Inspection and Design Basics Review

NZ TRANSPORT AGENCY
WAKA KOTAHI

Roadside Safety Topics

Safe Roadsides

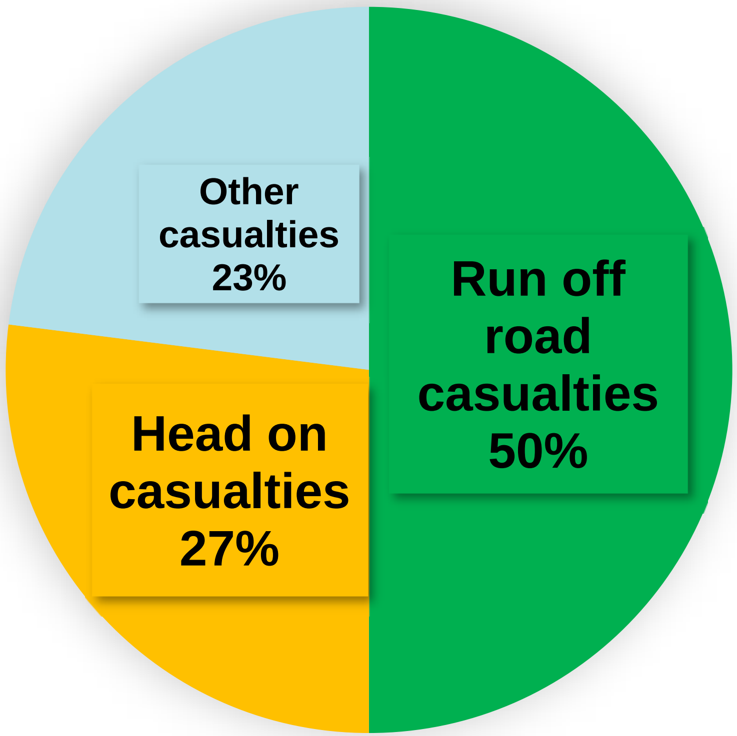
Safe System

5 Rs approach to hazard protection

Bank slope definitions

Single vehicle run off the road crashes

- Typical statistic for recent years: on average one person is killed on New Zealand roads every 24 hours and a further seven are seriously injured
- Motor vehicle crashes are a leading cause of death for those from 15 through 29 years old



Total fatalities

- Run off the road + Head on casualties = 77%
  these are situations that may have been avoided if a barrier system or other (5Rs) mitigation had been in place
- Safety barriers can make a big difference

The data used here is from 2019 because the numbers haven't changed much in recent years

NZ Transport Agency

Ideally - keep them on the road

If vehicles do come off the road ensure the roadside is either forgiving or provide side protection (ie a guardrail)

At worst - Reduce crash severity

When vehicles **strike immovable objects** the **crash forces are exerted on vehicle occupants** and more often than not the result is a fatality

Recent vehicle models with better star ratings may improve the situation but are unlikely to change the outcome that much

Roadside safety hazard treatment priorities

What we refer to as the 5 Rs

- Remove
- Relocate
- Redesign (reduce impact severity)
- Redirect (shield)
- Retro-reflect (delineate)

- **look at these in sequence so you don't miss the obvious fix.**
- **Apply the first one practicable** with regard to physical possibility and/or cost effectiveness

Hazard Mitigation - Remove

- Here we have a Parallel drainage hazard and a headwall presenting a **roadside point hazard**
- The **hazards have been removed by piping the drainage** and backfilling the drain to leave a smooth grassed berm
- This example was **near Whanganui** It was **expensive but solved the problem**

Relocate

- During upgrades **consider Relocating power poles** within the road reserve OR
- **Undergrounding** is another option, but it is expensive
- In some instances power poles that have been struck by vehicles have been reinstated in the same location

Redesign

If hazards are not easily removed then they can be redesigned, examples include:

- shear base columns
- Traversable culvert end treatments

Redirect

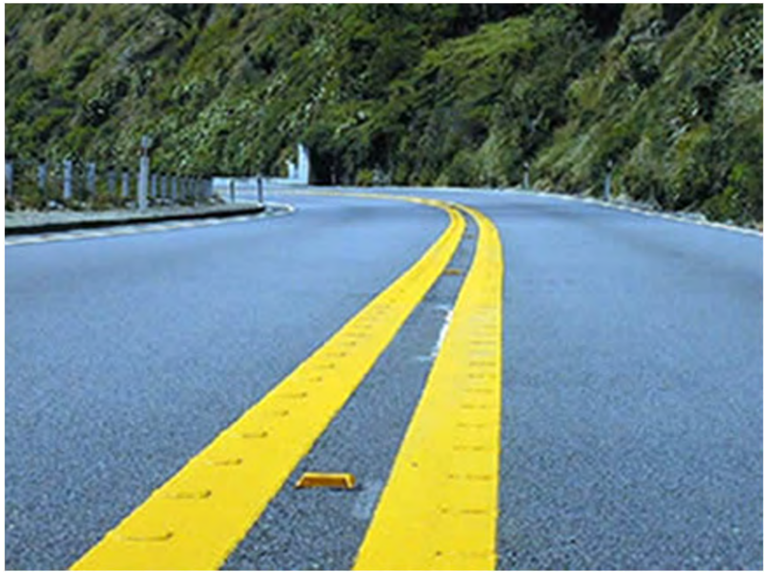
- Having satisfied ourselves that **we could not REMOVE, RELOCATE or REDESIGN** we come to the use of barriers to **REDIRECT**
- Redirect **meaning redirect vehicles safely back onto the road**

Retro-Reflect

If a guardrail is installed we have introduced a hazard and **need to retro-reflect the terminal end.**

In some cases **where guardrails can't be used then retro-reflecting may be the solution**, examples:

Tunnel entrance



Road centerline delineation for areas of no overtaking

Design envelope – formerly clear zone

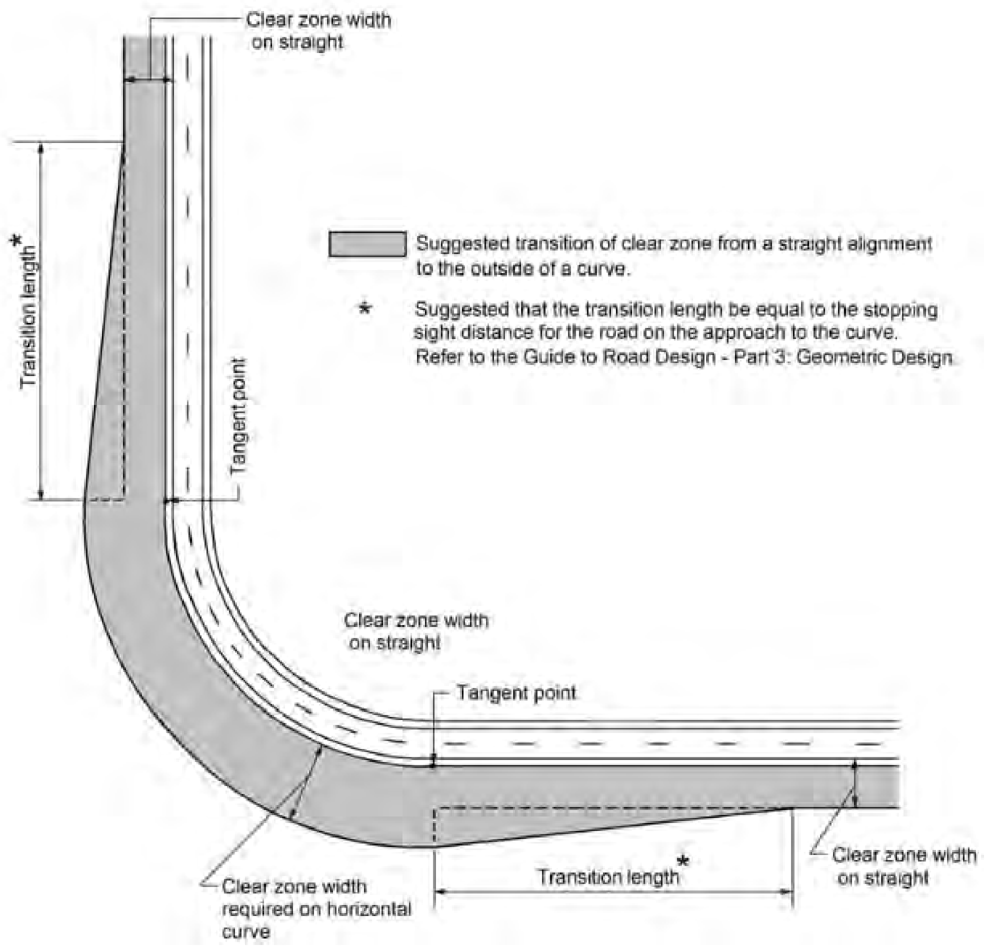
Design envelope = roadside area of interest. Hazards within the envelope should be treated or shielded as part of providing a safe roadside

- Clear zones are an outdated concept that have some value but do not ensure reasonable safety
- Unfortunately New Zealand topography and narrow road reserves make it difficult to provide clear zones economically and we must consider other solutions
- Can be used in determining the design envelope when constrained by budget

Design Envelope – the theory

Grey hatch = clear zone

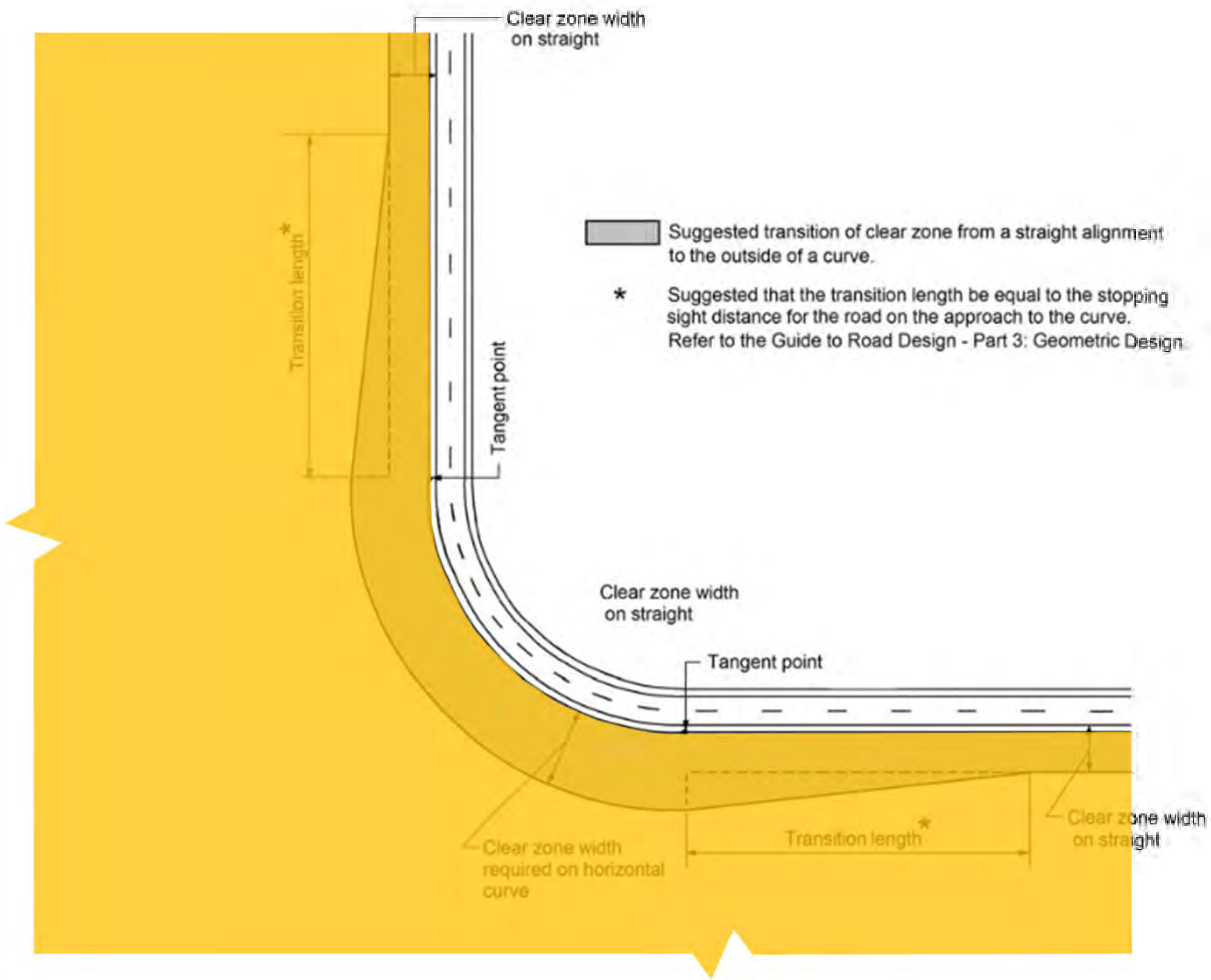
Orange hatch (next slide) = risk assessment to determine design envelope



Design Envelope – the theory

Grey hatch (previous slide) = clear zone

Orange hatch = risk assessment to determine design envelope



Poor roadside

What are the issues?

- Non-compliant end terminal
- Power pole
- Drop-off and vegetation

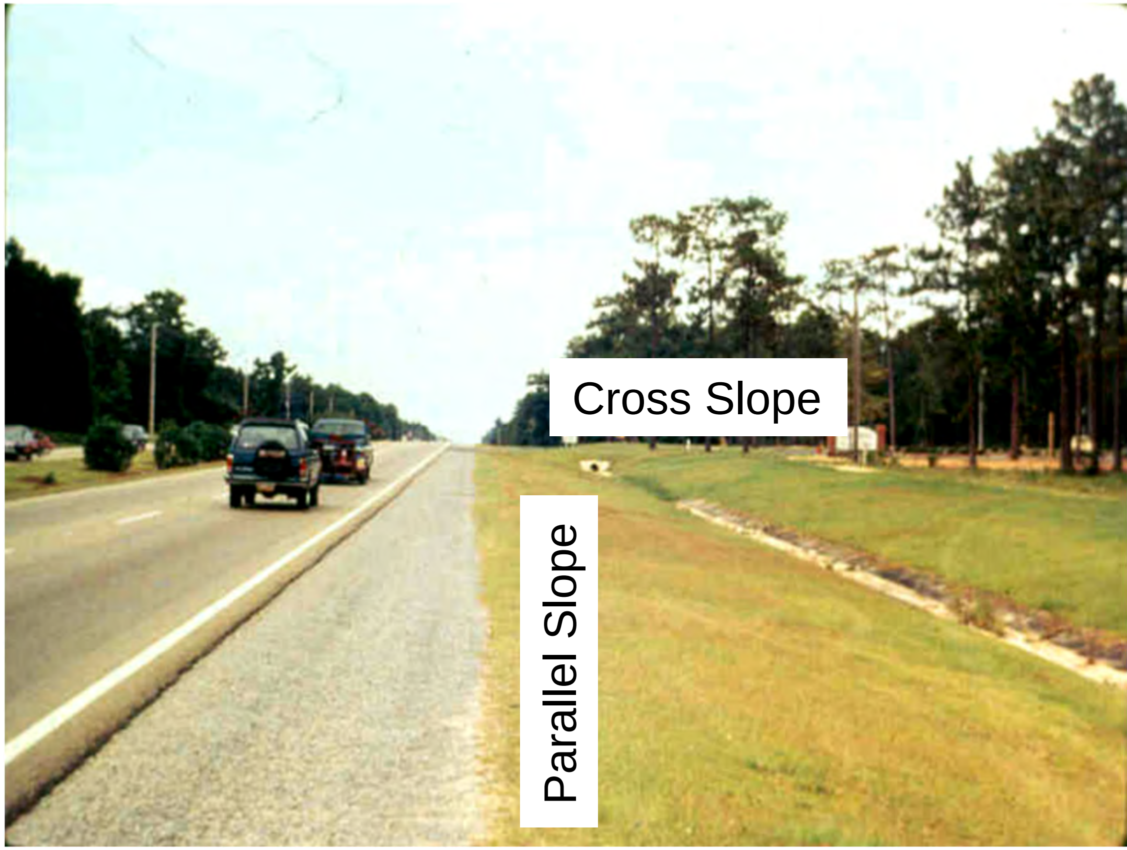
What can be done?

- Install compliant terminal
- Remove power pole
- Improve shoulder grading & seal
- Extend barrier

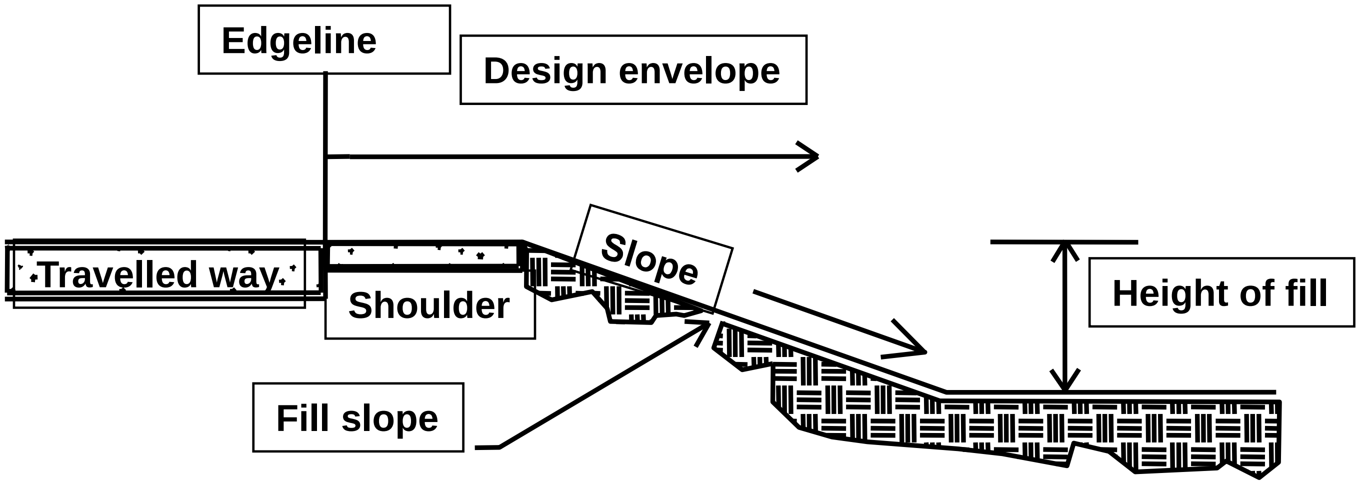
Slopes

- **Parallel slopes** are parallel to the traffic lane

- **Cross slopes** are perpendicular to the traffic lane



Landform hazards - parallel slopes



Slope	Cars*
Recoverable	>6:1
Non- recoverable	
- Traversable	6:1-4:1
- Non-traversable (critical)	<4:1

*Heavy vehicle stability is usually significantly worse than for light vehicles.

- If a **vehicle runs off onto a slope it may or may not recover**
- Slope steepness is defined in the table as **traversable or non-traversable**
- **Traversable slopes** are **further split into recoverable and non-recoverable**
- Note – the higher center of gravity for large trucks means that slopes need to be very flat in order to be recoverable

Landform hazard mitigation

Steep roadside

Here we have a parallel slope - it is over 3:1 which is critical.

Better grading, but potentially too soft

Landform hazard mitigation

Unshielded roadside

Shielded roadside

Before and after, **no option but to install a barrier**

Tree hazard mitigation

Trunk > 100 mm diameter = not frangible

Also consider hazard height (max 100 mm)

With this **incomplete job**, the stumps will snag a vehicle.

The 100 mm (diameter) number is based on treated timber – some trees will be ‘non-frangible’ when much thinner

Ditch hazard mitigation

Non-traversable ditch

Traversable ditch

Ditch hazard mitigation

- Barrier used here to mitigate a parallel drainage structure
- If culvert ends are not able to be treated due to their position or alignment, then barrier protection is the only option
- This may cause issues at driveways or side roads with regards to sight distances, mowing and access for maintenance

Cross culvert hazard mitigation

Where pipes protrude out of the embankment, cut pipe to suit the embankment and use traversable end treatments

Parallel culvert hazard mitigation

- Colliding end on with a culvert presents a roadside hazard. This can rip the wheel off of a vehicle
- Historically small diameter pipes were not treated due to cost

Kiwisafer is a cheaper option to provide a traversable end treatment

Barrier locations

Median barrier - a longitudinal barrier used to separate opposing traffic lanes to prevent head on collisions

Bridge barrier – used for bridge side protection usually a higher containment level due to hazard and requires specialist design

Roadside barrier - a longitudinal barrier used to shield roadside obstacles or non-traversable terrain features

Compliance Topics

NZ Transport Agency Waka Kotahi notes

Crash tested and approved products

Changes to test criteria

Performance levels

Compliance standard – NZTA M23

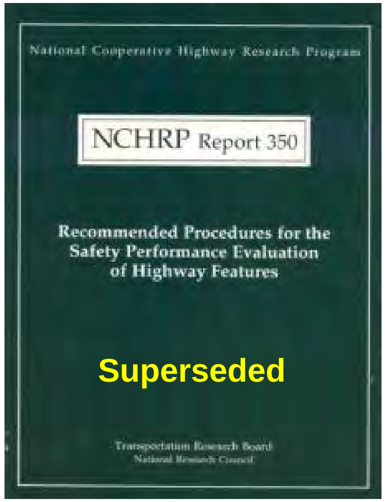
Specification for road safety barrier systems

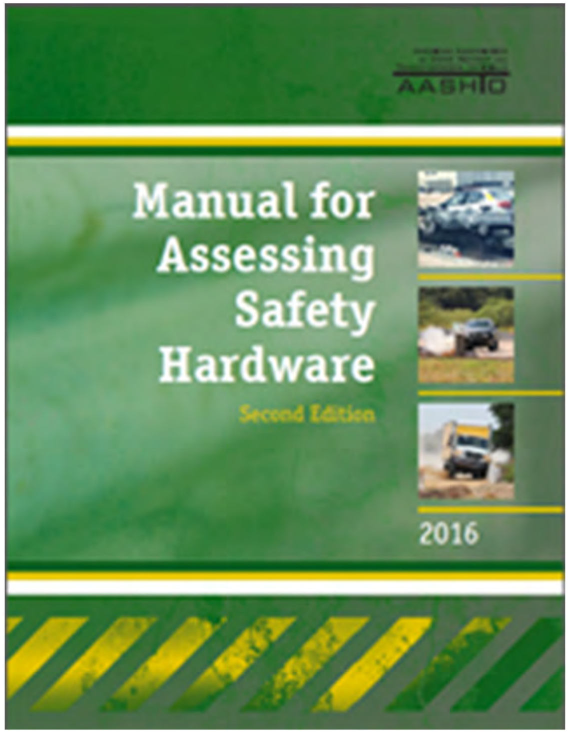
- The current version reflects 20+ years of in-service experience with barrier systems under NZTA M23.
- Applies to all road safety barrier systems installed on state highways.
- Contains products that have been crash tested to an accepted protocol
- Includes technical memorandum – eg ground beam

https://www.nzta.govt.nz/resources/road-safety-barrier-systems

Compliance standards

NCHRP 350 and MASH





Pre-November 2012

Relevant to many legacy products.

Post November 2012

Compliant products gradually mandated from ~2018 to ~2020.

NCHRP 350 and **MASH** set out the testing and performance standards applicable to the development of new hardware

Evaluation Criteria

MASH establishes three criteria for evaluating the safety performance of roadside hardware

- Structural Adequacy
  - Barrier should contain or re-direct vehicle
  - the vehicle should not penetrate, under ride, or override the installation, although controlled lateral deflection of the test article is acceptable.
- Occupant Risk
  - Deceleration of Vehicle Occupants
  - Test article / debris should not penetrate the vehicle
- Post Impact Vehicle Response
  - After impact vehicle behaviour (roll / departure angle)

MASH: Barrier Test Matrix

Test Vehicles
- 1,100 kg small car
- 2,270 kg utility

TL1
- 50 km/h
- 25°

TL2
- 70 km/h
- 25°

TL3
- 100 km/h
- 25°

TL4 includes TL1 to TL3 vehicles and 10,000 kg truck at 90 km/h and 15°

TL5 & TL6 include TL1 to TL4 vehicles and 36,000 kg trucks at 80 km/h and 15°

- 6 different test levels (TL 1 – 6)
- 3 types of barrier (Flexible, semi rigid and rigid)
- 3 test variables (speed, impact angle and vehicle type)

Crash energy

$IS = \frac{1}{2} m(V\sin\theta)^2$

Consider the effects on impact severity:

- **Speed**
- **Steeper angle of impact**
- **Heavier vehicle**

M kg	**V** km/h	**θ**	**IS** kJ
2000	100	25	137.8
2000	120	25	198.5
2000	100	30	192.9
2270	100	25	156.4

The message here is that change in speed or impact angle have the effect of increasing IS (impact strength) exponentially

- Increase from 100km/h to 120 km/h gives 137.8 kJ to 198.5 kJ (almost 50% extra energy) - people speeding may exceed the barrier capability
- 25 degrees to 30 degrees gives 137.8 kJ to 192.9 kJ (almost 50% extra energy) - on a curve a high angle crash may exceed the barrier capability
- MASH mass increase of 270 kg gives ~140 kJ to ~160 kJ, i.e. not as significant as speed or angle (almost 50 % additional mass is required to make IS = 190 kJ)

Barrier performance

- Test Level 3 (TL-3) is the minimum performance level for all state highway road safety barriers, terminals and crash cushions.

- Higher performance barriers will be required in many situations.

- Heavy truck, low speed shallow angle – lowered the crash energy – it held because the impact energy was within TL-3 containment levels

- Note ribbon strength (splice bolts), and

- Post rotation

Barrier hardware not listed in NZTA: M23

Requires site or project specific submission to NZ Transport Agency Lead Safety Advisor (Roads and Roadsides), demonstrating:

- Compliance
- Benefits over NZTA: M23 listed hardware.

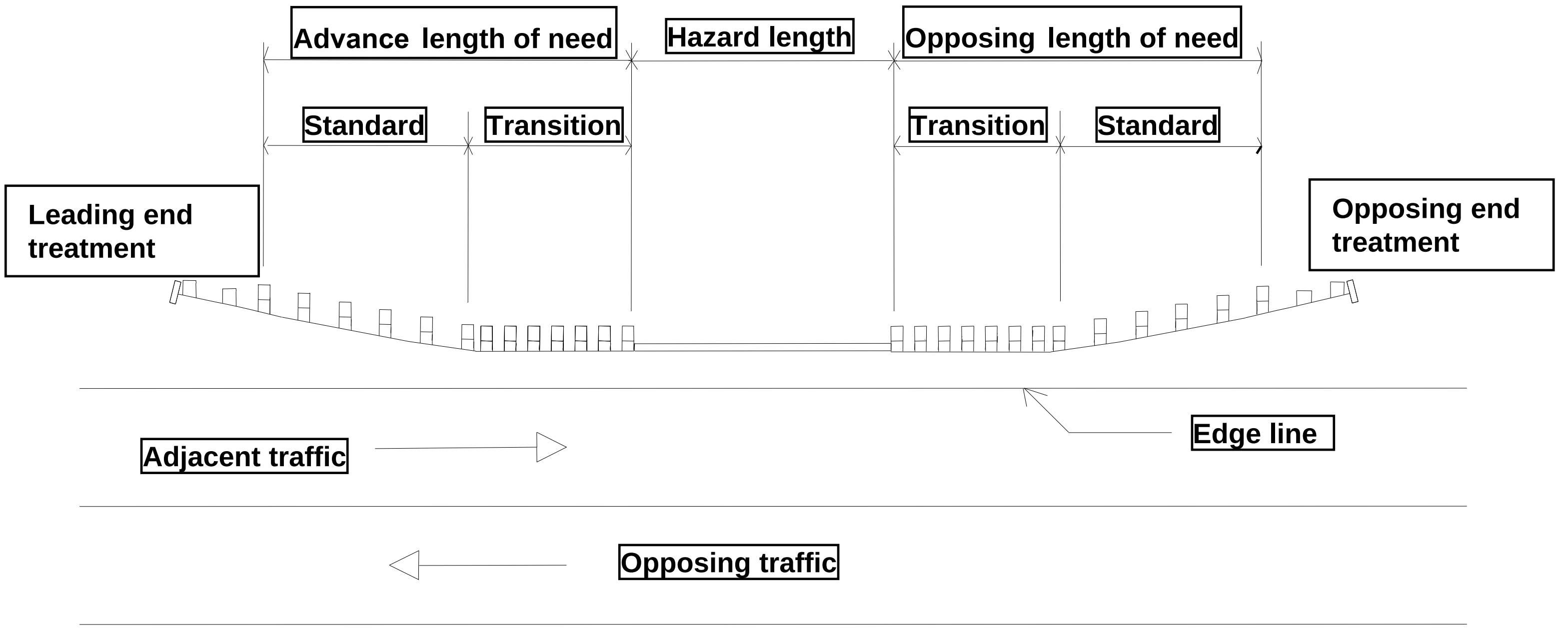
Barrier Design Topics

- Barrier types
- Length of need
- Flares and transitions
- Terminal ends
- Grading
- Barriers and kerbs

Barrier design overview

- Length of need
- Choice of barrier system (eg deflection)
- Choice of end treatment (eg gating area)
- Offset from lanes
- Run-out length

Barrier system design elements

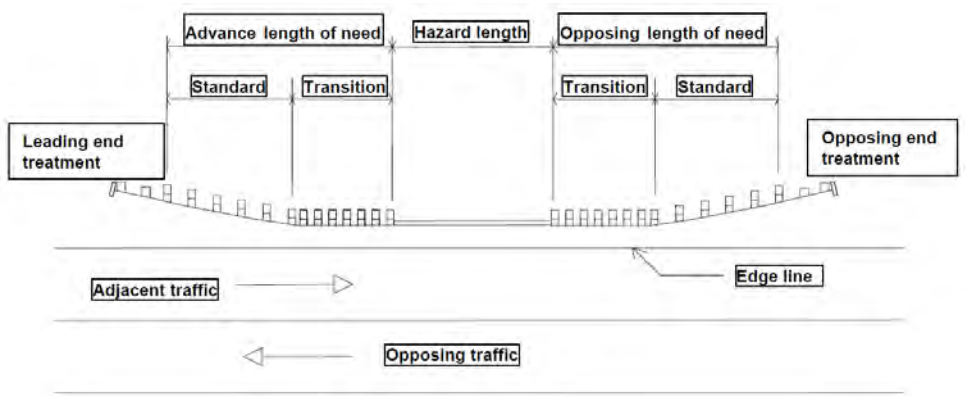


$$L_{TOTAL} = L_{ADVANCE} + L_{HAZARD} + L_{OPPOSING}$$

Barrier system design elements

Typical Barrier layout will include the following elements

- **End Treatment** – Crashworthy Terminal end treatment to accommodate end on impacts and provide anchorage to the guardrail
- **Length of Need (LON)** – total length of barrier required to adequately shield the area of concern
- **Standard section** – standard guardrail section (either flared or tangential)
- **Transition section** – this is the transition between 2 different barrier types or between barrier and concrete bridge component (parapet or bridge rail) to prevent vehicle pocketing or snagging



Design Considerations

- Adequate space for deflection must be provided to fixed objects
- Approach terrain must be level (maximum 10:1) to not affect the stability of the vehicle
- Kerbs can cause vehicles to vault over the barrier
- Poorly designed barriers are a hazard

Design Considerations

Poor design, installation or maintenance can lead to poor outcomes

Deflection Distance

- Ensure there is sufficient space between the guardrail system and any hazards behind to allow for deflection and avoid pocketing
- If there is no option but to have them close then the guardrail can be stiffened adjacent to and in advance of the hazard (both directions) by using a stiffer system (or potentially by adding posts)
- Use standard details, these are known to work predictably

Design deflections

Refer to NZTA M23 Appendix A for actual test deflections

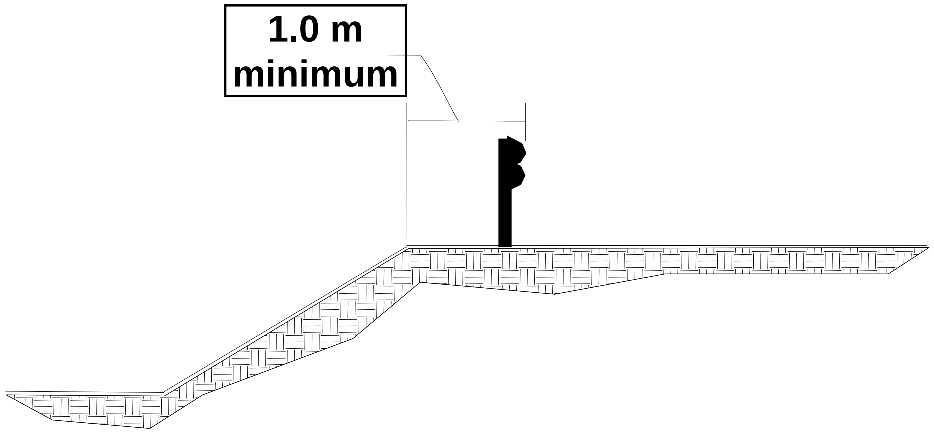
- Dependent on:
  - Impact speed
  - Impact angle
  - Vehicle mass
  - Barrier system rigidity

- Typically 0 to 2.5 metres (2270 kg vehicle at 100 km/h & 25° [TL-3])

Inadequate deflection distance

Installations such as these will not keep an errant vehicle away from the fixed objects

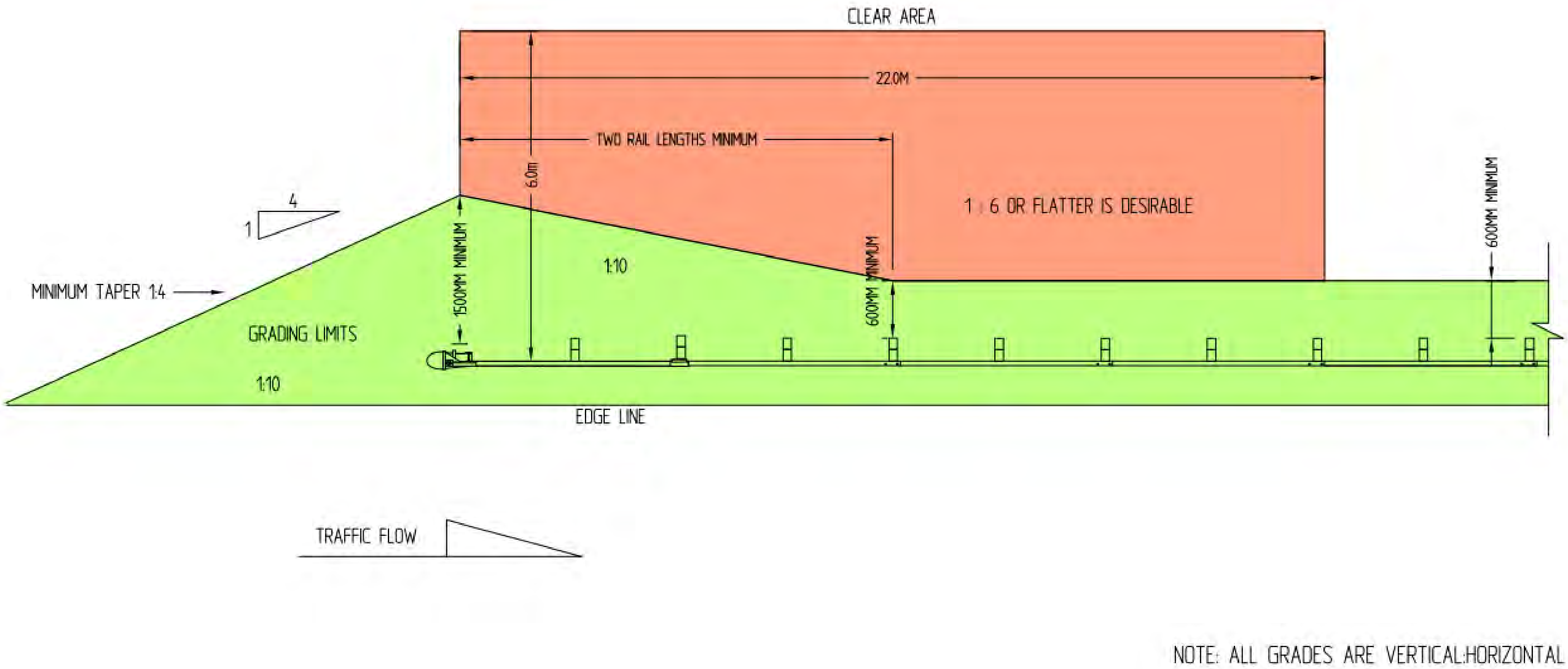
Placement and slope break



- A **minimum of 1.0 m is required** behind the guardrail post to the shoulder break point (absolute minimum 0.6 m)
- **Preferable to have slopes of 1V:2H or flatter** behind the shoulder breakpoint

The example shown is not a good one!

NZTA standard detail: RSB-3 typical grading plan



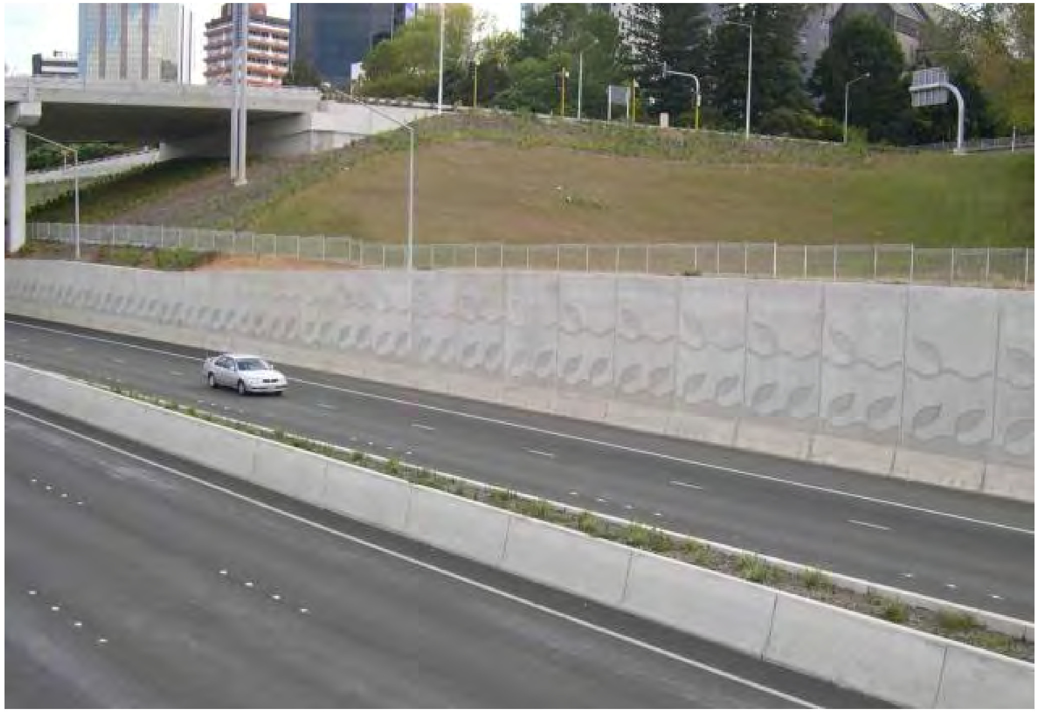
Barrier offset

Austroads Guide to Road Design Part 6: Roadside Design, Safety and Barriers - Table 6.5

	Rural high speed	Rural low speed	Urban freeways	Urban roads
Desirable	4 – 6 m	3 – 6 m	4 – 6 m	2.5 – 3 m
Minimum	3 m	2.5 m	3 m	1 m

- Often width constraints mean low offset must be considered
- Uses of the shoulder such as cycling, agricultural vehicles, access, sight distance etc must be considered
- Ground support for barrier is often a factor (distance to batter)

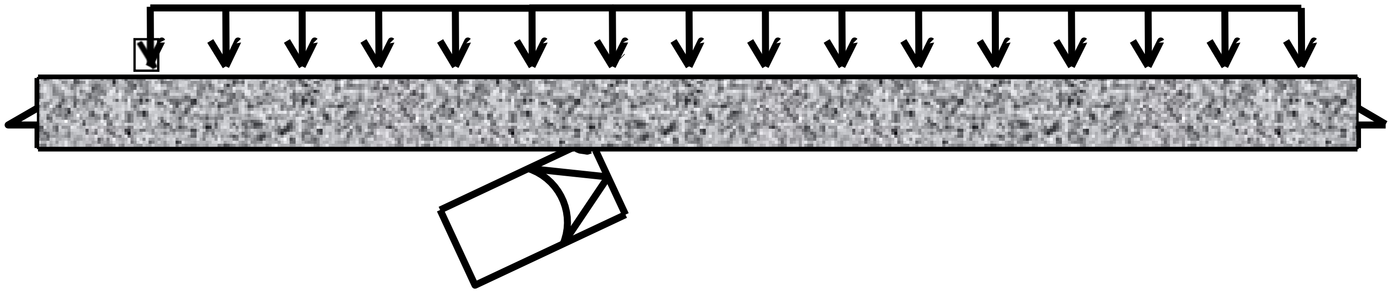
Rigid barrier systems



- Key feature **DEFLECTION = 0** (more force exerted on occupants)
- Eg back to back median barriers, integrated with concrete wall

Rigid barrier force diagram

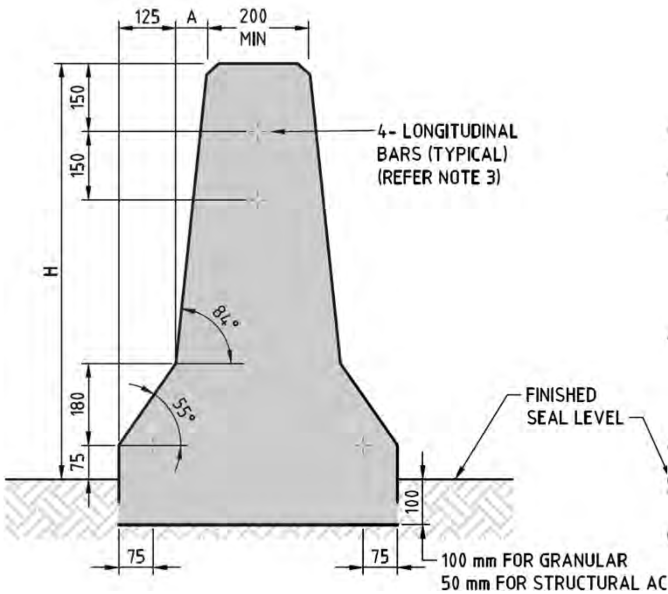
Lateral resistance exerted by barrier mass
and anchorage (at least every 48 m)



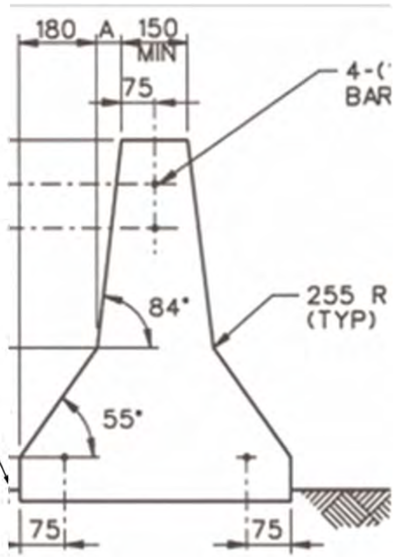
- Rigid barriers resist impact loads by transferring impact loads directly into the ground, through the anchors and keying into the pavement
- The barrier acts as a stiff beam to transfer impact forces along its length
- As the name implies, barriers in this category experience little or no lateral deflection upon impact
- **Deflection = 0 – but higher IMPACT SEVERITY**
- 48 m anchor spacing for TL-4, 24 m for TL-5

Rigid barrier

F-shape



NJB/safety shape (superseded)

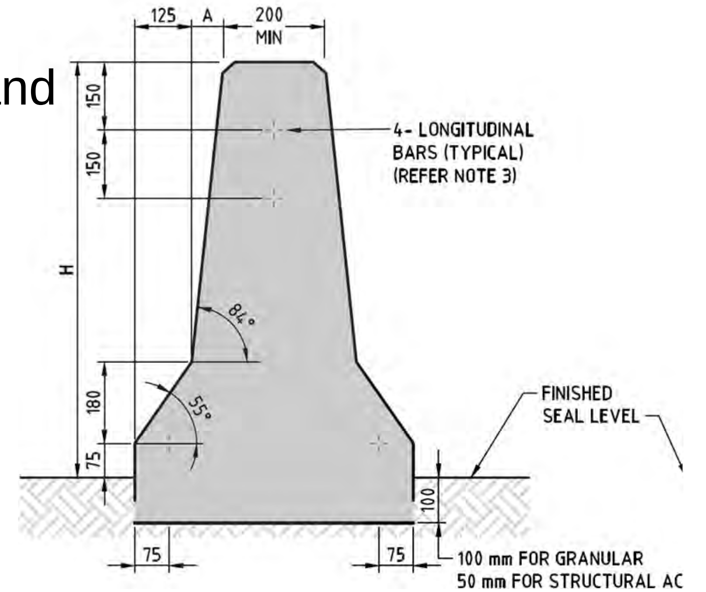


Rigid barrier

F Shaped barrier profile

- Height above pavement surface (TL 4 = 915 +/- 25mm, TL5 = 1070 +/- 25mm)
- Reveal height = 75mm (+/- 25mm)
- Base width (TL 4 = 570mm +/- 5mm, TL 5 = 620mm +/- 5mm) and foundation embedment (300mm)
- Neck thickness (200mm min)
- If pre-cast - barrier segment length (6m min)
- Grading up to face of barrier to be 1 in 10 or flatter
- Segment alignment (No miss alignment of more than 20mm)
- Approved segment jointing (refer TNZ M/23)
- Paved surfacing up to traffic side of barrier
- Reinforcement (reinforcement finder or demolish a barrier segment)

F-shape

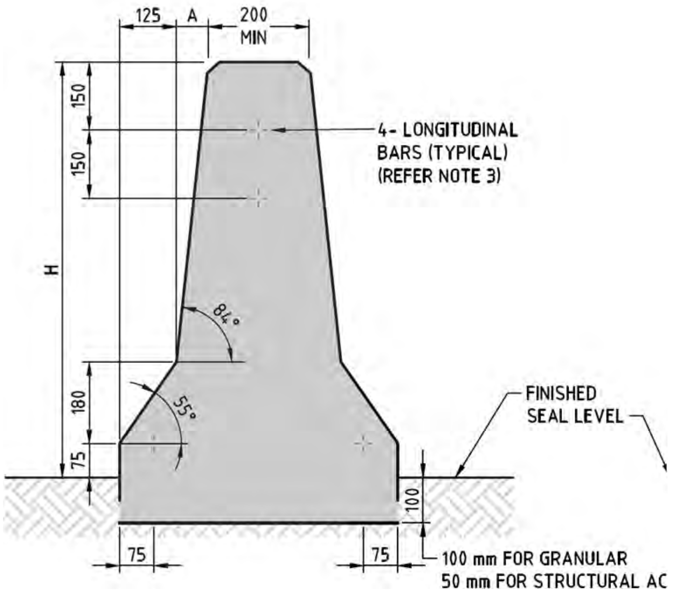


Rigid barrier

F Shaped barrier profile (continued)

- Concrete strength (Schmidt Hammer or concrete cores)
- Verticality in relation to road camber
- Pattern/relief if present appropriate
- Maximum offset from edge line = 4.6m
- Barrier alignment is consistent
- Flare rates provided appropriate for speed environment and proximity to travelled way
- Hazard offset allowance for vehicle roll over
- No kerb in front of barrier
- Appropriate transitions used when transitioning to barrier of differing profile or stiffness

F-shape



Selection considerations

- Due to low deflection rigid barriers are good candidates for narrow medians with little space for deflection
- Minimal impact damage to barrier
- low impact damage results low maintenance costs

Selection considerations continued

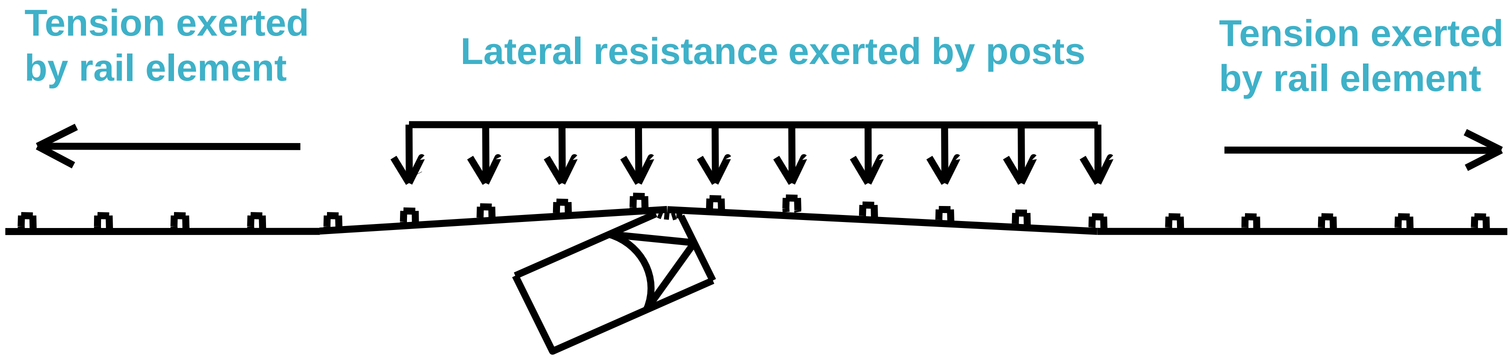
The minimal impact damage results in the additional benefits of:

- Reduction in lane closures for repair
- Barriers remain useable
- Contains large vehicles
- Low impact angles are likely

Semi-rigid barrier systems

- Weakpost W-beam
- Strong post W-beam
- Thrie-beam barrier
- Ezy-guard HC & sentry thriebeam

Semi-rigid barrier force diagram



Strong beam systems are the most common and work by:

- **Redirecting** vehicles predominantly **through beam action**
- The **crash forces** are exerted through the beam to the **posts and into the ground**
- **Tensile forces** within the rail **contributes to effectiveness**
- **End anchors maintain the tension** within the system
- **Deflection is approximately 1.5 m** to 1.0 m

Semi-rigid systems

- Deflection about 1.5 m
- More forgiving (for vehicle occupants) than rigid barrier
- Requires regular maintenance schedules
- Remains serviceable after some impacts
- Easily transitioned to rigid barrier

Semi-rigid barrier types

- Deflection ~ 2.0 to 1.0 m
- Moderate occupant severity

Most common guardrail form in NZ is the weak post W-beam consisting of:

- W-beam
- Steel driven posts
- Deflection ~1.5 m
- Strong/timber post and blockout systems are legacy systems but still common on the network

Blockouts

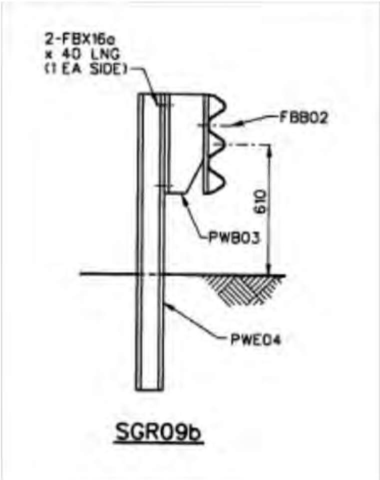
Strong post – legacy system

Good – toenails

Bad – blockout rotation

- With strong posts systems blockouts are required to prevent wheel snagging (poor crash performance)
- Weak posts break so do not require blockouts
- Blockouts must be fixed in place to prevent rotation and transfer crash forces to the beam
- Timber block outs need to be toenailed to prevent block out rotation
- Routered for steel strong post eg end terminal

Thrie-beam



- 150 mm steel I post + 350 mm modified blockout
- Thrie beam rail (2.7mm thick but 4.0 m PCD)
- Rail backing plates required at intermediate posts
- Height to top of rail 860 mm (public domain)
- Adequate deflection distance provided (0.6- 0.9 m depending on mass of impact vehicle)
- Appropriate transitions used when transitioning to barrier of differing profile or stiffness
- Curvature of rail undesirable

Aesthetic guardrail: TL-2

Not fully accepted in M23

Aesthetic guardrail: TL-2

Not fully accepted in M23

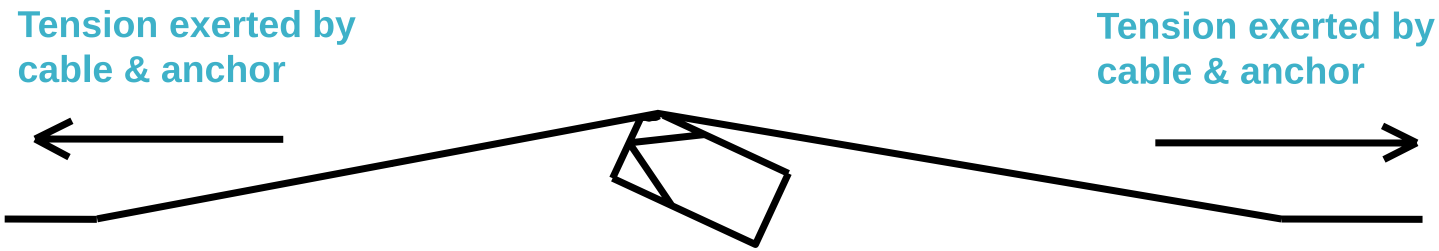
- Varieties of Timber Faced Guardrail and Lograil products available in NZ
- Not to be used on state highways (although in some rare cases where risk is low, can be used with special approval)
- Does not have any crashworthy terminal ends
- Can be used in speed environments up to 70 km/h with RCA approval

Flexible barrier systems

Flexible barriers are defined by their primary function (median vs side protection)

Flexible Barrier Force Diagram

- **Anchors are critical** since the barrier works on tension
- Posts provide little resistance, mostly just holding the cable at the correct height
- Crash impact severity is lower, but high deflection
- Flexible systems resist impact through the development of tension in the cables.



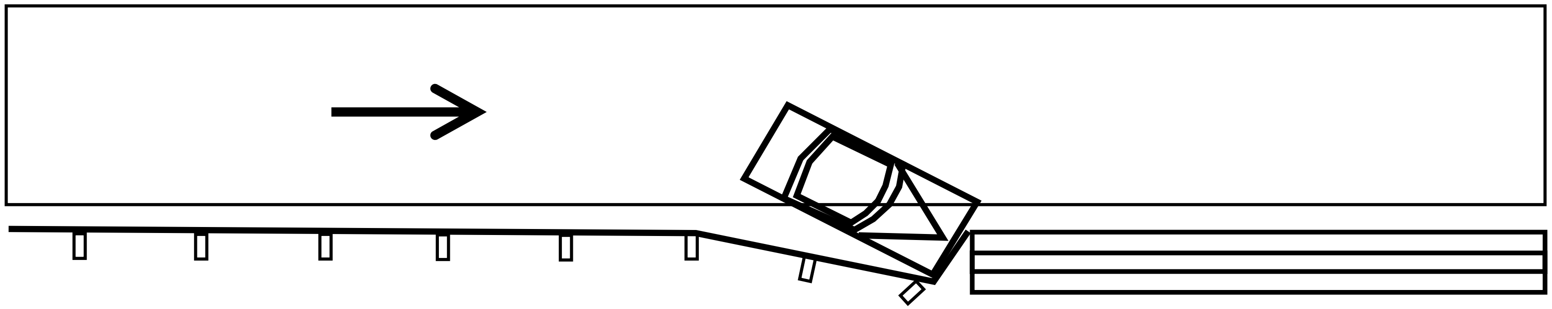
- Flexible – **crash energy taken up in the cable tension** – it is important that tension is maintained
- As the cables are deflected laterally by the impacting vehicle, large tensile forces build up, and the lateral component of those forces redirect the vehicle.

Flexible barrier selection considerations

- Lowest occupant severity of the three barrier types (but deflection is large and not resilient to minor damage)
- Lowest cost
- Better aesthetics in some cases
- Can be dropped for emergency access
- Maintenance can be quick
- Capable of containing a large range of vehicle types
- In all cases these considerations come with some caveats eg
  - Severity could be worse for motorcyclist than rigid or W-beam + underrun
  - Cost can be high in poor ground conditions
  - Sometimes the aesthetics are worse/subjective

Transitions

Provided between barriers of different stiffness to minimise pocketing



Semi-rigid barrier

Rigid barrier

Inadequate transitioning between guardrails of different height or stiffness can result in unpredictable behaviour – in this case pocketing against a power pole

Transitions

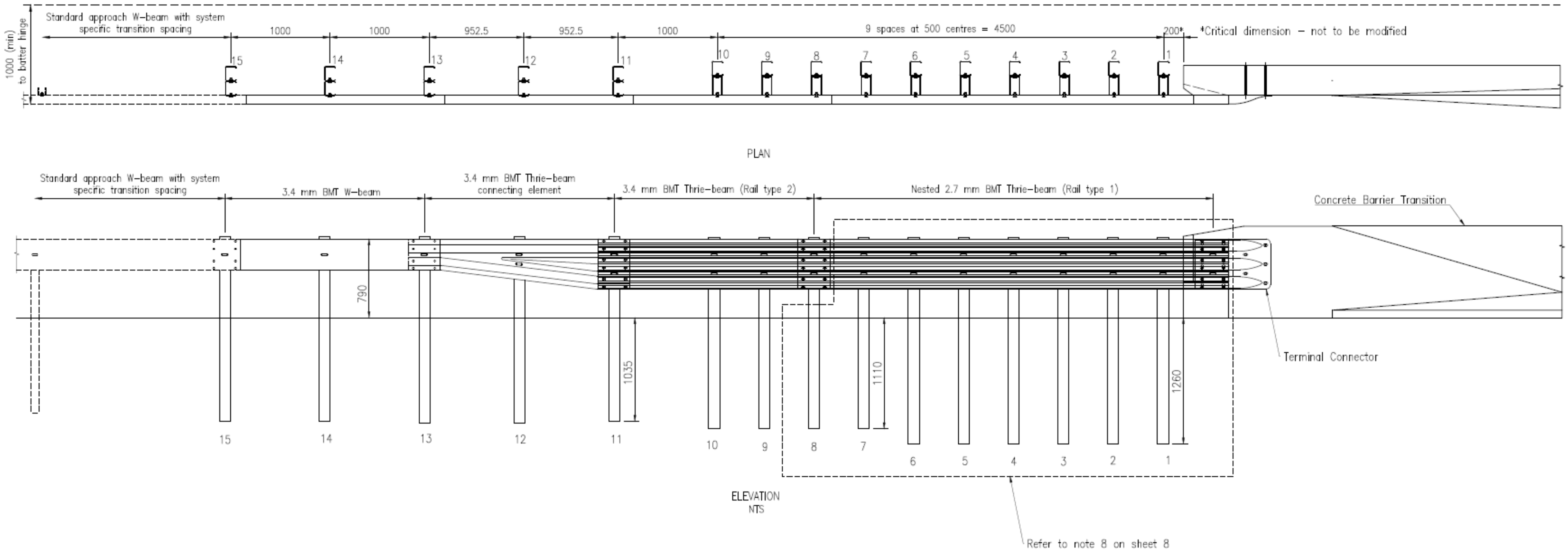
This is an **example of pocketing** due to no or inadequate transition.

Notice how **the rail is deformed back from the wall but is still anchored to it preventing the vehicle from direct contact** with the end of the bridge rail .

The **additional posts and perhaps some stiffening** (nested rail) for the transition and keeps the vehicle from pocketing.

NZTA standard detail: semi-rigid to rigid transition

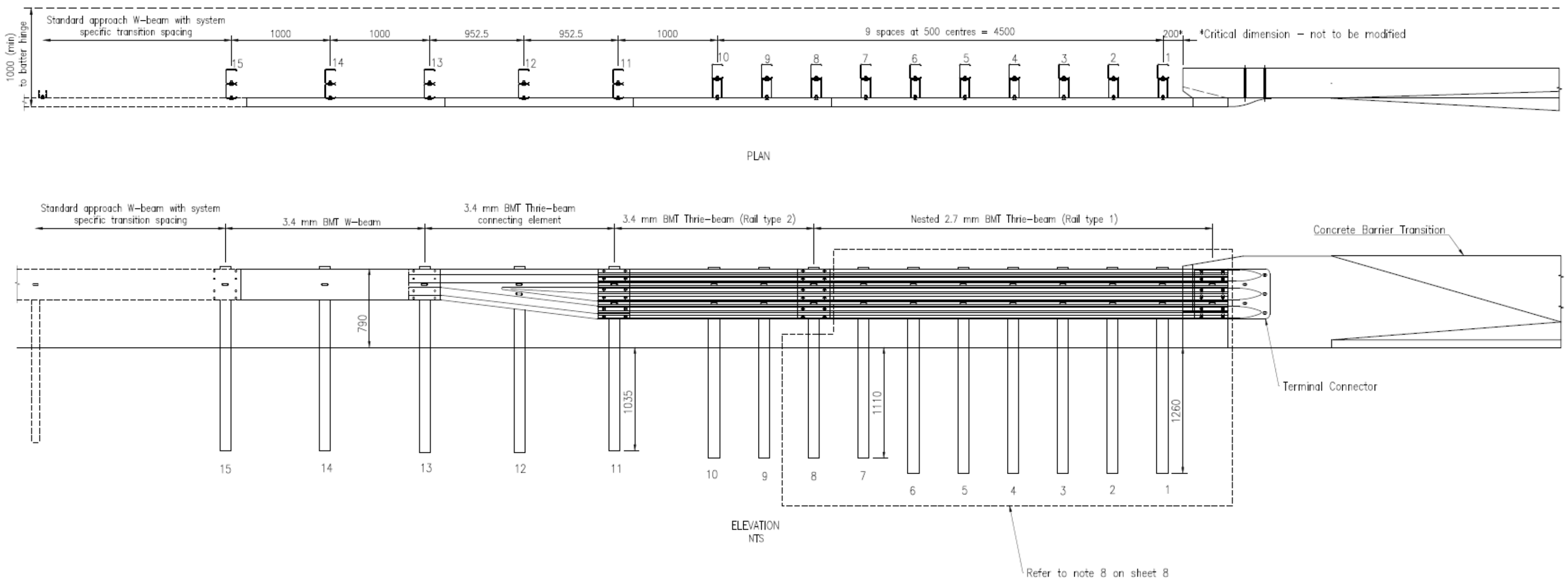
RSB-5M



NZ Transport Agency

NZTA standard detail: semi-rigid to rigid transition

RSB-5M



- **Deflection is gradually altered from approximately 1.5m** , through 1.0m to 0.75m and then 0.5m and 0.25m before reaching the bridge concrete which is 0 deflection
- Uses Thriebeam connector, then post spacing and thicker rail, then a combination of post spacing and nested rail

TL-3 transition

- Reinforced concrete anchor block, transitioning from vertical face to F-shape profile
- Inverted ‘T’ foundation
- Gradual increase in strength and stiffness from W-beam to concrete

- **Deflection is gradually altered from approximately 1.5 m** , through 1.0 m to 0.75 m and then 0.5 m and 0.25 m before reaching the concrete which is 0 deflection
- Uses closer post spacing, Thrie-beam connector, then thicker rail and post spacing, then a combination of post spacing and nested rail

Flexible to semi-rigid transition

Where there is space for deflection, it is preferable for the preceding barrier to overlap in front of the following barrier.

In constrained situations use the RSB-7 layouts

The flexible barrier must continue past the semi-rigid, there needs to be enough barrier overlap to ensure the LON points overlap

Flexible to semi-rigid transition

This example uses the correct transition and has worked well, although this is not always the case.

This example is the wrong way round, so the WRB could interfere with the operation of the w-beam terminal.

This is complicated and best avoided, or given due consideration if unavoidable

Height and shape transition

Kerb and channel

Kerbs

- Do not prevent vehicle leaving roadway
- Can cause loss of control
- Can cause rollover
- Can cause vaulting

Kerbs can provide enough lift under impact conditions that during a crash vehicles can become airborne and where a barrier is present can vault over the barrier

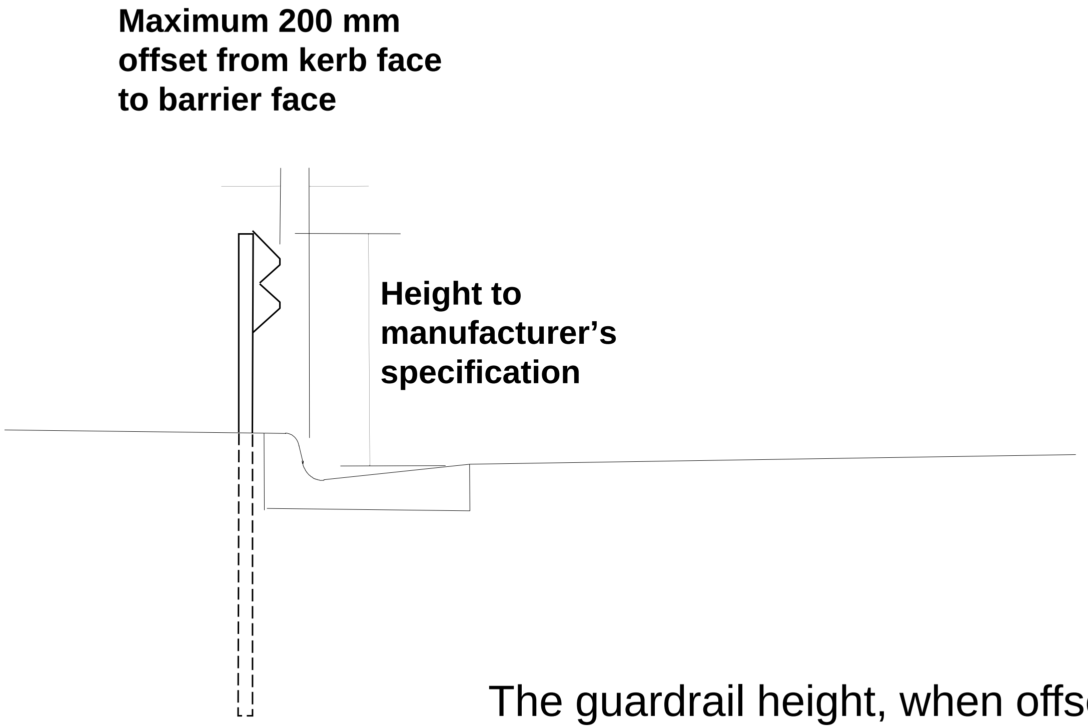
Kerb use with road safety barrier

Kerbs are not desirable in combination with road safety barrier

However, if necessary:

- The maximum kerb height is 100mm
- Use mountable kerb
- The barrier face should coincide with the kerb face (so an impacting vehicle engages the barrier prior to the suspension encountering the kerb). Sometimes this can be difficult eg with flexible barriers

Preferred location not possible?



The guardrail height, when offset from the kerb, is **measured from the ground underneath the rail.**

End treatments

Barrier end hazards

- Viner, in a study of guardrail impacts, estimates that 25% of guardrail impacts are end crashes
- The proper way to interpret this statistic is that impacts with guardrail ends are so severe that 25% of all reported guardrail crashes are end impacts

End treatment functions

- Provide anchorage
- Provide crashworthy barrier end (ie will not spear, vault, or roll)
- Capable of developing the full tensile strength of the barrier
- Able to protect vehicle occupants for both end-on and angle impacts

The development of terminals, providing acceptable impact performance for corrugated beam barrier systems, has been a difficult task, especially for small cars. In the past 25 years several terminal designs have evolved, and are now recognized for providing acceptable performance.

Location of terminal

- Leading and trailing end terminals
- Leading, intermediate and trailing end anchorages
- Traversable recovery area (clear area) beyond gating terminal
- Gating Vs Non gating terminal ends
- Gating clear area 18.5 m x 6 m
- Terminal locations should be adjusted to accommodate even increments of beam rail, based on the standard 3.81 m section length.

Selection considerations

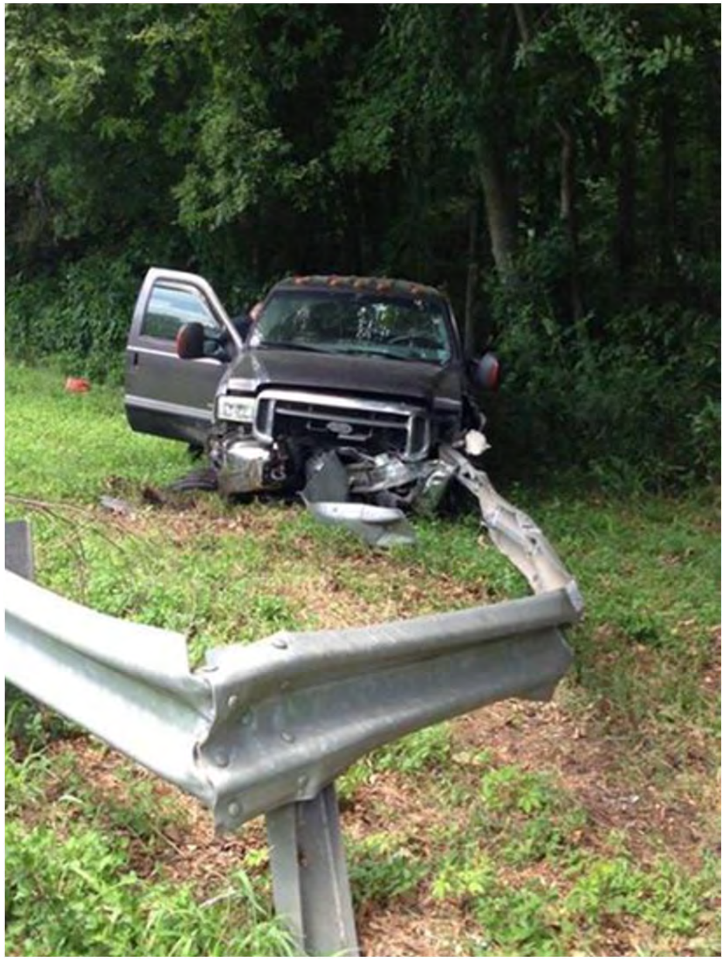
- Performance characteristics (TL-?)
- Tangential or flared
- Gating or non-gating

Redirection vs. gating

- All terminal ends are gating (usually up to 3rd post)
- Only some crash cushions are fully redirective
- Non-redirective includes trailing terminals (gating) and curved rail treatments (capture)

Gating

- Vehicle passes through barrier
- No redirection
- Little to no energy absorption
- Note the requirement for a gating clear area with gating terminals



Gating and redirection issues?

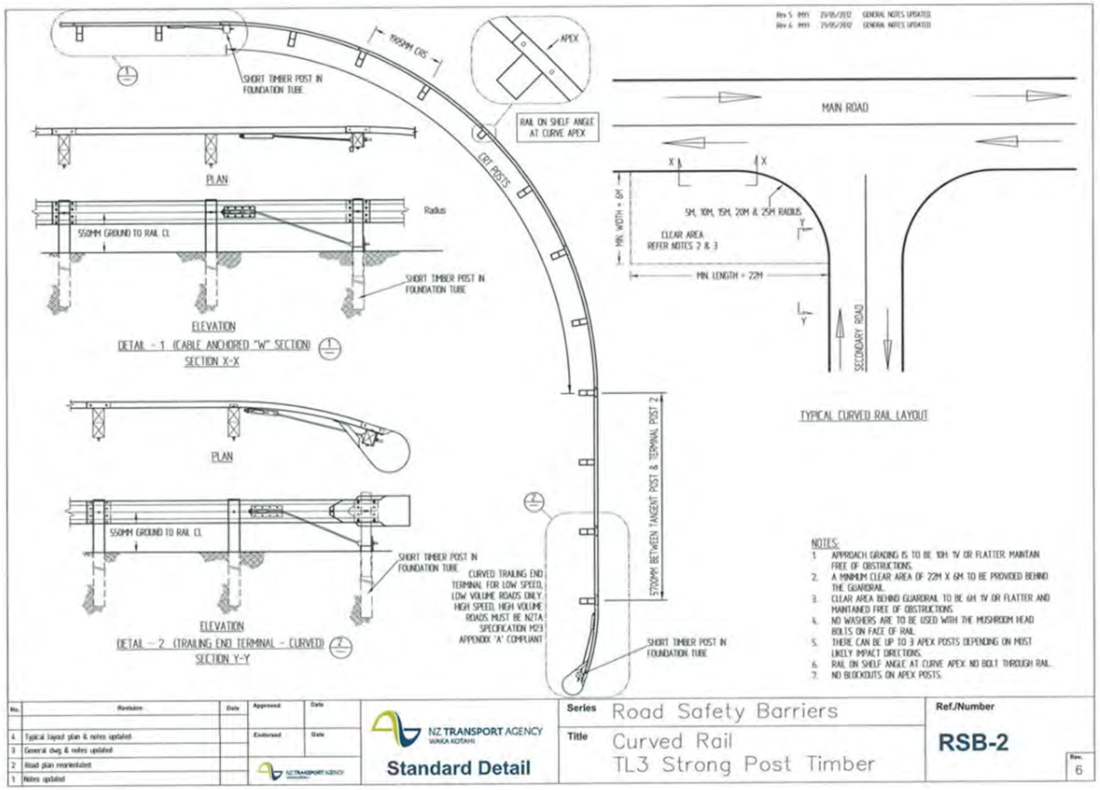
- No gating clear area
- No suitable deflection = pocketing

Roadside grading

When grading plan cannot be achieved (eg topography, right of way):

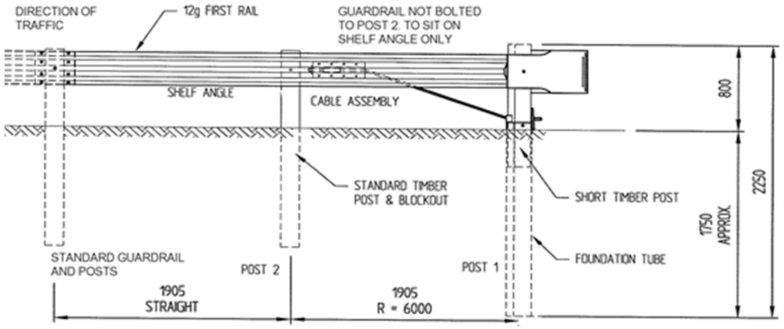
- Select another terminal
- Extend barrier length
- Seek departure acceptance

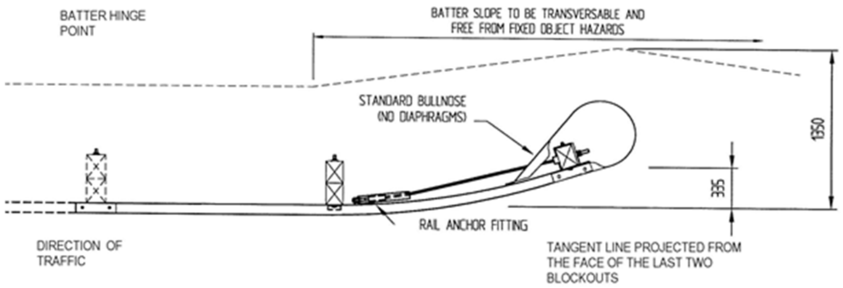
Curved Rail Treatment



Ensure intermediate anchors and apex posts are present and correct

Trailing end terminal





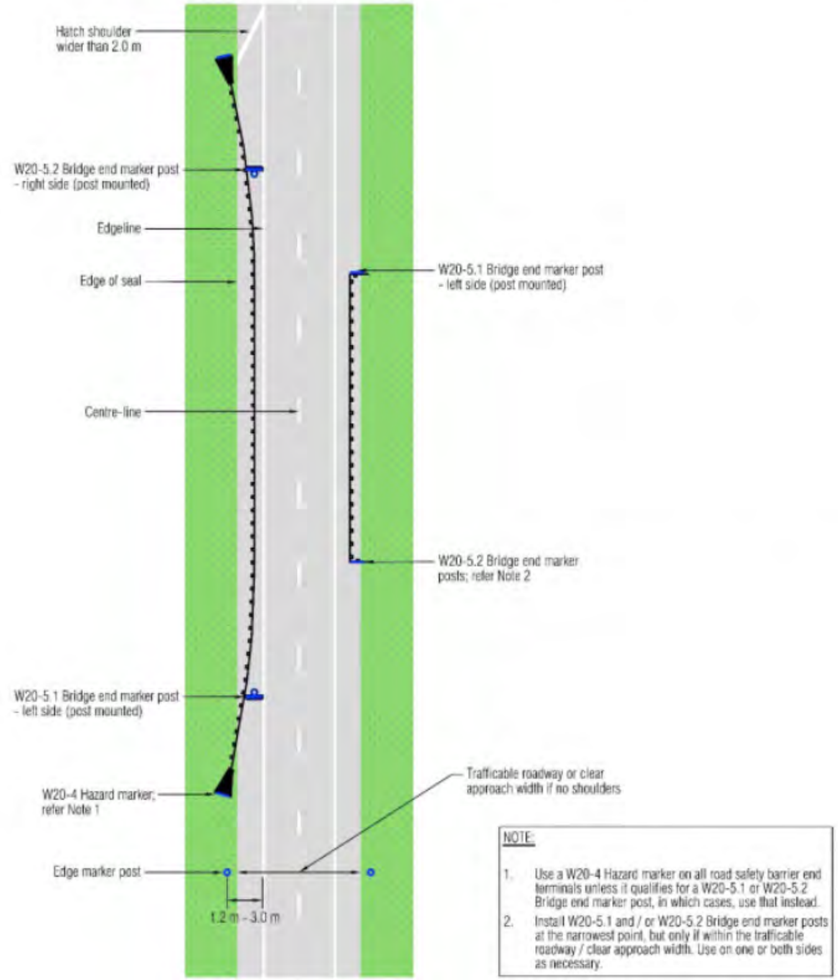
Trailing end terminal

- Must only be installed where it cannot be struck end-on by a vehicle, ie on a one-way road, or facing away from traffic stream.
- Anchor correctly attached and taut
- Soil tube and ground strut correct height (not > 100 mm)
- Bearing plate at base of first post orientated correctly and does not rotate
- Second post generally not bolted to rail

Delineation

TCD Manual

Figure 6-12: Hazard markers installation of signs and markings



Delineation

- Preference for road delineation (EMPs) to be in front of the guardrail and parallel to the edge of the road
- Can be attached to guardrail if:
    - Does not interfere with barrier operation
    - Alignment provides good indication of road alignment

Delineation?

Correct – width marker at narrowest point

Incorrect – width marker not at narrowest point

Potentially incorrect – no hazard marker (unless it genuinely isn't required)

Incorrect – width marker not at narrowest point