A BRIEF INTRODUCTION TO SAFETY BARRIERS

This session introduces:
- The three groups of safety barriers
- Some of the different types of barrier in each group
- End treatments
- Criteria for the selection of safety barrier
- Some common safety considerations for barriers

SAFETY BARRIERS

A safety barrier may be defined as "a physical barrier installed alongside a road in order to contain errant vehicles, to shield them from striking fixed objects or from rolling over undrivable slopes, to redirect them along the road and to thus minimise injury to the vehicle occupants". Safety barriers - despite their name - can themselves constitute a hazard. All reasonable steps should be taken to eliminate the need for safety barriers through the use of good design and construction practice. But, not all safety barriers can be eliminated. It is important that they be used only where appropriate and that their installation be undertaken correctly.

Safety barriers are entirely dependent upon their ability to reduce crash severity, since of necessity they are closer to the broad and longer than the hazard they guard. Thus, it is conceivable that they will have a higher crash rate than the given hazard. There are some situations where safety barrier may help to prevent crashes because of their assistance with delineation of the road.

Warrants for safety barriers

Safety barriers are costly to install and maintain. They also represent a hazard to errant vehicles. During design therefore every effort should be made to eliminate the need for roadside barriers. Their use and installation should always be reviewed critically and carried out according to manufacturer instructions.

The primary purpose of a longitudinal barrier is to protect motorists from a collision with a fixed roadside object that is likely to be more severe than a collision with the barrier itself. While roadside barriers may occasionally be used to protect pedestrians or other bystanders (e.g. road workers) from vehicular traffic, it is important that this be considered only as a last resort and generally in low speed environments. In these cases the primary purpose of the barrier is to act as an impenetrable shield, not necessarily a system that will smoothly redirect errant vehicles.

Barriers should not be installed only because vehicles are running off the road, or have the potential to run off the road. If the resulting damage and injuries without a barrier are minor, one needs to ask whether a barrier will improve – or worsen – the crash situation.

Similarly the decision to shield fixed roadside objects is one that must take into account the nature of the object itself and the likelihood that it will be hit. Given that the recommended clear zone width is set to take into account the probability of a collision, consideration should be given to shielding any fixed object within the clear zone, provided the severity of collision with the barrier is less severe than a collision with the hazard.
However, a decision to install a roadside barrier must also take account of the increased likelihood of a collision through the installation of barrier (maybe 25m minimum length required for correct performance) to protect a hazard (perhaps one metre wide).

Safety barriers may be warranted:

- On embankments where the slope is greater than 1 in 6, and the vertical height difference exceeds one metre.
- To shield a roadside hazard – defined as an object greater than 100mm in diameter, and within the agreed clear zone (typically within 9 metres of the edge of the nearest lane on a highway with volumes exceeding 5000 vpd and operating speeds of 100km/h).
- On narrow medians, with vehicle volumes exceeding 5,000 vpd.
- Where the road formation narrows – typically at bridges.
- On the outside of substandard curves.
- To shield structures (and occasionally pedestrians).

Safety barriers are placed generally parallel to traffic flow. They function by capturing and redirecting errant vehicles away from potential hazards. They are classified by their rigidity into three groups:

- Flexible barriers e.g. wire rope barriers
- Semi-rigid barriers e.g. steel W-beam guard fence
- Rigid barriers e.g. concrete median barrier or bridge railings.

Also sometimes included as a group of safety barriers are impact attenuators (or crash cushions). These safety devices are worthy of a separate session on their own, and will be dealt with elsewhere in the workshop.

Flexible barriers

Flexible wire rope safety barrier (WRSB) systems are now widely used in many countries around the world. These barriers consist of a number (generally three or four) of wire ropes (cables) held in place by steel posts at spacings in the order of 2.4m. The ropes deflect when struck by an errant vehicle, guiding the vehicle along the barrier while the posts progressive collapse. The posts absorb the kinetic energy of the vehicle, slowing it down.

Where adequate deflection width is available, wire rope safety barrier systems provide a much more forgiving roadside barriers than the more rigid systems. Advice should be sought from the manufacturer when it is proposed for use.

Deflections of WRSB depend on the post spacing, the size and speed of the impacting vehicle, and the angle of impact. For 4-wire Bريفן, deflections are generally in the order of 1.2 metres for posts at 2.4 metre centres and a 60km/h impact speed. This can go up to deflections of 1.7 metres for a 110km/h impact speed.

Reducing the post spacing to 1.0 metre reduces these deflections to about 0.9 metres and 1.4 metres respectively. For 4-wire Flexfence, with post spacings of 2.5 metres the deflections can be 0.9 metres at 60km/h and 1.4 metres at 110 km/h.

In all cases, check with the manufacturer for the maximum deflections likely due to impacts at the maximum anticipated speed along the road in question.

If placed on a median, the width of the median should be at least twice that of the maximum deflection, with additional width provided if the barrier is installed on a horizontal curve.
It is undesirable to have kerb and channel in front of WRSB, especially where vehicle operating speeds will exceed 80km/h. If this cannot be achieved, the manufacturer’s instructions should be followed – in which case WRSB has the potential to perform better than the rigid or semi rigid barriers.

The Brifen fence is a proprietary WRSB system that has four wire ropes supported on galvanised steel S section posts. The upper 2 ropes are located in shallow slots at the top of the posts, while the lower two ropes are interwoven on either side of the posts about 95 mm lower.

Each rope is made up of 21 strands of high tensile carbon steel, each having a breaking strain in excess of one tonne. Once installed, the cables are tensioned individually to 22.24kN by tightening the turnbuckles at each end.

Each S section post is located in a concrete-encased ground socket. The posts are designed to progressively collapse on impact – on average 8-10 posts are destroyed in a typical car/WRSB impact. (Some 300 posts were destroyed in one impact when a B-double truck drove into a centre-of-road WRSB and was contained on the correct side of the road for a length of more than 500metres!)

A post that is damaged can be readily removed from its socket and replaced with a new post. Rapid reinstatement of damaged wire rope safety barriers is one of the positive features of this type of barrier. A mowing strip is often placed under the barrier in order to minimise or eliminate weed growth and to reduce mowing problems.

When struck by an errant vehicle, the kinetic energy is absorbed by the wire ropes and posts. The posts collapse and the tensioned cables contain the vehicle, gradually deflecting the vehicle back towards its correct path along the road and allowing the vehicle to be brought to a controlled stop. WRSB is able to contain errant vehicles and to bring them to a halt with lower occupant deceleration than either semi-rigid or rigid barrier systems. Injuries to the occupants of the vehicles therefore tend to be less severe.
FOUR STRAND FLEXFENCE WIRE ROPE SAFETY BARRIER

Flexfence is another propriety WRSB system. Its four rope system is approved for use in Victoria (and numerous other states/nations). The four cables are in a vertical line, supported in a vertical slot in the top of the post, and spaced equally apart at 80 mm centres. Tensioning of the fence is carried out with a hydraulic device once the cables are in place. The posts are installed in plastic sleeves set in 350mm diameter concrete footing. The operation of the Flexfence is similar to that of Brifen. When struck by an errant vehicle, the kinetic energy is absorbed by the wire ropes and posts. The posts collapse and the tensioned cables contain the vehicle, gradually deflecting the vehicle back towards its correct path along the road and allowing the vehicle to be brought to a controlled stop.

Semi-rigid (steel W-beam guard fence) barriers

This type of barrier is the most widely used type in the world. It is a W section galvanised steel barrier set on spacing blocks that are set on steel or hardwood posts. These barriers work through restraining and redirecting errant vehicles through a combination of beam bending and tensioning. Lateral restraint is provided by the posts. As with all safety barriers the guard fence is required to serve dual and conflicting roles. It must be capable of redirecting and/or containing an errant vehicle while, at the same time, not imposing intolerable deceleration forces on the vehicle occupants.

Blocked out W-beam guard fence is made up of several components each with an important part to play in the successful operation of the guard fence during a collision. These components are:
- The W-beam rail - this steel rail must be strong enough to withstand the high axial tensile stresses, as well as bending stresses, that develop as the kinetic energy of the vehicle is dissipated through distortion and crushing of the vehicle, the rail and the soil. Individual rail sections must also be securely connected to the next length, and overlapped away from the direction of the oncoming traffic to avoid snagging.

- The posts (timber or steel) - provide rigidity to the whole system and to hold the W-beam rail at the correct height both before and during a collision. It is vitally important that the posts are spaced correctly and are the correct length, not only above ground level, but below it as well.

- The blocks - prevent snagging on the posts and help to avoid vehicle rollover by providing restraining forces above the centre of gravity of the vehicle.

- The anchorages - are essential for the W-beam to develop its full tensile strength by providing a restraining force at either end. An anchorage commonly used in Australia is an adaptation of the original Breakaway Cable Terminal (BCT) developed in the USA.

- The terminals - the BCT used in Victoria incorporates slotted W-beam rails that crumple if the barrier is stuck end-on, reducing the possibility of the rails spearing a vehicle.

The W–beam uses posts at (usually) 2.5metre centres, 178mm deep blockouts, and a rail mounting height of 686 mm to the top of the rail. Earlier forms of W-section barrier had heavier gauge steel at greater centres, (up to 3.8 metre spacings). This was found to have the potential to cause pocketing and thus more severe impact for the occupants. Pocketing is when an errant vehicle deflects the barrier, but then hits a rigid object as it does and is “pocketed” in a bend in the deformed barrier. This is a severe problem at places such as bridge end posts, where incorrectly installed W- section barrier can lead an errant vehicle into (rather then protect from) the end post.

Satisfactory barrier performance is dependent on the proper mounting height of the beam, a generally flat, smooth approach slope. Semi-rigid barriers should not be installed on slopes exceeding 10:1, its height must be carefully considered and retained throughout its life, and its placement with respect to kerb and channel require special consideration. In short, it should not be used behind kerb and channel where vehicle speeds are likely to cause vaulting. It may be used with the barrier face flush with or in front of the kerb face, or alternatively at least 3 metres
behind the kerb. This is to minimise the risk of the errant vehicle tripping on the kerb and vaulting the barrier. With semi-mountable kerb, the face of the guardrail should be either less than 1 metre or more than 3 m. behind the kerb. There are no restrictions with fully mountable kerbs.

During impact, the steel beam bears against the vehicle front bumper. Lateral resistance is developed in the beam, which in turn is restrained by the end anchors. As it deflects laterally, it stretches and large tensile forces develop in the beam and help to redirect the vehicle. The posts develop bending resistance as they bend and these impart additional redirective force on the vehicle.

Critical during the impact is the role of the block outs. The block outs (spacers) are placed between the barrier and the post. They are designed to prevent wheel contact on the posts during impact, and they assist in maintaining the proper height of the barrier at this critical time. This helps to prevent the errant vehicle from vaulting over the barrier.

Another type of semi-rigid safety barrier is the Tric-Bloc concrete barrier. This is a freestanding concrete barrier made of 2-metre long sections that are connected by steel pins. Although it is a concrete barrier, it is considered a semi-rigid barrier as it does deflect when struck because it is not permanently anchored. The deflection caused by a car under most impacts is negligible. It is well suited for use at roadwork sites as it can be readily relocated and the units can be quickly and securely connected. Because it stands on small concrete footings, water is able to pass beneath the barrier, avoiding possible ponding problems.

Each 2-metre section has a trapezoidal plan section that facilitates ready connecting to create curved lengths with a radius of approximately 75 metres.

**TRIC-BLOC CONCRETE BARRIER IS AN EXAMPLE OF A SEMI RIGID BARRIER**

**Rigid Barriers**

Concrete barriers that are placed in situ or are keyed into the road pavement and joined to create a solid wall are in the category of safety barriers known as “rigid”. Rigid barriers are not designed to yield under impact from an errant vehicle. They are primarily used at locations where little or no movement of the barrier can be tolerated. (for example as median barriers on divided high-speed arterials or on bridges). Some temporary concrete barriers are used at construction sites and these may deflect by a small amount because they are unrestrained at their base.
Concrete barriers were developed in the United States of America in the 1960’s for use on narrow medians. They developed and evolved into several profiles – each one having a vertical base section, a flatter lower section and then a taller and steeper upper section. The 75 mm vertical base of the barriers plays no role in the safety of the barriers, but allows for future re-sheeting of the road with an overlay.

The more widely used concrete rigid barriers now include the Vertical face barrier, the Constant (single) slope barrier, the New Jersey barrier, and the F shape barrier. Diagrams of the cross sections for these four barriers are shown below.

The last two profiles are the most widely used rigid barriers. They are particularly preferred on urban freeways where the clearance to the through lane may be restricted, where median widths are narrow, and where vehicle volumes are generally high throughout the whole 24 hour period. An errant vehicle that strikes such barriers – if it strikes at a sufficiently low angle (about 20 degrees) will tend to ride up the lower slope and then the almost vertical face of the barrier. The lifting of the vehicle and the deformation of the vehicle suspension absorb vehicle energy, slowing it down and tending to redirect it.

Studies have indicated that the lower safety profile of the F shape barrier is less likely to cause small vehicles to overturn than is the New Jersey profile. The F shape profile has therefore gained acceptance as the standard rigid barrier for use on Victorian roads.

The vertical face barrier and the constant slope barrier were developed in order to further reduce the potential for small vehicle to be overturned during an impact. They do provide some improvement in this regard, but they also generate higher impact severities and are thus not so widely used.
SINGLE (CONSTANT) SLOPE BARRIER

NEW JERSEY BARRIER
The right hand diagram shows a typical barrier used on a median with two carriageways at different levels. The barrier is designed to take up the difference in levels while providing safety during an impact.

Experience has shown that the 810mm height of the rigid barriers is sufficient to contain passenger cars travelling at up to 100km/h. It has also redirected intercity buses travelling at 85km/h and impacting at 16 degrees. These barriers have an excellent record containing all sorts of vehicles, but cannot and should not be relied upon to contain all vehicles at all times.

The containment of trucks and buses in particular is generally untested against, or does not meet, most standards. These barriers are therefore not designed to prevent truck rollovers. Other specially designed structural (generally higher) barriers have successfully restrained trucks. Specialised advice is needed for these barriers.

AASHTO (1989) provides warrants for the use of rigid median barriers on high-speed, controlled access roads with relatively flat medians. The optional areas should allow consideration of actual crash histories to be taken into account.

While concrete barriers can be very effective, care is required to ensure that the ends of the barriers are correctly protected. There have been many recorded incidents of vehicles striking the unprotected end of barriers, often resulting in fatalities. Common ways to end a rigid barrier include curving the barrier through a radius of 40m or thereabouts so that the end is positioned outside the clear zone, or fitting a crash attenuator.

While the development of concrete barriers has led to a fairly detailed understanding of the shape requirements to satisfactorily dissipate the energies involved in a collision, it must be remembered that most concrete barriers are very rigid systems that do not deform in any way. Therefore in all but very shallow angle collisions they may represent a more significant hazard to errant vehicles than semi-rigid or flexible systems.
The greater the offset to such a rigid barrier the greater is the probability of high angle impacts resulting in severe crashes. Standard designs for longitudinal barriers are available from most road authorities.

**SELECTION OF SAFETY BARRIERS**

The selection of a safety barrier system should take into account the following factors:

- **Restraint requirements** – determine the level of restraint that the barrier is to provide. Determine the traffic volume and vehicle mix, the critical site features and the consequences of vehicle penetration. Where there are high numbers of commercial vehicles, and catastrophic outcomes can be foreseen, the use of a barrier system with a higher performance level may be warranted.

- **Deflection** – sufficient clearance must be provided between the barrier and the hazard to allow for the dynamic deflection of the barrier during impact. Indicative deflections during high speed impacts by cars are:
  
  - rigid: 0.1m
  - Semi-rigid: 1.0m with 2.5 m spacings
  - Flexible: 2.0m for 2.5 m spacings, 1.2 m for 1.0m spacings

- **Site conditions** – vertical and horizontal alignments may be an issue for WRSB. Rigid systems need good horizontal alignment in order to minimise the risk of high angle impacts. Offsets should be as great as practical from the edge of the trafficked lane – to allow the driver to regain control of the vehicle and to permit safe parking for broken down vehicles. Rigid barriers are generally located 1-3 metres from the lane, but not more than 4 metres. The area in front of these barriers should ideally be paved – another reason for keeping the distance short. Shielding of embankments usually requires minimum 500mm spacing between the barrier and the edge of the embankment in order to obtain suitable post strength. Barriers should be installed outside the “shy line” (the point at which drivers tend to move away from an obstacle alongside the road) – generally this is about 1 m at 50km/h and about 3 m at 110km/h. Cross slopes need to be considered. Semi-rigid barriers require a maximum slope of 10:1, and WRSB a maximum slope of 6:1. Kerb and channel is a key safety factor – this is covered later in this session.

- **Safety performance** – WRSB generally provide lesser deceleration forces on the occupants of the errant vehicle and hence offer greater safety. Other factors to consider are structural adequacy, and post impact trajectory.

- **Continuity and consistency** – avoid short lengths of barrier, and wherever possible continue through with the one barrier type.

- **End treatments** – WRSB terminals generally offer few safety concerns. The ends of W-beam guardrail may penetrate a vehicle and cause major injuries to the occupants. The blunt ends of a concrete barrier may generate massive deceleration forces that exceed human tolerances.

- **Maintenance** – includes the routine maintenance of the barrier itself, the repair of the barrier after an impact, and the effect of the barrier on routine maintenance of the adjacent road.
- **Sight distance** – maximising the distance from the trafficked lane to the barrier improves sight distance at intersections and on horizontal curves.

- **Aesthetics** – WRSB are generally regarded as the most attractive group of barriers. They also minimise the gathering of sand or snow in such environments.

- **Whole of Life costs** – the cost of a barrier usually depends on the length proposed. WRSB has decreased in price in recent years and appears to be competitive with W-beam guardrail. Rigid barriers are the most expensive to install, but have the lowest maintenance costs.

### USE OF KERB ADJACENT TO SAFETY BARRIER

Kerb and channel should not be used on high-speed roads such as freeways and rural highways. Semi-mountable kerbs may be used along these roads where needed, with attention to drainage needs. The following table gives the criteria for the placement of safety barrier near kerb and channel or semi-mountable kerb. The use of kerbing near safety barriers should always be closely reviewed.

<table>
<thead>
<tr>
<th>KERB TYPE OR SHOULDER</th>
<th>CLEARANCE TO GUARD FENCE (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BARRIER KERB</strong></td>
<td>Not to be used on high speed roads. Guardrail should be either in front of the kerb or at least 3 metres behind the kerb. These offsets remain as desirable standards on intermediate speed roads, although the kerbing could (if necessary) be located behind the guard fence.</td>
</tr>
<tr>
<td><strong>SEMI-MOUNTABLE KERB</strong></td>
<td>Guardrail either 0 or up to 1 metre behind the kerb or at least 3 metres behind the kerb.</td>
</tr>
<tr>
<td><strong>MOUNTABLE KERB</strong></td>
<td>No restrictions.</td>
</tr>
<tr>
<td><strong>SHOULDER</strong></td>
<td>1. <strong>SHOULDER WIDTH \geq 3 \text{ m}:</strong> Guardrail generally 0 metres to 1 metre behind shoulder.</td>
</tr>
<tr>
<td></td>
<td>2. <strong>SHOULDER WIDTH \geq 2.5 \text{ m}:</strong> Guardrail should be 500mm to 1 metre behind shoulder.</td>
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**Notes**
1. Guardrail clearances in the table are appropriate for use where vehicle speeds are sufficient to cause vaulting. In low speed areas such as car parks, there are no restrictions on the location of kerbs and guard fence, and B type kerbs can be located 0.3 metres to 0.5 metres from the face of the rail to minimise the likelihood of panel damage with low speed impacts.

2. All clearances measured to back of kerb.
END TREATMENTS

A barrier end treatment functions by:

- Decelerating the vehicle to a stop within a short distance, or
- Permitting controlled penetration of the vehicle behind the device, or
- Containing and redirecting the vehicle, or
- A combination of the above

Provision of a crashworthy end treatment is mandatory where the safety barrier terminates within the clear zone or where it is likely to be hit end on by an errant vehicle. There are two basic types of end treatments:

- Gating systems – these are designed to breakaway during impact, and to allow the errant vehicle to pass safely behind the barrier. These require a driveable runout area behind the barrier of 20 metres long by 6 metres wide for 100km/h impact speeds. There should be absolutely no fixed objects within the run-out area, and the slope must be driveable - otherwise the gating system will create a hazard.

- Non-gating systems – these are designed to safely decelerate an errant vehicle that impacts on the nose without permitting it to pass behind the barrier. For impacts beyond the nose, the vehicle is contained and redirected. These systems do not need a run-out area.

SAFETY CONSIDERATIONS OF SAFETY BARRIERS

Safety considerations may be grouped under the headings of length, height, width and end treatment. The length of a barrier is a critical design feature – too short and the errant vehicle may pass behind the barrier and strike the object, too long and money can be wasted.

The height of the safety barrier is critical – too high and the errant vehicle can experience barrier intrusion, too low and the vehicle may vault over the barrier.

The width (or offset) of the barrier from the road is also critical. Too close to the road leads to increased “innocent” impact with the barrier, too far away (and thus closer to the object) means less opportunity for deflection before the vehicle hits the object. The further away from the road, the greater the chance of a high angle impact also – these are generally more severe to the occupants of the errant vehicle.

When undertaking a road safety audit, or a crash investigation, ask the following questions, and more.

- Is the safety barrier necessary?
- Is the safety barrier an acceptable type, and the right type for the site? (Wooden rails, old cables, and lightweight pedestrian fencing are not acceptable safety barriers)
- Can the anticipated deflection of the barrier by the vehicle occur with safety? (Is the available width adequate to prevent pocketing?)
- Will the barrier redirect the vehicle? (What is the possibility of penetrating the barrier or snagging on the barrier?)
- Is the end treatment satisfactory from a safety perspective? (Ramped ends, fish tail ends, incorrectly installed Breakaway Cable Terminals and blunt end rigid barriers are unsafe)
- Will the safety barrier be able to be readily repaired after it is struck and damaged? (The safety of maintenance workers should be a major consideration in road safety engineering)
Safety considerations for flexible barriers

**Length**
- Is the barrier needed?
- Does the WRSB meet the length of need?
- Does it fully cover the object it is intended to shield?

**Height**
- Is the WRSB installed where the approach slope from the pavement is essentially flat, up to a maximum slope of 6:1?
- Is the WRSB installed at the approved height?
- Is there any kerb between the WRSB and the road? Could it cause vaulting?

**Width (offset)**
- Is there sufficient space between the WRSB and the object to take up all the likely deflection of the barrier during an impact by a vehicle travelling at the speeds typical on that road? (Otherwise, the errant vehicle will strike the object!)
- Is the WRSB outside the minimum side clearance from the nearest lane?

**End treatments**
- Is the end treatment an approved type?

Safety considerations for semi-rigid barriers

**Length**
- Is the barrier needed?
- Does the barrier meet the length of need?
- Does it fully "cover" the object it is intended to shield?
- Are the steel sections overlapped in the correct direction? (away from traffic).
- Are posts spaced correctly? (usually 2.5 metre centres)

**Height**
- Is the barrier installed where the approach slope from the pavement is essentially flat, up to a maximum slope of 10:1?
- Is the barrier installed at the approved height?
- Is there any kerb between the barrier and the road? If so, will it cause vaulting?

**Width (offset)**
- Is there sufficient space between the barrier and the object to take up all the likely deflection of the barrier during an impact by a vehicle travelling at the speeds typical on that road? (Otherwise, the errant vehicle will still strike the object!)
- Does the barrier cause a sight restriction problem?
- Have the posts been stiffened (at shorter centres) at any connections to rigid barriers?
- Is the barrier outside the minimum side clearance from the nearest lane?

**End treatments**
- Is the end treatment an approved type?
- With BCT’s, is there a clear run-out area behind the terminal.

Safety considerations for rigid barriers

**Length**
- Is the barrier needed?
- Does the barrier meet the length of need?
- Does it fully "cover" the object it is intended to shield?

**Height**
- Is the barrier installed where the approach slope of the paved area is essentially flat, up to a maximum slope of 10:1?
Is the barrier at the approved height?
Is there any kerb between the barrier and the road? If so, will it create a vaulting problem?

**Width (offset)**
Is the barrier outside the minimum side clearance from the nearest lane?
Does the barrier cause a sight restriction problem?

**End treatments**
Is the end treatment an approved type?