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MOTORCYCLES AND CRASH BARRIERS

Prepared for the NSW Motorcycle Council

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Preface

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The opinions expressed in this report are those of the authors and not necessarily those of the Motorcycle Council of NSW.

Contents

1. Introduction

This report has grown out of a need to better quantify the threat to motorcyclists from crash barriers within Australia. The available mass data for vehicle crashes in NSW gives an indication of the scope of the problem. There are about 60 motorcycle fatalities in the state each year, of which slightly less than half involved a single vehicle (RTA, 1996).

The aim of this report was to collect the data to assist in defining the requirements of crash testing to encourage the use of crash barriers more appropriate for motorcycles and their riders.

To achieve this aim, this report consists of the following sections:

- A review of published international and Australian papers of motorcycle crash studies;
- A comparison with the overall motorcycle crash situation in NSW.
- The methodology and results of an analysis of the NSW Coroners fatal motorcycle crash files for 1998 and 1999, a total of 113 cases, with special emphasis for those involving roadside objects;
- Detailed case studies of the fatal motorcycle cases, which involved crash barriers.

2. Review of Published Data

2.1 International Crash Study Data

Motorcycle crashes into crash barriers represent a small proportion of all motorcycle accidents, but a disproportionate number of motorcycle fatalities. In the United Kingdom, Department of Transport data indicates that 137 (0.3%) of the 41,451 motorcycle accidents reported in that year involved crash barriers yet they represented 14 (2.1%) of all motorcycle fatalities (BMF, 1998).

Similarly in Canada, collisions with crash barriers represented 34 (0.4%) of all motorcycle accidents but accounted for 2 (1.5%) of all motorcycle fatalities (Transport Canada 1980).

US Fatal Accident Reporting System FARS crash data shows that impacts with crash barriers account for 4.0% of fatal motorcycle impacts (NHTSA, 1989).

The situation in Australia for motorcycle fatalities involving crash barriers is similar. In a South Australian study of fatal motorcycle crashes 2.6% of fatal motorcycle impacts were found to involve initial impacts with safety barriers (ATSB, 2000). This same paper reported on the results of an analysis of Australian Coronial records for 1994-96, which identified 9 motorcyclist fatalities involving impacts with a crash barrier. This represents 2.4% of all motorcyclist fatalities during those years.

The proportion of motorcycle casualties as opposed to fatalities involving crash barriers in Australia appears to be slightly higher again. An in-depth study of 222 motorcycle casualty crashes in the Melbourne metropolitan found that 8 (3.6%) of the crashes involved crash barriers (ATSB, 2000).

2.2 Injury Incidence for Motorcycle and Crash Barriers in Australia

An estimate of the number of motorcyclist injuries in Australia resulting from motorcycle impacts with crash barriers can be obtained by extrapolating from traffic accident data and the results of the Australian investigations cited above. National road accident data indicates that 2,826 motorcyclists were hospitalized and a further 199 killed in 1992 (FORS, 1992). In addition, NSW data from police reports indicates that the number of motorcycle injuries has stabilized in this state since 1992 with approximately 50-60 killed, 630-640 seriously injured and 1,200-1,300 suffering minor injury (RTA, 1995).

NSW roads consistently account for approximately 30% of Australian motorcycle fatalities (RTA, 1995) and for 25% of motorcyclists seriously injured (FORS,1992). Using the figures of 2.5% and 3.6% for the proportion of motorcyclist fatalities and casualty admissions respectively involving crash barrier impacts, we can obtain an indication of the annual number of motorcyclists injured in crashes, which involve impacts with crash barriers. The calculations are outlined below:

No. Killed	50-60	x	2.5%/30%	=	4-5
No. Seriously Injured	630-40	x	3.6%/25%	=	91-92
No. of Other Injured	1,200-300	x	3.6%/25%	=	173-187

Alternatively using the 1992 Australian data the proportions killed or injured in collisions involving crash barriers are estimated to be:

No. Killed	199	x	2.5%	=	5
No. Hospitalized	2,826	x	3.6%	=	101

Reasonable minimum estimates of the numbers of motorcyclists killed and seriously injured in motorcycle impacts involving crash barriers in Australia therefore, would be 5 fatalities and 90 to 100 seriously injured per year. The estimate of 180 for those otherwise injured in motorcycle crashes involving crash barriers should be treated cautiously as the proportion of the number of other injured motorcyclists resulting from crash barrier impacts is derived from studies of casualty impacts. Nevertheless, it is reasonable to assume that the number of 'other' injured motorcyclists is significantly greater than the number seriously injured in crashes involving safety barriers.

A number of motorcycle crash studies shed some light upon the issues involved in minimising injury to motorcyclists involved in impacts with crash barriers. The existing research can be divided into crash investigation studies and crash barriers testing.

2.3 Crash Investigation Studies

Introduction

Real world crash investigations relevant to motorcycle impacts with crash barriers have been conducted by Domhan (1987), Hell and Lobb (1993); Ouellet (1982); Otte (1994); Quincey et al (1988); and Transport Canada (1980). The study, on which the paper by Ouellet (1982) was based, by Hurt et al (1981) was amongst the first to specifically raise the issue of motorcyclist impacts with crash barriers.

Ouellet (1982)
The Hurt et al (1981) study was of 900 motorcycle impacts in the Los Angeles area and was conducted over a 5 year period. Other reviewers have made the comment that the study was "well designed, the fieldwork was careful and conscientious and a very valuable report produced" (Ryan and McLean, 1988). The study used a formal sampling technique, monitoring of the notification system, with alterations made to ensure a useful sample and a control group of riders to obtain predisposing factors to the crashes. It does however, now suffer from being out of date.

In a paper based on this research (Ouellet, 1982), the author noted that 63 (or 7%) of the 900 motorcyclist crashes involved bodily (excluding head and neck) contact with a crash barrier. Six (10%) of the 59 rider fatalities involved bodily impacts with W-beam safety barriers and metal mesh fences. He noted that crash barriers are relatively more dangerous than motorcycle crashes generally. There were 9.5 fatalities per 100 motorcyclist impacts with crash barriers as opposed to there being 6.6 deaths per 100 motorcycle crashes generally.
While most impacts involved 2 or more surfaces, the study found that AIS3+ injuries occurred in 46% of crashes involving the rider's body (excluding the head and neck) directly impacting trees or poles, 30% with barriers and 4% of body impacts to the road or pavement. A similar pattern is shown for head and neck impacts with 41%, 34% and 16% of head or neck impacts with poles/trees, barriers and the pavement respectively being associated with AIS3+ injuries[1]. Ouellet suggests that the reason for the greater severity of injuries presented by barriers and posts or trees is that they often present rigid surfaces that are perpendicular to the motion of the rider.

The study further indicates that in the case of head impacts, barriers are particularly injurious when compared to other fixed objects. The author notes that AIS3+ injuries occurred in 66% of head impacts with barriers as opposed to 59% head impacts with trees or poles and 19% of head impacts with the pavement. More details of the injury

[1] The Abbreviated Injury Scale or AIS is a standard method of categorising injury type and severity, AAAM (1990). The injury severity levels range from AIS1or minor injury through AIS3, which is serious injury, to AIS6 or maximum injury.

distribution associated with body and head-neck contacts with these surfaces are given in Figures 1and 2.

Figure 1 Proportion of Motorcyclists with Head or Neck Injuries from Impacts with a Class of Object in each Injury Severity Category, from Ouellet (1982).

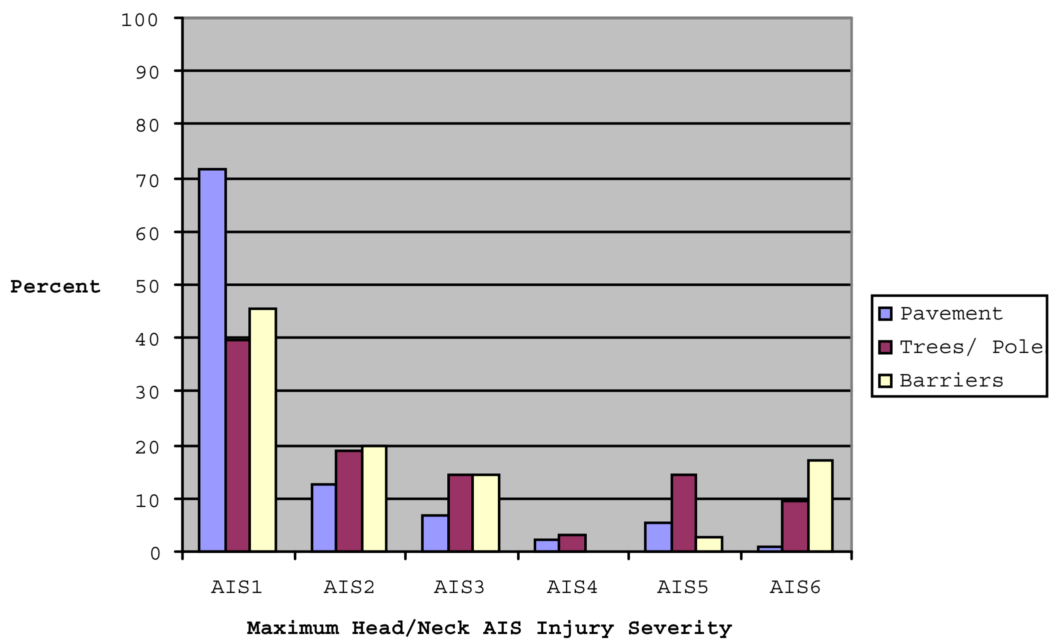
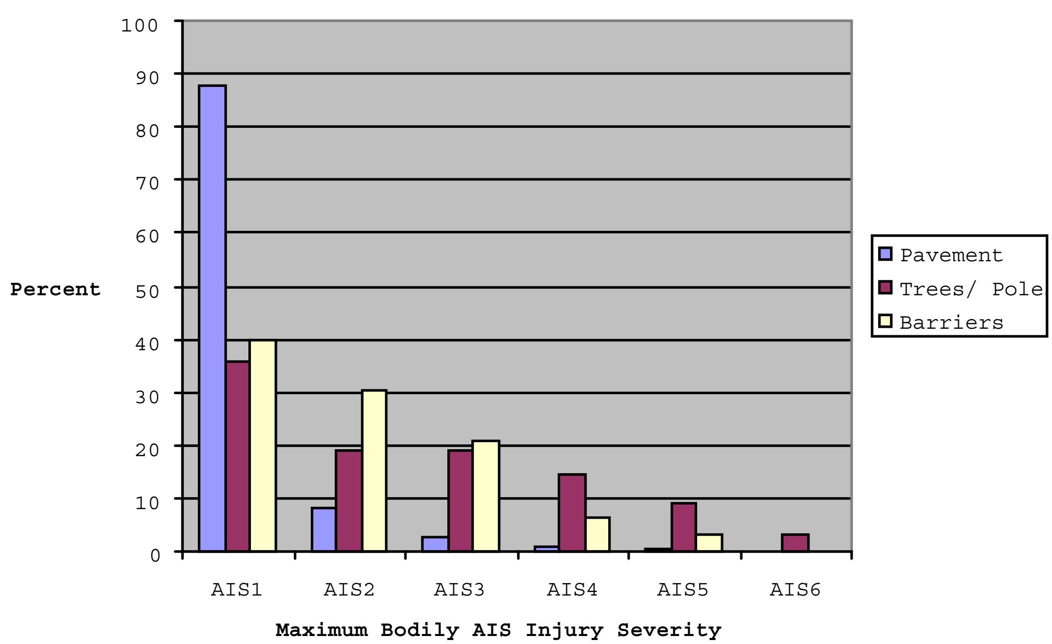


Figure 2 Proportion of Motorcyclists with Bodily (not Head and Neck) Injuries from Impacts with a Class of Object in each Injury Severity Category, from Ouellet (1982).



The author (Ouellet, 1982) observed that every rider that struck a W-beam or metal mesh barrier in their accident investigation suffered at least multiple extremity fractures. In W-beam barrier impacts the motorcyclists tend to strike the barrier “at a shallow angle, and fall and tumble along the tops of the posts”. Alternatively, if they slide into the barrier, they “tumble along striking the bases of the posts”. In the wire mesh barrier impacts the "mounting posts cause the most severe injuries, either by deceleration of the torso or by fractures of the extremities. Ouellet also suggests that the least injurious safety barriers for motorcyclists are smooth concrete barriers, which present no protruding surfaces to the motorcyclist in a crash.

Domhan (1987)

A later paper by Domhan (1987) confirms many of the observations made by Ouellet about crash barriers. In his paper on crash barriers and passive safety of motorcyclists in Germany he reports upon real world data regarding motorcyclist impacts with crash barriers in Germany. The author indicates that German freeways are fully equipped with median barriers (generally using double W-beams with frangible posts) and side crash barriers are in place along 30% to 35% of the length of these roads. He quotes from studies into motorcycle accidents in two regions of Germany by the Federal Road Research Institute (BASt).

In 1984, in the non-metropolitan areas of one region of Germany out of the 2,793 motorcycle crashes studied. Seven motorcyclists were killed (32 per 100 crashes) in 22 motorcycle crashes involving crash barriers; compared with only four fatalities (13 per 100 crashes) out of 30 for the remaining crashes involving fixed objects, and a total of 44 fatalities (1.6 per 100 crashes) recorded for the study.

The severity of injuries incurred by motorcyclists impacting crash barriers was confirmed by the other BASt study also reported on by Domhan. In this study of 207 motorcyclists, injured in a region with a hilly landscape, three out of 50 motorcyclists impacting crash barriers were killed and 31 severely injured. Less than one third escaped with light injuries.

Transport Canada (1980)

A third study provides more specific evidence as to the types of impacts that are most injurious to motorcyclists. A Transport Canada (1980) analysis of motorcycle crash data in Canada during April to September 1980 provides information upon the frequency and importance of fixed objects as a source of injury to motorcyclists. In particular, 1974 data from Ontario's road accident database (TRAID) provides more detailed information upon the number of fatal and non-fatal motorcyclist impacts with different types of fixed objects.

The data from this report indicates that the most injurious types of objects for a motorcyclist to hit are, in order; posts, trees, poles, crash barriers, and culverts/kerbs, see Table 1 below. Five (15%) of the 34 motorcycle-to-post impacts involved fatalities

Table 1 Motorcyclist Collisions with Fixed Objects in Ontario, from Transport Canada, 1980.

Fixed Object	Fatal Crashes	Proportion of Crashes with Object Type (%)	Total Crashes with Object Type
Post	5	14.7	34
Tree	2	8.7	23
Pole	3	6.7	45
Crash Barrier	2	5.9	34
Culvert/Kerb	3	3.6	84
Wall/Bridge Pier	0	0.0	7
Other	4	5.0	80
TOTAL	**19**	**6.2**	**307**

as compared to 2 (6%) of 34 crash barrier impacts and 3 (4%) of 84 'kerb or culvert' impacts. A motorcyclist hitting a post in Ontario therefore has approximately a 1 in 7 chance of being killed compared to 1 in 17 on impacting a crash barrier and less than 1 in 25 on impacting a 'kerb or culvert'.

Quincey et al (1980)

Quincey et al (1980) conducted a 3-year on-site investigation of motorcycle impacts with crash barriers on 940km of rural and 70km of urban highways in France over the period 1978-1979. Median barriers spanned the entire length of both types of highway and roadside crash barriers were placed on 40% of the length of the rural and 62% of the urban highways.

The investigation found that the severity of injuries for motorcyclists impacting crash barriers was generally greater than with other types of motorcycle crashes. In the 27 motorcycle crashes into crash barriers on rural highways the following occurred. Eight motorcyclists were killed (30 fatalities per 100 crashes) and 23 injured (85 injuries per 100 crashes) compared to 11 killed (4 per 100 crashes) and 183 injured (72 per 100 crashes) for other types of motorcycle crashes.

A similar result was obtained on urban motorways although the numbers of fatalities and injuries per crash were somewhat lower probably because of the lower speed limits on these roads. On these roads four were killed and injured (11 per 100 crashes) out of 38 motorcycle crashes with an initial crash barrier impact compared to 2 (2 per 100 crashes) for all other types of motorcycle crashes investigated. Put simply, these figures suggest that motorcyclists were over 5 times more likely to be killed or seriously injured in impacts with crash barriers than in other types of crashes on these roads.

This study also showed that motorcyclists struck crash barriers in different ways, for the 38 fatal barrier impacts:

- 16 (42%) impacted the crash barrier while riding their bike,
- 13 (34%) slid into the crash barrier with their bike, and
- 9 (24%) slid into the crash barrier after separating from the bike.

In a majority of fatal barrier crashes (58%) the rider slide into the barrier, having come off the motorcycle.

Further evidence into the manner in which motorcyclists impact crash barriers is available from the Australian fatal accident database for 1992 (FORS, 1992). This data indicates that approximately 25% of Australian fatal motorcycle accidents are the result of running off the road at a bend and another 10% running off straight roads. This together with the results of the Quincey et al study, indicates that the typical fatal motorcycle impact with a crash barrier involves the rider loosing control on a bend and sliding out into a barrier.

Hell and Lobb (1993)

Hell and Lobb (1993) investigated 173 motorcycle crashes around Munich involving at least minor injuries to motorcycle riders during 1985-90. Crashes were reported by the Bavarian police and were reconstructed and categorized by type of impact, the injuries incurred by the rider(s) and the safety apparel worn following on-site investigation.

Hell and Lobb's figures for motorcyclists with AIS2+ injuries to various body regions in crashes are reported in Table 2. The crashes were of greater injury severity than the average police-reported motorcycle crash in Germany with 50 (24%) of the 210 motorcyclists being killed in the study as opposed to 2% of riders in police-reported crashes in Germany. Nevertheless, the study does indicate that the most likely areas

Table 2 Number and Proportion of Motorcyclists in Different Types of Casualty Crashes in Bavaria with AIS2+ Injuries to Specified Body Regions, from Hell and Lobb (1993).

Body Region	Collisions with Fixed Objects		Free Slipping or Sliding Crashes		Motorcyclists in all Accidents	
Total Riders in Crash Type	N = 27		N = 35		N = 190	
	No.	%	No.	%	No.	%
Head	17	63	7	20	81	43
Thorax	13	48	3	9	48	25
Abdomen	5	19	3	9	30	16
Pelvis	2	7	1	3	15	8
Spine	9	33	3	9	23	12
Upper Extremities	10	37	6	17	57	30
Lower Extremities	10	37	5	14	70	37

of the body to be injured for motorcyclists in collisions are (in order) the legs, head, and thorax. In motorcyclist collisions with fixed objects the chances of AIS2+ injuries to the spine were trebled whilst the chances of AIS2+ injuries to the thorax were doubled and those to the head were increased by 50% above the chances of similar injuries in motorcycle crashes generally.

Otte (1994)

Otte (1994) analysed a the results of a similar study, but with an emphasis upon leg injuries. This research involved the investigation of 496 motorcycle accidents by a multi-disciplinary team from the Accident Research Unit, Hanover during 1985-1992. The motorcycle crashes were documented and classified by the type of crash, injuries sustained and, the presence or absence of leg fairings according to a random sampling plan. The results were then evaluated using a statistical weighting procedure to ensure that they represented all motorcycle accidents in Germany.

A difficulty with this paper is that it does not distinguish between solo crashes involving impacts with fixed objects and solo crashes not involving impacts with fixed objects. Despite this it indicates that the likelihood of AIS2+ head and thorax injuries are increased by over 50% and 100% respectively in solo collisions (including impacts with fixed objects) as opposed to both collisions with cars and solo collisions as a group.

Table 3 Proportion of Motorcyclists in Different Crash Types with and without Leg Protection having AIS2+ Injuries to Specified Body Regions of the Body, from Otte (1994).

	Motorcycles with Leg Fairings		Motorcycles without Leg Fairings	
Body Region	**Solo and Fixed Object Crashes**	**Car and Solo Crashes**	**Solo and Fixed Object Crashes**	**Car and Solo Crashes**
Total	N = 19	N = 89	N = 62	N = 249
Head	13.4%	8.2%	11.8%	6.9%
Thorax	22.3%	10.8%	13.1%	6.8%

2.4 Motorcycle and Crash Barrier Testing

Quincey et al (1988)

The final area of research reported in the literature is dummy and human cadaver tests of crash barriers. Quincey et al (1988) tested three types of crash barriers with dummies. The dummy was laid upon its back with its head forward on a platform. The platform was accelerated to 55km/h at a 30-degree angle to the crash barrier. It was then stopped so that the dummy slid 2m before impacting the barrier. The three crash barrier types tested included: a lowered W-beam barrier, one with a beam covering the lower posts and a concrete barrier. The Head Injury Criteria[2] values were 110 for the concrete barrier and 175-365 for each of the double crash barriers tested - although the 3ms clipped head accelerations were greatest for the concrete barrier.

Domhan (1987)

Impact attenuators for crash barrier posts have also been designed and tested in Germany. The attenuators are post coverings composed of neoprene and were tested at the Heidelberg University Institute for Forensic Medicine. The results of the tests indicated that 35km/h impacts with IPE-100 crash barrier posts resulted in severe injuries of AIS4 level, whereas the posts covered with attenuators resulted in injuries of only AIS1 to AIS2 (Domhan, 1987).

ISO Standards

More recently the International Standards Organisation has developed a standard for the methodology to be used when crash testing of motorcycles and protective equipment and analysing the results (ISO, 1996). This standard is very comprehensive, and includes a specialised adaptation of the Hybrid III crash test dummy (Zellner et al, 1996). It also proposes a means of calculating the cost to society of the injuries to the motorcyclist derived from the dummy responses (Kebschull et al, 1998). The standard has been used for motorcycle/car type impacts; as yet it has not been applied to crash barrier evaluation.

[2] The Head Injury Criteria limit, for when significant head injury will occur, is usually taken to be 1000.

The ISO standard has been built around a significant amount of development testing. This experience with motorcycle/vehicle impacts has shown that several factors need to be considered when designing the crash testing with motorcycles for it to be of value and be able to show correlation with real crashes. A motorcycle crash is more complex than a vehicle crash as the critical impact is between the rider and the object, not between the motorcycle and the object. A typical motorcycle crash therefore has several stages and each stage must be accurately reproduced. The major injuries often occur after the initial impact between the motorcycle and the barrier, and are due to the secondary impact between the rider and another fixed object such as the road surface, a pole or a part of the barrier.

2.5 Discussion

The literature review indicates that most motorcycle collisions with crash barriers occur at shallow angles with the rider typically sliding into the barrier at a bend (Quincey et al, 1988) and (FORS, 1992).

Approximately 60% of fatal motorcycle collisions with crash barriers involve the rider sliding with or without their bike into the barrier (Quincey et al, 1988). In the other 40% the rider remains upright on the motorcycle.

The severity of injuries to motorcyclists are greater for collisions with fixed objects than with other vehicles and even greater than for crashes in which the rider(s) run off or slide along the road (Domhan, 1987), (Quincey et al, 1988) and (Transport Canada, 1980). Ouellet (1982) suggests that the reasons for this are :

- The rigidity of these objects; and,
- The velocity component perpendicular to the impacting surface is greater than in many other types of collisions.

The probability of being killed as a result of impacting a crash barrier is more than double that for motorcycle crashes generally. The likelihood of incurring fatal injuries upon impacting an object, however, is greatest for posts then, trees, poles, crash barriers and kerbs (Transport Canada, 1980). Although Ouellet's (1982) research suggests that severe head injuries (AIS3+), are much more likely following a head impacts with a crash barrier, than in head impacts with any of the other fixed objects mentioned above.

The chances of injury upon hitting a fixed object appear to be related to the impact area and the rigidity of the object. Thus impacts with small rigid objects such as posts are more likely to cause injury than impacts with trees or walls because the small impact area increases the stress upon the impacted portion of a motorcyclist. This has been supported both by dummy tests (Domhan, 1987) and (Quincey et al, 1988) and real world crash data (Transport Canada, 1980).

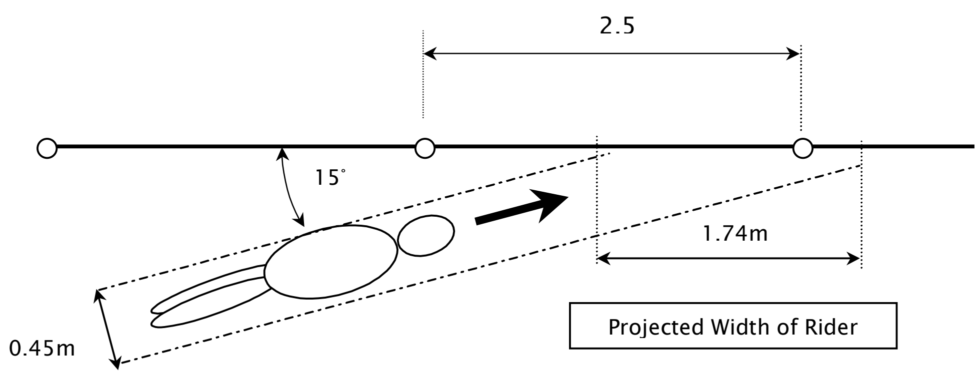
Another factor in the severity of injuries experienced by motorcyclists is the portion of the body struck in a crash. The most likely areas of the body to be injured for motorcyclists in collisions are in order, the legs, head, and thorax (Hell and Lobb, 1993). In motorcyclist collisions with fixed objects however, the chances of AIS2+ head, thorax and spinal injuries are increased far more than for other regions of the body - by over 50% for the head and over double for the chest and spine. (Hell and Lobb, 1993) and (Otte, 1994). This suggests that another factor behind the greater severity of injuries incurred by motorcyclists in barrier crashes may be that they are more likely to strike vital regions of the body.

Ouellet (1982) suggests that for those riders remaining upright on impact with crash barriers (about 40% from Quincey et al, 1988), most injuries occur when, after the shallow impact with the safety barrier, the rider slides and tumbles along the tops of the posts supporting the safety barrier. For those riders who have come off the motorcycle (about 60% from Quincey et al, 1988) before impact with crash barriers, most injuries occur as the rider slides and tumbles along the base of the posts. This is a concern for wire rope safety fences, which require a greater number of posts per length. The smaller gaps between the posts in the wire rope safety barriers are likely to lead to more direct impacts with the supporting posts.

The Flexfence wire rope safety barrier used in Victoria has one post every 2.5m (VICRoads, 1998) and more of each post is exposed in these barriers than the more traditional W-beam safety barriers. A rider is more likely to experience a direct impact with a post.

An illustration of this is provided by considering such a shallow barrier impact, see Figure 3. If it is assumed that the rider slides into the crash barrier at an angle of 15 degrees. The minimum width of a rider is 45cm, when they are sliding lengthwise on their back, head or feet first, into the barrier as illustrated below. In this situation the rider has a 70% chance of directly impacting a barrier post. The chance is still greater for riders sliding or rolling sideways or impacting at even shallower angles.

Figure 3 Projected Width of the Motorcyclist into a Crash Barrier in a Shallow Angled Impact



This is particularly undesirable given that impacts with posts were found to be the most likely to cause severe injuries than impacts with any other types of fixed object. Given that wire rope barrier fences are generally installed on straight roads in Australia (ATSB, 2000), it is probable that most impacts would be at an angle of less than 30 degrees. The likelihood of riders severely injuring themselves should they run off the road would therefore be high with a probability of hitting a post being greater than 35% for 30 degree angle impacts and over 70% for 15 degree angle impacts. The likelihood of death and severe injury upon hitting these the posts would in turn be greater than 14.7% (from Transport Canada, 1980) and over 50% (from Ouellet, 1982) respectively. These figures do not take into account rope only impacts where the likelihood and severity of impacts by motorcyclists is unknown.

The Flexfence wire rope safety barriers used in Victoria are tensioned to 80kN and deflect 1.3m when impacted at 110km/h by a 1.5 tonne vehicle (VICroads, 1988). The barrier will act as a rigid barrier when impacted by a motorcyclist.

The work by Ouellet found that the motorcyclists usually had impacts with several surfaces, and this is supported by data from the NSW fatal case review, where the post barrier impact trajectory of the rider was significant with regard to injury causation. The dummy must be able to respond to the crash with a realistic trajectory post impact. It must also be possible to accurately assess the likely injury from the dummy responses. If these requirements of biofidelity for the dummy[3], are not met then any comparison between different barrier types will most likely be poor, due to non repeatable test results.

[3] Biofidelity is the ability of the dummy to act in a human-like manner.

3. Fatal Motorcycle Crashes – NSW

3.1 Methodology

Data was obtained from the NSW Coroner files for all fatal motorcycle crashes for the years 1988-1989. Information was obtained upon 102 of 113 motorcycle fatalities, which involved 100 out of 111 separate crashes in that period. Some files were unavailable due to the coronial investigation not yet being completed. Where available, information from the files was obtained and coded to provide a description of the conditions, type of crash and the injuries incurred. See Appendices for a sample coding form. Particular attention was paid to impacts with fixed objects and those impacts involving crash barriers, and roadside posts, fences and walls.

3.2 Analysis

A summary of the crash types overall is provided in Table 4.

Table 4 Motorcycle Fatalities in NSW, 1998-99.

Crash Type	Description of Crash		Fatal Crashes
M/C and Moving Object	M/C on Straight Road	M/C on Wrong Side of Road	15
		Other Vehicle on Wrong Side of Road	5
		Vehicle and M/C on Correct Side of Road	7
		Vehicle Turning	6
	M/C at Intersection	M/C Turning	0
		Vehicle Turning	14
		Vehicle and M/C Continuing in Straight Path	5
	Sub-Total		**63**
M/C and Fixed Object			39
Other		Off Road	9
		Don't Know	2
Incomplete			9
	Total		**113**

Sixty-three of the fatalities involved another vehicle, 39 a fixed object, nine were just off the road, two were unknown and nine were incomplete.The impacts with a fixed object are summarised in Table 5 in terms of the initial impact, and in Table 6 in terms of the most likely fatal impact.

Crash barrier impacts were involved in 8 (8%) of all motorcycle fatalities for which data was available in this period. In addition, a further 9% were the result of impacts with fences, posts, or walls. They formed a part of the 39 motorcycle fatalities, which involved impacts with fixed objects representing 39% of all motorcycle fatalities for which data was available. Crash barrier impacts featured in one fifth of these types of crashes.

The fixed objects most frequently hit first were kerbs or culverts, followed by crash barriers, representing 9% and 8% respectively, of all fatal motorcycle accidents for which data was available. Impacts with trees and telegraph poles however, were more likely to be identified as responsible for the fatal injuries incurred in motorcycle accidents than kerbs/culverts and crash barriers. This is primarily due to the fact that motorcyclists frequently hit other objects after an initial impact with a kerb or crash barrier making it difficult to determine the cause of their most serious injuries.

The crash data also indicates the most likely scenarios for impacts with crash barriers. All except one of the impacts with crash barriers were with w-beam barriers. The other fatality involved a concrete median barrier, which the rider impacted first before sliding past the end of the barrier and into a signpost and oncoming traffic. This confirms the findings from the literature review, which indicated that concrete barriers are safer for motorcyclists than W-beam barriers.

It is also clear from the tables that impacts with crash barriers are more likely to be the result of motorcyclists running off the left hand (passenger) side of the road than in impacts with any other fixed object. Five of the eight fatalities involving crash barriers came about in this way, whereas only one arose from riders crossing the right hand side of the road or median strip and one from impacts with crash barriers at intersections. The majority of the fatal impacts were at relatively shallow angles with respect to the crash barriers. This is supported by a more detailed analysis of the crash barrier

Table 5 Initial Impacts For Motorcycle Fatalities Involving Fixed Objects, NSW 1998-99

Object Impacted	Off LHS of Road	Off RHS of Road	Intersection/ Roundabout	Off Road Driving	DK/ Other	TOTAL
Crash Barrier	4	1	1			**6**
Crash Barrier Post	1				1	**2**
Kerb, Culvert or Median Strip	3	1	4		1	**9**
Fence	1				1	**2**
Ground Only		1			1	**2**
Other					1	**1**
Post		2		2	1	**5**
Telegraph Pole	1					**1**
Tree	2		1	1	2	**6**
Vehicle/Bike					2	**2**
Wall						**0**
Wire (fence)	1	1		1		**3**
TOTAL	**13**	**6**	**6**	**4**	**10**	**39**

Table 6 Fatal Impacts For Motorcycle Fatalities Involving Fixed Objects, NSW 1998-99

Object Impacted	LHS of Road	RHS of Road/Lane	Intersection	Off Road Driving	DK or Other	TOTAL
Crash Barrier	2		1			**3**
Crash Barrier Post	1				1	**2**
Kerb, Culvert, Median Strip						**0**
Fence					1	**1**
Ground Only		1			1	**2**
Other						**0**
Post		1		2		**3**
Telegraph Pole	2					**2**
Tree	1		2	1	3	**7**
Various/Unknown	5	2	2		4	**13**
Vehicle/Bike	2	1	1	1		**5**
Wall						**0**
Wire (fence)		1				**1**
TOTAL	**13**	**6**	**6**	**4**	**10**	**39**

impacts with 5 out of eight fatalities arising from impacts at an angle of 45 degrees of less. Given the shallow angle of most impacts it is not surprising that two of the eight fatalities arose from impacts with crash barrier posts as a shallow impact increases the likelihood of a direct impact with any barrier posts.

In addition the fatal cases indicate the kinematics of the riders prior to the impact with crash barrier. Two of the eight riders were airborne prior to impact and one slid into the barrier. Three of the remaining riders were riding their motorcycles at impact and the kinematics of the remaining two riders could not be determined from the records.

The most frequent type of fatal impacts with crash barriers occurred when the rider lost control on a right hand bend and impacted the barrier on the left-hand side of the road. As would be expected from the literature most crash barrier impacts were at shallow angles.

The speed of the motorcycle at impact is difficult to determine accurately from the files but two measures are available; the police estimate and the speed limit in the area of the crash. Both these indicate that the impacts, which result from loss of control on a corner, occurred at speeds above 60 km/h.

The case studies of fatal motorcycle crashes with barriers are included, in Appendix 1. These confirm that most fatal injuries are the result of impacts with some other object rather than the crash barrier beam (or solid concrete in concrete crash barriers), such as a crash barrier post, some other post/pole, a vehicle or a heavy impact with the ground. To protect motorcyclists, crash barriers need to protect the rider from:

- Impacts with any supporting posts; and
- Subsequent impacts with other vehicles, or other fixed object.

4. Summary

The literature review indicated that:

- The probability of a motorcyclist being killed as a result of impacting a crash barrier is more than double that for motorcycle crashes generally;
- The chances of injury upon hitting a fixed object appear to be related to the impact area and the rigidity of the object. Hence small rigid objects such as posts are most likely to cause injury;
- The severity of injuries experienced by motorcyclists depends on the portion of the body struck in the crash;
- Most motorcycle collisions with crash barriers occur at shallow angles with the rider typically sliding into the barrier at a bend (Quincey et al, 1988) and (FORS, 1992);
- For those riders remaining upright when impacting the crash barriers, most injuries occur when after shallow impact the rider slides and tumbles into the tops of the supporting posts (Ouellet, 1982); and,
- For those riders not remaining upright, most injuries occur when after shallow impact the rider slides and tumbles into the bottom of the supporting posts (Ouellet, 1982).

A study of fatal motorcycle crashes in NSW has shown that:

- Fatal impacts with crash barriers occurred most frequently when the rider lost control on a right hand bend and impacted the barrier on the left hand side of the road;
- Most crash barrier impacts were at shallow angles;
- Fatal injuries were most likely to result from impacts with some other object rather than the crash barrier beam (or solid concrete in concrete crash barriers), such as a crash barrier post, some other post/pole, a vehicle or a heavy impact with the ground;
- The speed of the motorcycle at impact is difficult to accurately assess, but is greater than 60 km/h.

Motorcycle mpacts with crash barriers are estimated to be the cause of 5 fatalities and 100 seroius injuries each year in Australia. The only method available for assessing the safety implications for motorcycles of existing and new crash barrier designs is to carry out full scale crash testing. A test method has been developed by the International Standards Organisation (ISO, 1996), which is designed for assessing protective devices for motorcyclists. This standard presents an approach which is suitable to use as the basis for testing motorcycle impacts with crash barriers.

In summary, the requirements for a test to ensure adequate protection to motorcyclists impacting a crash barrier are as follows:

- Shallow impact angle, between 15° and 45°;
- A helmeted dummy with appropriate biofidelity, to be able to accurately simulate post impact kinematics of the rider with adequate biomechanical responses;
- A minimum of two test configurations are needed with a surrogate motorcyclist (or dummy):
    1. mounted on an upright motorcycle; and
    2. sliding on the ground without the motorcycle;
- Speed of the motorcycle should be greater than 60 km/h.

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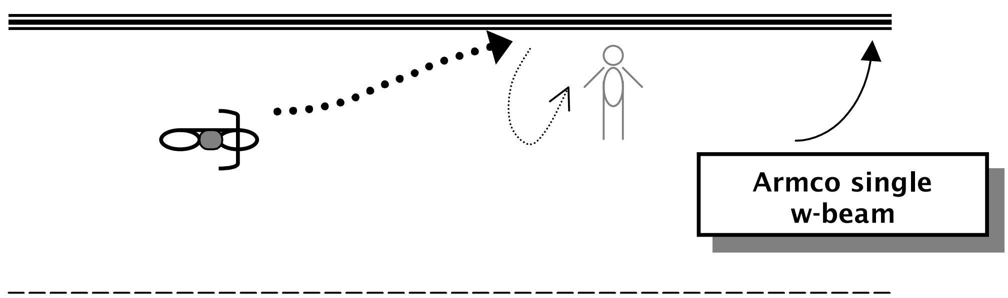
APPENDIX 1 - Fatal Crash Case Studies

The following case studies are based on the NSW Coroner's reports into fatal motorcycle crash barrier impacts in Australia during 1998 and 1999. They highlight some of the most salient aspects of motorcycle impacts with roadside objects. The most frequent type of fatal motorcyclist impact with a crash barrier was where the rider lost control on a right hand bend and impacted a barrier on the left hand side of the road.

Case 1

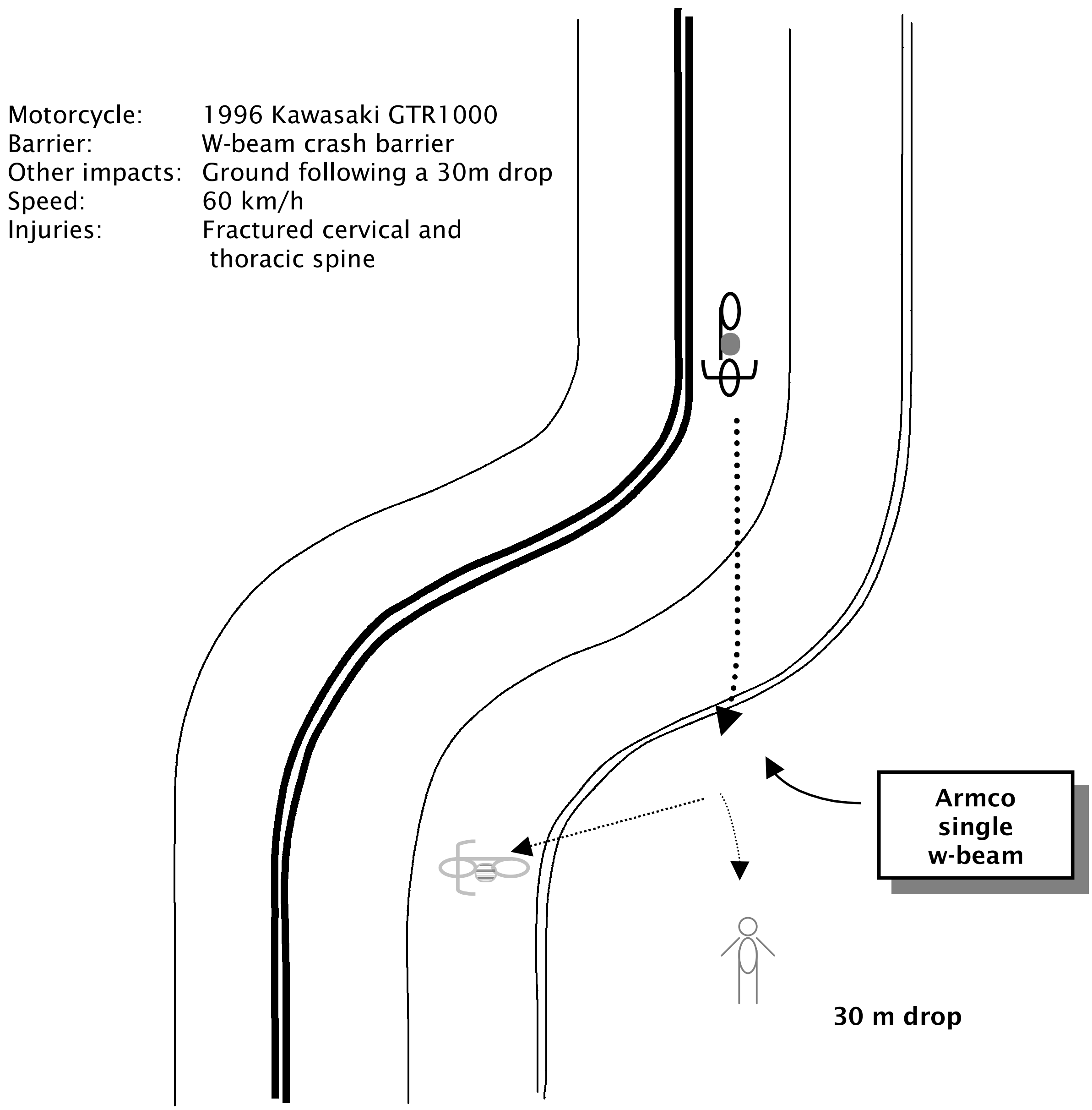
A motorcyclist rode into a crash barrier at between 70 and 80 km/h and an angle of impact of approximately 30 degrees on the left-hand side of a straight section of road. The rider was thrown into the air and then landed on the road. The rider was riding without a helmet and it is unclear whether the major injuries were sustained upon impact with the crash barrier or the ground.

Motorbike:	Honda 250cc Trail bike
Barrier:	W-beam crash barrier
Other impacts:	Ground after being thrown up into the air.
Speed:	70-80 km/h
Injuries:	Extensive skull fracture, subaponeurotic bruising and sub-dural haemorrhage, Comatose, CPR applied.
Other:	No helmet worn



Case 2

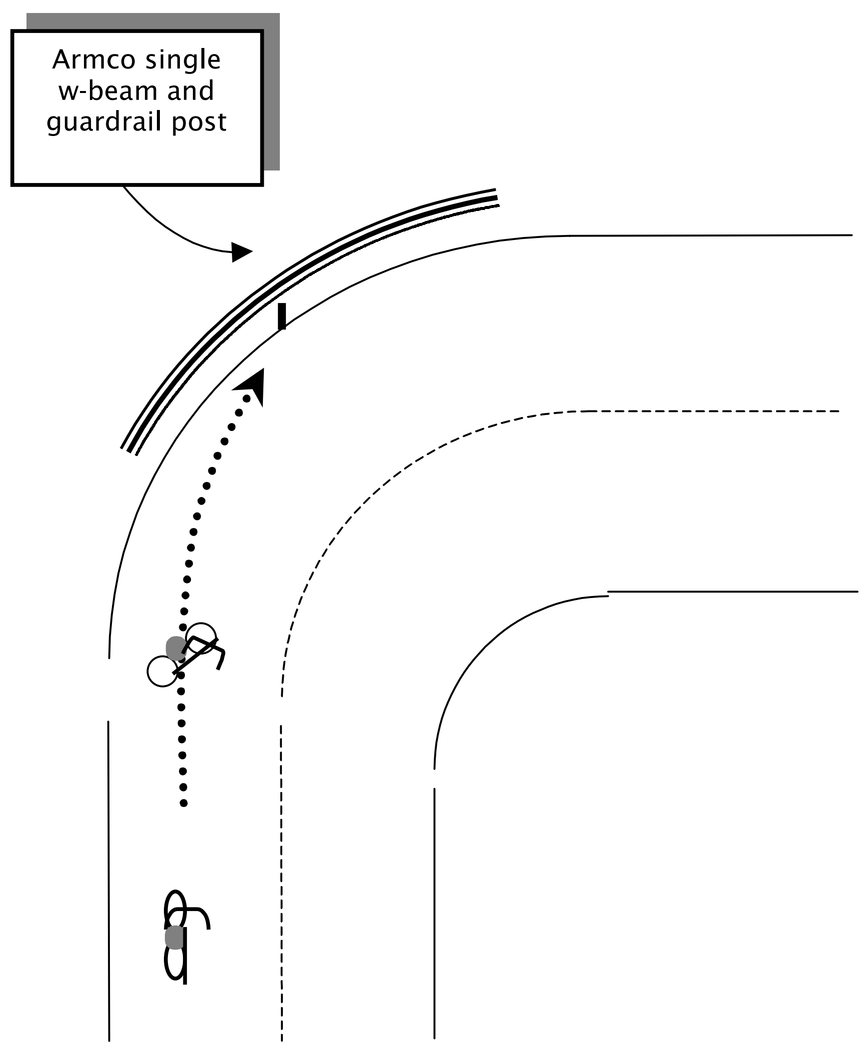
This crash occurred with a crash barrier in a metropolitan area. The rider impacted a w-beam crash barrier at approximately 45 degrees and an estimated speed of 60km/h after failing to take a sharp right hand bend. The motorcycle, a Kawasaki GTR1000 bounced back into the lane and the rider was launched over the crash barrier and down a 30m drop. The main injuries found were severe neck and chest injuries with fractures of the cervical and thoracic spine.



Case 3

The motorcycle rider ran off the left-hand side of the road into a crash barrier on the outside of a right hand bend. In this case the rider fell on to their right side and slid into the crash barrier at an angle of approximately 45 degrees. The front of the rider's helmet collided with a crash barrier post causing severe neck and spinal injuries.

Motorcycle:	1998 Yamaha
Barrier:	W-beam
Other impacts:	Helmet front with guardrail post.
Speed:	Unknown
Injuries:	Transection of spinal cord
	Fracture and dislocation of cervical vertebrae
	Severe neck laceration

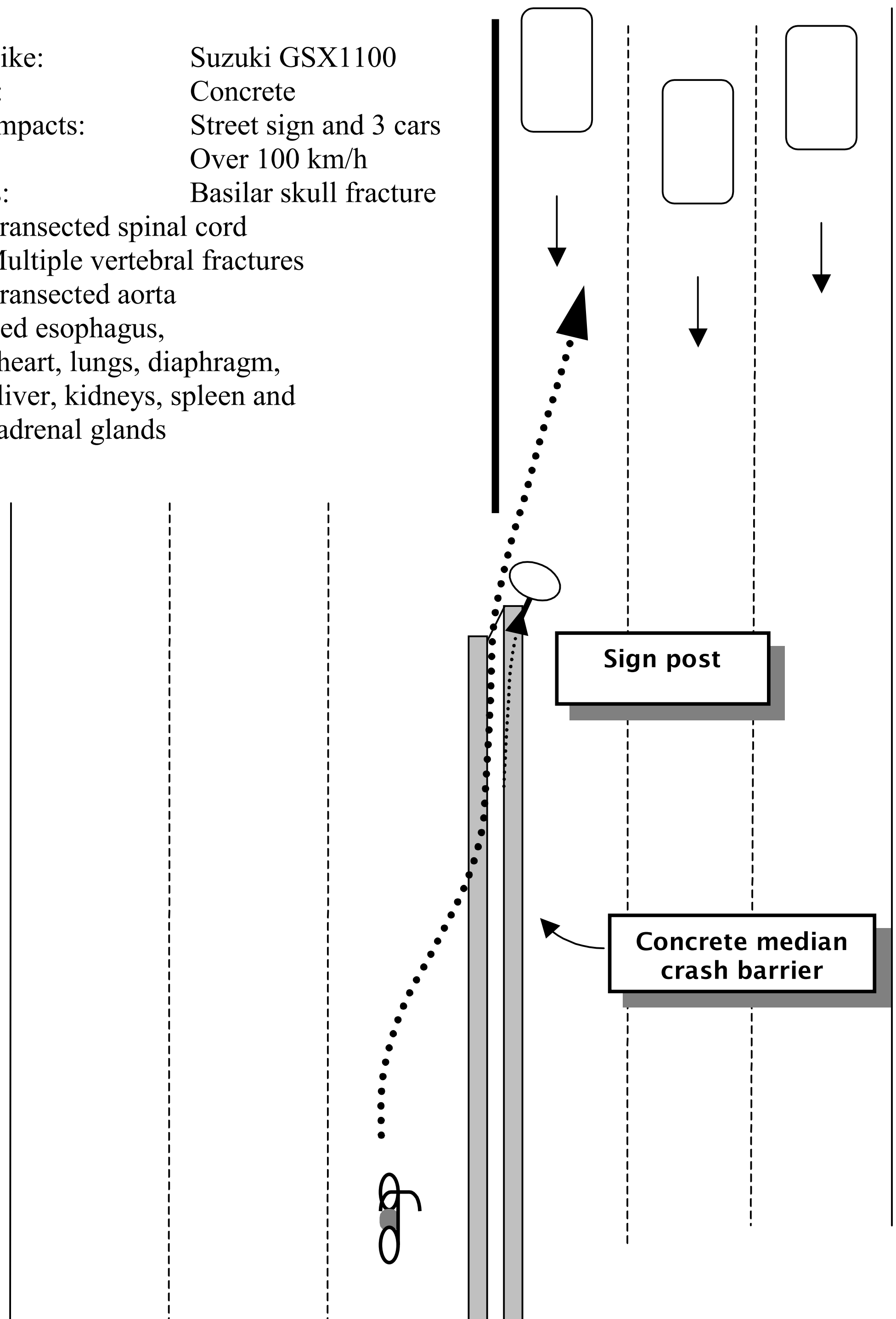


Case 4

This case was the only one involving a concrete barrier. The rider, travelling in excess of 100km/h collided with the concrete median barrier on a bridge at an angle of approximately 30 degrees. The rider slid along the barrier and hit a road sign at the end of the barrier and then veered into oncoming traffic. The major injuries were probably the result of impacts with the cars or the sign rather than the median barrier

Motorbike:	Suzuki GSX1100
Barrier:	Concrete
Other impacts:	Street sign and 3 cars
Speed:	Over 100 km/h
Injuries:	Basilar skull fracture

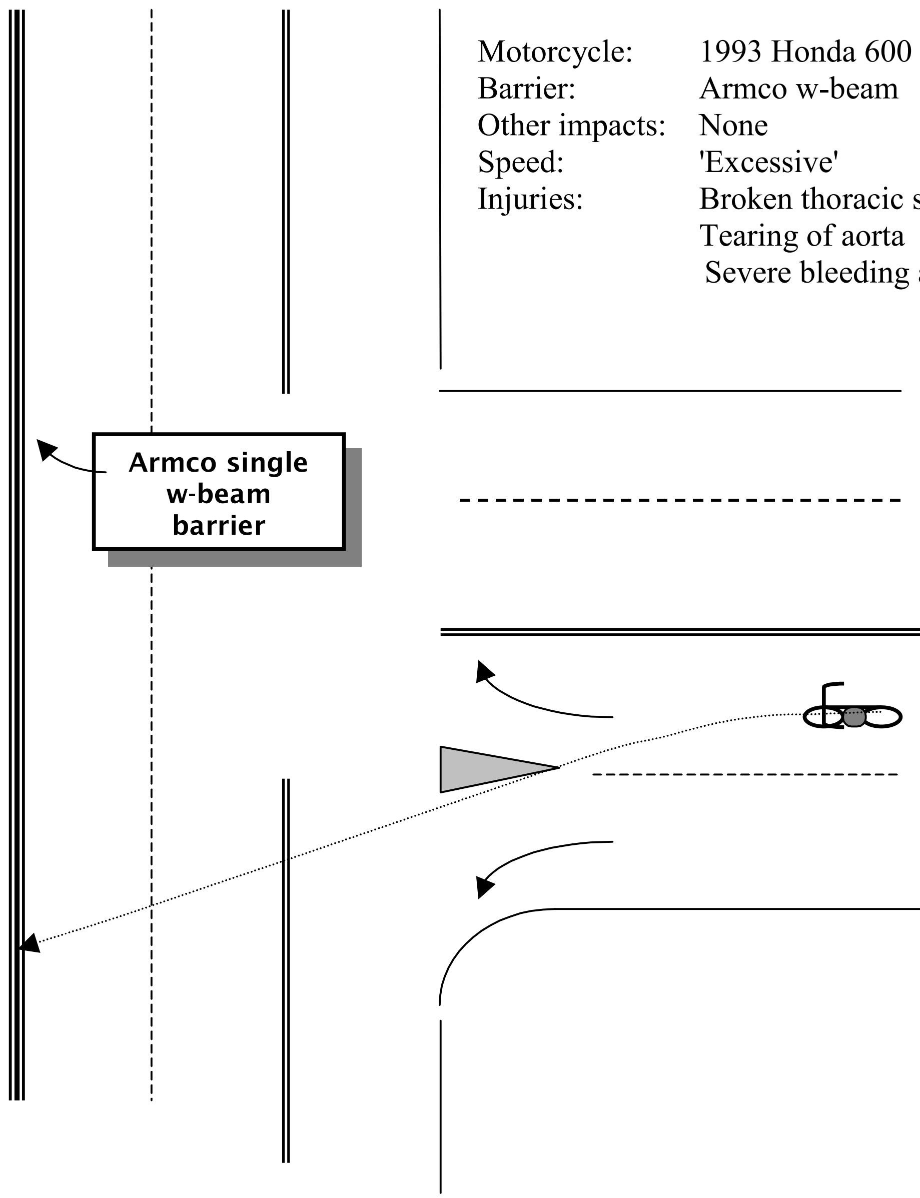
Transecned spinal cord
Multiple vertebral fractures
Transected aorta
Lacerated esophagus, heart, lungs, diaphragm, liver, kidneys, spleen and adrenal glands



Case 5

The rider attempted to turn left from the inside lane of a two-lane approach to a T-intersection. Turning sharply left at excessive speed before a divider for the inside and outside lanes the rider lost control and impacted the crash barrier on the opposite side of the intersection at an angle of roughly 75 degrees

Motorcycle:	1993 Honda 600
Barrier:	Armco w-beam
Other impacts:	None
Speed:	'Excessive'
Injuries:	Broken thoracic spine Tearing of aorta Severe bleeding around lungs



APPENDIX 2 Data Collection Form

MOTORCYCLE AND ROADSIDE BARRIER PROJECT

Case Number:

Major Impact with Roadside Barrier: Yes/No **Rider/Pillion Passenger**
Barrier Type:
Barrier Description (include sketch):

Type of Motorcycle (Age, make, model, engine size):

Sketch of Crash Site: include angle of impact

Description of Crash:

RUM Code:
Angle of Impact with Barrier:
Estimated Speed of Motorcycle:
Source of Estimate:

Helmet Worn:
Description of Helmet Damage, if available:

Description of Injuries:
Head

Neck and Spine

Thorax

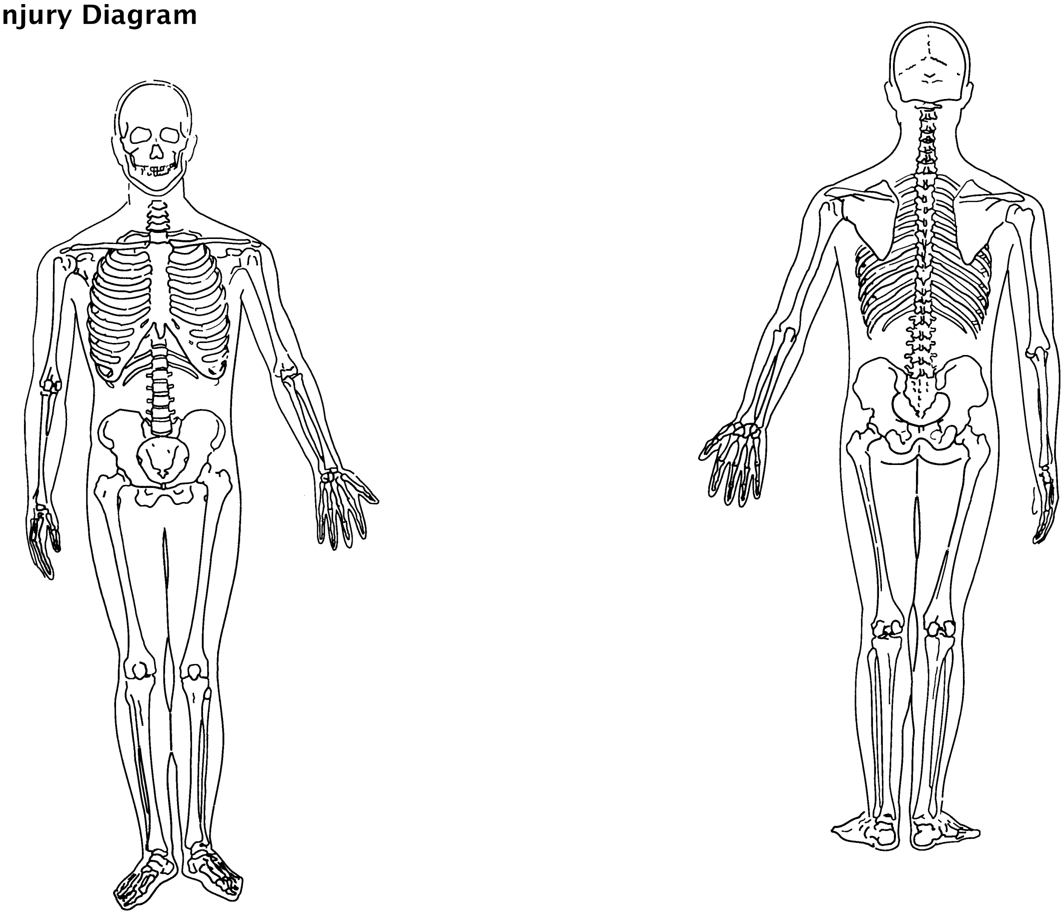
Abdomen

Pelvis

Upper extremities

Lower Extremities

Injury Diagram



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