

A compendium providing a summary of the current knowledge on the implementation and effectiveness of narrow median WRBs on high risk roads with constrained cross-sections

Contact Details

Bill Frith WSP Research
and Evaluation,

33 The Esplanade, Petone,
Lower Hutt, 5012

+64 4 5870690

+64 21 2446897

Document Details:

Date: 1/2/2020

Reference: 5-20088.00

Status: Final

Prepared by: Bill Frith

Reviewed by Fergus Tate

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Executive summary

Moving towards implementation of a Safe System approach, Waka Kotahi intends to prioritise the installation of median barriers on high speed corridors with traffic volumes of excess of 6,000 vehicles per day. Doing so will address the greater risk of death or serious injury crashes from head-on crashes while also addressing around 40% of the run of road/loss of control type crashes. Traditionally, the installation of median barriers has been associated with expensive seal and pavement widening requirements, land purchase, services relocations, provision for turnarounds etc. This had led to median barrier interventions being delayed or not deemed cost-effective.

This report looks specifically at the issue of installing median barriers on relatively narrow cross-section 2-lane 2-way rural, high speed (80km/h and above) roads with annual average daily traffic (AADT) of 6000 vehicle per day or more and high risk of head-on and off road to the right crashes.

This report looks at previous experience of implementing wire rope barriers in these cross-section constrained situations and guidance on their implementation and barrier maintenance issues. The report considers previous experience of narrow 2-way 2-lane roads with wire rope barriers both here and overseas and the guidance available regarding in what circumstances such barriers may be safely implemented. This report also looks at the maintenance implications of median strikes on such roads.

The conclusions are that:

- WRBs are very effective at saving lives and injuries from head-on crashes and off-road to the right crashes and fit the profile of a Safe System crash countermeasure.
- A median barrier should be the priority where 3 barrier systems cannot be immediately achieved.
- Guidance documents recommend not placing WRBs on medians less than around 2.5m wide. This is to avoid possible encroachment of vehicles into opposing traffic after contacting the barrier.
- The encroachment of vehicles into the opposing traffic after contacting the barrier is a perceived safety risk but this research has not found any crashes of this type recorded in the literature.
- Narrow medians at constrained locations are allowed in the appropriate Australasian guidance documents, by exception. They are widely and successfully used in Sweden and in Norway including in situations with 9 and 10 metre cross-sections incorporating wire rope or metal median barriers.
- There is precedent for the use of WRBs on narrow medians, down in some cases to a width of 1m where the cross section of the road is constrained. Examples are Centennial Highway, the former section of SH1 near Rangiriri and Swedish and Norwegian 1+1 roads. These roads have been associated with large crash savings, particularly from the prevention of head-on crashes which generally have serious or fatal consequences.
- The costs of barrier repairs after strikes (on average \$2700 per strike at 2016 prices) appear very low compared to the social costs of road fatalities and injuries. These, at June 2019 prices are \$4.53 million per fatality and \$477600 per serious injury. Other costs like signage and road markings (e.g. ATPs) are also likely to be very small in comparison.
- There is sound guidance regarding safe provision for cyclists in Waka Kotahi's Standard Safety Intervention Toolkit. Internationally, and in New Zealand there is little evidence

pointing to narrow cross-section rural roads with central barriers being a large source of danger to cyclists.

1 Background

Moving towards implementation of a Safe System approach, Waka Kotahi intends to prioritise the installation of median barriers on high speed corridors with traffic volumes of excess of 6,000 vehicles per day (vpd) to address the greater risk of death or serious injury crashes from head-on crashes while also addressing around 40% of the run of road/loss of control type crashes.

Wire rope median barriers (WRBs) are a primary safe system intervention increasingly used on high speed rural roads and corridors to reduce the harm resulting from head-on and run-off road type crashes. All median barriers are successful in reducing harm but WRBs, because of their forgiving nature and relatively low up-front cost have become a preferred option in many situations around the world. Where WRBs have been installed on New Zealand roads they have resulted in marked decreases in the number of fatal and serious injury crashes. One of the main issues that impacts the implementation of these median barriers is the impact on maintenance and operational requirements. Others are property access, intersections and the movement of over dimensional vehicles.

Traditionally, the installation of median barriers has been associated with expensive seal and pavement widening requirements, land purchase, services relocations, provision for turnarounds etc. This had led to median barrier interventions being delayed or not deemed cost-effective.

There exist roads with physical constraints limiting them to narrow cross-sections which could benefit from barriers. The ability to construct the barriers within these constraints can be the difference between their being affordable or unaffordable within available funding.

This report is specifically about relatively narrow cross-section 2-lane 2-way roads with high risk of head-on and off road to the right crashes and Annual Average Daily Traffic (AADT) 6000vpd or greater. It looks at previous experience of implementing WRBs in these cross-section constrained situations, and guidance on their implementation and barrier maintenance issues.

2 International practice for narrow median WRBs

Narrow medians, with and without barriers, are in widespread use around the world. In particular, they may occur on roads which follow the Swedish 2+1 model. In other contexts, they may occur on 2-lane 2-way roads with cross-section width constraints. The use of barriers on medians narrower than generally recommended is allowed for by exception in road design guidance. In New Zealand the guidance documents are two Austroads Road Design Guides (Austroads, 2020 and Austroads 2020a). However, median barriers on narrow cross sections are widely and successfully used in Sweden and in Norway. Importantly the Austroads Safe System Assessment Framework (Austroads, 2016), which can be used to assess to what extent a stretch of road fulfils Safe System criteria, shows significant risk reduction results from the installation of a barrier and any attendant changes.

2.1 2+1 roads

Vadeby (2016) describes 2+1 roads as having a continuous three-lane cross section with alternating passing lanes with the two directions of travel separated by a flush median with a WRB. Outside of Sweden similar roads exist, but not necessarily with a WRB. Romana et al (2018) provide table 1 which lists several countries with 2+1 roads and compares their cross-sections. For those listed with median barriers, the median width varies from 0.5m to 2.5m.

Country	Median barrier	Width (m)				
		Single-lane	Two-lane	Paved shoulder	Median	Total paved
Swedish MML [10]	Yes	3.75	3.25	0.50	1.75	13.00
Swedish MLV [10]	Yes	3.25	3.25	0.75	1.00	12.25
German EKL1 [14]	No	3.50	3.25–3.50	0.50–0.75	1.00	15.50
German EKL2 [14]	No	3.50	3.25–3.50	0.50–0.75	0.50	15.00
Finland [21]	Yes	3.75	3.25–3.50	0.90–1.25	1.70	14.35
Finland [21]	No	3.75	3.25–3.50	1.25	0.00	13.00
Denmark [27]	No	3.75	3.50–3.75	0.50	1.00	13.00
Norway [28]	Yes	3.50	3.25	0.75–1.50	2.50	14.75
Ireland [8]	Yes	3.50	3.50	0.50–1.00	1.00	13.00
Ireland [8]	Yes	3.25–3.50	3.50	0.50	1.00	12.25
United Kingdom [32]	No	3.50	3.50	1.00	1.00	13.50
United Kingdom [32]	No	3.50	3.50	1.00	0.75	13.00
South Korea [15]	No	3.50	3.25	1.50	1.50	14.50
South Korea [15]	No	3.50	3.25	1.50	0.50	13.50
France	Yes	3.00	3.00	1.50	1.50	13.50
France	No	3.25	3.25	0.50	1.00	12.50
Poland [22, 33]	Yes	3.50	3.50	1.00	0.50	13.00
Poland [33]	No	3.50	3.50	1.00	0.50–1.00	13.00–13.50
Spain [12]	Yes	3.50	3.20	1.00–1.50	1.60	14.00
Spain [23]	Yes	3.50	3.25–3.50	1.50	1.00	14.25
Japan [38]	Yes	3.25	3.25	1.00	1.25	13.00
Texas, US [39]	No	3.35–3.65	3.35–3.65	0.90–3.00	0.00	11.85–16.95

Table 1: Cross section details of 2+1 roads from several countries

While the narrowest median of 0.5m is in Poland further investigation of the situation in Poland (see figure 1 from Tracz and Kieć, 2016) indicates that the Polish 0.5m medians had guideposts separating the traffic rather than a wire rope or concrete barrier. For countries with median barriers, rather than guideposts, the lowest width was 1m in Sweden where the practice is to use wire rope barriers.

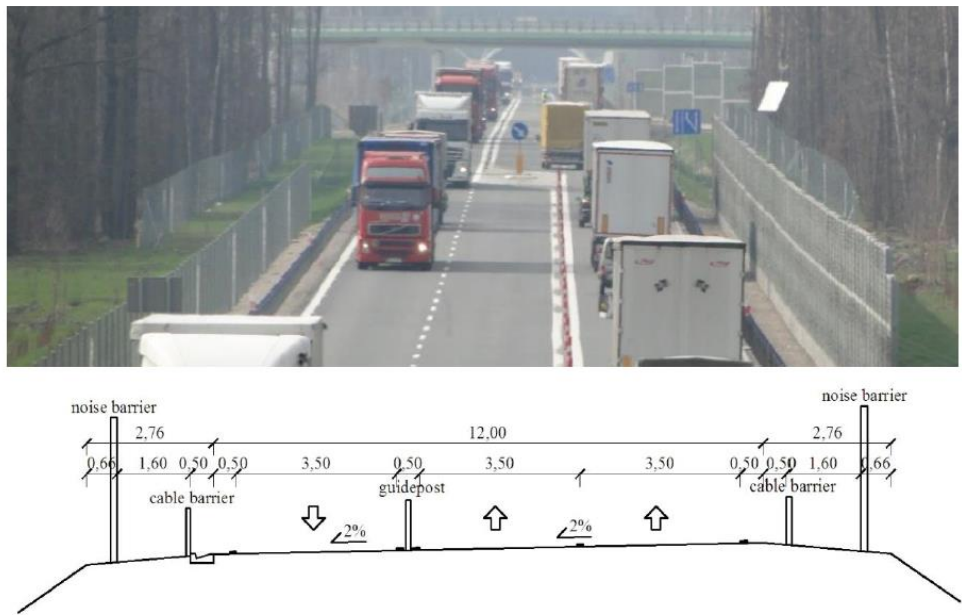


Figure 1: 2+1 cross section and photo of the Yarrow bypass, Poland, with guideposts on the median

2.1.1 Swedish 2+1 roads

The Swedish 2+1 roads are generally 12 -13m wide with typically 1.5m medians. Figure 2 from Bergh et al (2016), shows a 13m wide road with a 1.5m median. However, the median width may be as low as 1m or as wide as 2.5m. The 1m barriers have been used in Sweden on 9-10m cross-

section roads called *narrow 2+1 roads*. These are described in more detail later in this document. For new construction the preference is for 1.5m medians due to maintenance issues associated with snow removal (Remgard, Mats personal communication, 2020).

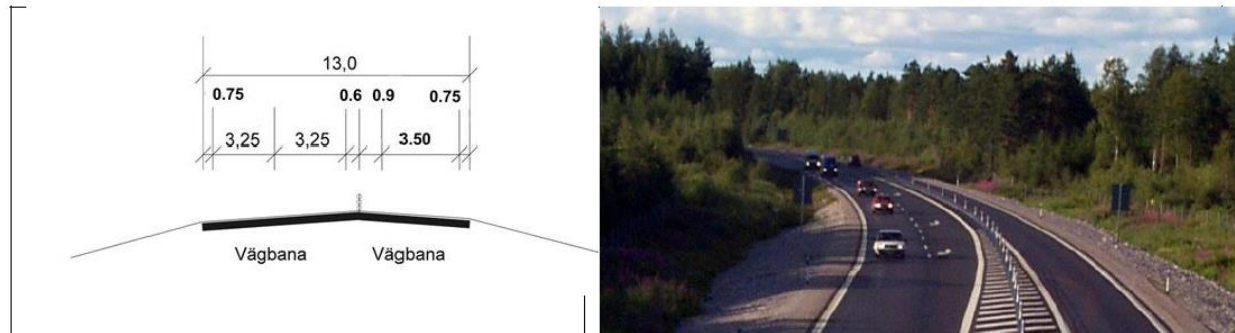


Figure 2: Typical 2+1 median barrier design for 13m roads with 1.5m median

Some 13m roads also have 1.25m median barriers as shown in figure 3 from Larrson et al (2003) with a wider lane on the one-lane side of the carriageway.



Figure 3: Drawing of 13 m 2+1 road with 1,25 m wide median and a wire rope barrier,

Another variant is the MLV 2+1 road with a 12.25m wide pavement width and three 3.25m lanes, 0.75m shoulders, and a 1m median. As shown in figure 2 and figure 3, the Swedish 2+1 roads tend to have 0.75m shoulders which are considered, in that country to be wide enough to accommodate cyclists.

2.1.2 2+1 roads outside Sweden

Gazzini (2008) describes 2+1 roads used in a pilot study of this configuration in Ireland. Table 1 lists them as having 1m medians, However, Gazzini shows them as 2m (for 14m roads) and 1.25 m (for 13m roads) respectively in figure 4. According to the Irish National Roads Authority (NRA) (2007) the WRB is permitted to deflect no more than 0.2m into the opposing traffic lane. After 2007 the 2+1 concept was abandoned, and the government announced that all schemes which were defined as 2+1 in the planning phase would now be progressed as 2+2s. No formal crash studies of Irish 2+1 roads are available. but according to the Irish Times¹ the NRA has stated that no serious crashes occurred on the 2+1 roads during the pilot study. The abandonment happened after a Government economic analysis found 4 lane dual carriageways a more cost-effective option.

¹ <https://www.irishtimes.com/life-and-style/motors/nra-decides-against-2-1-road-design-1.951308>

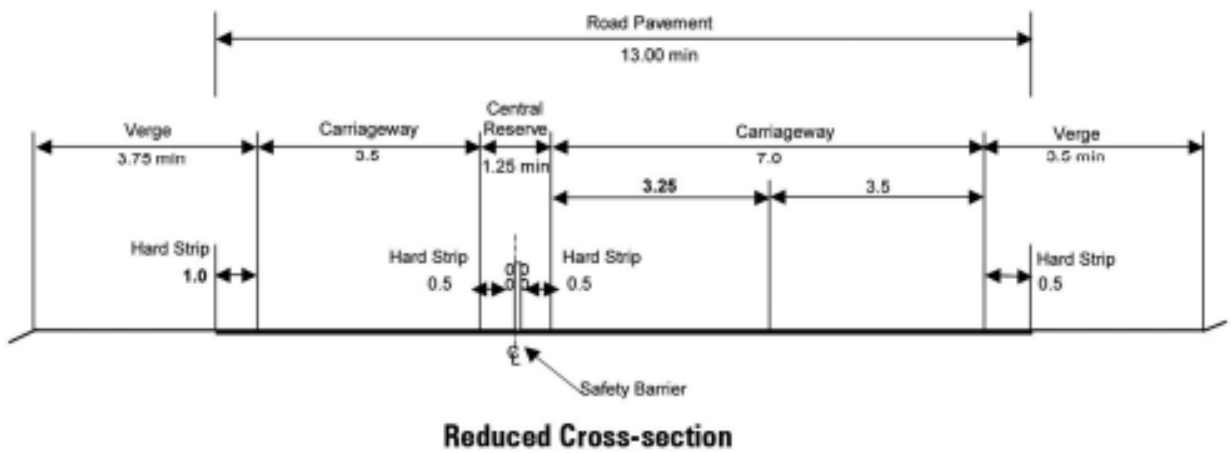
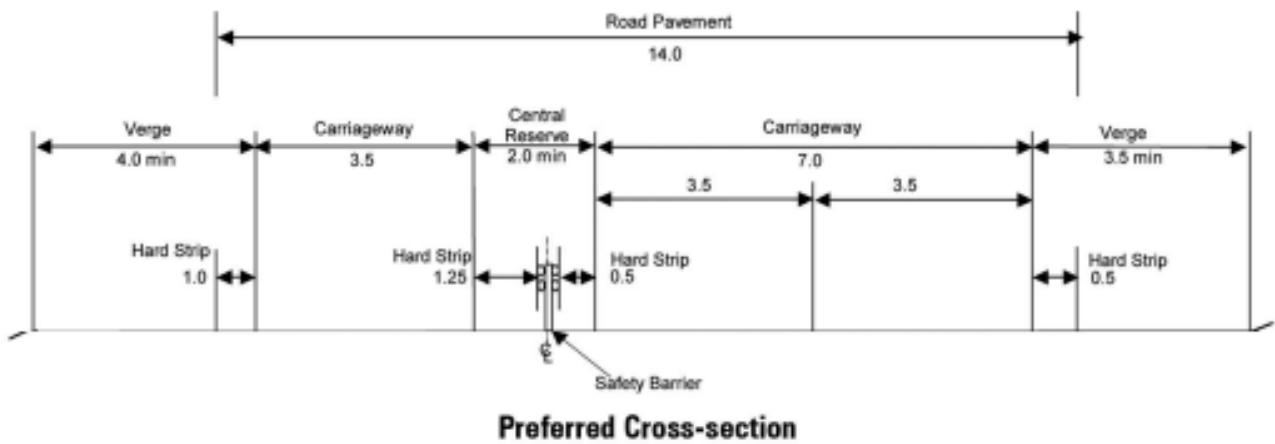


Figure 4: Cross-sections of Irish 2+1 roads

Norwegian 2+1 roads are discussed in Trandem (2016) who provides a cross-section diagrams (figure 5) with a median width of 2.5m including two 0.75m central shoulders.

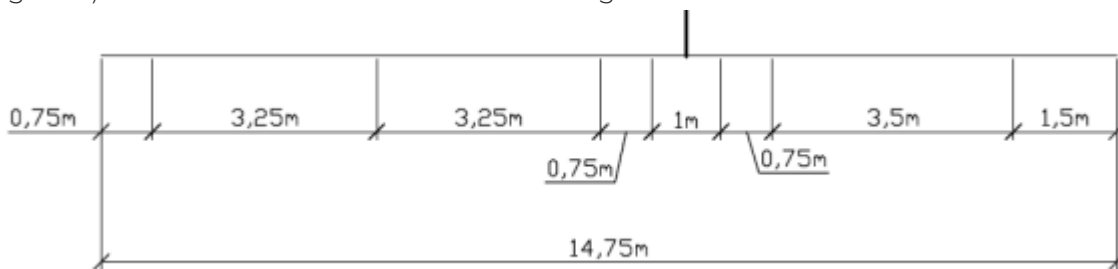


Figure 5: Cross-section of Norwegian 2+1 roads

Norway uses more rigid steel barriers rather than WRBs. Figure 6 depicts a narrow Norwegian 10m wide road with a steel median barrier.



Figure 6: A narrow Norwegian 10m wide road with a steel median barrier.

Figure 7 depicts a wider cross-section road with 3 steel barriers.



Figure 7: A wider cross-section Norwegian road with 3 steel barriers

A Japanese cross-section from Munehiri et al (2015) is shown in figure 8 accompanied by a photograph (figure 9) from a different source. No measurement is given for the median width in figure 8. Google earth views of the stretch of road in question showed varying widths.

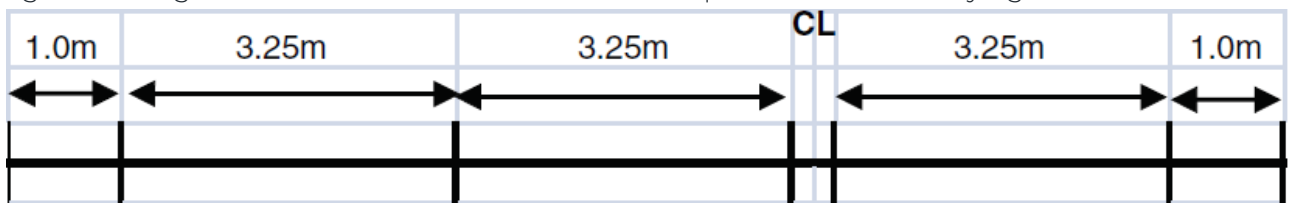


Figure 8: Cross-section of a Japanese 2+1 road



Figure 9: Japanese 2+1 road Source:

<https://www.asahi.com/articles/photo/AS20180413000964.html>

The lane widths are narrow by our standards (although not unprecedentedly so as they the same as those on Centennial Highway). It is also sometimes not clear as to whether markings like the ATMs beside the median barrier are included in the median measurements.

2.2 Swedish 2-way, 2- lane rural roads with barriers

Sweden also has standalone two-way, two-lane, rural roads where the traffic streams are separated by a WRB. These are called 1+1 roads. The 1+1 roads are 9-10m wide roads to which the medians have been added without widening. Figure 10 from Bergh et al (2016) illustrates the design of a 9m wide 1+1 road. These stretches alternate with stretches with passing lanes on one side. The direction of the passing lane alternates as with 2+1 roads and the 1+ 1 segments plus the passing lane segments are collectively known as *narrow 2+1 roads*.

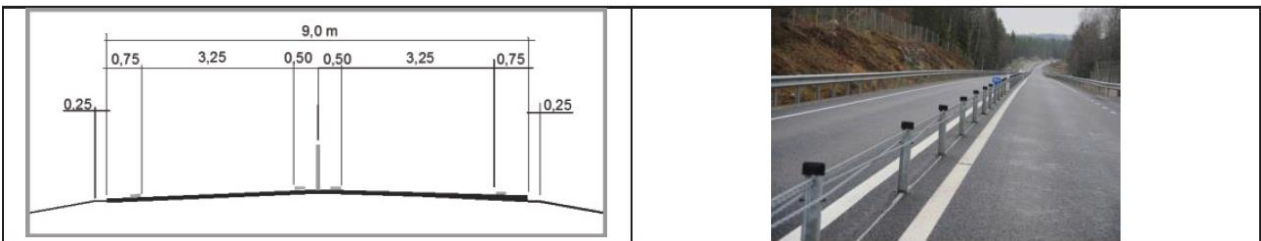


Figure 10: Cross-section and view of a Swedish 1+1 road

The road length share of passing lanes is between 15 – 30% on these roads compared to 40% for the 13m 2+1 roads. Figure 11 from Vadeby (2016) contrasts a 1+1 segment of a narrow 2+1 road with a segment of a standard 2+1 road.



Figure 11: A 1+1 section of 9-10 m 2+1 road, (left photo) and a 3 lane 13m 2+1 road, (right photo).

2.3 New Zealand examples

2.3.1 Centennial highway

In New Zealand the first implementation of a WRB on a narrow (1.5m) median, on a 2-way 2-lane rural road, was on Centennial Highway between Pukerua Bay and Paekakariki in 2003 (Marsh & Pilgrim, 2010). This was a stretch of SH1 with a record of serious and fatal head-on crashes. The WRB which was installed along with a reduction in speed limit from 100km/hr to 80km/hr was instrumental in producing a dramatic and lasting reduction in head-on crashes. The design involved 3.25m lane widths and 1m shoulders providing a total road width of 10m (see figure 12). There was separate provision for pedestrians and cyclists on the seaward side of the road.

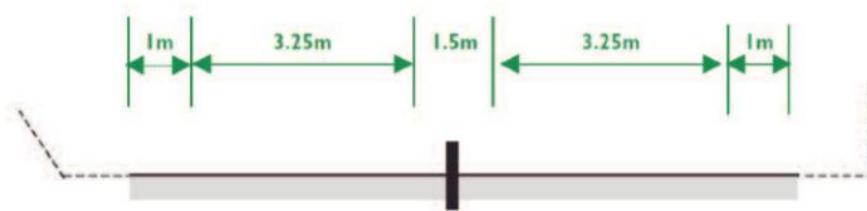


Figure 12: Median treatment as implemented on Centennial highway (from Marsh & Pilgrim, 2010)

The cross-section is illustrated in figure 13, a photograph of the road from Pilgrim and Marsh (2010).



Figure 13: Narrow median wire rope barrier installation on Centennial Highway

Beyond the road's 1m shoulder on the seaward side is a cycle/footpath and on the landward side there are isolated widened sections which would allow drivers to pull over if necessary. This 10m road width is within the range of widths (9-10m) of Swedish 1+1 roads with WRBs. There were concerns as to the extent of barrier deflection into the opposing lane in the event of a strike with an offset of only 0.75m between the median barrier and the centreline. This could not be

completely mitigated. The barrier was installed in two sections. The first section was installed with a maximum test level 3 (TL3) design deflection of 1.9m at a post spacing of 2.0m. However, the posts were spaced at 1m apart to reduce the amount of deflection. The second section with installed with post spacing to achieve a maximum TL3 design deflection of 1.5m. The chances of deflection into the opposing lane were further ameliorated by a movement of traffic to the left away from the barrier after the installation of the barrier. This was observed by video monitoring. This was not a cycling issue as a combined cycle/pedestrian path exists beside the carriageway. The expected safety improvement was confirmed by the crash data, reported in section 4 of this document. The authors made the following concluding observations:

The use of a narrow median has proven to significantly reduce crash severity and is considered an appropriate solution when retrofitting existing roads, particularly in constrained environments. However, it is recommended that wider medians are adopted wherever possible to minimise the associated maintenance costs. Ideally, the median width should provide at least sufficient space to fully accommodate the design deflection of the selected barrier system.

Section 6 of this report deals with barrier strikes and maintenance.

2.3.2 State Highway 1 near Rangiriri

In 2004/5 9km 2+1 road, modelled on Swedish practice, was installed as part of SH1 near Rangiriri on a temporary basis before the building of an expressway. There are no published cross-section details for this road but a preliminary report to Transit NZ (Beca, 2002) recommended the following dimensions

- 2 x 3.25m traffic lanes in one direction
- 1 x 3.5m lane in the opposite direction
- 1.5m central flush median with wire rope
- 1.5m sealed shoulder on the single-lane side
- 0.5m sealed shoulder on the two -lane side

The barrier had a dramatic impact on head-on crashes, which is reported in section 4 of this document.

3 The safety impact of narrow 2+1 and 1+1 roads

Like wider 2+1 roads, the narrow 2+1 and 1+1 roads have had a substantial positive impact on safety. Vadely (2016) illustrates this with figure 14 looking at the FSI (Fatal and Serious Injury) rate for the main road types in Sweden.

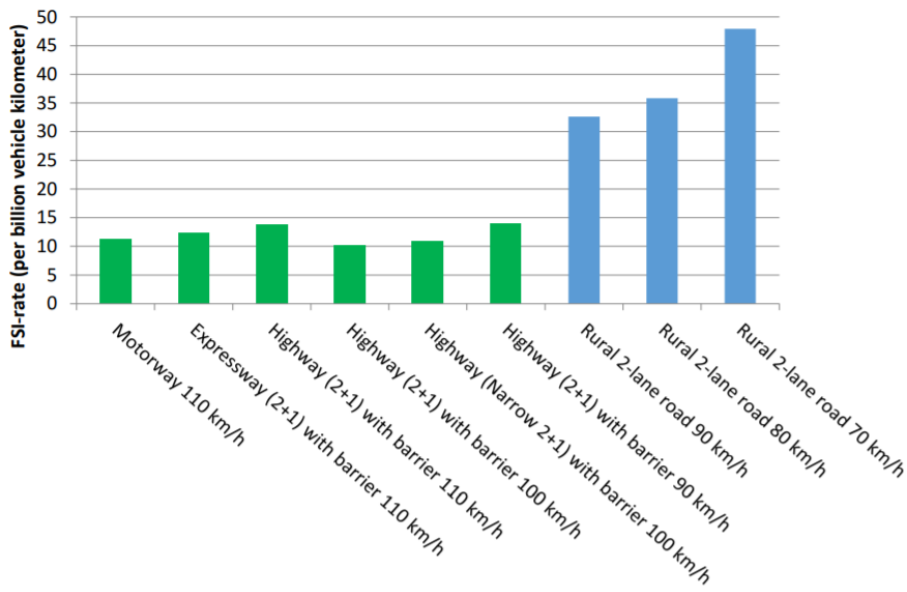


Figure 14: FSI rates for the main road types in Sweden.

Figure 14 indicates that the FSI rate of narrow 2+1 roads with barriers is less than half that of remaining rural 2-lane 2-way roads and is roughly comparable to other 2+1 roads-i.e. installing the barriers has made the 2-lane 2-way rural roads very much safer.

O'Neil and Marsh (2019) provided a similar chart for New Zealand corridors (Figure 15). Noticing that the vertical axis scales differ by a factor of 10, it is apparent that the two charts are remarkably similar.

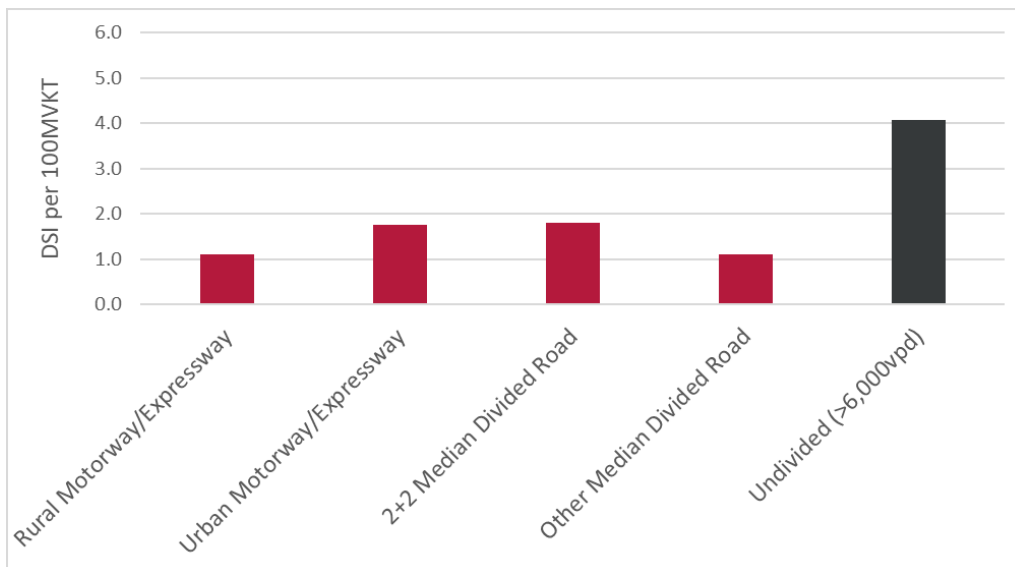


Figure 15: DSI (excluding intersection crashes) per 100 Million Vehicle Kilometres Travelled (VKT) for all New Zealand corridors (2013-17)

Vadely also carried out a before and after study of the conversion of 2-lane 2-way rural roads to narrow 2+1 roads. The results are shown in table 2. The table includes an Empirical Bayes analysis which allows for regression to the mean and a before and after study with control which does not. The numbers in the table are percentages. It is obvious that the reductions in injuries associated with the move are substantial and that little regression to the mean occurred as the

results of the two analyses are very similar. Links refer to stretches between intersections, and total refers to links plus intersections.

	Empirical Bayes		Before and after study with control	
	Injury crashes	Fatalities and seriously injured (FSI)	Injury crashes	Fatalities and seriously injured (FSI)
Links	-27.0 ± 23.3	-62.9 ± 27.2	-27.6 ± 23.1	-63.0 ± 27.1
Total	-	-	-20.5 ± 22.4	-50.4 ± 28.9

Table 2: Changes in injury crashes and FSIs after changing narrow 2 lane 2-way roads into 2+1 roads.

These figures indicate that use of a WRB is much more effective than separation by painted medians or centrelines. For Sweden, the reduction in FSIs with painted medians was an estimated 32% (Carlsson, 2009) compared with over 60% above for wire rope separation. Vadely (2016) reports that German 2+1 roads with painted medians have about 36% lower risk for fatal and injury crashes than conventional 2-lane roads, again well short of the Swedish figures for similar wire rope separated roads.

Crowther and Swears (2010) reported head-on crash numbers before and after the installation of a Swedish modelled 9 km 2+1 road in the Waikato near Rangiriri with a 1.25m median. Figure 16 from their paper illustrates the result.

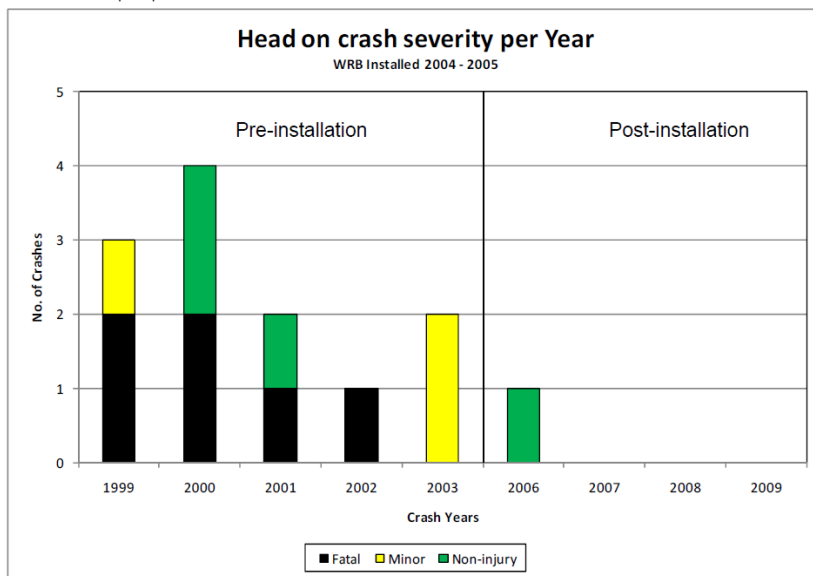


Figure 16: Graph of head on crashes by year-Waikato 2+1 highway segment

The one post-installation head on crash was non-median related as it occurred at an intersection where there was a gap in the median, Therefore, where it existed, the median barrier was 100% effective in preventing head-on crashes over that period. There was an increase in non-injury crashes, reflecting the success of the barrier in ameliorating the severity of crashes

In addition, Pilgrim and Marsh (2010) reported in the five years following the installation of the wire rope barrier on Centennial Highway (2005-2009) there were no recorded serious crashes and only 2 minor injury crashes. None of these crashes were head-on. There was an increase in non-injury crashes, reflecting the success of the barrier in ameliorating the severity of crashes.

4 Three rows of barrier vs median barrier only

A median barrier plus two side barriers is obviously a better solution than a median barrier only, as in addition to head on crashes, road users receive improved protection against injury consequences from all run of road incidents as opposed to only those run off road incidents which would involve crossing the median. However, in circumstances where all 3 barriers cannot be achieved, then a median barrier alone is generally the best option, for AADTs of 6000 or greater, until a full complement of barriers becomes possible. This is because having a median barrier will address the greater risk of death or serious injury crashes from head-on crashes while also addressing upwards of around 40% of the run of road/loss of control type crashes. It is possible to illustrate this by reference to figure 17 from the High Risk Rural Roads Guide (Waka Kotahi-NZTA, 2011). It is apparent from the figure that 10% of off-road DSIs are from crashes on a straight going off the road to the right. Twenty-nine percent are from drivers failing to execute a left turn. By the laws of physics, the clear majority of these will cross the centre of the road and go off road to the right. By simple addition we can then estimate that around 39% (10% +29%) of off-road crashes will be off road to the right. This number will be conservative as Waka Kotahi-NZTA (2010) points out an additional source of off-road to the right crashes by stating:

Note that vehicles initially leave the roadway to the left but while attempting to recover swerve across road to the right.

The residual 7% from other movements will also contribute an unknown number of crashes which leave the road to the right. Assuming that these extras add at least another 1%, this means that a central median barrier will address all head-on crashes and upwards of 40% of off road crashes.

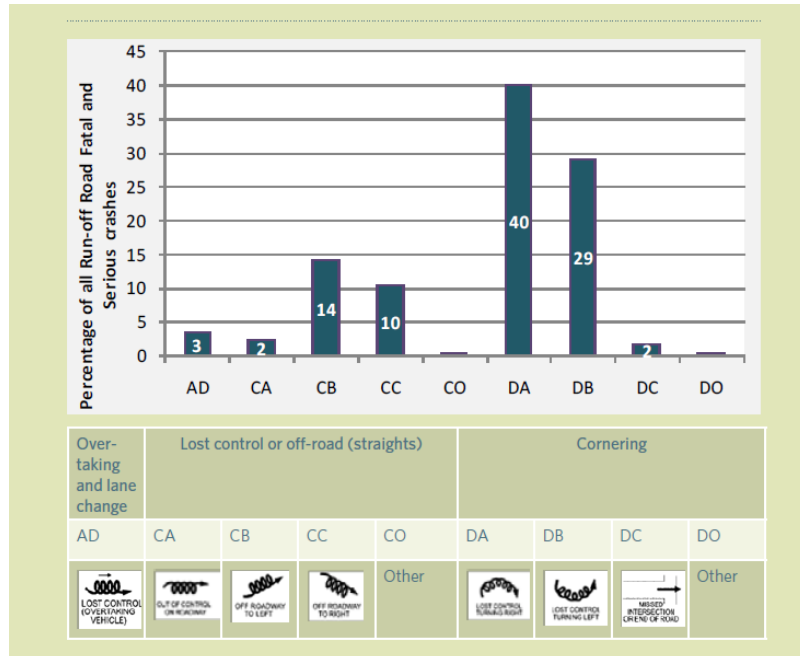


Figure 17: Main movement types for rural run-off road crashes, fatal and serious-excluding motorways (2005-2009)

This amounts to a potential to save up to 1062 deaths over the 2005-2009 time period of figure 3.5 (see figure 18) in Waka Kotahi-NZTA (2010)

FIGURE 3-5 Key crash types - crashes and severity of crashes

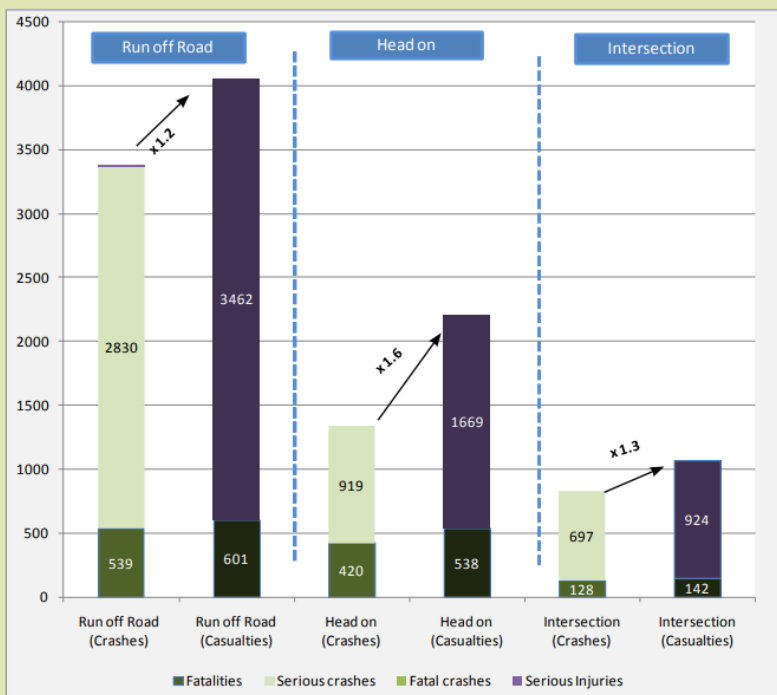


Figure 18: Key crash types-crashes and severity of crashes -From Figure 3.5 Waka Kotahi-NZTA (2010)

Side barriers would have the potential to save 601 deaths. This means that the priority for installing barriers along a length of road is central barriers first and then side barriers,

This impact of a central barrier can improve the IRAP rating of a 2-way 2-lane road with flexible side barriers from a 3-star rating to 5 stars, as shown in tables 3 and 4 from Austroads (2020b). Table 3 relates to roads with AADT of 4000vpd to 14000vpd while table 4 relates to AADTs of up to 4000. It is curious that narrower cross-sections appear in the 5-star IRAP category for 100km/hr in table 4 but not in table 3. There is no explanation given for this anomaly. In all cases star ratings rise when a median barrier is added to a road with 2 side barriers. Unfortunately, the stereotypes do not include rural 2-lane, 2-way roads with a median barrier but no side barriers.

ROAD DESCRIPTION: rural highway, single carriageway, two-lane two-way, AADT 4 000-14 000															
ID	Star rating (Global IRAP) (Stars)		Predicted FSI crashes/100 million vkt (ANRAM)		Formation width (m)	Lane width (m)	Shoulder width (left) (m)	Sealed shoulder width (left) (m)	Runout distance (roadside) (m)	Verge (batter) slope (1:x)	Safety barrier - roadside	Centre barrier	Wide centreline width (m)	Audio-tactile edge line marking (Y/N)	Audio-tactile canteline marking (Y/N)
	Curvature: straight - moderate		Curvature: straight - moderate												
	110 km/h	100 km/h	110 km/h	100 km/h											
1	4.9	5.2	0.02	0.02	15.0	3.5	2.5	2.5	-	-	Flexible	Flexible	2.0-3.0	Y	Y
2	3.7	3.9	2.18-2.24	1.63-1.68	13.0	3.5	2.5	2.5	-	-	Flexible	-	1.0	Y	N
3	3.6	3.8	2.23-2.29	1.68-1.72	11.0	3.5	1.5	0.5	4.0	6.0	Flexible (targeted)	-	1.0	Y	Y
4	3.6	3.9	2.60-2.68	1.96-2.01	12.0	3.5	2.5	2.5	-	-	Flexible	-	-	N	N
5	3.4	3.7	2.65-2.72	1.99-2.05	11.0	3.5	1.5	0.5	4.0	6.0	-	-	1.0	Y	Y
6	3.0	3.4	3.47-3.57	2.61-2.69	9.0	3.5	1.0	1.0	4.0	3.0	-	-	-	Y	Y
7	2.7	3.2-3.1	4.25-4.38	3.19-3.29	9.0	3.5	1.0	1.0	4.0	3.0	-	-	-	N	N
8	2.2-2.1	2.7	5.30-5.46	3.98-4.10	8.0	3.5	0.5	0.5	4.0	3.0	-	-	-	N	N

Table 3: Road stereotype no. 3 from Austroads (2020b) page 37

ROAD DESCRIPTION: rural highway, single carriageway, two-lane two-way, AADT 1 000–4 000															
ID	Star rating (Global iRAP) (Stars)		Predicted FSI crashes/100 million vkt (ANRAM)		Formation width (m)	Lane width (m)	Shoulder width (left) (m)	Sealed shoulder width (left) (m)	Runout distance (roadside) (m)	Verge (batter) slope (1:x)	Safety barrier - roadside	Centre barrier	Wide centreline (m)	Audio-tactile edge line marking (Y/N)	Audio-tactile centeline marking (Y/N)
	Curvature: straight - moderate		Curvature: straight - moderate												
	100 km/h	80 km/h	100 km/h	80 km/h											
1	5.2	5.6	0.02	0.01	13.0-14.5	3.5	2.0-2.5	2.0-2.5	-	-	Flexible	Flexible	3.0/2.0	Y	Y
2	4.8-4.7	5.3	0.72-0.74	0.37-0.38	12.0	3.5	2.0	2.0	-	-	Flexible	-	1.0	Y	Y
3	4.3	5.1	1.43-1.47	0.73-0.75	10.6	3.3	1.5	1.5	6.0	6	Flexible (targeted)	-	1.0	Y	N
4	4.0	5.0-4.9	1.74-1.78	0.89-0.92	11.0	3.5	2.0	2.0	6.0	6	Flexible (targeted)	-	-	N	N
5	3.8	4.8	2.49-2.56	1.28-1.32	8.6	3.3	1.0	1.0	6.0	3	-	-	-	Y	N
6	3.7	4.5	3.32-3.42	1.70-1.76	8.6	3.3	1.0	0.0	6.0	3	-	-	-	N	N

Table 4: Road stereotype no. 3 from Austroads (2020b) page 37

5 Deflection containment of WRBs

5.1 General discussion

It is universally agreed that barrier deflections should be contained within the median except when precluded by roadway width constraints. This implies that medians less than around 1.5m wide can be used but only by justification based on width constraints. Barriers on medians below that width have been shown to have worthwhile safety benefits in Sweden.

Wire rope barriers will deflect when hit by a passing vehicle towards the opposing traffic stream. The amount of deflection will depend on angle of attack, the mass of the vehicle, the speed of the vehicle and the design of the barrier. Standards for wire rope barriers are based on tests involving specific vehicles, of specific mass hitting a barrier at specified speeds and angles. It is to be expected, that in general, impact angles would tend to be lower on narrower cross-section roads. The various brands of barrier state in their documentation how far the barrier will deflect under these conditions. If the median is narrow, barrier deflection may be reduced by the following means:

- Some barrier designs deflect more than others so careful selection of barrier is important
- The spacing of the posts can impact on deflection-more posts means less deflection.

5.2 Safety impact

It seems logical that too little deflection may result in greater vehicle damage to the striking vehicle and injury to its occupants. DIER (Department of Infrastructure, Energy and Resources, Tasmania) (2007) contains severity indices for collisions with several types of barrier. At 100km/hr or more design speed the indices are: wire rope: 2.5 and 3.0 for W beam, Tric bloc (a portable concrete barrier) and Thrie Beam (2 pieces of w-beam mounted together into one structure). Molan et al (2020), using American data, found that WRB crashes were less severe than rigid or guard rail crashes in areas of speed limit greater than 55ml/hr (88.5 km/hr). severity, light vehicles showed odds ratios equal to 4.5 and 3.3 when the crash involved rigid and guardrail barriers, respectively, in compared to WRBs. It is therefore most likely that in practice, WRBs would result in considerably less harm to occupants. Truck crashes showed no significant difference. No research information was found regarding any differences in crash severity between WRBs with different deflection characteristics.

Regarding motorcycles Carlsson (2009) found that DSI and fatality risks for motorcyclists reduced by 40-50% on 2+1 roads with WRBs. A comparison of WRBs and W beam guardrail was carried out by Daniello and Gabler (2011).who found no significant difference in the odds of severe injury between the 2 types of barrier. More detail on motorcycles and barriers including several

additional references can be found in the Waka Kotahi document *Flexible Barriers – Why we install wire-rope barriers on New Zealand roads*².

These findings for WRBs need to be balanced against the possible externalities coming from extension of the barrier into a live traffic lane in the opposing direction. WRBs rebound and do not deform permanently into the opposing lane.

All other things being equal, the amount of deflection is related to the post spacing. DIER ((2007) contains table 5. This provides approximate estimates of deflections by post spacing derived from tests carried out of various wire rope barriers. These tests were conducted under NCHRP 350 (1993) TL3 conditions (2000 kg vehicle, 100 km/hr, impact angle 25 degrees). These results may of course be pessimistic for 80km/hr speed environments and for smaller vehicles (2000kg approximates to the weight of a Toyota Hilux double cab Ute).

Post Spacing (m)	Approximate Deflection (m)
1.0	1.5
2.0	2.0
2.5	2.5
3.0	2.7
5.0	3.4

Table 5: Approximate Deflection of Wire Rope Safety Barriers

This means that a wire rope barrier, on a 1m wide median, with a 1m post spacing, if hit under those conditions would deflect into the opposing lane by approximately 1m. Nilsson and Prior (2004) features table 6 which relates speed of vehicle hitting the barrier to deflection. It is attributed to the RTA road design guide of the time and relates to collision by a 1500 kg Holden Commodore vehicle with a wire rope barrier on a 200m radius curve at a 25° angle of impact. This radius is at the extreme of radii on which a WRB may be used. This indicates a deflection of 1.2m for an 80km/hr collision under those conditions.

Safety barrier type	Dynamic deflection (m) for straight line of barrier			
	80km/h	90km/h	100km/h	110km/h
Wire rope safety barrier	1.2	1.3	1.4	1.5
Steel guardrail	1.2	1.3	1.4	1.6
Concrete barrier	0	0	0	0

Table 6: Speed of impacting vehicle related to barrier deflection

Pieglowski (2005) discusses a hypothetical scenario where after striking a barrier a vehicle may be “trapped” on the wrong side of the road by the barrier which has deflected beyond the edge of the median. It would then become a hazard to oncoming traffic. Such an incursion might also cause opposing traffic to bank up. He mentions that there had been no such cases in Sweden at the time of writing. The reason why this scenario is not known to occur is that it is designed out of the system by setting of standards based on crash testing. An example of vehicle behaviour at the extreme is the test carried out by RTA in 2003 and reported on in table 4. RTA (2003) contains the photographs depicted in figure 19 which show the progress of the vehicle down the barrier. The progress is depicted down the page.

² <https://www.nzta.govt.nz/assets/Roads-and-Rail/docs/Report-to-the-Minister-of-Transport-on-median-barriers.pdf>

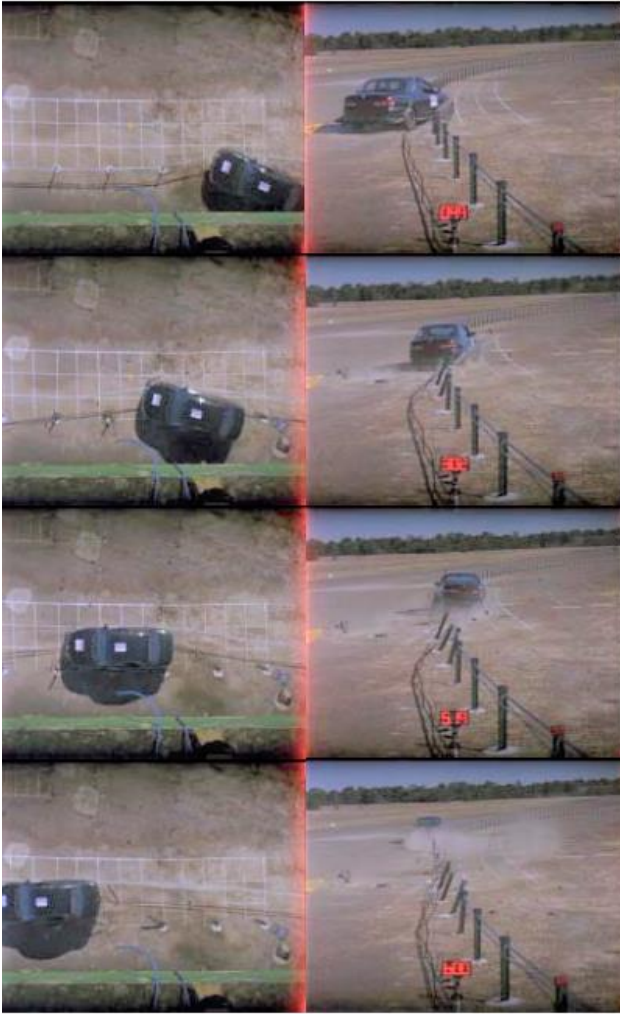


Figure 19: Video of RTA test: Holden Commodore vs wire rope barrier

The leftmost column photographs are taken from above on a crane and the rightmost ones from the ground. The car travels down the barrier which extends as it hits, and the car comes to rest on the same side of the road as it started. The test vehicle was past the original line of the barrier for about 1.5 seconds, after which it returned to the traffic lane. This 1.5 seconds provided the only opportunity to contact opposing vehicles. An actual on-road example is Centennial Highway where video observations of strikes found the barrier encroached into the opposing lane for 0.2 seconds³.

The probability of such collisions may be mitigated to some extent by the psychological impact of the median barrier in making vehicles tend to travel further the left of their lanes. There is no reliable information available on the proportion of real world collisions with wire-rope median barriers which result in incursions into the opposing traffic stream. Therefore, the real-world safety impact of such collisions is best measured by the real-world number of collisions with opposing traffic in cases where barrier widths are relatively small. Statistics quoted in section 4 above show that such barriers do indeed have a very favourable impact on such head-on crashes. In short there is ample evidence that head on crashes related to the deflection of vehicles into opposing lanes are extremely rare, if not non-existent, even at very narrow median widths down to 1m.

³ Personal communication, Fergus Tate

5.3 Austroads guidance

This report has already mentioned in section 4 new road stereotypes contained in Austroads (2020b) Network Design for Road Safety (Stereotypes for Cross-sections and Intersections) User Guide. The Austroads Guide to Road Design Part 3 Appendix E (Austroads, 2020a) contains a recommended minimum width of 2.2m for a median containing a WRB. It also recommends that the guide be read in conjunction with The Austroads Guide to Road Design part 6, Safety and Barriers (Austroads, 2020). Austroads (2020) makes the point, already stated earlier, that it is preferable to contain deflection of the barrier within the median. The guide quotes a statement by NSW Roads and Maritime Services that:

1.6m is the minimum median width for installation of WRBs as the half-median width of 0.8 m is generally sufficient to contain dislodged cables and bent posts from damaged installations.

It also quotes the RTA (2003) crash test on a 200m radius curve at 80 km/h impact speed and 25° angle of impact and states that under special circumstances related to space constraints:

it may be appropriate to allow partial encroachment of the deflected barrier into the opposing traffic lane. (p191)

This 1.6m minimum is close to Swedish practices which generally use 1.5m as a minimum. The allowance of partial encroachment under special circumstances is consistent with previous Swedish use of 1m medians on narrow 2+1 and 1+1 roads where the roadway width is constrained. A recent return of Sweden to 1.5m medians on narrow roads (Remgard, Mats personal communication, 2020) is related to snow removal issues rather than encroachment issues,

Table 7: from Austroads (2020) pg. 192, details barrier containment issues by barrier width.

Median width	Consequences of 1.7 m deflection at 100 km/h	Debris after impact on 200 m curve
2.8 m	Deflection will encroach 0.3 m into opposing carriageway.	Bent posts and cables lie within median.
2.0 m	Deflection will encroach 0.7 m into opposing carriageway.	Bent posts and cables lie within median.
1.6 m	Deflection will encroach up to 0.9 m into opposing carriageway.	Bent posts lie within median. Cables may lie on edge of carriageway.

Table 7: Barrier containment issues by barrier width

5.4 VicRoads Guidance

VicRoads has recently produced its own guidance for barriers on roads with narrow medians (VicRoads, 2018). Referring to possible collisions of deflected vehicles with oncoming traffic, they quote the Austroads recommended minimum of 2.2m. They note that such a width tolerates a maximum allowable deflection of 0.5m into the opposing traffic for an impacting vehicle and indicate that smaller widths may be allowed by exception.

This *recommended width* is accompanied in a hierarchy by a *minimum recommended width* and *minimum widths for highly constrained situations* (table 8). The minimum width for highly constrained situations (1.4m) should only be made narrower after consideration of barrier hits and the barrier being deflected into the opposing traffic stream. The guidance also suggests, but does not mandate, that median widths of less than 2.2 m may not be acceptable at AADTs greater than 4000. No evidence is provided for this assertion, nor are the volume bands in table 8 well justified.

	Road Class Volume	Total Width	Shoulder	Lane Width	Median	Lane Width	Shoulder	Comment
1.1	B or C <1500 AADT	9.6	1.0 (0.5 US + 0.5 SS)	3.1	1.4	3.1	1.0 (0.5 US + 0.5 SS)	Highly Constrained Context
1.2	B or C <1500 AADT	10.6-11.4	1.5 (1.0 US + 0.5 SS)	3.1	1.4-2.2	3.1	1.5 (1.0 US + 0.5 SS)	Minimum Recommended
1.3	B or C >1500 AADT	11.4	1.5 (0.5 US + 1.0 SS)	3.5	1.4	3.5	1.5 (0.5 US + 1.0 SS)	Highly Constrained Context
1.4	B or C >1500 AADT	12.4-13.2	2.0 (1.0 US + 1.0 SS)	3.5	1.4-2.2	3.5	2.0 (1.0 US + 1.0 SS)	Minimum Recommended
1.5	B or C >1500 AADT	13.2-16.2	2.0 (1.0 US + 1.0 SS)	3.5	2.2-6.2	3.5	2.0 (1.0 US + 1.0 SS)	Recommended
1.6	A <1500 AADT	10.6	1.5 (0.5 US + 1.0 SS)	3.1	1.4	3.1	1.5 (0.5 US + 1.0 SS)	Highly Constrained Context
1.7	A <1500 AADT	11.6-12.4	2.0 (0.5 US + 1.5 SS)	3.1	1.4-2.2	3.1	2.0 (0.5 US + 1.5 SS)	Minimum Recommended
1.8	A <1500 AADT	12.4-15.4	2.0 (0.5 US + 1.5 SS)	3.1	2.2-6.2	3.1	2.0 (0.5 US + 1.5 SS)	Recommended
1.9	A >1500 AADT	12.4	2.0 (0.5 US + 1.5 SS)	3.5	1.4	3.5	2.0 (0.5 US + 1.5 SS)	Highly Constrained Context
1.10	A >1500 AADT	13.4-14.2	2.5 (1.0 US + 1.5 SS)	3.5	1.4-2.2	3.5	2.5 (1.0 US + 1.5 SS)	Minimum Recommended
1.11	A >1500 AADT	14.2-17.2	2.5 (1.0 US + 1.5 SS)	3.5	2.2-6.2	3.5	2.5 (1.0 US + 1.5 SS)	Recommended

Note 1: A 3.0m left shoulder should adopted on major state highways

Note 2: Shoulder widths may be wider when central barrier is implemented in conjunction with verge barrier

Table 8: Cross-sections and comments for roads with WRBs in narrow medians (VicRoads, 2018)

6 Barrier strikes and maintenance

6.1 Strike frequency

Generally, the smaller the median width the more likely impacts on the barrier will occur. These can involve maintenance and traffic disruption costs. In Sweden, Bergh and Carlsson (2001) quotes an outcome of 0.8 such impacts per million vehicle kilometres with 30% being reported to the Police. About 50 % of the crashes occurred in winter, a season when only 25% of the relevant travel occurs. Bergh and Carlsson also mention that Audio Tactile Markings (ATMs) and visual devices have been used to reduce barrier strikes. ATMs are also suggested by Marsh and Pilgrim (2010) Crowther and Swears (2010) and Smith et al (2016).

Sweden's major 2+1 roads are called MML and MLV with MML having a higher level of access than MLV. A later report (Carlsson, 2009) presents an improved picture providing estimates of 0.50 strikes per million axle pair km (broadly equivalent to vehicles per million vehicle km) for MML⁴

⁴ Collision-free expressway usually with 2+1 lanes and median with a barrier (often wire guardrail). The width is 13 to 14 metres MML has interchanges with exit- and entry lanes. Slow moving traffic, cyclists etc. are not allowed (Carlsson, 2009).

roads and 0.59 strikes for MLV⁵ roads. For the MML roads with an overall collision rate of 0.50, the rate is 0.70 for the segments on the 1-lane side of the road and 0.33 for segments on the 2-lane side of the road. This reflects the greater proximity of the median barrier to the traffic in the 1-lane segments. Carlsson also estimated that for MLV roads a median of width greater than 1.75m provided an up to 20% reduction of barrier strikes compared to similar roads with slimmer medians.

In New Zealand, Crowther and Swears, 2010 reported median WRB strikes on a 9km section of State Highway 1 near Rangiriri based on the Swedish 2+1 system. They reported a post-installation strike rate of 0.6 per million vehicle kilometres of travel, similar to the Swedish MLV roads. It was also found that 50% of the strikes were not reported to the Police. Nine crash clusters were identified by the authors with 8 of them appearing on the single lane side of the road. This would mean that the crash rate per million vehicle kilometres would be greater for those sections. However, unlike the case of Carlsson, 2009, the rates for 2-lane and 1-lane sections are not available for comparison.

Centennial Highway reported on by Pilgrim and Marsh (2010) was equipped with its WRB in two tranches. Table 9 describes the rate of median strikes on the 2 sections. The frequency for the initial installation is 1 crash per 0.9 million VKT and the frequency for final 3.5km length, including the extension, is 1 crashes per 1.5 million VKT

	Total length	Traffic volume	Number of impacts	Period (years)	Frequency (per km per year)	Frequency (1 crash per x million vkt)
Initial installation	0.7km	21,958	11	1.83	8.6	0.9
Extension	3.5km	22,382	46	2.33	5.6	1.5

Table 9: Rate of median strikes on the initial and final sections of WRB on Centennial Highway

For the purpose of this report the rates in table 9 were recalculated in crashes per million VKT. This yielded a frequency of 1.07 for the initial installation and for 0.69 for the final length. The figure of 0.69 for the final section, is close to that for similar roads in Sweden and that reported by Crowther and Swears (2010) for SH1 Rangiriri. It may reflect a reduction after drivers had got used to the idea of such a road.

It is worth noting that according to Pilgrim and Marsh (2010) The WRB system used on the first 700m stage had a design deflection of 1.9m at a post spacing of 2.0m. To minimise the amount of deflection, the post spacing was reduced to 1m. For the extension, the WRB post spacing was designed for a maximum deflection of 1.5m.

The above strike frequencies indicate that existing 1+1 systems used in New Zealand with narrow medians have roughly similar strike rates to those found in Sweden.

6.2 Maintenance implications of barrier strikes

6.2.1 Discussion

The probability of strikes is generally considered greater if vehicles are traveling closer to a barrier. This has produced maintenance concerns. However, the very confines of their situation, on 2-lane, 2-way roads with narrow cross section may encourage drivers to travel further to the left of their

⁵ Collision-free road, generally comprising 2+1 lanes and median with a barrier (often wire guardrail). The width is 13 to 14 metres. MLVs have at-grade intersections with an opening in the median barrier. The cross section at large intersections is usually 1+1 through lanes and with a lane for left-turn traffic. There are also designs with a roundabout (Carlsson, 2009),

lane and at a slower pace. This may ameliorate this problem somewhat by increasing their distance from the barrier and at the same time reducing the speed at which a strike might occur.

It also must be remembered that 9-10 m wide Swedish I+1 roads have broadly similar strike rates to those experienced on Centennial Highway and at Rangiriri. There is evidence (Marsh and Pilgrim, 2010) that at Centennial Highway drivers tended to track further from the barrier than they did from the centreline before the barrier was installed. The evidence relates to video footage taken before and after the barrier installation. This is illustrated in Table 10 from Marsh and Pilgrim (2010),

Southbound observations	
Before installation	After installation
<ul style="list-style-type: none"> Majority of vehicles tracking along the centre of the lane (83%) Some vehicles tracking to the right side of the lane (17%) No vehicles tracking to the left side of the lane, cutting the edgeline, or cutting the centreline. 	<ul style="list-style-type: none"> Proportion of vehicles tracking along the centre of the lane largely unchanged (84%) Slight decrease in vehicles tracking to the right side of the lane (10%) Vehicles tracking to the left side of the lane increased (6%) 2% of vehicles cutting the left edgeline, no vehicles cutting the median centreline
Northbound observations	
Before installation	After installation
<ul style="list-style-type: none"> Majority of vehicles tracking along the centre of the lane (71%) Some vehicles tracking to the left side of the lane (28%) 1% of vehicles tracking to the right No vehicles cutting the left edgeline or the centreline. 	<ul style="list-style-type: none"> Some vehicles tracking along the centre of the lane (17%) Majority of vehicles tracking to the left side of the lane (83%) No vehicles tracking to the right side of the lane or cutting the median centreline 5% of vehicles cutting the left edgeline

Table 10: Tracking of vehicles before and after installation of Centennial Highway wire rope barrier

This indicates that the presence of the barrier, combined with other changes like the narrower lanes, encouraged drivers to track further from the centre of the road in the northbound direction. This is not surprising as drivers may react to objects close to their lane by slowing or moving away or both. In the southbound direction the proportion of vehicle tracking along the centre of the lane was largely unchanged accompanied with a slight move towards the left for the rest of the traffic. This may relate to the proximity of the barrier.

According to the Austroads (2010)

When roadside features such as bridge railings, parapets, retaining walls, fences or roadside road safety barriers are located too close to traffic, drivers in the adjacent traffic lane tend to reduce speed, drive off-centre in the lane, or move into another lane. pg87.

The use of the words *too close* above may not be appropriate for all contexts as in some cases such lateral movements may be advantageous, as at Centennial Highway, if they are of reasonable scale for their context and are not associated with a safety issue, such as possible crowding of cyclists.

The existence of the behaviours described in Austroads (2010) has support in the literature independent of Marsh and Pilgrim, 2010. An example is Tenkink (1989), cited in Martens et al (1997), Tenkink investigated the influence of three different obstacles on driving speed. For all obstacles, the space between the road and the obstacles was varied between 0.68m, 1.68m and 2.68m. The point obstacles were reflecting road studs, plastic cones or large red and white striped metal panels (Janssen et al, 2006). His research found that more space between the obstacle and the road side leads to higher speeds, and a more threatening object leads to a stronger reduction

in speed. Tenkink also found that the primary reaction to a small available space between the road side and the obstacle is lateral displacement. A cautionary note is that this work concerned roadside obstacles, not obstacles in the centre of the road.

Marsh and Pilgrim (2010) did not report on speed so it is not known if the barrier changed speeds at all. However, the speed limit had recently changed from 100km/hr to 80 km/hr and lanes had narrowed, so to attribute any speed change to the barrier would be difficult. However, if the tenor of the literature is correct, the smaller amount of space available to traffic would have put a downward pressure on speeds. Results from Rangiriri (Crowther and Swears, 2010) are pertinent here. Table 11 illustrates the speed changes post barrier at Rangiriri. There the speeds reduced on both sections.

Survey Period	Single Lane Speed	Two Lane Speed
Before	97 km/h	102 km/h
After	95 km/h	100 km/h

Table 11: Speed changes after WRB installation on SH1 near Rangiriri

Using New Zealand data, Smith et al (2016) modelled the impact of various factors on central WRB strikes- both “nuisance strikes” where the striking vehicle stays mobile and all strikes including the more serious police reported strikes. In both cases they found that horizontal alignment, median width, posted speed limit and ATPs were important variables. The signs of the coefficients were all unsurprising, with the presence of the following indicating fewer strikes:

- Wider medians
- Lower posted speed limit
- ATPs

Higher values of horizontal alignment indicated more strikes. Other analyses carried out indicated that uneven vertical alignment also encouraged strikes. This would reinforce the case for ATPs and lower speed limits when WRBs are required on narrow medians.

Smith et al (2016), cite work in train at the time of writing by the then NZ Transport Agency Hamilton project services team. This work indicated that whole of life cost reached a minimum value when medians with WRBs had a width of 3m with costs increasing again after that value. This supports the notion of lower width barriers being permissible, but only where dictated by constraints.

6.2.2 *Costs of barriers strikes*

Waka Kotahi intends to prioritise the installation of median barriers on corridors with traffic volumes in excess of 6,000 vehicles per day. Smith et al (2016) estimated the average cost (2016 dollars) for repairing a barrier strike at \$2700.00. As a comparator the average cost for a w-beam strike was \$2000.00.

The costs of barrier repairs after strikes (on average \$2700 per strike at 2016 prices) appear very low compared to the social costs of road fatalities and injuries. These, at June 2016 prices are \$1.315 million averaged over deaths and serious injuries(DSIs). Other costs have not been investigated but it would also appear likely that they would also be small compared to the social costs related to death and injury.

It can be calculated that 6000 vehicles per day over a 10km length will yield 6000*365*10 VKT per year or 21.9 million VKT per year. Combining the rate of 0.7 strikes/ million VKT at Centennial Highway with 2016 costs per strike from Smith et al (2016) would produce an average of 15.3 strikes per year. This would have a cost of around \$41,000 per year. Table 12 details the number of strikes and their damage repair costs on a 10km length of a two-lane, two-way rural road with a WRB and makes several comparisons related to the social costs of fatal and serious injuries. The AADT range used is from 6000 vehicles per day through to 24000 vpd. a little less than the

26,000 Centennial Highway VKT of today. Comparisons are made with the social costs of average DSIs for 10km of undivided open roads with greater than 6000 vpd. These number 9.5⁶ with a social cost of \$12.5 million.

AADT	6000	12000	18000	24000
Annual average strikes ⁷ for a 10km length of WRB at 0.7 strikes per 10 ⁶ VKT	15.33	30.66	46	61.3
Annual strike damage repair cost (2016 dollars) ⁸ for a 10km length of WRB	41391	82782	124173	165564
Damage repair cost of a 10km length as a percentage of average social cost per death I and serious injury ⁹ .	3.1	6.2	9.3	12.4
DSIs saved to offset repair cost.	0.031	0.062	0.093	0.124
Strike damage repair cost of a 10km length as a percentage of the social cost of DSIs for 10km of undivided open roads with AADT >6000 vpd ¹⁰ (Circa 1 DSI/km See O'Neil and Marsh (2016), figure 1.)	0.3	0.6	1.0	1.3
Ratio of social cost of DSIs for 10km of undivided road with >6000 vpd ¹¹ to strike damage cost for the same length of central WRB	317	158	106	79
Km of road for central WRB strike cost to equal social cost of an average open road DSI	317	158	106	79
Km of road for central WRB strike cost to equal social cost of a DSI for 10km of undivided road with >6000 vpd ¹²	3170	1529	1026	769

Table 12: Annual repair cost of strikes on a 10km length of central WRB on a two lane, two-way rural road related to social cost of deaths and serious injuries.

It is apparent from table 12 that for all the 10 km lengths cited, the cost of the barrier strikes is a relatively small fraction (3.1% to 12.4%) of the average social cost of one DSI and an even smaller proportion (0.3% to 1.3%) of the social cost of the average of 9.5 DSIs for a 10km stretch of undivided roads with AADT greater than 6000vpd. The ratio of social cost without barrier to strike cost with barrier ranges between 323 (6000vpd to 82 (24000 vpd). At an AADT of 6000 vpd **over 3000 km of central wire rope barrier** would need to be installed for the annual cost of repairing strikes to equal the average social cost of one fatal or serious injury.

6.2.3 Overall maintenance costs

According to the NZTA Annual report for 2018/2019¹³ the achieved average maintenance cost per state highway lane kilometre in that year was \$22,997. A 10km length of 2-lane 2-way road has 20 lane kilometres. For context, therefore, the average maintenance cost for such a state highway length would be \$459,940.00, around a 35% of the average social cost of a DSI. Put another way, it

⁶ O'Neil and Marsh (2019)

⁷ Assuming the number of strikes increases linearly with AADT

⁸ Jones et al (2016)

⁹ \$ 1.315 million June 2016 prices

¹⁰ O'Neil and Marsh (2019)

¹¹ O'Neil and Marsh (2019)

¹² O'Neil and Marsh (2019)

¹³ <https://www.nzta.govt.nz/assets/resources/annual-report-nzta/2018-19/nzta-nltf-annual-reports-2019-complete.pdf>

would be necessary to save around 0.35 of a DSI to justify, that expenditure on safety grounds only. There is no information on how this varies with AADT, but this information, if available would provide valuable extra context.

6.2.4 Repair processes

Jones et al (2016) questioned RCAs on their choice of barrier. They found that most of the RCAs preferred to install WRBs if possible. This preference related to a perception that it is easy to repair WRBs following a strike. In most cases, this could be achieved during the clean-up after a crash, thus reducing contractor callout time and consequently maintenance costs.

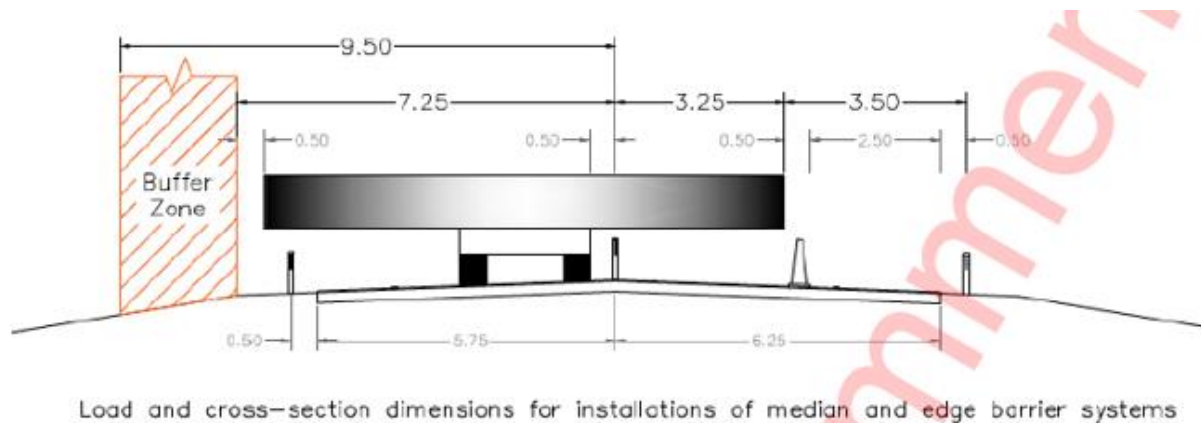
7 Potential disruption to traffic

7.1 Heavy and over dimensional vehicles

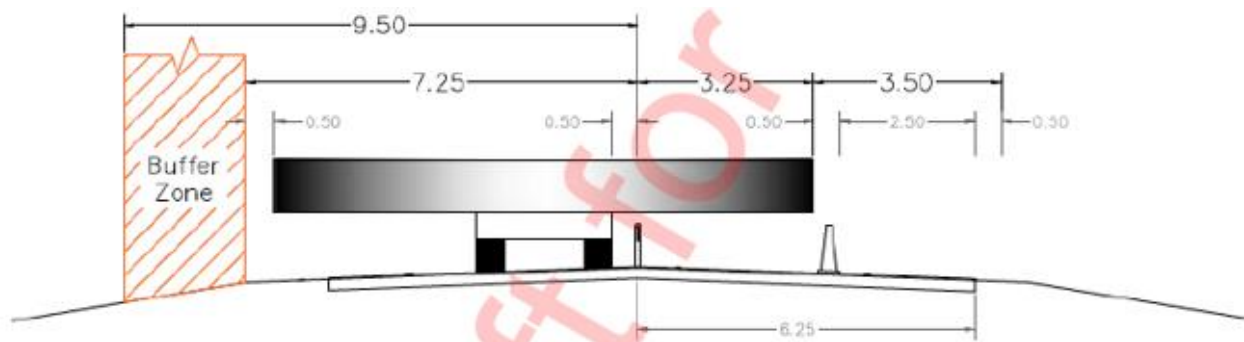
The Waka Kotahi Standard Safety Intervention Toolkit¹⁴ indicates that where median barriers are placed on national (HV) and regional ONRC corridors which have been identified and agreed as over dimensional load routes that roadside objects should be offset appropriately according to Waka Kotahi guidance. The toolkit gives as examples street lights, signage and vegetation. Waka Kotahi has recently produced a draft Technical Memorandum TM -2505 *Design vehicle selection* in its road design series. The Technical Memorandum's Purpose is stated thus:

to provide guidance to project teams on the process of selecting an appropriate 'design vehicle', check vehicle' and, where appropriate for a project. It also provides advice around the accommodation of abnormal or exceptional vehicles and loads as required.

The memorandum emphasises the need for designs to accommodate the swept path envelopes of all vehicles which can be expected to use the road. It provides in its Appendix A cross-section diagrams which illustrate the requirements for over dimensional loads where there is a central median barrier only and where there are also roadside median barriers. These diagrams are shown in figure 20.



¹⁴ <https://www.nzta.govt.nz/assets/resources/standard-safety-intervention-toolkit/standard-safety-intervention-toolkit.pdf>



Load and cross-section dimensions for installations of median barrier only

Figure 20: Load and cross-sectional dimensions for installation of median and edge barrier systems for median barrier only and median barrier plus edge barriers.

The figure is accompanied with the following explanatory notes:

1. 7.25m is the minimum width required between a median barrier system and a roadside object to accommodate a 10m wide load on a standard 2.5m wide trailer. Note that the load is raised to clear the barrier system and encroaches into the opposing carriageway by up to 3.50m.
2. Lighting columns and supports for roadside furniture should be positioned a minimum of 1.5m behind barrier system.
3. The road furniture itself should be positioned at an offset greater than 6.75m from the face of the median barrier system
4. The diagrams show a vehicle approximately 0.5m from the median barrier and there is insufficient space available for the opposing traffic (2.50m vs 3.0m min).
5. The buffer zone illustrates the additional width required for loads between 6.25 and 8.0m wide to be transported without overhanging into the opposing carriageway.

The Heavy Haulage Association (HHA) has issued its own guidance¹⁵ which makes the following suggestions related to median barriers, aimed at facilitating the passage of over dimensional loads.:

- The median barrier being no more than 2km long before a break to reduce waiting time of other traffic.
- Pull-over areas at barrier ends to allow load pilots to stop on-coming traffic to give passage to the load.

7.2 Emergency vehicles and road policing vehicles

It is very important that emergency vehicles and road policing vehicles attending crashes can gain timely access and egress to crash sites on narrow cross section roads with median barriers (Frith et al, 2018). Referring to WRBs, Bergh et al (2001) indicate that on Swedish 2+1 roads the barrier should have emergency openings every 3-5 km to allow rescue vehicles to turn. Figure 21 depicts an emergency crossing facility on a Norwegian road with steel side and central medians.

¹⁵ <https://www.hha.org.nz/assets/Resources/NZHHA-Roading-Design-Spec-For-OD-Loads-Version-8.pdf>



Figure 21: emergency turning facility on a steel barrier divided Norwegian road.

7.3 Turnaround facilities in general

There is little in the way of definite guidance in this area, with the Swedish literature being silent on this topic. However, it is possible to look at specific instances where such provision was made or contemplated. One such case appears in a report presented by MWH (2013) to Waka Kotahi regarding upgrading SH1 from Otaki to North of Levin. The intent was to replace the existing road with a 2-way 2-lane road with w-beam barriers along the side and a WRB on the median. The stretch in question was a 2.8 km section of SH1 from just south of Pukehou Rail overbridge (RP 995/0.25) to north of Taylors Road (RP 995/3.05). The report envisaged turn around facilities at Taylors Road and north of the end of the wire rope barrier near the Pukehou Bridge. This implies a distance between turnaround facilities near 2.8km. The Centennial Highway stretch with the WRB is 3.5 km long with the possibility of turnaround at each end. Table 13 looks at the maximum return journey time needed to complete a u-turn on a median divided road at various median gap spacings and at 80 km/hr and 100km/hr. The maximum time is defined as the time needed for a vehicle which has just come level with a median gap to complete the return journey using the next available gap.

Distance between median gaps (Km)	1.5	2	3	3.5
Maximum time needed	135 seconds (80 km/hr)	180 seconds (80 km/hr)	270 seconds (80 km/hr)	315 seconds (80 km/hr)
	108 seconds (100 km/hr)	144 seconds (100 km/hr)	216 seconds (100 km/hr)	252 seconds (100 km/hr)

Table 13: Maximum time needed to make the return journey to complete a u-turn, at various median gap spacings and at 80 km/hr and 100 km/hr.

7.4 Property access and intersections

The Swedish view is that these are best avoided (Bergh, 2016). This has some face validity, but the figure from Vadely (2016) does not appear to show an obvious safety difference between those Swedish 2+1 roads with accesses and those without. Crowther and Swears (2010) provide evidence of excellent safety results for SH1 near Rangiriri. This stretch of 9km contained ten T intersections, one crossroads and nine private property accesses.

A non-safety concern is inconvenience caused to the occupants of vehicles which must travel further than before owing to the presence of the barrier. This needs to be kept within reasonable

bounds. MWH (2016) looked at a WRB divided solution for SH1 north of Levin. They found that for the 18 properties fronting SH1 the WRB would increase their round-trip times by an average of 41 seconds, an increase of around 5% to a trip to and from Levin or Foxton.

8 Traffic delays

There is evidence that crashes and breakdowns may be more difficult to clear on rural 2-lane roads with a barrier. However, Bergh (2016) indicates that Swedish 2+1 roads do not experience greater delays than other roads including motorways. The main sources of one-off delays are breakdowns and crashes.

8.1 Breakdowns

Capital Journeys logs breakdowns on state highways as far north as Levin and has provided figures pertaining to the stretch of Centennial Drive on SH1 where the wire rope barrier is installed.

The figures indicate that over the 4.6 km length of the barrier there were 53 breakdowns over the period from January 2018 to the time of data supply (15/12/2020), or approximately 18 per year. Given the road's AADT of circa 26,000 vehicles, this approximates to 56 incidents per 100million vehicle kilometres over the section with the barrier. This sort of rate would apply to any such road, and it can be expected that such breakdowns would be more difficult to clear on a road with a barrier than one without a barrier. However, this problem can be ameliorated by good design for tow truck access or access by such organisations as AA or insurance company vehicle rescue services and prompt notification of the appropriate services, so that they can be dispatched promptly. Pull over facilities may also be provided or occur naturally as they do relatively often in New Zealand. Figure 22 depicts a Norwegian road with pullover facilities provide on both sides.



Figure 22: Norwegian road with pullover facilities provide on both sides.

8.2 Crashes

Crashes, in particular serious crashes take time to clear and can cause serious delays (Frith et al (2018). The strength of 2-lane 2-way roads with central barriers is the ability of the central barrier to reduce the number of serious crashes particularly head on crashes and off road to the right crashes. This combined with astute design of the barrier to facilitate emergency services access should result in a reduction of crash related delays when a barrier is installed. Current Waka Kotahi experience is that in the case of crashes, roads with medians are less likely to be closed in

both directions than roads without medians. Bergh et al (2016) calculating total incident delay and total axle pair km by road type and then by division obtained a comparable disturbance index. The 2+1 median barrier road had the lowest disturbance index 0.7, lower than motorways (0.9) and all other roads. Bergh suggests that this low figure could be explained by the low numbers of severe crashes associated with that type of road. Figure 20 in section 7.2 depicts an emergency turning facility on a steel barrier divided Norwegian road.

9 Provision for cyclists

This report relates to sealed 2-way, 2-lane state highways with a speed limit of 80km/hr or more and AADT greater than 6000vpd. According to RAMM the percentage of total State Highway network lane kilometres with AADT greater than 6000vpd is around 22%.

Between 2015 and 2019 inclusive, there were 42 serious or fatal crashes involving cyclists on these roads. This included 9 fatal crashes. For none of these crashes did the Police report the presence of “guardrail” nor was narrowness of roadway mentioned as a factor. Nine (21%) of these crashes were at intersections, 7 (17%) were rear-end crashes and 13 (31%) were overtaking crashes. There were 2 head-on crashes not associated with overtaking.

Best practice is to allow adequate room on the shoulder for the passage of cyclists, without the necessity for them to enter a live lane. At present this cannot always be achieved due to constraints on cross-sections. In New Zealand the target shoulder seal width where cycles are to be accommodated varies with the AADT¹⁶. Waka Kotahi NZTA (2019) in the Standard Safety Intervention Toolkit makes the following statement applying to both 3 barrier installations and where a median barrier is installed without roadside barriers.

The sealed shoulder width will need to accommodate cyclists if the corridor is part of the identified cycle network in accordance with Transport Agency guidance. However, on other corridors, narrower shoulders can be treated to provide a continuous treatment. Careful consideration of cyclist requirements (including consultation) should be carried out.

The Safe System approach means always reducing harm. In some situations, where the status quo is for cyclists to use the live lane, a Safe System approach would allow introduction of a barrier which would reduce overall injury without compromising the safety of cyclists. This would be looked at on a case by case basis and would include consideration of the importance of the location as a route for cyclists. Alternatively, separate provision for cyclists might be possible as sometimes occurs in Sweden (Remgard, Mats, personal communication, 2020). In Sweden the shoulder the requirements vary with the presence or absence of cyclists according to table 14 from CEDR (2013),

¹⁶ <https://www.nzta.govt.nz/walking-cycling-and-public-transport/cycling/cycling-standards-and-guidance/cycling-network-guidance/designing-a-cycle-facility/between-intersections/sealed-shoulders/>

Motorway	110	2.00
Divided single carriageway (2+1) [No cyclists]	100	0.50–0.75
Divided single carriageway (2+1) [With cyclists]	100	0.75–1.00
Single carriageway [No cyclists]	80	0.5
Single carriageway [With Cyclists]	80	0.75

Table 14: Swedish shoulder requirements related to cyclists (column 2 is speed limit, column 3 is shoulder width)

The minimum shoulder width for a divided single carriageway with cyclists is 0.75m. In 2019 Sweden reported 17 cyclist road deaths¹⁷. Of these 3 occurred on roads with speed limit 80km/hr or more.

In New Zealand, the Cycling Safety Panel Report of 2014 (p 19) featured figure 23 which is a chart of same direction fatal and serious crash numbers involving cyclists, over the ten year period 2003-2012, against sealed shoulder width. It can be seen that the numbers of such crashes tend to stabilise at less than around 5 (or 0.5 per year, on average) over the period once the width becomes greater than 0.7m. The Swedish shoulder restriction of 0.75m in the presence of cyclists may relate to this type of crash pattern.

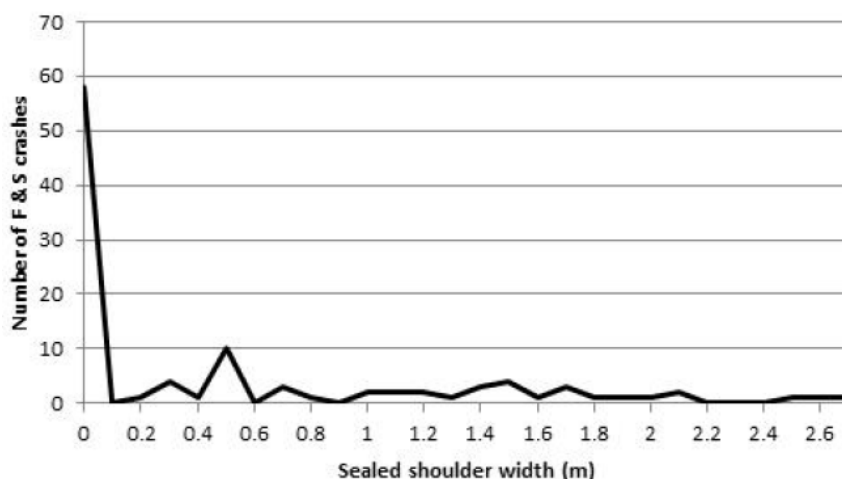


Figure 23: Same direction rural fatal and serious cyclist crashes by shoulder width 2003-2012

The US Federal Highways Administration¹⁸ states:

When providing paved shoulders for bicycle use, a minimum width of 1.2 m (4 ft) is recommended, However, even 0.6 m (2 ft) of shoulder width will benefit more experienced bicyclists.

The very large risk of head-on and off road to the right injury must also be compared to the risk of cyclists in this situation, and the possible things which might be done to ameliorate these risks. A

¹⁷ <https://www.trafa.se/en/road-traffic/road-traffic-injuries/>

¹⁸ <https://www.fhwa.dot.gov/publications/research/safety/pedbike/05085/chapt14.cfm>

recent report from Sweden looks at the potential of different measure to prevent injuries with risk of high health loss among cyclists (Rizzi et al, 2020). Changing the minimum of 0.75m shoulder requirements for cyclists (or a separate path) on Sweden's narrow cross-section roads with median barriers does not feature in a wide range of potential measures canvassed as possible injury ameliorators. Another Swedish study (Ohlin et al, 2019) found that of the 17% of cyclist injuries from collisions with motor vehicles only 1% were related to being overtaken by a motor vehicle, which is the type of interaction one would expect at lower cross-sections. It would be suspected that there would be a minority of such cases in rural areas as cyclists mainly ride for relatively short distances, with an average trip leg of 4km¹⁹.

Given that the priority in terms of saving death and injury is the central barrier followed by road side barriers, in some cases where the cross-section is very narrow having only a central barrier or setting back the barrier from the sealed shoulder to make more room for cyclists might be considered as a step to assist the safety of cyclists.

10 Conclusions

- WRBs are very effective at saving lives and injuries from head-on crashes and off-road to the right crashes and fit the profile of a Safe System crash countermeasure.
- A median barrier should be the priority where 3 barrier systems cannot be immediately achieved
- Guidance documents recommend not placing WRBs on medians less than around 2.5m wide. This is to avoid possible encroachment of vehicles into opposing traffic after contacting the barrier.
- The encroach of vehicles into the opposing traffic after contacting the barrier is a perceived safety risk but this research has not found any crashes of this type recorded in the literature.
- Narrow medians at constrained locations are allowed in the appropriate Australasian guidance documents, by exception. Narrow medians at constrained locations are allowed in the appropriate Australasian guidance documents, by exception. They are widely and successfully used in Sweden and in Norway including in situations with 9 and 10 metre cross-sections incorporating wire rope or metal median barriers.
- There is precedent for the use of WRPs on narrow medians, down in some cases to a width of 1m where the cross section of the road is constrained. Examples are Centennial Highway, the former section of SH1 near Rangiriri and Swedish and Norwegian 1+1 roads. These roads have been associated with large crash savings., particularly from the prevention of head-on crashes which generally have serious or fatal consequences.
- The costs of barrier repairs after strikes (on average \$2700 per strike at 2016 prices) appear very low compared to the social costs of road fatalities and injuries. These, at June 2019 prices are \$4.53 million per fatality and \$477600 per serious injury. Other costs like signage and road markings (egg ATPs) are also likely to be very small in comparison.
- There is sound guidance regarding safe provision for cyclists in Waka Kotahi's Standard Safety Intervention Toolkit. Internationally, and in New Zealand there is little evidence

¹⁹ <https://www.transport.govt.nz/statistics-and-insights/household-travel/#:~:text=The%20New%20Zealand%20Household%20Travel%20Survey%20is%20an,recording%20all%20their%20travel%20over%20a%207-day%20period.>

pointing at narrow cross-section rural roads with central barriers being a large source of danger to cyclists.

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