Consistent with the RTA's Safe System approach, which acknowledges the inevitability of human errors, the feasibility of reducing the entering speeds of the through traffic into the T-junction and other measures to minimise conflict points may be considered for the junctions where crashes have occurred.

Notes

1 Gipsicam is a mobile mapping system that records photo images of RTA's State road network. It also provides accurate Geographic Positioning System (GPS) coordinates for the photo location. The roads are re-surveyed every two to three years, and the survey date is clearly marked on the image. It enables users to view images of the State road network in 10-metre intervals for both directions.

2 At-fault vehicle is defined as the key and second vehicle involved in the turning movement based on the vehicle travel directions provided in the crash data. Second vehicle is defined as the next vehicle that collided with the at-fault vehicle.

3 At-fault driver is defined as the driver controlling the at-fault vehicle who made the gap selection decision for the turning movement – that is, the driver who failed to give way.

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Evaluation of narrow median wire rope barrier installation on Centennial Highway, New Zealand

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Abstract

This paper reports on the performance of a wire rope barrier on a narrow median installation on Centennial Highway, New Zealand. Since the time the speed limit was reduced from 100km/h to 80km/h and the wire rope median barrier was installed, no fatalities or serious injuries have occurred. The median barrier was introduced in two stages and has been very successful in reducing road trauma. Prior to stage one the average annual social cost of crashes on Centennial Highway was $5,796,889.[1] This has since reduced to an average social cost of $65,400 per year.

Surveillance of the Centennial Highway median barrier showed that vehicles generally sustained relatively little damage when they struck the barrier and were often observed to drive away after the impact. Drivers also tended to travel more centrally within their lane with the barrier in place.

While the narrow median on Centennial Highway has resulted in an increase in maintenance costs due to impacts on the wire rope barrier, this cost has been significantly offset by reductions in trauma costs. This paper presents a number of challenges that needed to be overcome to construct the narrow median wire rope barrier and evaluates the success of the barrier in reducing road trauma along this section of state highway.

Keywords

Head-on crashes, Wire rope, Median barriers

Introduction

Coast Road, also known as Centennial Highway, is a picturesque stretch of State Highway 1 that extends along the New Zealand coastline around 30km north of Wellington and serves as the main access route to the nation's capital city. Road closures and delays caused by crashes result in significant disruption, often impacting significantly on commercial carriers.

By the late 1990s, the reputation of this section of two-lane, two-way highway as a scenic travel route had become overshadowed by a notoriety for serious road crashes. While Centennial Highway did not feature unduly as having a high crash rate, the crashes that occurred were generally severe and often involved fatalities.

A number of fatal crashes in the late 1990s fuelled public concern. The New Zealand Transport Agency (then Transit New Zealand) responded with a series of measures, including enhanced road marking and signage. These measures had seemingly been successful in eliminating serious injury crashes for two years.

Then in 2004, the incidence of two fatal head-on crashes reignited the community's concern. A strong public call for action was fuelled by intensive media focus. This time the response was stepped up by reducing the speed limit to 80km/h and installing a median barrier to reduce the likelihood of high severity head-on crashes.

This paper presents a number of challenges that needed to be overcome to construct the narrow median wire rope barrier and evaluates the success of the barrier in reducing road trauma along this section of state highway.

Background

Public concern about the safety of Centennial Highway peaked in the late 1990s following a number of serious road crashes. In the five years from 1996 to 2000 there were 14 head-on crashes along the 3.5km stretch of Centennial Highway that winds its way along the coastline between the two townships of Pukerua Bay and Paekakariki.

Implementing physical changes to this section of highway presented a significant challenge. The road extends through a narrow corridor carved between a rocky coastline and a steep hill range. This physical constraint is compounded even further by a parallel railway line running along the hillside. The traffic volume along this section of highway is around 22,000 vehicles per day [1].

In 2000 a package of safety improvements was implemented to address the incidence of high severity crashes without confronting the physical constraints of the road and its boundaries. The measures included:

- removal of a southbound passing lane
- signs advising of speed and entry to a high accident area
- passing and parking restrictions
- extra wide and profiled (tactile) double yellow centre lines
- red-coloured, raised reflectorised pavement markers on the edge lines.

Additionally, roadside vegetation was trimmed to improve visibility and the adjacent seawall was painted to more clearly mark its presence. In 2001, further improvements were carried out to correct the shape of one of the curves and to install a section of roadside guardrail.

From 2001 to 2004, the measures appeared to have had the desired effect of reducing crashes; the number of high-severity crashes had reduced significantly. However, public concern was reignited in the middle of 2004 following the quick succession of two head-on crashes that resulted in fatalities.

As a result, the speed limit was dropped from 100km/h to 80km/h on 23 August 2004 and the challenge of installing a median barrier in this difficult environment began. Around three months later a wire rope median barrier was in place, separating north and southbound traffic over a length of around 700m where the most recent fatalities had occurred. Physical works on the median barrier began on 26 October 2004 and on 22 November 2004 the NZ$1 million project was completed.

The safety improvement afforded by the median barrier became well established over the following two years and calls continued to have the barrier extended over the remainder of the length of road. Works to complete the remaining 2.8km along this section began in September 2006 and were completed in October 2007 at a cost of $14.5 million.

Finding an innovative solution

The typical standard width for a road of this type with a median barrier is shown in Figure 1. However, because of the physical constraints along this road corridor it was not going to be possible to provide a desirable standard width median treatment without huge cost. These physical constraints include a coastline and seawall on one side of the road and a steep rocky hillside on the other.

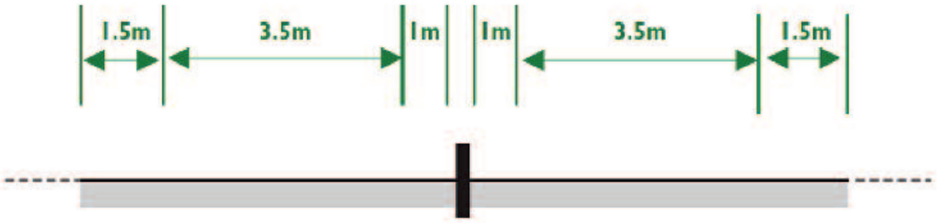

Figure 1. Typical median treatment

Wire rope *Steel w-beam* *Concrete*

Figure 2. Different median barrier types

A feasibility study was carried out to investigate the potential use of a wire rope barrier, a semi-rigid steel w-beam barrier and a solid concrete barrier (Figure 2). The solution needed to improve safety while allowing access for emergency vehicles in the event of an incident. If a semi-rigid or solid barrier was installed and a crash caused one lane to be closed, the ability for emergency vehicles to reach the incident would be hampered. In addition, the barrier solution needed to allow flexibility to carry out maintenance activities on the road.

A wire rope barrier was considered the most appropriate solution for this location. The capital investment required was significantly less than that for a solid concrete barrier, which was a significant factor in this instance to enable a solution to be implemented quickly. In addition, it was considered that a semi-rigid w-beam barrier would cause greater delays during repairs and, with a narrow median, an impact could potentially result in permanent deflection of the barrier encroaching into the opposing lane until such time that repairs could be carried out.

A wire rope barrier could be dropped quickly if there was an incident to facilitate emergency service access and, with a number of reasonably tight (200 to 300m radius) curves along this section of road, a wire rope barrier was considered to have the least impact on forward visibility. A wire rope barrier was also considered to be the least visually intrusive on this scenic stretch of State highway.

The chosen option proposed a 1.5m wide wire rope median with a slightly reduced lane width (from 3.5m to 3.25m), providing a minimum overall road width of 10 metres (Figure 3). The solution needed to ensure a minimum width for each lane of at least 5m to enable two vehicles to pass each other in the event of a breakdown.

Wire rope median barriers are used extensively on Sweden's 'collision free' roads [2]. These roads are generally 2+1 or 2+2 highways and expressways that have been treated with median barriers to separate the opposing traffic directions. The 2+1 roads are three lane roads with two lanes in one direction and one lane in the other, alternating every few kilometres and separated with a median barrier, usually a wire rope barrier (Figure 4). Around 1800 kilometres of collision-free roads have been constructed and opened to traffic as at 1 January 2008.

A study by the Swedish National Road and Transport Research Institute (VTI) to evaluate the in-service performance of roads treated with wire rope medians showed that this barrier system significantly reduces road trauma. The study compared normal 13 metre wide roads and expressways to MML and MLV collision-free roads. MML expressways have interchanges with access provided via entry and exit lanes. MLV highways have at-grade intersections with breaks in the median barrier.

MML expressways with posted speed limits of 110km/h and 90km/h showed an overall reduction in fatalities and serious injuries (FSI) of 57% and 62%, respectively. MLV highways with posted speed limits of 110km/h and 90km/h showed a FSI reduction of 39% and 63%, respectively [2]. These reductions represent the overall performance for links plus junctions.

New Zealand has a number of road sections treated with narrow medians similar to Sweden's 2+1 roads. However, the Centennial Highway installation was the first use of a median barrier on a two-lane, two-way (1+1) road in New Zealand. Part of the consultation process involved working with the emergency services to demonstrate the level of accessibility that could be maintained in the event of an incident blocking one of

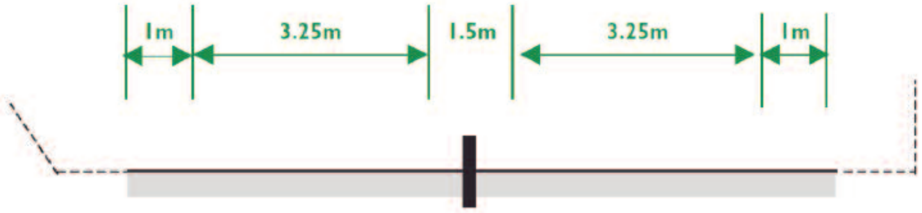

Figure 3. Selected median treatment

Figure 4. Swedish 2+1 road

the lanes. A demonstration was carried out to show how easily the wire ropes could be lifted and the posts removed.

The wire rope barrier system used on the first 700m stage had been tested to international standards with a test level 3 (TL3) design deflection [3] of 1.9m at a post spacing of 2.0m and a design deflection of 2.5m at a post spacing of 3.0m [4]. With an offset of 0.75m between the median barrier and the centerline, this meant that deflection upon impact was likely to extend into the opposing traffic lane. To minimise the amount of deflection, the post spacing was reduced to 1m. For the remaining 2.8km extension, the wire rope barrier post spacing was selected to achieve a maximum TL3 design deflection of 1.5m.

Surveillance of the barrier in operation, as described later in this paper, has captured a number of incidents involving a vehicle hitting the wire rope barrier in close proximity to vehicles travelling in the opposing traffic lane. There has been no evidence of problems associated with potential deflection into the opposing lane from crash records or from observations of performance during an impact. Figure 5 shows the final Centennial Highway cross section incorporating a wire rope barrier on a narrow median reserve.

Figure 5. Narrow median wire rope barrier installation on Centennial Highway

Safety and operational performance

Review of crash data

Historical crash data has been obtained from the New Zealand Crash Analysis System (CAS), which includes records of all vehicle crashes that are reported to the police in New Zealand [5]. Any crash on a public road in New Zealand that results in injury is required by law to be reported to a police officer, although it is acknowledged that not all injury crashes are reported, particularly the less severe crashes.

The attending police officer completes a traffic crash report and codes injuries as fatal, serious or minor. A fatal crash involves injuries that result in death within 30 days of the crash. A serious crash involves an injury such as a fracture, concussion, severe cuts or other injury that requires medical treatment or removal to and retention in hospital. A minor injury crash involves injuries of a minor nature such as sprains and bruises that are typically treated onsite.

Table 1 provides a summary of crashes on Centennial Highway between 1996 and 2009. This represents all crashes reported along the 3.5km coastal section of Centennial Highway that has been treated with a wire rope median barrier. All social costs are based on 2008 figures published by the New Zealand Ministry of Transport: Fatal crash $4,039,000, Serious $717,000, Minor $84,000, Non-Inj $2500 [6].

Prior to construction of the first 700m length of median barrier in 2004 there were 12 fatal crashes and 4 serious injury crashes in nine years. Of these, 8 of the fatal crashes and all of the serious injury crashes were head-on crashes. There have been no fatal or serious crashes, nor any head-on crashes, since 2004.

Prior to the safety improvements in 2000, the average annual social cost of crashes on Centennial Highway was $6,877,300 (average for 1996 to 2000 inclusive). The average annual social cost of crashes then reduced slightly to $4,446,375 per year up to 2004 (average for 2001 to 2004 inclusive), when the first 700m section of median barrier was installed and the speed limit over the entire 3.5km length was dropped to 80km/h. Since 2004 the average annual social cost of crashes has reduced to $65,400 per year (average for 2005 to 2009 inclusive).

Year	Fatal	Serious	Minor	Non-Inj	Social Cost	Head-on % of all crashes	Head-on % of F & S crashes
1996	1	0	0	3	$4,046,500	25%	100%
1997	1	0	0	5	$4,051,500	50%	100%
1998	1	1	3	3	$5,015,500	25%	50%
1999	2	0	1	6	$8,177,000	56%	100%
2000	3	1	3	4	$13,096,000	27%	50%
2001	1	1	1	4	$4,850,000	14%	50%
2002	0	1	0	2	$722,000	33%	100%
2003	0	0	0	3	$7,500	33%	0%
2004	3	0	1	2	$12,206,000	67%	100%
2005	0	0	2	3	$175,500	0%	0%
2006	0	0	0	4	$10,000	0%	0%
2007	0	0	1	7	$101,500	0%	0%
2008	0	0	0	7	$17,500	0%	0%
2009	0	0	0	9	$22,500	0%	0%

Table 1. Centennial Highway crash history (social cost of crashes)

The crash data confirm that the level of trauma has been significantly reduced on Centennial Highway as a result of the median barrier, although it is acknowledged that a proportion of these gains may also be due to other measures such as the lowered speed limit. Even though the speed limit on Centennial Highway was also dropped from 100km/h to 80km/h in 2004, there has been a notable increase in the number of non-injury crashes. Many of these crashes involve impacts on the wire rope median barrier although, as outlined later in this paper, the number of barrier impacts appears to be under-reported in CAS.

Perceptual measures such as the narrowed lane width and the presence of the median barrier are also likely to have had some impact on the improved safety performance. However, the authors consider that the elimination of head-on crashes since 2004 is predominately due to the installation of the wire rope median barrier and that this is supported by continued strikes on the median barrier.

Surveillance monitoring

Because a wire rope barrier had not previously been constructed in New Zealand on a 1+1 road with such a narrow median and high traffic volume, a video camera surveillance system was installed to monitor driver behaviours and to record any hits on the barrier.

The surveillance system comprised three CCTV cameras installed at different points along the initial 700m length of wire rope barrier. Three days were selected to represent a 'before installation' scenario (19 October 2004), an 'immediately after installation' scenario (30 November 2004), and a 'some time after installation' scenario (27 January 2005).

The lateral positioning of vehicles relative to the centreline was assessed by viewing five-minute segments of footage from the morning and evening peaks.

Because the camera footage was not sufficiently clear it was not possible to reliably obtain detailed measurements of the lateral position of vehicles onscreen. Instead, vehicle positions were described in general terms according to three different zones – 'Left', 'Centre' and 'Right' – relative to the edgeline and centreline. Any subtle changes between the 'immediately after installation' and 'some time after installation' scenarios were difficult to detect and were therefore combined into a general 'after installation' scenario.

Comparison of footage from before and after the median barrier installation showed that drivers tended to travel more centrally within their lane with the median barrier in place (Figure 6). On the inside of a left hand bend, however, the proportion of drivers tracking to the left of their lane was generally higher, with a small increase in the number of vehicles cutting the left edgeline.

Drivers tend to react to objects placed close to the edge of a traffic lane by slowing or steering away [7]. The results indicate that the median barrier placed close to the edge of the traffic lane, potentially in combination with other perceptual measures such as the narrowed lane widths, has created a tendency for drivers to track further away from the centreline.

Lane position observations from Camera 3 are summarised in Table 2. An example view from Camera 3 is shown on the left of Figure 6. Vehicles shown on the right side of the double yellow centreline are travelling northbound and vehicles on the left side are travelling southbound.

Southbound observations	
Before installation	**After installation**
• 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.	• 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**
• 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.	• 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 2. Lane position observations from Camera 3

Figure 6. Lane position before and after installation

The southbound results indicated a shift from a distribution skewed slightly to the right of the lane before installation to a distribution skewed slightly to the left of the lane after installation. The northbound results showed a significant shift towards the left, i.e., vehicles tended to cut towards the inside of the left bend. However, this shift may not actually be as pronounced as the results suggest because the majority of vehicles classed as 'Centre' in the 'before installation' scenario were offset slightly to the left. Therefore, any small shift to the left in the 'after installation' scenario would be enough to change the classification from 'Centre' to 'Left' [8].

For the first 18 months following the initial 700m installation, particular attention was paid to any incidents involving vehicles hitting the wire rope median barrier. Footage from a number of these incidents was obtained from the CCTV recorded images for evaluation.

Generally, vehicles that hit the barrier sustained relatively little damage and were observed to drive away. By way of example, one sunny afternoon a northbound motorist momentarily fell asleep at the wheel and drifted towards the centre of the road. On contact with the barrier the driver awoke and continued the journey without incident. Without the barrier the driver would have veered into oncoming traffic.

A second incident involved a heavy vehicle drifting into the median barrier. Again, without the barrier, the driver would have veered into oncoming traffic. Both of these examples are illustrated by the surveillance footage shown in Figure 7. In summary, the surveillance footage further confirms the improved level of safety along this stretch of highway.

Figure 7. Two separate incidents involving vehicles hitting the median barrier

Barrier strike rate and maintenance costs

One of the advantages of a wire rope system compared to a semi-rigid w-beam alternative is the ability to carry out repairs quickly following an impact. Often the network maintenance contractor is able to carry wire rope barrier posts to the site and carry out repairs while onsite by placing the new posts into the existing sockets. These repairs can often be carried out in a matter of minutes with minimal disruption to traffic. By comparison, a w-beam barrier requires the damaged posts to be removed and replaced, which will often involve either driving the new posts or boring new holes.

Because this installation had generated such attention amongst the public, the network maintenance contractor was asked to keep records of strikes on the barrier. Latest records to the end of February 2010 indicate that there have been a total of 61 recorded strikes on the barrier since 2004.

The first 700m section was hit 11 times between November 2004, when the first 700m section was completed, and September 2006, when works commenced to extend the barrier. This is assumed to represent an operational period of 22 months without construction. The extension was completed in October 2007, providing median barrier protection over a total length of 3.5km. An operational period of 28 months has been assumed, since construction was completed to February 2010. During this period, the median barrier was struck 46 times. There were a further four strikes that occurred during the construction period for the extension.

Traffic volumes have been obtained from a permanent telemetry site located around 500m north of this section of State Highway with an annual average daily traffic (AADT) volume of 21,958 recorded in 2004 and 22,382 in 2008 [1]. From the maintenance records it is possible to determine the frequency of strikes on the median barrier as summarised in Table 3.

There were 8.6 recorded impacts per kilometre per year, or one crash per 0.9 million vehicle kilometres of travel (vkt) on the initial 700m length of median barrier. The complete 3.5km length has a crash rate of 5.6 recorded impacts per km per year, or 1 crash per 1.5 million vehicle km. This compares with impact frequencies experienced on Swedish and New Zealand 2+1 roads.

Beca Carter Hollings and Ferner Ltd [9] was commissioned to determine if the Swedish 2+1 cable barrier system [2] was an appropriate interim solution for a section of State Highway 1 in New Zealand located between Longswamp and Rangiriri. Beca reported that 'information from the Swedish experience was used to estimate the frequency of barrier impacts and their costs. The Swedish predicted one barrier impact per 1-2 million vehicle kilometres of travel. The initial observed rate was around one per 1 million but appears to be dropping (Bergh, 1999). In our analysis we [Beca] have assumed the barrier will be hit once every 1.5 million vehicle kms … The adopted barrier impact rate would see the barrier hit on average once every 10 days'.

Opus International Consultants Ltd [10] has since reported 86 impacts on the Rangiriri 2+1 wire rope median barrier during 2006 and 2007. This was found to represent an average of one impact every 8.48 days or approximately 1.13 impacts per 1.5 million vehicle km. From more recent monitoring, this hit rate appears to be dropping. Opus also determined that the average impact on the Rangiriri installation resulted in 15 damaged posts at an average cost of NZ$2579 per repair, or NZ$12,295 per km per year.

	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 3. Frequency of vehicle impacts on the median barrier

The average impact along Centennial Highway resulted in 12 damaged posts at a repair cost of $1356. This represents an average cost of $11,644 per km per year for the initial 700m section and an average cost of $7649 per km per year for the extended 3.5km section. The maximum recorded repair cost was $6345, which resulted in damage to 56 posts. For 90% of impacts the damage was limited to 24 posts or less at a cost of $2394 or less. All costs include traffic management.

The Centennial Highway experience was similar to that of Sweden and Rangiriri with regard to increased maintenance cost associated with impacts on the wire rope median barrier. 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.

Lane markings were supplemented on Centennial Highway with yellow reflective strips attached to the wire rope barrier posts and yellow raised retroreflective pavement markers placed along the centre edgelines to heighten the level of delineation at night. These reflective elements were installed at 10 to 12m spacing which is now the standard adopted in New Zealand [11].

Experience from narrow median wire rope barrier installations in New Zealand suggests that there may be merit in applying audio tactile profiled (ATP) line markings (rumble strips) on the centrelines to reduce the likelihood of strikes on the barrier. Further research is recommended to determine the likely reduction of median barrier strikes with the installation of ATP centreline markings. This would enable a benefit cost evaluation to be carried out to determine whether the installation of ATP markings is likely to offset the maintenance costs associated with barrier impacts on new and existing installations.

Conclusions and recommendations

This paper reports on the performance of a wire rope barrier on a narrow median installation on Centennial Highway, New Zealand. The median barrier was introduced in two stages and has been very successful in reducing road trauma. Prior to stage one, the average annual social cost of crashes on Centennial Highway was $5,796,889. This has since reduced to an average social cost of $65,400 per year.

Surveillance of the Centennial Highway median barrier showed that vehicles generally sustained relatively little damage when they struck the barrier and were often observed to drive away after the impact. Drivers also tended to travel more centrally within their lane with the barrier in place.

The use of a narrow median wire rope barrier 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 be 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.

Further research is recommended to determine the likely reduction of median barrier strikes with the installation of ATP centreline markings. This would enable a benefit cost evaluation to be carried out to determine whether the installation of ATP markings is likely to offset the maintenance costs associated with barrier impacts on new and existing installations.

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Notes

1. All dollar values are in New Zealand dollars

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