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Original Road Safety Research

A Crash Testing Evaluation of Motorcyclist Protection Systems for use on Steel W-Beam Safety Barriers

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Key Findings

- Motorcyclist Protection Systems can reduce the risk of fatality and serious injury to sliding motorcyclists, without compromising the safety of other road users
- Two products – the Ingal MPR and the HIASA – demonstrated an acceptable level of injury risk to a sliding motorcyclist impacting at 60 km/h
- A third public domain product and the W-Beam alone did not demonstrate an acceptable level of injury risk to a sliding motorcyclist impacting at 60km/h

Abstract

Safety barriers are a popular and proven countermeasure used to protect vehicle occupants from roadside hazards. However, international and Australian research demonstrates that safety barriers can pose significant safety risks to motorcyclists in the event of a crash. The Centre for Road Safety (CRS) undertook a series of crash tests of three currently available Motorcyclist Protection Systems (MPS) to investigate whether the addition of MPS to a standard W-Beam reduces the injury risk for an impacting motorcyclist, without compromising the safety of other road users. Two of the MPS tested demonstrated an acceptable level of injury risk to a sliding motorcyclist impacting at 60 km/h, and a greatly reduced injury risk, compared with the W-beam alone, where impact was likely to be fatal. None of the MPS demonstrated any adverse impact on the injury risk to vehicle occupants, or the vehicle's trajectory.

Keywords

Motorcyclist, Injury risk, Road safety barriers, Motorcycle under run, rub rail, Crash test

Introduction

This study explores the risks posed to motorcyclists by safety barriers and evaluates three MPS developed to reduce the injury risk to motorcyclists arising from barrier impacts. It represents the first full-scale crash testing of MPS in Australia.

Background to the study

There is a growing concern about the safety of motorcyclists on NSW roads. While total fatalities on NSW roads decreased by 23 percent between 2009 and 2015, motorcyclist fatalities have remained fairly stable averaging 63 per year (Transport for NSW, 2016). Motorcyclists are overrepresented in road trauma, representing 16 percent of fatalities and 18 percent of serious injuries between 2009 and 2013, yet only 4 percent of motor vehicle registrations in NSW (Australian Bureau of Statistics, 2009, 2010, 2011, 2012, 2013; Transport for NSW, 2016). Motorcyclists are approximately 30 times more likely to be fatally injured and 41 times more likely to be seriously injured than car occupants per kilometre travelled (Department of Infrastructure Transport Regional Development and Local Government, 2008).

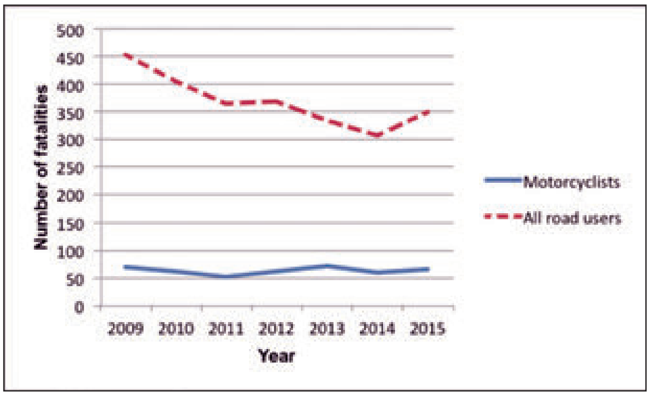


Figure 1. Number of fatalities on NSW roads, 2009-2015

The increasing number of motorcyclists on NSW roads and their overrepresentation in road trauma highlights the need to develop effective countermeasures which reduce the likelihood and severity of motorcycle crashes.

Safety barriers are an effective measure for reducing injury risk to vehicle occupants by protecting them from impacts with roadside hazards, such as trees, poles and embankments. While safety barriers also reduce the risk of serious injury to motorcyclists compared to roadside hazards, such as trees and poles, they can still pose significant injury risks to motorcyclists (Elvik 1995; Gabler 2007; Bambach, Grzebieta & McIntosh, 2010; Bambach, Grzebieta, Tebecis, & Friswell, 2012; Bambach, Mitchell & Grzebiata, 2012). Internationally, impacts with a safety barrier are a factor in between 8 and 16 percent of motorcycle fatalities (EuroRAP, 2008). Similar results have been found in Australia, with around 8 percent of motorcycle fatalities in NSW between 2001 and 2006 involving an impact with a safety barrier (Jama, Grzebieta, Friswell & McIntosh, 2011).

Motorcyclists are far more likely to be fatally injured upon impact with a safety barrier compared with car occupants. Gabler (2007) found, based on a study of US crashes between 2000 and 2005, that approximately one in eight motorcyclists impacting a safety barrier was fatally injured, compared with only one or two of every 1000 car occupants. European research suggests that motorcyclists are 15 times more likely to be fatally injured in crashes with barriers than car occupants (EuroRAP, 2008).

The nature of injuries sustained by a motorcyclist during an impact with a safety barrier depends on the manner in which the motorcyclist impacts the barrier. The most common crash scenarios involve the motorcyclist and motorcycle impacting the safety barrier together in an upright position, and the motorcyclist impacting the safety barrier after sliding along the ground, either while still in contact with the motorcycle or after separation has occurred (Bambach et al., 2010; Ruiz et al., 2010). A number of studies have shown that motorcyclist impacts with safety barriers are split approximately equally between upright and sliding impacts (Berg et al., 2005; Bambach et al. 2010). An impact in the upright position leaves the motorcyclist exposed to sharp edges and protrusions connected to the upper areas of the safety barrier, whereas an impact in the sliding position exposes the motorcyclist to a significant chance of impact with the barrier posts (Gibson & Benetatos, 2000; Peldschus et al., 2007). Barrier posts present a substantial risk of fatal and serious injury to motorcyclists upon impact due to their rigid nature, relatively small impact area, sharp pointed edges and installation that is perpendicular to the expected impact trajectory. These combine to result in higher stresses inflicted on the body of the motorcyclist.

Jama et al. (2011) in an in-depth study of motorcycle crashes in Australia and New Zealand demonstrated that motorcyclist fatalities involving an impact with a barrier predominantly occurred on curves and involved a steel W-Beam barrier (around 70 percent). Relatively few involved a concrete barrier or a wire rope barrier. The high number of impacts involving W-Beam barriers is likely to reflect their extensive use throughout the road network and particularly on curves, where motorcyclists are more likely to impact a barrier. Fatalities tended to occur during daylight hours, on clear days with dry road surface conditions, and frequently on a weekend, suggesting recreational riding. Speeding or alcohol were also recorded as being a factor in a significant number of the fatalities, and drug use was evident in a small number of cases.

Motorcyclists tend to have been overlooked in the design of safety barriers, due to both their underrepresentation as road users and the challenges in developing protective technologies for these road users. In recognition of the need to improve motorcycle safety, a range of motorcycle friendly barriers or Motorcyclist Protection Systems (MPS) have been developed. There are two main types of MPS - continuous systems, which consist of an additional rail that fits between the barrier rail and the ground, and discontinuous systems, which consist of a protective 'cushion' that surrounds the individual posts that support the barrier. These products are intended to absorb kinetic energy through deformation during an impact, therefore helping to reduce the risk of injuries due to rapid deceleration. Upon impact the brackets of the MPS deflect and deform to absorb some of the impact energy, while the panel surface, also absorbing energy, functions as a continuous guide to redirect the motorcyclist along the barrier. The function of the MPS is to protect sliding motorcyclists from impacting support posts, continuing underneath the existing barrier and into other hazards, and/or to minimise re-entry into the lane of traffic after interaction.

Crash testing of MPS undertaken in Europe has produced promising results in terms of reduced injury risk to motorcyclists impacting safety barriers, without an adverse impact on the injury risk to passenger car occupants. Work by Bambach, Grzebiata, Olivier and McIntosh (2011) also indicates that the installation of MPS has the potential to reduce injuries that would normally be fatal to more minor

Figure 2. Ingal MPR

Figure 3. HIASA MPS

Figure 4. Public domain MP

injuries. The likelihood of head injury following a barrier impact is more than halved for either an upright or sliding impact with a continuous system. The deceleration forces for a chest impact are almost halved when impacting a discontinuous system.

Methods

Three continuous MPS - Ingal MPR, HIASA and a public domain product, shown in Figures 2 to 4 - were crash tested to evaluate the injury risks posed to an impacting motorcyclist. These MPS are able to be fitted to a standard W-beam barrier which is used widely across the NSW road network. They were available on the Australian market at the time of the study and had been submitted to NSW Roads and Maritime Services (RMS) for assessment and approval for use on NSW roads. Additional crash tests were carried out to examine whether the MPS had any adverse impact on vehicle occupants. A standard G4 W-Beam barrier alone served as a comparison and was used for informative purposes only. All testing was carried out at Crashlab, a commercial business unit of RMS.

Motorcyclist crash tests

Twelve crash tests were undertaken between November 2014 and February 2015 to evaluate the injury risks posed to an impacting motorcyclist by each of the MPS and to compare these with the injury risk of impacting a W-Beam alone. Testing was undertaken in accordance with the European test specification CEN/TS 1317-8:2012, which was seen as current industry best practice for evaluating MPS at the time testing was undertaken.This test specification has subsequently been recommended in the new Australian and New Zealand standard for barrier testing and installation AS/NZS3845:2015, which was released after this study was completed.

The test procedures simulate a sliding motorcyclist impacting the barrier head first, using a modified anthropomorphic device (ATD) or crash test dummy (as shown in Figure 5). These modifications enable the ATD to behave more like a sliding motorcyclist rather than a seated vehicle occupant. The modifications are described in CEN/TS 1317-8:2012, and include a "standing" pelvis, to enable the ATD to lie flat, a frangible shoulder assembly to better simulate motorcyclist trajectory and injuries when impacting the MPS, a foam neck shield to ensure the helmet's chin strap could be securely fastened and an alternate lumbar spine to allow for the inclusion of the internal data acquisition system.

Testing is carried out at two different points of impact with the MPS (post-centred and mid-span), with an impact speed of either 60 km/h or 70 km/h, and an impact angle of 30°. This corresponds to test configurations 1.60, 1.70, 3.60 and 3.70 set out in CEN/TS 1317-8:2012. The impact configuration represents severe rather than typical impact conditions and enables test repeatability and use of well-established measurement criteria. MPS are assessed against a range of criteria. These include injury risk to the head and neck, and the behaviour of the MPS (in terms of damage to the barrier) and the ATD (in terms of injury damage or protrusion beyond the barrier).

A standard G4 W-beam barrier was installed in accordance with AS/NZS 3845:1999 for each motorcyclist test. The W-beam was 42m in length (including trailing terminals at each end), with 21 steel posts spaced 2m apart. Panels of MPS were fitted below the existing W-beam rails and were attached through the use of brackets attached to either the c-block (in the case of the HIASA and the public domain) or the W-beam post (in the case of the Ingal MPR). The public domain MPS attachment to the W-beam is shown in Figure

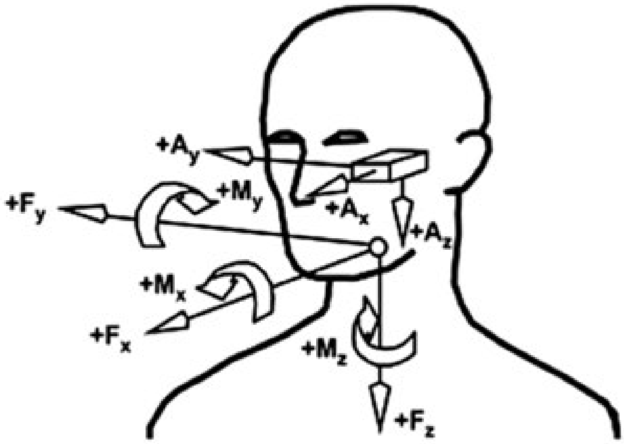
Figure 5. Set up used in the motorcyclist crash tests

Figure 6. The public domain MPS attached to the W-Beam barrier

6. The height of the MPS above the ground at the nominal point of impact ranged between 50mm and 64mm for the Ingal MPR, 31mm and 35mm for the HIASA and 53mm and 59mm for the public domain product.

A modified Hybrid III 50th percentile male ATD was used in testing. The total mass of the test ATD, including instrumentation, helmet and protective clothing, was approximately 86.5 kg. The helmet used in the testing complied with Australian Standard AS/NZS 1698:2006 and the performance requirements of European standard CEN/TS 1317 8:2012 Annex F.

Early crash test results conducted at 70 km/h indicated that a number of the injury risk measures were higher than expected (exceeding Severity I levels), likely due to differences in soil conditions or in the structure and installation of barriers, in Australia compared with Europe. Subsequent crash tests, particularly the post-centred tests, were therefore generally run with the lower impact speed of 60 km/h.



Fx - anterior-posterior shear force, Fy - lateral shear force. Fz - tension-compression force, Mx- lateral bending moment on the neck, My - flexion/extension moment on the neck, Mz - torsion moment (Mz).

Figure 7. Directions for forces, accelerations, and moments in the ATD (CEN/TS 1317 8:2012 P8)

Passenger car occupant crash tests

Three crash tests examined the injury risks posed to passenger car occupants by each of the MPS and a further crash test was carried out with the W-beam alone for comparison. Passenger car tests were carried out in accordance with the Australian and New Zealand standard for barrier testing and installation AS/NZS 3845:1999, which was current at the time of the study. In particular, Test 3-11 of the recommended testing procedures in the United States National Cooperative Highway Research Program (NCHRP) Report 350, which the Australian standard references, was used. These test procedures stipulate that a 2000 kg pickup truck travelling at a speed of 100 km/h impact a barrier installation at an angle of 25°. In the current study a 1600 kg sedan, which is permitted under AS/NZS 3845:1999, was used. The W-beam barrier fitted with each of the three MPS was assessed against standard criteria relating to structural adequacy of the barrier, occupant injury risk and the vehicle trajectory after the collision. The W-beam only was also assessed against these criteria, for comparison.

These criteria ensure that the barrier performs as it was designed and contains and redirects the vehicle without subjecting the vehicle occupants to undue injury risk, or to subsequent crash risk or hazards. The barrier should preferably prevent the vehicle from being redirected back into the traffic lanes. Occupant injury risk is measured by instrumentation located at the center of gravity of the vehicle and is based on the velocity at which a hypothetical unrestrained occupant would strike some part of the vehicle interior.

A 1600 kg Holden VT Commodore sedan (models ranged from 1998 to 2000) was used as the test vehicle. A Hybrid III 50th percentile male ATD with a mass of 88 kg was placed in the driver seating position.

A standard G4 W-beam was installed in accordance with AS/NZS 3845:1999 for each passenger car occupant test. The barrier was 68 m in length, including trailing terminals at each end, with 35 steel posts spaced 2m apart. The top edge of the rail was 710 mm high. This was varied for the Ingal MPR which was installed on a slightly shorter barrier, 60m

Table 1. Ingal MPR - motorcyclist test results

	Mid-span 60 km/h	**Post-centred 60 km/h**	**Mid-span 70 km/h**	**Post-centred 70 km/h**	***Severity Level I criteria***	***Severity Level II criteria***
Head Injury Criterion (HIC_{36})	160	169	284	406	***650***	***1000***
Neck shear (kN)	1.5	1.7	2.4	2.0	***1.9***	***3.1***
Neck tension (kN)	1.4	2.0	1.7	2.0	***2.7***	***3.3***
Neck compression (kN)	2.3	2.5	3.1	2.7	***3.2***	***4.0***
Neck lateral bending (N-m)	-59.2	-51.0	45.2	-90.8	***134.0***	***134.0***
Neck extension (N-m)	30.2	24.0	31.7	38.2	***42.0***	***57.0***
Neck flexion (N-m)	67.9	76.1	111.3	100.9	***190.0***	***190.0***
Injury criteria	Severity I	Severity 1	Severity II	Severity II		
ATD criteria	Met	Met	Met	Not met		
MPS criteria	Met	Met	Met	Met		
Overall test	Met	Met	Met	Not met		

Table 2. HIASA - motorcyclist test results

	Mid-span 60 km/h	**Post-centred 60 km/h**	**Mid-span 70 km/h**	***Severity Level I criteria***	***Severity Level II criteria***
Head Injury Criterion (HIC_{36})	169	114	742	***650***	***1000***
Neck shear (kN)	0.3	0.9	1.1	***1.9***	***3.1***
Neck tension (kN)	1.8	1.4	2.8	***2.7***	***3.3***
Neck compression (kN)	1.8	1.7	2.4	***3.2***	***4.0***
Neck lateral bending (N-m)	-58.7	-58.5	77.8	***134.0***	***134.0***
Neck extension (N-m)	25.7	30.7	47.6	***42.0***	***57.0***
Neck flexion (N-m)	22.7	51.6	49.6	***190.0***	***190.0***
Injury criteria	Severity I	Severity I	Severity II		
ATD criteria	Met	Met	Not met		
MPS criteria	Met	Met	Met		
Overall test	Met	Met	Not met		

in length, with 31 steel posts, spaced 2 m apart and the top edge of the rail 720 mm high. This was due to the conditions at the test site at the time of the test, and was expected to have minimal effect on the test results.

Results

The key findings of the crash tests are presented in this section. Full details are available in the individual crash test reports available from CRS (Crashlab, unpublished).

Tables 1 to 4 show the results of the motorcyclist crash tests for each of the three MPS and the W-beam alone against the standard evaluation criteria set out in CEN/TS 1317-8:2012. Tolerances for impact speed, impact angle and impact point were met in all twelve tests. Figure 7 shows the direction for forces, accelerations, and moments in the ATD to assist with the interpretation of the test results.

Motorcyclist crash tests

As shown in Table 1, the Ingal MPR met all performance requirements at 60 km/h for both the mid-span and post-centred impact at the Severity I (less serious) injury levels. The Ingal MPR therefore demonstrated an acceptable level of injury risk to a sliding motorcyclist. At 70 km/h the Ingal MPR did not meet the performance requirements for the post-centred impact - the ATD criteria were not met with lacerations evident to the left chest, neck and shoulder area of the ATD.

Table 2 shows the HIASA met all performance requirements at 60 km/h for both the mid-span and post-centred impact

Table 3. Public domain – motorcyclist test results

	Mid-span 60 km/h	**Post-centred 60 km/h**	**Mid-span 70 km/h**	***Severity Level I criteria***	***Severity Level II criteria***
Head Injury Criterion (HIC_{36})	344	492	487	***650***	***1000***
Neck shear (kN)	0.6	-0.4	1.0	***1.9***	***3.1***
Neck tension (kN)	1.8	2.3	4.0	***2.7***	***3.3***
Neck compression (kN)	5.9	3.6	6.3	***3.2***	***4.0***
Neck lateral bending (N-m)	96.3	-66.2	104.5	***134.0***	***134.0***
Neck extension (N-m)	13.2	25.6	24.4	***42.0***	***57.0***
Neck flexion (N-m)	14.4	24.8	38.0	***190.0***	***190.0***
Injury criteria	Not met	Severity II	Not met		
ATD criteria	Not met	Not met	Not met		
MPS criteria	Met	Met	Met		
Overall test	Met	Met	Not met		

Table 4. W-beam – motorcyclist test results

	Post-centred 60 km/h	**Mid-span 70 km/h**	***Severity Level I Criteria***	***Severity Level II criteria***
Head Injury Criterion (HIC_{36})	7985	194	***650***	***1000***
Neck shear (kN)	>8.2	-0.6	***1.9***	***3.1***
Neck tension (kN)	1.5	5.1	***2.7***	***3.3***
Neck compression (kN)	>15.7	0.9	***3.2***	***4.0***
Neck lateral bending (N-m)	>502.1	63.5	***134.0***	***134.0***
Neck extension (N-m)	167.4	31.8	***42.0***	***57.0***
Neck flexion (N-m)	100.2	35.7	***190.0***	***190.0***
Injury criteria	Not met	Not met		
ATD criteria	Not met	Not met		
MPS criteria	Met	Met		
Overall test	Not met	Not met		

at the Severity I (less serious) injury levels. This MPS also demonstrated an acceptable level of injury to a sliding motorcyclist. At 70 km/h the MPS did not meet the performance requirements for the mid-span impact - the ATD criteria were not met due to the left foot of the ATD protruding beyond the MPS.

From Table 3 it can be seen that the public domain product did not meet the performance requirements at either 60 km/h or 70 km/h. The maximum allowable injury levels (Severity II) were exceeded in the mid-span test at both 60 km/h and 70 km/h. The ATD criteria were also not met due to the ATD protruding beyond the MPS.

The W-beam alone, similarly, did not meet the performance requirements at 60 km/h or 70 km/h. The maximum allowable injury levels (Severity II) were exceeded in the post-centred test at 60 km/h and the mid-span test at 70 km/h. The ATD criteria were also not met due to lacerations to the ATD. The post-centred impact with the W-Beam alone resulted in a number of injury measures exceeding the maximum recordable levels, indicating that a motorcyclist who impacted the post would most likely be fatally injured.

While not a testing requirement under CEN/TS 1317-8:2012 it was noteworthy that in all twelve motorcycle tests the frangible screws, which form part of the ATD's modified shoulder, failed (generally on the left side) and there was evidence of deformation to several of the ribs (also generally on the left side). Research by Bambach et al. (2010) suggests that the thorax features prominently in fatal motorcycle barrier crashes, with the highest incidence of injury and the highest incidence of maximum injury in the thorax region, followed by the head region. The need for further development of thorax injury criteria indicative of injury risk for a motorcyclist impact of this type which has been

Table 5. Passenger car test results – vehicle measures

	Ingal MPR	HIASA	Public domain	W-beam only
Impact downstream of post no.	8	9	9	8
Impact speed (km/h)	99.3	99.2	99.6	99.0
Exit speed (km/h)	30.6	48.7	48.8	46.3
Impact angle (◦)	25.8	24.6	25.4	25.1
Exit angle (◦)	12.6	-4.2	3.4	1.3
Exit angle as a % of impact angle	48.8	-17.1	13.4	5.2
Maximum roll (◦)	-20.1	-36.1	-4.1	9.9
Maximum pitch(◦)	-5.4	8.1	2.5	-3.3
Maximum yaw (◦)	-31.4	-30.3	-33.2	-40.1
Impact Severity (kJ)	116.2	105.3	112.7	108.9

Table 6. Passenger car test results - simulated injury risk

	Ingal MPR	HIASA	Public domain	W-beam only	Criteria	
					Preferred value	***Maximum value***
Mandatory requirements						
Occupant Impact velocity, x (m/s)	6.7	4.2	5.0	4.7	***9***	***12***
Ridedown Acceleration, x (g)	-11.1	-13.9	-10.1	-10.5	***15***	***20***
Non-mandatory requirements						
Occupant Impact Velocity, y (m/s)	4.1	5.3	5.2	4.5	***9***	***12***
Theoretical Head impact velocity (km/h)	26.7	24	24.5	23	***NA***	***30***
Ridedown Acceleration, y (g)	-7.9	-10.4	-7.2	-12.1	***15***	***20***
Acceleration Severity Index	0.79	0.83	0.72	0.79	***1***	***1.9***
Post Head Deceleration (g)	12.7	14.2	10.1	15.9	***NA***	***NA***

Table 7. Passenger car test results – assessment against evaluation criteria

	Ingal MPR	HIASA	Public domain	W-beam only
Structural adequacy of barrier				
Barrier contains and redirects vehicle	Pass	Pass	Pass	Pass
Occupant risk				
Minimal intrusion into occupant compartment	Pass	Pass	Pass	Pass*
Vehicle remains upright	Pass	Pass	Pass	Pass
Vehicle trajectory				
Vehicle preferably should not intrude into adjacent traffic lanes	Pass	Pass	Pass	Marginal
Occupant Impact Velocity ≤ 12m/s and Occupant ridedown acceleration ≤ 20g	Pass	Pass	Pass	Pass
Vehicle exit angle < 60% of impact angle	Pass	Pass	Pass	Pass

Table 8. Passenger car test results – barrier deflection

	Ingal MPR	HIASA	Public domain	W-beam only
Dynamic rail deflection, y (m)	0.88	0.87	0.89	0.98
Permanent rail deflection, y (m)	0.64	0.56	0.60	0.66
Permanent working width, y (m)	0.80	0.89	1.10	1.02
Permanent deflection of end terminals, x (m)	0.00	0.00	0.03	0.03

discussed by Grzebiata, Bamabach and McIntosh (2013) is clearly supported by the findings of this study. The new standard AS/NZS 3845:2015, which was published after this study, and now references CEN/TS 1317-8:2012, includes measures of thorax compression, based on some of this work.

Passenger car crash test results

Tables 5 to 8 show the results of the passenger car crash tests for each of the three MPS and the W-beam alone, which were conducted to assess whether the MPS were likely to have an adverse impact on the injury risk to vehicle occupants. Tolerances for impact speed and impact angle were met in all four tests. Impact severity measures were all within the maximum allowable value. Note that the negative exit angle of the vehicle following impact with the HIASA MPS indicates that the vehicle rotated towards the barrier upon exit.

There are two key values of interest for the simulated injury risk, which are set out as mandatory testing requirements in NCHRP Report 350. The first is the Occupant Impact Velocity in the longitudinal (x) direction, which is the velocity with which the occupant would strike part of the car's interior. The second is the Ridedown Acceleration in the longitudinal (x) direction which is the vehicle acceleration transferred to the vehicle occupant after interior impact is made. These values are computed from the vehicle's trajectory, using the flail space model (see Gabauer & Gabler, 2008). The model assumes the occupant is unrestrained in the vehicle and 'flails' within set bounds. The values are calculated from the point when the occupant moves outside the 'flail' space, and ignore the vehicle's pitch (around the y-axis) and yaw (around the z-axis) motions for ease of computation. The other values, while not mandatory requirements under NCHRP Report 350, are reported for comprehensiveness and to enable comparison with other testing.

It can be seen that for each of the MPS, as well as the W-beam alone, the injury risk to passenger car occupants were within acceptable levels. In each test the Occupant Impact Velocity values were below both the preferred and maximum values of 9m/s and 12m/s, respectively and the Ridedown Acceleration values were below the preferred and maximum values of 15g and 20g, respectively.

Note that the assessment of occupant risk for the W-beam only differs from that presented in the crash test report where the assessment was reported as "Marginal". This was due to part of the barrier being projected 26m down the barrier and being considered a potential hazard to other traffic, pedestrians or personnel in a work zone.

While some destruction of the barrier was evident, and parts of the barrier (blockout or stiffener plates) were projected down the installation, in each case, it can be seen from Table 7 that the W-beam fitted with each of the MPS demonstrated acceptable levels of structural adequacy, occupant risk and vehicle trajectory. The W-beam fitted with each of the MPS was able to satisfactorily contain and redirect the vehicle, without the vehicle penetrating the barrier. There was minimal deformation and intrusion of the barrier into the occupant compartment and vehicles remained upright during, and following the impact.

Table 8 shows the degree of barrier deflection for each of the four tests. Whilst this is not an evaluative criterion of the testing, the findings are reported for comprehensiveness and comparison. It can be seen that the W-Beam alone tended to have the highest degree of barrier deflection.

Conclusion

Two of the MPS tested – the Ingal MPR and the HIASA – demonstrated acceptable levels of injury risk to a sliding motorcyclist impacting at 60 km/h, and a greatly reduced injury risk compared with a W-beam barrier with no MPS installed, where impact was likely to result in fatality. These two MPS met all test requirements for injury risk, MPS and ATD behaviour for both mid-span and post-centred impacts at this test speed. The Severity I (lesser) injury criteria were met in all cases. The other MPS tested – the public domain product, however, did not meet the testing requirements for injury risk to a sliding motorcyclist impacting at 60 km/h. None of the MPS demonstrated any adverse impact on the injury risk to vehicle occupants, and the vehicle's trajectory.

The crash tests suggest that the addition of MPS to a standard W-beam may reduce the risk of fatality and serious injury to sliding motorcyclists, without compromising the safety of other road users. Further research, however, is required to understand the injury risks that MPS pose to motorcyclists impacting in an upright or alternative position and how the MPS perform in real world conditions. Given that motorcycle impacts with roadside barriers are more prevalent on curves, it makes sense to start targeting the installation of MPS toward the outside of curved alignments on popular motorcycle recreational routes or where there is a history of motorcycle crashes.

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