Diary

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RoSPA Road Safety Conference 2017
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March 20-23
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1st International Roadside Safety Conference
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CARSP Conference 2017
Toronto, Canada
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October 10-12
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Road Safety & Simulation International Conference 2017
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Peer-reviewed papers

Original Road Safety Research

Decompartmentalising road safety barrier stiffness in the context of vehicle occupant risk

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Key Findings

- Road safety barriers present a continuum of vehicle occupant risk.
- Such a continuum is a function of impact conditions and system flexibility.
- Conventional descriptors "rigid", "semi-rigid" and "flexible" may be inadequate.

Abstract

Road safety barriers are selected for deployment on the basis of four basic criteria; costs, deflection performance, containment capacity, and severity outcomes. System specific severity risk to occupants of errant vehicles is not well established. Contemporary technical governance in the Australian context recognises three generic barrier types discerned by relative stiffness: rigid, semi-rigid, and flexible. This study explores how the occupant severity indicator Acceleration Severity Index (ASI) varies as a function of impact configuration and system stiffness. This study demonstrates that systems available to road safety practitioners may be better served by a continuum rather than a generic classification system.

Keywords

Road safety barriers, Acceleration Severity Index

Introduction

Road safety barriers are selected for deployment on the basis of four basic criteria:

- Costs
- Deflection performance
- Containment capacity
- Severity outcomes

Information regarding device-specific deflections and containment capacity is readily available to practitioners. Reasonable estimates of capital, maintenance and repair costs for any system can be relatively easily established. However device specific severity risk to occupants of errant vehicles is less well established.

Contemporary technical governance in the Australian context recognises three generic barrier types, discerned by relative stiffness. According to the Guide to Road Design Part 6 (Austroads, 2009) road safety barriers are described as flexible, semi-rigid or rigid. Australian/New Zealand Standard AS/NZS 3845.1:2015 (Standards Australia, 2015) is complicit in this regard. By such definitions, the rigid classification includes concrete barriers and steel bridge rail barriers. Flexible barriers are typically wire rope (cable) barriers, while semi-rigid barriers include post-mounted steel rail systems. Thereafter, in terms of vehicle occupant severity Jurewicz et al (2014) provide Fatal and Serious Injury (FSI) ratios for each of these three generic road safety barrier types, albeit noting that the differences between values are "*not statistically significant*". Likewise, the Australian National Risk Assessment Model (ANRAM) (Jurewicz, Steinmetz, & Turner, 2014) provides risk factors for three generic barrier types, viz, 'concrete', 'metal' and 'wire rope'.

However the assumption that different barriers and the occupant risk they present can be placed into such discrete categories may be an over-simplification. Rather it may be appropriate to observe that barriers present a continuum of stiffness, and that occupant severity outcomes are as much a function of the stiffness of the barrier as the configuration of the impact.

This study is an exploration of how the occupant severity indicator Acceleration Severity Index (ASI) measured during crash testing might be expected to vary as a function of barrier stiffness and the configuration of the impact.

Background

Road safety barriers deployed by Australian road authorities are homologated against established test protocols that prescribe the requirements for full-scale crash testing. Such testing is a function of both the test vehicle in terms of mass and shape, and the impact conditions: speed and angle of incidence. Australian/New Zealand Standard AS/NZS 3845.1:2015 (Standards Australia, 2015) nominates the Manual for Assessing Safety Hardware (MASH) (AASHTO, 2009) as the preferred test protocol for the homologation of road safety barriers. MASH provides that a road safety barrier intended for the containment of light passenger vehicles (i.e., cars) is tested using a 2270 kg pick-up (a utility) and an 1100 kg small car. The larger vehicle test is a test of the capacity of the barrier, while the smaller vehicle test is intended to show that the road safety barrier does not present undue risk to the occupants of smaller/lighter vehicles.

Since a light vehicle is used to test for occupant risk, it is reasonable to expect that a slightly heavier vehicle would present a lower level of occupant risk, and that (notwithstanding other confounding factors such as vehicle age and vehicle safety rating) for the same impact conditions a continuum of occupant risk would exist as a function of vehicle mass. Further, it is reasonable to expect that occupant risk is a function of the Impact Severity, or kinetic energy of the impact. And since speed and angle are components of Impact Severity, occupant risk is also a function of speed and angle of impact. This is supported variously throughout published literature.

For example, Monash University conducted a series of crash tests using identical vehicles to impact three barrier systems (F-shape concrete (rigid), U-section post guardrail with 2.5 m post-spacings (semi-rigid) and an unidentified proprietary wire rope system with 2.5 m post-spacings and unspecified rope tension (flexible)) each at 80 km/h and 45 degrees and at 110 km/h at 20 degrees (Corben et al., 2000; Grzebieta et al., 2002). Ydenius et al. (2001) report that impact with the concrete barrier at 80 km/h and 45 degrees was the most severe impact configuration in terms of all metrics employed, but that "*at slight impact angles (< 20°) the perpendicular forces on the barrier are relatively small, which most likely leads to a moderate vehicle crash severity*".

Similarly, Hammonds and Troutbeck (2012) report on parametric comparison testing of three barrier systems (F-shape concrete (rigid), C-section post guardrail with 2.0 m post-spacings (semi-rigid) and an unidentified proprietary wire rope system with 2.5 m post-spacings and rope tension 20 kN (flexible)). Each barrier type was subjected to impact at 100 km/h and 20 degrees by four vehicles: an 1100 kg small car (Daihatsu Charade), an 1850 kg intermediate car (Holden Commodore), a 2500 kg larger passenger car (Toyota Landcruiser), and an 8000 kg single unit truck (Mitsubishi). Hammonds and Troutbeck report (among other things) that "*when designing for reduced occupant injury, there is little practical difference between wire rope and W-Beam*", but that the occupant severity indicators measured during impacts with the concrete barrier, while more severe than for the other two barrier types, were still within acceptable limits, and "*well below those recorded in the ANCAP tests*". Importantly, in the context of this study, Hammonds and Troutbeck propose that for non-rigid 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*" (Hammonds & Troutbeck, 2012).

Michie et al (1971) observe that in terms of lateral acceleration, a rigid barrier was found to perform favourably when compared to semi-rigid systems in shallow angle (less than 15 degrees) impacts, and that in operator-driven tests where the barrier was repeatedly struck at 50 mph at 8 degrees "*no vehicle damage or driver injuries were observed*". The authors caution however that in large angle (> 20°) impacts, vehicle redirection is "*abrupt*". This is consistent with Bronstad et al (1987) who report on the evaluation of an array of longitudinal road safety barriers tested against the provisions of the US test protocol NCHRP Report 230 (Michie, 1981), finding that 15 degree impacts are not a discerning test for occupant risk, but that 20 degree impacts are a discerning test. Consistent with Ydenius et al (2001), Michie et al (1971) find that vehicle mass is "*a most important parameter*", and that lighter vehicles are likely to experience more severe redirection.

The intent of this study is to explore how one particular occupant severity indicator measured during crash testing is observed to vary as a function of the conditions of impact and barrier stiffness.

Acceleration Severity Index

Acceleration Severity Index (ASI) is a non-dimensional occupant severity indicator calculated from orthogonal time-averaged time-acceleration traces measured during crash testing at the centre of mass of the impacting vehicle. ASI is calculated according to the expression in Equation 1:

$$ASI = max\left[\left(\frac{a_x}{\hat{a}_x}\right)^2 + \left(\frac{a_y}{\hat{a}_y}\right)^2 + \left(\frac{a_z}{\hat{a}_z}\right)^2\right]^{\frac{1}{2}} \qquad \text{Equation 1}$$

where are average component vehicle accelerations respectively in the longitudinal, lateral and vertical direction measured over a prescribed time interval (50 milliseconds), and are corresponding threshold values for the respective component accelerations (Gabauer & Gabler, 2005).

The denominator values for the component threshold accelerations as adopted in both the US and European test protocols are respectively g, g and g (and g = acceleration due to gravity). These threshold values are consistent with those presented by Weaver et al (1975) for lap-belted occupants, and are notably equivalent to approximately 60% of the threshold values proposed for the lap and shoulder belt restraint condition. ASI is a mandatory measure under the European test protocol EN1317-1/EN1317-2 (European Committee for Standardization, 2010a, 2010b) which use ASI (among other things) to classify barriers according to occupant severity. ASI is also required to be measured under Australian/New Zealand Standard AS/NZS 3845.1:2015 (Standards Australia, 2015), but there are no mandatory performance criteria.

Objectives

In summary, it is reasonable to hypothesise that occupant severity indicator ASI may be expected to increase as a function of:

- Decreasing vehicle mass;
- Increasing impact speed;
- Increasing impact angle;
- Increasing barrier stiffness.

The aim of this study is to present an argument that:

1. generic road safety barrier types cannot be categorised generically, but comprise a continuum of solutions in terms of barrier stiffness, and,
2. occupant injury risk as a function of barrier stiffness is similarly a continuum, and a function of the configuration (mass, speed and angle) of the impacting vehicle.

The objective of this study is to present a graphical analysis of the results of full scale crash testing to demonstrate that both occupant risk indicator ASI results and barrier stiffness are represented by a continuum and are not categorical.

Methodology

Vehicle mass, impact speed, impact angle, dynamic deflection and ASI are each recorded for 63 road safety barrier hardware crash tests sourced (mainly) from the FHWA website (US Department of Transportation Federal Highway Administration) supplemented with a small amount of other limited literature obtained generally from the public domain. This data is tabulated in Table 1. Impact severity for each impact is calculated in accordance with the expression at Equation 2 (Sicking & Ross Jr, 1986), and is measured in terms of energy.

$$IS = {}^{1}/_{2}\, m(v.\sin\theta)^2 \qquad \text{Equation 2}$$

where

IS = Impact Severity (kJ)

m = mass (t)

v = vehicle speed (m/s)

θ = angle of incidence (degrees)

In terms of road safety barrier characteristics, the term ‘stiffness’ represents resistance to deformation, which is also the decelerating force imposed on an impacting vehicle. And since energy is the product of force and distance, so barrier stiffness (as resistive force) is energy per unit of displacement. However, because rigid barriers by definition exhibit practically zero dynamic deflection and hence effectively an infinite stiffness which is inconvenient in calculation, the term ‘flexibility’ is coined here as the reciprocal of ‘stiffness’. For the purpose of this study, barrier ‘flexibility’ is calculated in accordance with the expression at Equation 3.

$$Flexibility = \frac{DD}{IS} \qquad \text{Equation 3}$$

where DD is dynamic deflection (m). Hence, ASI can be plotted against ‘flexibility’ for all 63 records.

Firstly, the data is disaggregated by generic barrier type, according to the following classifications:

- Bridge rail (BR);
- Transitions (TR);
- Strong Post W-Beam (SPWB);
- Thrie-beam (TB);
- Weak Post (WPWB);
- Wire rope (WR).

Secondly, the data is disaggregated according to the nominal configuration (mass, speed, angle) of the crash test. Three nominal crash test configurations (NCHRP Report 350 (Ross et al., 1993) and MASH (AASHTO, 2009) tests 3-10, 3-11 and 4-12) dominate the impact conditions in the data set. For the sake of this study, transition tests designated 3-21 and 4-22 are considered equivalent in terms of configuration to 3-11 and 4-12 tests respectively. Descriptive data of 60 of the 63 tests (three 1100 kg MASH 3-10 tests are omitted) are provided in Table 2.

Table 1. Crash test data (63 crash tests)

Type	Test ref.	Nominal test configuration	Mass	Speed	Angle	Dynamic deflection	ASI	Source[a]
BR	421323-1	4-12	8009	81.40	14.3	0.000	0.56	(Footnote[b])
BR	421323-2	3-11	2063	98.30	26.4	0.000	1.86	(Footnote[b])
BR	TTI 404251-2	3-11	2000	99.40	25.4	0.000	1.70	FHWA b066
BR	TTI 404251-3	4-12	8000	79.60	14.9	0.010	0.50	FHWA b066
BR	TTI 404311-1	3-10	820	100.00	20.8	0.000	1.80	FHWA b055
BR	TTI 404311-2	3-11	2000	100.70	25.8	0.040	1.66	FHWA b055
BR	TTI 404311-3	4-12	8000	78.70	14.9	0.005	0.51	FHWA b055
BR	418049-7	3-11	2000	101.40	24.8	0.005	1.50	FHWA b224
BR	400001-SCW1	3-11	2000	101.60	25.2	0.000	1.60	FHWA b073
TR	404211-12	3-21	2000	101.30	24.2	0.070	1.85	FHWA B065
TR	404211-9	3-21	2000	100.80	25.6	0.077	1.68	FHWA B077
TR	TTI 401181-1	4-21	2135	102.30	24.9	0.200	1.74	FHWA b146
TR	TTI 401181-2	4-21	2108	96.90	25.2	0.060	1.73	FHWA b146
TR	TTI 401181-3	4-22	8106	80.80	13.6	0.180	0.34	FHWA b146
SPWB	400001-CF11	3-11	2000	101.40	26.3	0.811	0.81	FHWA b080
SPWB	471470-26	3-11	2000	100.80	24.3	0.820	0.95	(Footnote[c])
SPWB	41-1655-001	3-11	1992	100.40	25.0	1.300	0.90	FHWA b080a
SPWB	41-1655-002	3-10	816	101.80	20.0	0.500	1.10	FHWA b080a
SPWB	53-0017-001	3-11	1995	99.70	25.0	0.900	0.70	FHWA b109b
SPWB	MGSNB-1	3-11	2273	100.90	24.7	0.867	0.86	(Footnote[d])
SPWB	MGSNB-2	3-10	1092[e]	101.40	25.5	0.740	0.97	(Footnote[d])
TB	220570-5	3-10	877	102.60	19.8	0.340	1.26	FHWA b148
TB	220570-6	4-12	8192	78.80	15.3	0.810	0.26	FHWA b148
TB	220570-7	3-11	2290	99.00	24.5	0.630	1.43	FHWA b148
WPWB	-	3-10	906[f]	101.70	20.0	1.020	0.63	FHWA b229
WPWB	-	3-11	2258	99.70	25.0	1.670	0.58	FHWA b229
WPWB	220570-4	3-11	825	102.10	20.3	0.490	1.05	FHWA b140
WPWB	57073101	3-10	837	102.20	20.3	0.680	0.66	FHWA b162
WPWB	57073112	3-11	2233	98.00	24.5	1.050	0.59	FHWA b162
WPWB	5707b3111	3-11	2053	100.50	24.5	1.150	0.56	FHWA b162
WPWB	570734121	4-12	8050	78.30	15.0	1.220	0.22	FHWA b162b
WPWB	102350.97.05.1.5.2	3-10	1110[e]	100.80	25.0	0.960	0.73	FHWA b229
WPWB	102350.97.05.1.5.1	3-11	2273	99.00	25.0	1.280	0.58	FHWA b229
WR	MIRA-99-436009	3-11	1999	99.40	26.0	2.400	0.36	FHWA b082[g]
WR	MIRA-99-436008	3-10	898	101.00	20.0	1.040	0.55	FHWA b082[g]
WR	400001-MSC2	3-11	2040	100.70	25.3	1.990	0.60	FHWA b096
WR	400001-TCR1	3-11	2045	100.60	24.2	2.400	0.37	FHWA b119
WR	400001-TCR2	3-11	2050	99.40	25.7	2.800	0.36	FHWA b119a
WR	MIRA-05-D0002	3-10	807	100.80	21.3	1.350	0.55	FHWA b082b
WR	400001-SFR4	3-11	2074	99.30	25.7	1.800	0.49	FHWA b096a
WR	-	3-10	827	100.20	20.0	0.762	0.66	FHWA b137

Type	Test ref.	Nominal test configuration	Mass	Speed	Angle	Dynamic deflection	ASI	Source[a]
WR	-	3-11	2065	102.40	25.0	2.620	0.33	FHWA b137
WR	400001-TCR8	3-11	2106	96.50	24.7	2.360	0.45	FHWA b141
WR	400001-SFR5	3-11	2123	98.10	26.4	2.310	0.42	FHWA b096a
WR	400001-TCR9	4-12	8196	82.50	14.1	2.205	0.14	FHWA b141
WR	MIRA-05-c0050	4-12	8050	79.70	15.8	2.210	0.18	FHWA b082b
WR	TR-P26021-01-A	3-11	2020	99.85	25.0	2.000	0.44	FHWA b137b
WR	TR-P26028-01-B	3-11	2020	101.50	25.0	2.800	0.44	FHWA b137b
WR	400001-TCR12	3-11	2102	102.60	24.9	3.410	0.40	FHWA b141b
WR	P26133-01	3-10	812	97.51	25.0	1.500	0.84	FHWA b137c
WR	P26133-03	3-11	2222	97.05	25.0	2.610	0.35	FHWA b137c
WR	P26133-04	3-10	845	101.63	20.0	1.430	0.63	FHWA b137c
WR	570723102	3-10	829	100.50	20.1	1.400	0.54	FHWA b167
WR	50724121	4-12	8050	84.50	15.0	2.290	0.15	FHWA b167
WR	570723118	3-11	2080	99.50	25.0	2.550	0.46	FHWA b184a
WR	400001-NSM10	3-11	2313	101.71	26.6	2.926	0.40	FHWA b193rev
WR	400001-NSM11	3-10	816	99.50	21.4	0.985	0.50	FHWA b193rev
WR	405160-11-1	3-11	2051	100.26	25.4	3.109	0.67	FHWA b227
WR	102350.02-6-311	3-11	2044	97.60	25.0	1.540	0.44	FHWA b222
WR	102350.02-6-412	4-12	8050	82.50	15.0	1.650	0.17	FHWA b222
WR	102350.02-6 T3	3-10	834.5	99.70	20.0	1.280	0.60	FHWA b222
WR	400001-TCR40	3-11	2288	100.58	25.8	2.926	0.36	FHWA b232
WR	400001-TCR41	3-10	1091[e]	74.35	26.1	2.286	0.72	FHWA b232

Footnotes

a. All FHWA references are sourced from FHWA website (US Department of Transportation Federal Highway Administration)

b. Alberson et al (2004)

c. Mak et al (1999) / Plaxico et al (2000)

d. Reid et al (2013)

e. MASH 3-10 tests employ a nominal 1100 kg vehicle impacting at a nominal 25 degree angle.

f. 906 kg is recorded as a gross test vehicle weight, rather than a test inertial weight.

g. MIRA test reports referenced in FHWA letter b082 made available by Queensland Department of Transport and Main Roads.

Table 2. Combined descriptive data for 60 of 63 crash tests (MASH 3-10 tests omitted)

Nominal crash test	Mass (kg)		Speed (km/h)		Angle (degrees)		Count
	Nominal	Range	Nominal	Range	Nominal	Range	
3-10	820	807 - 906	100	97.5 - 102.6	20	19.8 - 25.0	14
3-11	2000	1992 - 2313	100	96.5 - 102.6	25	24.2 - 26.6	36
4-12	8000	8000 - 8196	80	78.3 - 84.5	15	13.6 - 15.8	10

Limitations

Firstly, the study takes the crash test data at face value as is presented in the crash test summary sheets. For example, it may be that some of the mass/speed/angle data is reported as nominal values rather than accurately recorded.

Secondly, it is observed that the European and US methods for calculating ASI are subtly different (Naish & Burbridge, 2015). Further, Anghileri (2003) reports on variations in reported ASI from round-robin testing of ASI conducted at six European laboratories, suggesting that variations in both the tests themselves and the process of evaluation may be responsible for some variation in calculated/reported ASI value.

Results

The results of plotting ASI against 'flexibility' are depicted in Figure 1. Figure 2 depicts the same data disaggregated respectively according to the six generic barrier classifications nominated above. Figure 3 depicts the same data (with three records removed) disaggregated according to the configuration of the common nominal impact conditions (in terms of mass, speed and angle) adopted in the respective crash test.

With regard to Figure 1 and Table 3 it is apparent that the range of ASI values is broadest where the flexibility is zero (i.e., the barrier is most stiff). At the y-axis, ASI values range from 0.50 to 1.86. However, the spread of data generally diminishes as barrier flexibility increases.

Moreover, there is a diminution in the ASI values recorded as the impacted systems become less stiff. Figure 2 and Table 3 indicate (as should be expected) that there is a stiffness hierarchy in terms of barrier classification, ranging from bridge rail (stiffest) to wire rope (least stiff). And generally, the wire rope returns the lowest values of occupant risk indicator ASI, while bridge rail returns the highest values. Figure 3 indicates that increase in barrier flexibility is associated with a decrease in recorded ASI value for each of the three crash test configurations.

Most obviously there are three distinct bands of results. The ASI value for the nominal 8000 kg, 80 km/h, 15 degree tests clearly represent the lower bound of the results, whereas the results from the nominal 800 kg, 100 km/h, 20 degree tests generally represent the upper bound. Also notably, the results from the nominal 2000 kg, 100 km/h, 25 degree tests are generally sandwiched between the results from the two other test configurations, but it is evident that as barrier flexibility approaches zero (near to the y-axis) the ASI results from this test configuration appear to rise sharply.

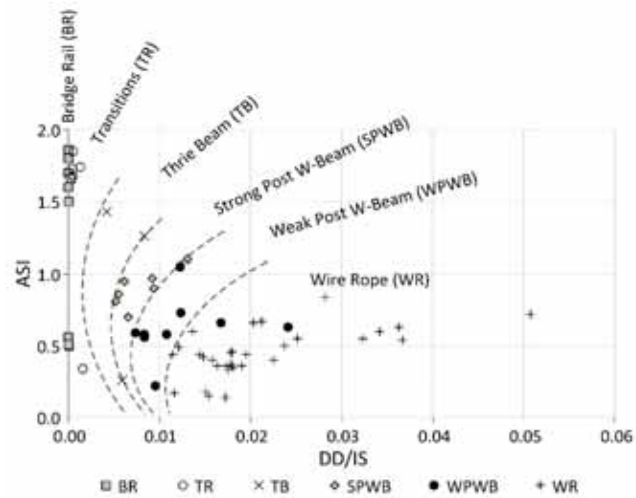

Figure 1. ASI v Flexibility (Dynamic Deflection/Impact Severity) for results from 63 crash tests

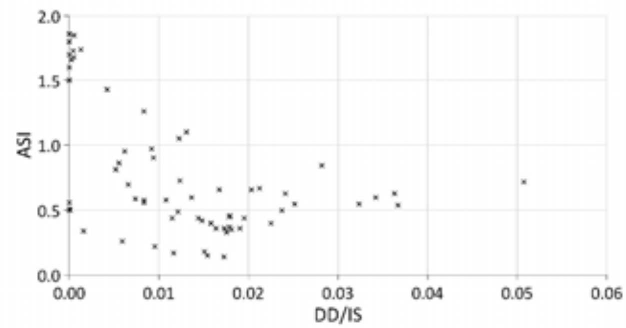

Figure 2. ASI v Flexibility (Dynamic Deflection/Impact Severity) for results from 63 crash tests disaggregated according to generic barrier classification

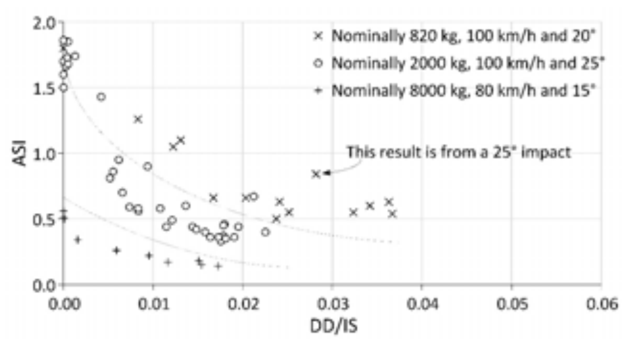

Figure 3. ASI v Flexibility (Dynamic Deflection/Impact Severity) for results from 60 crash tests disaggregated according to configuration of nominal impact conditions (mass, speed and angle)

Table 3. Summary of ASI results disaggregated by generic barrier type

	BR	TR	TB	SPWB	WPWB	WR
Max	1.86	1.85	1.43	1.10	1.05	0.84
Min	0.50	0.34	0.26	0.70	0.22	0.14
Count	9	5	3	7	9	30

Discussion

The results from all of the crash tests depicted in Figure 1 suggest that there may be a relationship between barrier flexibility and the ASI value recorded during crash testing, and moreover that ASI appears to be inversely proportional to barrier flexibility, perhaps represented by an exponential form. The results as depicted in Figure 3 reiterate this notion, but also suggest that the shape of the relationship curve is a function of the configuration of the impact. The results for the nominal 8000 kg, 80 km/h, 15 degree tests for example indicate a distinct decay curve, as do the results from the two other nominal crash test configurations. The following observations are apparent:

- ASI is highest for the lightest (kg) vehicle impacts (typically 100 km/h and 20 degrees).
- ASI is lowest for the heaviest (kg) vehicle impacts (typically 80 km/h and 15 degrees).

Notably the lowest values of ASI are also returned from impacts with the lowest impact speeds and highest for the highest impact speeds. Also, the effect of the flexibility (or stiffness) of the barrier is evident in the shape of the curve for each impact configuration. This is consistent with Anghileri, Luminari and Williams (2005) who report a "*weak correlation between … ASI and dynamic deflection*". In this regard, the following observations are suggested from the data:

- The shape of the ASI-flexibility curve is flattest for the lowest angle impact (15 degrees).
- The shape of the ASI-flexibility curve is steepest for the highest angle impact (25 degrees).

Together, these findings are consistent with the hypothesis proposed earlier that ASI may be expected to increase as a function of decreasing vehicle mass, increasing impact speed, increasing impact angle, and increasing barrier stiffness. Moreover, it is observed that the spread of occupant severity outcomes associated with more flexible systems is much narrower than the spread of occupant severity outcomes associated with stiffer systems, suggesting that occupant outcomes from impacts with more flexible systems are less susceptible to variation in the impact conditions than are occupant outcomes from impacts with stiffer systems. Further analysis of the effect of vehicle mass, impact speed, impact angle and barrier stiffness on the value of the occupant risk indicator is likely to be the subject of future work.

Apparent from Figure 2 is that barrier classifications are not fully discrete, but rather suggest some degree of overlap between systems. In the context of "*decompartmentalising road safety barrier stiffness*" the data suggests for example that weak post w-beam systems are likely to be more forgiving in terms of occupant injury than are strong post systems. Hence it is arguable that it is inappropriate to represent the spectrum of steel beam systems within a single barrier classification. At the other end of the steel beam spectrum, the data suggests that thrie beam and transition systems are generally less flexible than strong post w-beam systems and return higher values for the occupant risk indicator ASI. Since these are also steel beam systems, the point that it is inappropriate to represent the spectrum of systems within a single barrier classification is reiterated by the data. Indeed, it is arguable that combined, the suite of barrier solutions are better described by a continuum than the three generic barrier types 'concrete', 'metal' and 'wire rope'.

The results also suggest then that it would be appropriate in empirical studies of in-service performance to report the detail of the barrier in terms of the factors that might be expected to influence stiffness (for example post spacing, post type, rope configuration and tension).

Moreover, the results suggest that more specific detail about the impact configuration contributing to a given occupant outcome is necessary to make objective observations about the aggressiveness of any system.

Conclusions

The objective of this study was to present a graphical analysis of the results of full scale crash testing to demonstrate that both occupant risk indicator ASI results and barrier stiffness are represented by a continuum and are not categorical. This is achieved in Figure 2. The study has demonstrated that occupant risk measured in terms of ASI is likely to be a function of the speed, mass and angle of the impact as well as the stiffness of the system. The results suggest that it would be appropriate in empirical studies of in-service performance to report the detail of the barrier in terms of the factors that might be expected to influence stiffness of the system (for example post spacing, post type, rope configuration and tension) as well as the configuration of the impact (vehicle mass, impact speed and impact angle).

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