CRASH TEST OUTCOMES FOR THREE GENERIC BARRIER TYPES

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ABSTRACT

In 2009, NSW Roads and Maritime Services (then the NSW Roads and Traffic Authority) conducted a number of full-scale crash tests. The tests involved three barrier types; namely rigid, semi-rigid and flexible barriers. The tests utilised four vehicle types; namely a small passenger vehicle, medium size passenger vehicle, a large 4-wheel drive and a rigid truck. The barriers chosen are considered to be representative of barrier types in use in Australia and the vehicles representative of those in use below 8 tonne gross mass. For most of the tests, three instrumented dummies were utilised in the vehicle. These tests provide information about the relative performance of different barrier types and this information will influence when and where different barriers types are used on the road system. Aspects of the performance include capacity, deflection, energy absorption and impact severity (Head Impact Criterion (HIC)).

BACKGROUND

In 2009, NSW Roads and Maritime Services (RMS), then the NSW Roads and Traffic Authority conducted a number of full-scale tests on three barrier types; namely rigid, semi-rigid and flexible barriers. Whilst the barriers chosen are considered to be representative of similar barriers in regard to method of operation, it is not expected that other barriers in the same class will perform in exactly the same manner.

These tests do not represent acceptance tests for the products, although information gained from these tests may influence future product acceptance requirements.

These tests do provide information about the relative performance of different barrier types and this information will influence when and where different barrier types are used on the road system.

DESIGN CONSIDERATIONS

When designing a road and choosing a barrier type (ultimately leading to a single product selection), the following choices need to be made:

1. barrier capacity
2. barrier deflection
3. suitability for high centre of gravity vehicles, which can be caused to roll excessively
4. expected occupant outcomes.

1 Design is iterative and whilst these are stated in a general order, the emphasis may change with route or specific project.
These will each be explored in this examination of crash test outcomes for three generic barrier types.

**TEST CONDITIONS**

**Barriers**

The rigid barrier was an 810 mm high double sided F type barrier that is typical of concrete barriers used in NSW and throughout Australia. It was installed generally in accordance with the RMS requirements (RTA 1997) with the following exceptions:

- average height was 810 mm (820 mm required)
- average width at the base was 640 mm (600 mm required).

The embedment was between 260 mm and 290 mm in depth with an embedment width of approximately 500 mm beginning at the front face. The excavation had been intended to accommodate a single sided F Type barrier.

The semi-rigid barrier is a W-Beam barrier that was mounted on posts at 2.0 m centres. The top of the rail was 730 mm high and the rail conformed to AS/NZS3845:1999 (Standards Australia 1999). The posts were 1800 mm long and had a cross section that conforms with the C-post section in Figure F16 of AS/NZS 3845: 1999. The nominal top of rail height for an RMS installation (RTA 1999, 2007) is 706 mm+/- 20 mm and the target height was the top of the tolerance range i.e. 726 mm rounded upwards to 730 mm.

The wire rope was a modified installation of a proprietary product. Standard aspects of the installation include posts 1230 mm long at 2.5 m centres and ropes at 480 mm, 560 mm, 640 mm and 720 mm. The wire rope installation was 113.4 m from anchor to anchor. The only modification involved rope tensions set at 20 kN, rather than the specified 15 kN for this particular proprietary product. This decision recognises that proprietary wire rope systems are tested with nominal tensions varying between 15 kN and 25 kN.

**Soil**

The soil foundation material was the same for all tests. It is a disturbed material generally conforming to the RMS requirements for verge material. The test area was sealed except where damaged W-beam posts were replaced for each test.

**Vehicles**

Four different vehicles were used in the testing namely:

- a small car (Daihatsu Charade) with a mass of approximately 1100 kg including the dummies, (denoted as 1100C)
- an intermediate car (Holden Commodore) with a test mass of approximately 1850 kg including the dummies, (denoted as 1850C)
- a larger passenger car (Toyota Landcruiser\(^2\)) with a test mass of approximately 2500 kg including the dummies, (denoted as 2500P)
- a single unit truck (Mitsubishi) that was loaded to a gross static mass of 8000 kg (denoted as 8000T).

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\(^2\) Six cylinder with rigid front axle.
The vehicle and barrier were oriented such that the driver’s side of the vehicle impacted the barrier. The tests were run with the windows closed. It is considered that this would give the worst case outcome for the driver (see also the discussion on anthropomorphic test devices below). Occupant outcomes are discussed later in the paper.

**Speed and angle**

The target impact angles in all tests were 20° and the target impact speeds were 100 km/h for the 1100C, 1850C and the 2500P vehicles. The target impact speed for the truck was 80 km/h. The angle of 20° is modified from the range of values specified under the National Co-Operative Highway Research Programme No 350 (NCHRP 350) (Ross et al. 1993) for different mass vehicles. It is a compromise to allow the use of a single test installation. These tests were conducted not to comply with a standard but with the aim of providing a comparison between generic barrier types.

**Anthropomorphic test devices**

Each vehicle (other than the 8000T) was fitted with three anthropomorphic test devices (ATDs). One instrumented EuroSID ATD was positioned in the driver’s seat, one Hybrid III ATD in the front passenger seat and one Hybrid III ATD in the rear driver’s side seat. All ATD’s wore seat belts.

The decision to use the EuroSid was based primarily on the impact angle of 20 degrees and a desire to examine the lateral impact effects including any ATD with barrier interaction. The rear passenger was also placed on the driver’s side to examine any ATD with barrier interaction and to exacerbate any roll with the Type F profile for the small vehicle.

These contributed a total of 242 kg to the gross static mass of each vehicle.

**CAPACITY**

The barriers exhibited a range of outcomes and this might be expected.

The rigid concrete barrier was the only one to successfully contain and redirect the 8000T. It also contained and redirected the 1100C and the 1850C. Whilst it contained the 2500P, the redirection resulted in the vehicle rolling. The vehicle performances indicated that these test outcomes would be repeatable.

The W-Beam contained and redirected the 1100C and the 1850C. The vehicles performed in a stable manner. It did not contain the 8000T. It is considered that these test outcomes would be repeatable. Whilst the W-Beam contained the 2500P to the traffic side of the barrier, the vehicle rolled several times after leaving the barrier.
Figure 1: 2500P front wheel pinched

The wire rope contained and redirected the 1100C and the 1850C. The vehicles performed in a stable manner. It did not contain the 8000T. It is considered that these test outcomes would be repeatable. Whilst it also contained and redirected the 2500P, the wire rope pinched the front wheel stopping its rotation, causing the vehicle to pitch and yaw. This is shown in Figure 1. The test was not repeated and therefore the predictability of the outcome is not known.

DEFLECTION

The deflections are given in Table 1.

Deflections are a product of the flexibility of the system. The F type is very stiff and essentially does not deflect. The W beam barrier has a deflection depending on the post spacing and to a lesser extent how the vehicle interacts with the barrier. For wire rope barriers, the deflection is significantly affected by how many ropes effectively engage with the vehicle. (This has significant consequences in design.)

Table 1: Barrier deflections (m)

<table>
<thead>
<tr>
<th></th>
<th>Wire rope</th>
<th>W-Beam</th>
<th>Rigid type F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1100C</td>
<td>1.0</td>
<td>0.45</td>
<td>0.0</td>
</tr>
<tr>
<td>1850C</td>
<td>1.9</td>
<td>0.7</td>
<td>0.0</td>
</tr>
<tr>
<td>2500P</td>
<td>2.0</td>
<td>0.8</td>
<td>0.0</td>
</tr>
<tr>
<td>8000T</td>
<td>NA</td>
<td>NA</td>
<td>0.0</td>
</tr>
</tbody>
</table>

The deflections for the same vehicle type and mass for wire rope and W-Beam are graphed in Figure 2. The deflections for wire rope (flexible) are more than double those for W-Beam (semi rigid). For the rigid barrier the deflections are zero.
The deflections for wire rope show a distinctly non-linear relationship with lateral impact energy or impact severity. This will be discussed further in Energy Absorption, Overall Interaction.

HIGH CENTRE OF GRAVITY (ROLLOVER)

Mengent et al. (1989) developed an equation to predict the propensity for a vehicle to rollover. Using this relationship, the probability for a rollover was 21 per cent for the 2270P vehicle recommended for testing under the Manual for Assessing Safety Hardware (MASH) (AASHTO 2009), compared with 37 per cent for the Toyota Landcruisers used in these comparison tests. In other words, Toyota Landcruisers have a greater propensity to rollover. This is demonstrated by testing undertaken for National Co-Operative Highway Research Project (NCHRP) 22(14) on an 810 mm high New Jersey barrier with a 2007 Chevrolet Silverado under MASH TL3 test conditions (2270 kg vehicle, 100 km/h and 25°). In this test, the MASH 2270P vehicle was redirected without rolling over (Transportation Research Board 2010).

It is concluded that the adverse reactions with the concrete type F barrier with the 2500P vehicle are more likely to be a consequence of the vehicle’s characteristics rather than those of the barrier and that this may also have influenced the outcome with the W-Beam.

ENERGY ABSORPTION

In a crash test, the outcome can be affected by the performance of each of:

- the barrier
- the soil in which it is founded
- the vehicle
- the way in which the three interact.

Energy absorption during the test may occur in all the above and this is explored below.
Barrier damage

There was no structural damage to the rigid concrete barrier with any of the impacts. The barrier sustained cosmetic damage after the 8000T impact. This is illustrated in Figure 3.

![Rigid barrier after 8000T impact](image)

**Figure 3: Rigid barrier after 8000T impact**

The W-Beam sustained typical damage, including flattening of the rail, tearing at the splice bolts and bending of the posts, shown in Figure 4. There was no movement of the anchors recorded.

![W-Beam after 2500P impact](image)

**Figure 4: W-Beam after 2500P impact**

The posts of the wire rope bent and the tension in the system (3rd rope from ground) was retained at the installed level (20 kN) for the 1100C, the 1850C and the 2500P impacts. The impact damage for the 2500P is shown in Figure 5. There was no movement of the anchors recorded. After the 8000T impact, the tension was reduced to 15 kN. No movement of the anchors was recorded.
Soil foundation movement

The rigid barrier foundation did not move under any of the impacts.

The W-Beam posts performed in the expected manner, both bending at ground level and failing the adjacent soil. This can be seen in Figure 4 above.

The wire rope post foundations did not move under any of the impacts. This is illustrated in Figure 6 that shows the 8000T impact point.
Vehicle damage

To gauge the degree of vehicle damage, photographic evidence is given in Figure 7 below for the maximum vehicle that was successfully redirected by all barriers i.e. the 1850C.

The test reports describe the level of damage as being:

Rigid Concrete: Occupant Compartment Deformation Index was AS0000000

During the crash test the vehicle sustained damage to the windscreen, right front guard, left front guard, bonnet, bumper bar, right side panels, right side doors, right front suspension, engine sub-frame and the front of the chassis. The right front headlight and driver’s door mirror were dislodged. Note: The vehicle bonnet unlatched and raised upon impact with the barrier and remained raised after the vehicle came to rest.

W-Beam: Occupant Compartment Deformation Index was RF0000000

During the crash test the vehicle sustained damage to the right hand guard, bonnet, front windscreen, right hand side panels and right-hand side doors. The front bumper bar, right front wheel, right front suspension components and right front steering components were dislodged.
**Figure 7: 1850C damage (from top to bottom: rigid, W-beam, wire rope)**

Wire Rope: Occupant Compartment Deformation Index was AS0000000

During the crash test the vehicle sustained damage to the front bumper bar, windscreen, right front guard, right side panels, right side doors and A-pillar. The driver side mirror and right front headlight were dislodged.
Total energy lost

The total energy loss during the tests for which an exit velocity was recorded is given in Figure 8 below. The energy loss is the impact energy minus exit energy expressed as a percentage of impact energy.

![Figure 8: Vehicle energy loss](image)

The rigid system gives the lowest energy loss percentage as well as being the least dependent on lateral impact energy. Energy is lost through friction and vehicle damage.

The W-Beam impacts suffer the largest percentage loss through a combination of friction, barrier damage, soil failure and vehicle damage.

The wire rope impacts suffer energy loss through a combination of friction, barrier damage and vehicle damage.

As with the W-Beam impacts, the energy loss for the wire rope is dependent on lateral impact energy and indeed the relationship for the wire rope is near linear with a small positive intercept on the Y-axis. If the vehicles interact with the ropes in a similar manner and the degree of vehicle damage is similar, then the number of posts failed and the time in contact with the rope should be directly related to the lateral impact energy. This could be restated as the contact length should be a function of lateral energy.

The contact lengths were determined from overhead stills and these are reported in Figure 9.
Figure 9: Contact length initial determinations

Figure 9 suggests that there is something other than a direct relationship and the authors consider that the way in which the vehicles are interacting is having a fundamental impact on both the contact length and the deflection reported earlier in Figure 2.

For the 2500P, all four ropes are fully engaged. The 2500P is shown in Figure 1.

For the 1100C, all four ropes are engaged with the top rope biting into the A-pillar. The 1100C is shown in Figure 10 below.

Figure 10: 1100C interaction

The authors have viewed interactions between the 1850C (Commodore VT) in other crash tests and the interaction with this particular wire rope product is consistent for this vehicle make and model.
Initially, the restraint is provided by the two lower ropes and the top two ropes ride over the bonnet and up the A-pillar until they lodge under the right hand rear view mirror. In this position they provide some restraint until the mirror is torn from the vehicle. Following that, as the rear of the vehicle engages with the barrier, all ropes provide restraint. Figure 11 shows the interaction immediately the rear view mirror is severed. Only the two lower ropes provide full restraint throughout the redirection.

If the deflection and contact length graph is adjusted to reflect the different number of ropes engaged then the results appear to make some sense. These are given in Figure 12. In other words it is the way that the vehicle interacts with the system that determines the deflection (and contact length).
Overall interaction

Energy loss during impact can occur within each of the three elements: barrier damage, foundation/soil interaction and vehicle damage. A summary of the preceding discussion is given in Table 2.

### Table 2: Energy loss

<table>
<thead>
<tr>
<th></th>
<th>Wire rope (2+ ropes)</th>
<th>W-beam</th>
<th>Rigid type F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrier damage</td>
<td>Minimal</td>
<td>Significant</td>
<td>Nil</td>
</tr>
<tr>
<td>Soil movement</td>
<td>Nil</td>
<td>Significant</td>
<td>Nil</td>
</tr>
<tr>
<td>Structural vehicle damage</td>
<td>Minimal</td>
<td>Increased</td>
<td>Significant</td>
</tr>
</tbody>
</table>

Apart from friction losses, in impacts with the rigid barrier, the energy loss is converted to vehicle damage. The process is predictable and depends on the vehicle characteristics.

In impacts with the semi rigid W-beam at lateral energy levels represented by this crash testing, structural damage to the vehicle is reduced by comparison with the rigid barrier and the barrier now absorbs energy. This is achieved through flattening of the rail, bending of the posts and failure of soil at the base of the posts. Given that all three components are now absorbing energy, the interaction is not expected to be linear. The authors expect that different W-beam systems will absorb energy from these three components in different proportions. At lower lateral energies the blockout performs its primary function of keeping the wheel away from the post. Both the energy loss level and the smoothness of the interaction are improved.

In impacts with the wire rope, damage to the vehicle is further reduced by comparison with the W-beam barrier and the barrier absorbs energy. This is achieved through elastic deformation of the ropes and plastic bending of the posts. The interaction of the vehicle type with the barrier is
critical to predicting an outcome. Different vehicles, makes and models may have a significantly different interaction with wire rope barriers. The performance of wire ropes for the total vehicle population is unpredictable.

EXPECTED OCCUPANT OUTCOMES

Impact measures based on the vehicle acceleration

The flail-space model (Ross et al. 1993) uses two measures of occupant risk; the occupant impact velocity (lateral or longitudinal) and the ridedown acceleration. Both are dependant on vehicle centre of gravity accelerations.

For all tests in this comparison, the lateral occupant impact velocities increase with barrier and vehicle stiffness. The tests involving the Toyota Landcruiser (2500P) have higher impact velocities than those for the Holden Commodores (1850C) (Figure 13).

![Figure 13: Occupant impact velocities by vehicle and barrier type](image)

For the eight-tonne Mitsubishi trucks, the maximum ridedown acceleration values often occurred after the vehicle had lost contact with the barrier. In the case of the W-beam and the wire rope barrier, the truck breached the barrier and rode over it. Similarly, the Landcruiser impacting the F-type barrier also recorded higher ridedown decelerations after the vehicle had ceased to interact with the barrier.

The longitudinal occupant impact velocities and ridedown are dependent on whether a vehicle can easily slide along the barrier. Posts in the W-beam barrier may restrict the longitudinal movement and cause higher values particularly in smaller vehicles. This is shown in Figure 14.

Figures 13 and 14 indicate that the values are less than the maximum values for successful tests documented in NCHRP 350 and MASH. These comparison tests are not compliance tests, however, these measures indicate tolerable outcomes. The comparison tests using the 1850C Commodore are 23 percent more severe than the alternative 1500A MASH impacting at TL3.
conditions (100 km/h and 25 degrees) and the RMS tests using the 8000 kg truck were 10 percent more severe than the TL4 MASH tests. The severity of test with the 1100C Daihatsu and the 2500P Landcruiser were midway between the severities of MASH TL2 and TL3 tests.

![Graph showing occupant ridedown accelerations by vehicle and barrier type](image)

**Figure 14: Occupant ridedown accelerations by vehicle and barrier type**

The 1100C tests were less severe than the MASH TL3 test, because of the 20° impact angle in the RMS tests. Lower impact angles should assist redirection but the interaction might be different. The 25° impact angle is assumed to be the worst-case scenario. Anecdotally, other RMS testing has demonstrated that impacts at 20° may be more severe than a 25° one through the interaction of the vehicle with the posts. This issue needs further consideration and discussion.

In general, the impact values are less than the recommended maximums in MASH and NCHRP350.

**Impact severity utilising Head Impact Criterion (HIC36)**

As indicated earlier in the paper, the test vehicles (other than the 8000T) were fitted with ATDs (dummies). The HIC36 (US Department of Transportation, FMVSS 208) value is one indicator of dummy performance that has been analysed. HIC36 values were recorded from the dummies in the front driver and passenger positions and in the rear right hand side passenger position. Results were recorded for the total incident, that is, the impact with the barrier and the vehicle outcome after the vehicle had lost contact with the barrier including where it had rolled over.

The HIC36 values have a rather complicated formula based on the deceleration of the head of a 50th percentile male dummy averaged over 36 ms. A HIC36 value of 1000 corresponds to significant head injuries.

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3 The Crash Test reports carry a note pertaining to both passenger ATDs “The Hybrid III ATD is designed for frontal impact testing. Care should be taken with interpreting results as the crash test incorporated lateral forces which may not necessarily be reflected in the results of the ATD.”
HIC36 values were recorded between 500 and 950 for the rollovers. Barriers should not cause vehicles to rollover after impact and such behaviour would constitute a failure under a formal test regime such as EN 1317 (European Committee for Standardization 2010) and NCHRP 350 (Ross et al. 1993) and MASH (American Association of State Highway and Transportation Officials 2009).

Because this comparison series is primarily investigating the vehicle interaction with the barrier, it was decided to compare the HIC36 values when the vehicle is in contact with the barrier. The truck impacts were conducted without dummies and consequently the HIC36 values were not available.

The result for the 1850C vehicle (Holden Commodore) into the type F barrier was atypical, being a factor of 10 higher than other results. The three impacts (i.e. all three passenger vehicles fitted with dummies) with the F-type barrier resulted in the driver hitting the side window and or the vehicle structure in the first 150 ms of the impact. It is noted that both the lateral occupant impact velocities and the lateral ridedown accelerations for the impact by the Commodore were lower than the respective values for either the 1100C or the 2500P vehicles. The higher HIC36 value for the 1850C seems to be either related to the vehicle type or to a peculiarity of this particular test. It was considered that this HIC value for the Commodore impacting the concrete barrier should be excluded. The remaining HIC36 values for a vehicle in contact with a barrier are shown in Figure 15. This graph demonstrates that in general the wire rope barrier had lower HIC36 values than the W-beam, which are generally less than those for an F-type barrier.

![Figure 15: HIC36 values while the vehicle is in contact with the barrier](image)

For the impacts by Landcruisers, head decelerations are not necessarily lower than for other impacts. This is contrary to the belief that the larger vehicles are much safer.

Australasian New Car Assessment Program (ANCAP) tests also record HIC36 values and found that 5-star vehicles typically had HIC36 values greater than 200 for the driver and passengers. If a rational limit for HIC36 of 200 is used to identify ‘five star’ performance, then all barrier

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4 The HIC36 value for the 1850C impacting the F type barrier is 542, this was considered to be atypical and excluded.
impacts produce lower results. Further the difference between the W-beam and wire rope barrier is not significant. It should be noted that a value less than 200 does not guarantee that head injury will not occur just that the chance of it is very much reduced.

Considering the results from all dummies in the three seating positions, it is concluded that the HIC36 values for the wire rope barriers are better than those for the W-beam and these are better than the rigid Type F, being approximately 1/10, 1/5 and 1/2 of the 200 limit described above. It is considered that both the W-beam and wire rope barriers provide exceptional outcomes. The HIC36 values for the F type barrier also do not cause major concern in that other than the results for the 2500P, the HIC36 values are well below those recorded in the ANCAP tests. It should be kept in mind that these HIC results for the barrier tests relate to only the duration of the interaction with the barrier.

**Relationship of HIC36 to vehicle indicators**

Most safety barriers are conducted without anthropometric test devices (dummies like EuroSID and Hybrid III). The test results presented here provide an insight into general relationships between the HIC36 results and other measures.

Figure 16 explores one such relationship, that being HIC36 values and occupant impact velocities. The HIC 36 values are those for all dummies and the vector sum of the lateral and longitudinal occupant impact velocity values is used to represent the ‘occupant impact velocities’. Figure 13 illustrates that for all tests with wire rope and with rigid Type F, the lateral occupant impact velocity was always higher than the longitudinal occupant impact velocity. For W-Beam it was a mixed result, reflecting the interaction of the vehicle with the W-Beam posts. However, the vector sum is always higher than either of the component values and hence its use is conservative.

![Figure 16: HIC36 results against impact velocities](image)

MASH recommends the desirable limit for the lateral or longitudinal occupant impact velocities as 9 m/s. This figure demonstrates that impact velocities less than eight are expected to result in HIC36 values of less than 200.
Consequently the desirable limit for impact velocities of 9 m/s should result in acceptable HIC36 results.

Figure 17 explores a second relationship, that being HIC36 values and Acceleration Severity Index (ASI) values. The values derived from the ASI calculation (CEN 1998) provide a convenient over-view of the test as they combine the vehicle accelerations in three perpendicular directions averaged over a moving time interval of 50 ms. Each component of the acceleration is normalised by expressing it as a fraction of the limit value in that direction. Thus the ASI is dimensionless. For passengers wearing seat belts, the generally used limit accelerations are 12 g (longitudinal), 9 g (lateral) and 10 g vertical. In the absence of an instrumented dummy (ATD) in a vehicle it is often used as a vehicle based indicator of occupant injury.

The ASI values achieved in these tests were representative of those expected for each barrier type. The results, from this comparison with HIC36, indicate that an ASI of 1.0, which was considered to be a reasonable upper limit for lower occupant injury, produces low HIC36 values. Tests with ASI values greater than 1.0 can still give low occupant injury results (as indicated by HIC36) and be considered to be safe for the occupants.

It should be noted that the relationships discussed above are general in nature and tests should be evaluated using more than one parameter.

DISCUSSION

General statements can be made about the performance of the three generic barrier types.

The F type barrier is stiffer than the W-beam barrier, which is stiffer than the wire rope barrier. The stiffer the barrier the less energy is dissipated by the barrier, and more energy must be managed within the vehicle structure. Stiffer barriers have lower deflections and larger decelerations (presented as ride down accelerations) and occupant impact velocities. This is represented in Figure 8.
For the non-rigid systems i.e. W-beam and wire rope systems, the ‘apparent’ stiffness of the barrier is affected by the mass of the impacting vehicle and the manner in which it interacts with the barrier. Smaller vehicles tend to have higher lateral accelerations both in terms of the ridedown accelerations and the lateral impact velocity. These impact characteristics are defined in NCHRP350 (Ross et al. 1993) and MASH (American Association of State Highway and Transportation Officials 2009). In the impacts with wire rope, it is not only a lower mass but the tendency to engage with all four ropes that leads to these higher figures.

**Increasing impact velocities and ride down accelerations**

![Figure 18: Relative performance of different barrier systems](image)

Figure 18 is illustrative only and is intended to show the relative performance of the different types of barriers. It should be noted that wire rope systems have a greater potential variability depending on the design of the barrier. Both the W-beam and the concrete barriers are more consistent as there tends to be fewer differences in accepted designs used in Australia. It is expected that future designs of both W-beam and concrete barriers will affect their performance (and location on this figure) to some extent.

The performance of wire rope and W-Beam barriers is dependent on the ropes or the rail engaging with the vehicle’s body.

Despite the use of blockouts, the posts in the W-beam barrier restrict the longitudinal movement and cause higher longitudinal deceleration pulses. The posts in the wire rope barrier had a similar, but lesser effect on longitudinal ridedown decelerations. The F-type concrete barrier has a smooth profile and the longitudinal decelerations were lower than those for the W-Beam.

The W-beam guardrail performs adequately as demonstrated by the vehicle impact measures. However, its performance is sensitive to the rail height and the stiffness of the posts. Recent commercial development of W-beam barriers show improved performance through lighter posts and modified rail release mechanisms. An advantage of W-beam barriers is that they can be connected to concrete barriers (or bridge parapets) more easily and also do not rely on pre-tensioning of the system.

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5 Ride down accelerations are generally negative indicating a deceleration.
The performance of wire rope barriers is variable. The impact measures depend on the global stiffness of the system and on the number of ropes that engage with the vehicle. The stiffness of the system depends on the post stiffness, the post embedment details, the post spacing and the tension in the ropes near the impact. The system deflection provides an indication of the system stiffness. Because the tested system deflects more than other systems available in Australia, it is a more flexible system than other wire rope systems. The extent, to which the results would change if a stiffer wire rope system is used, is unknown and should be the subject of further analysis. Consequently, the lower values for impact measures from this comparison series for wire rope barriers may not be representative of all wire rope barriers and this will be explored separately.

Excluding anomalies, the HIC36 values were significantly less than 200 for all barrier types and HIC36 values higher than this 200 level are recorded in ANCAP tests for 4 and 5 star vehicles.

The results in this paper have implications for the assessment of products. For instance:

- At present, full scale testing does not require HIC36 measurements. If these measurements are available, then they may be used to increase understanding of the relationship between actual occupant head injuries and the more traditional impact measures specified in NCHRP 350 or MASH.
- The conclusion above that “Impacts with all barriers are likely to produce relatively minor injuries, demonstrated by the HIC36 values” suggests that the emphasis given to the upper limit of 1.0 for ASI values in current acceptance processes may need to be re-evaluated.
- Product acceptance processes review the performance of a barrier and typically very similar vehicles are used. However, the impacting vehicle’s rollover characteristic should also be assessed particularly if another vehicle type is used.

CONCLUSIONS

Based on the impacts reported here, it is concluded that:

Barrier capacity:

- The F type barrier has demonstrated that it can contain heavy vehicles (up to 8 t) under the test conditions described. The W-beam and the wire rope barriers have not been able to do so.

Barrier deflection:

- The way in which the vehicles are interacting with the wire rope barrier is having a fundamental impact on both the contact length and the deflection.
- The performance of the wire rope barrier used in this series is variable in that the deflection depends on the number of ropes that engage with the vehicle.

Suitability for high centre of gravity vehicles:

- The 2500P vehicle used in this comparison series has a higher rollover index than the vehicle used in NCHRP350 testing and this may have influenced the ability of the concrete and W-Beam barriers to successfully redirect this vehicle.

Occupant outcomes

- Impacts with all barriers are likely to produce relatively minor injuries, demonstrated by the HIC36 values (excluding the one anomaly) being significantly less than 200.
- The desirable limit for impact velocities of 9 m/s in NCHRP350 and MASH should result in acceptable HIC36 results.
Considering the results from all dummies in the three seating positions, it is concluded that the HIC36 values for the wire rope barriers are better than those for the W-beam and these are better than the rigid Type F, being approximately 1/10, 1/5 and 1/2 of the 200 limit described above. It is considered that both the W-beam and wire rope barriers provide exceptional outcomes. The HIC36 values for the F type barrier also do not cause major concern in that other than the results for the 2500P, the HIC values are well below those recorded in the ANCAP tests. It should be kept in mind that these HIC results for the barrier tests relate to only the duration of the interaction with the barrier.

The lateral occupant impact velocities for the Toyota Landcruiser give slightly higher impact velocities than the Holden Commodore. This is contrary to the notion that 4WD vehicles, because they are heavier, are typically decelerated at lower rates than sedans.

The occupant impact velocities and ride down decelerations for all three barrier types were less than the maximum values recommended by MASH and NCHRP 350, although it is recognised that these were not NCHRP350 or MASH test conditions.

The test results also have broad implications for road design. These include:

- Where capacity is the primary design constraint, then a high stiffness rigid barrier such as a reinforced concrete barrier appropriately anchored/embedded is required.
- Where deflection must be controlled then it is important to know the characteristics of the generic barrier type as well as the specific deflection performance of the individual product within that type.
- The deflection of the wire rope system used in this test comparison depended on the number of ropes that were engaged by the vehicle. Thus, where deflection must be controlled, care needs to be exercised in adopting test deflections without an appropriate factor of safety.
- The adverse reactions with the concrete type F barrier with the 2500P vehicle are more likely to be a consequence of the vehicle's characteristics rather than those of the barrier and that this may also have influenced the outcome with the W-Beam. Thus, where design is targeting the ability of a barrier to successfully redirect a high centre of gravity vehicle without rollover, the designer should understand that the commonly used test vehicles do not necessarily give the worst case rollover characteristics.
- When designing for reduced occupant injury, there is little practical difference between wire rope and W-Beam. Rigid concrete barrier also delivers HIC36 outcomes below 200.

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