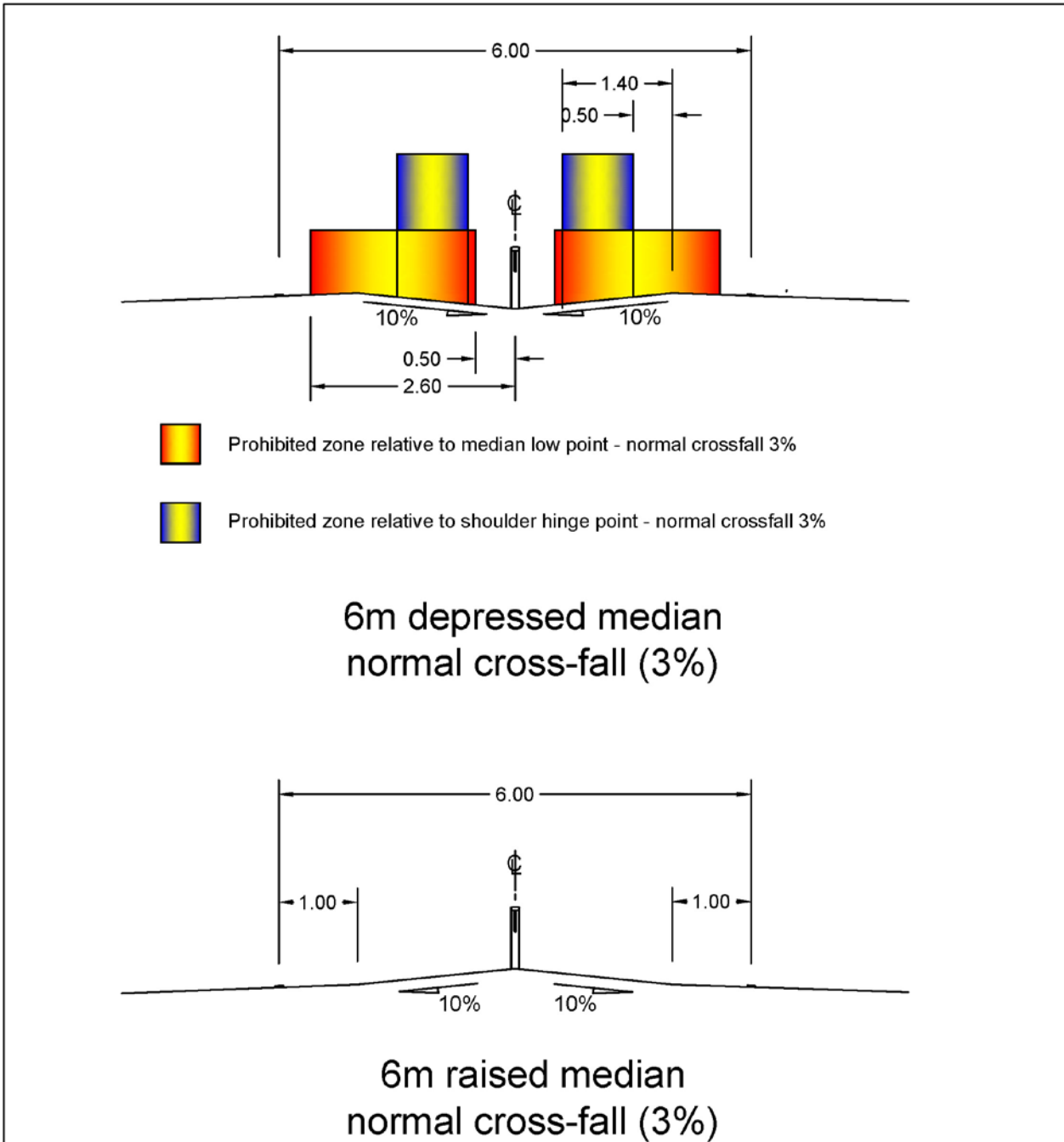
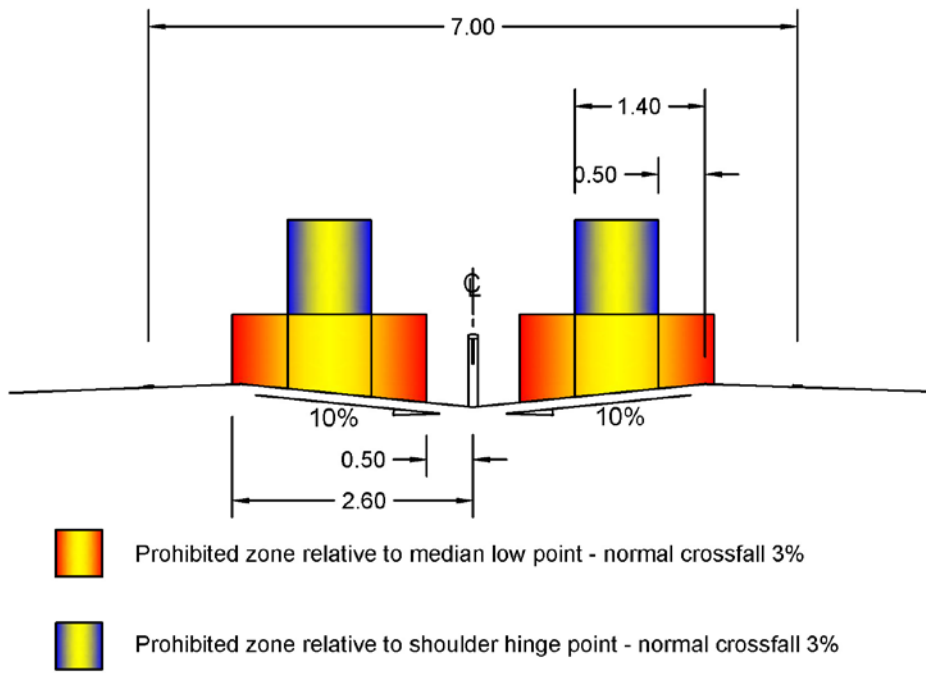
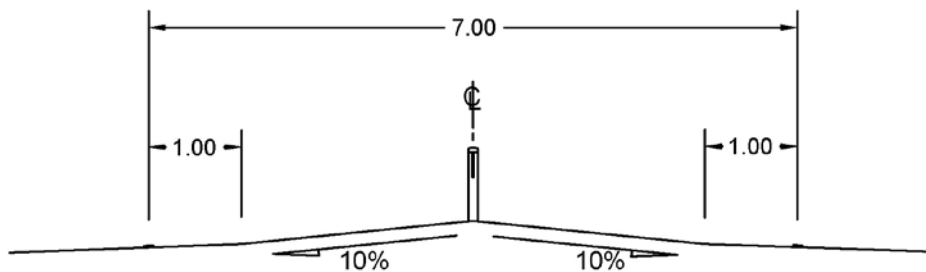


Figure D6 - Desirable 6m median

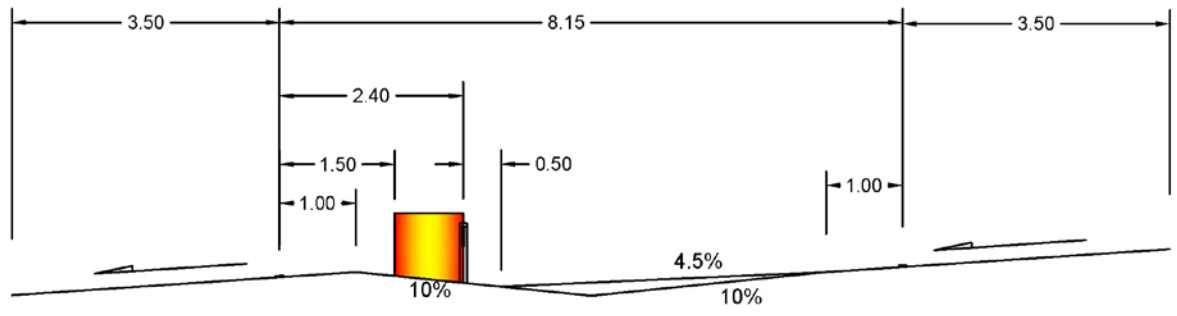


7m depressed median
normal cross-fall (3%)

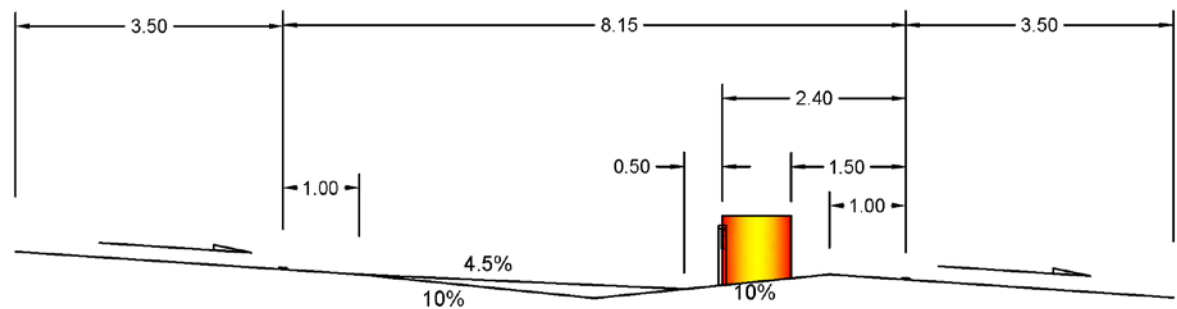


7m raised median
normal cross-fall (3%)

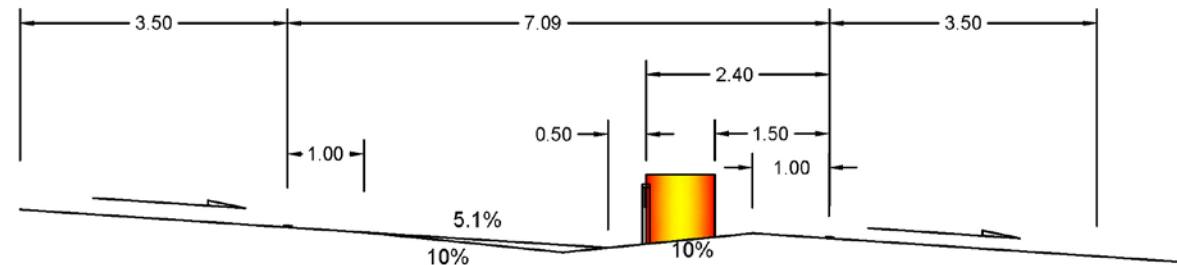
Figure D7 - 7m median



LH 730mR @ 6% super-elevation - barrier offset = 5.75m from edge-line for 209m SSD



RH 730mR @ 6% super-elevation - barrier offset = 5.75m from edgeline for 209m SSD

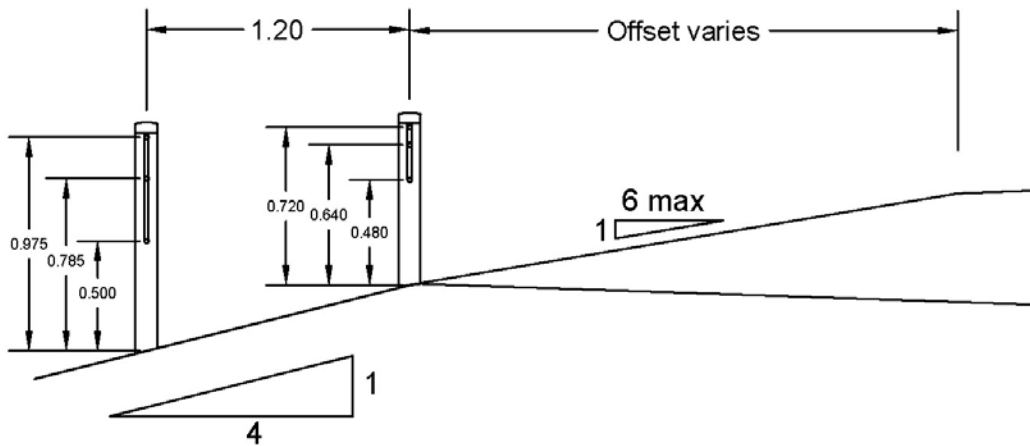


850mR @ 5% super-elevation - barrier offset = 4.69m from edge-line for 209m SSD

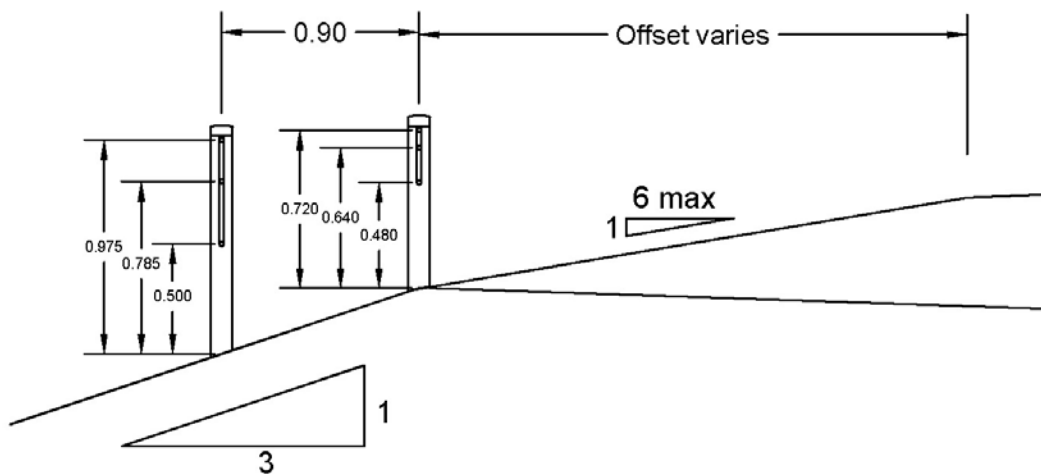
Illustrations of barrier position and median slopes
adjusted for sight distance
depressed median - superelevated

Figure D8 - Median widened for sight distance

Note - median low point varies



Barrier system position placed at hinge point or 1.2m beyond (1:4)



Barrier system position placed at hinge point or 0.9m beyond (1:3)
(Not Tested)

Figure D9 - Barrier at hinge point or on slope - not recommended

Note - 'Slope Barrier' has increased post length and wire spacing.