

# Fatal Motorcycle-Into-Road-Safety-Barrier Crashes

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## ABSTRACT

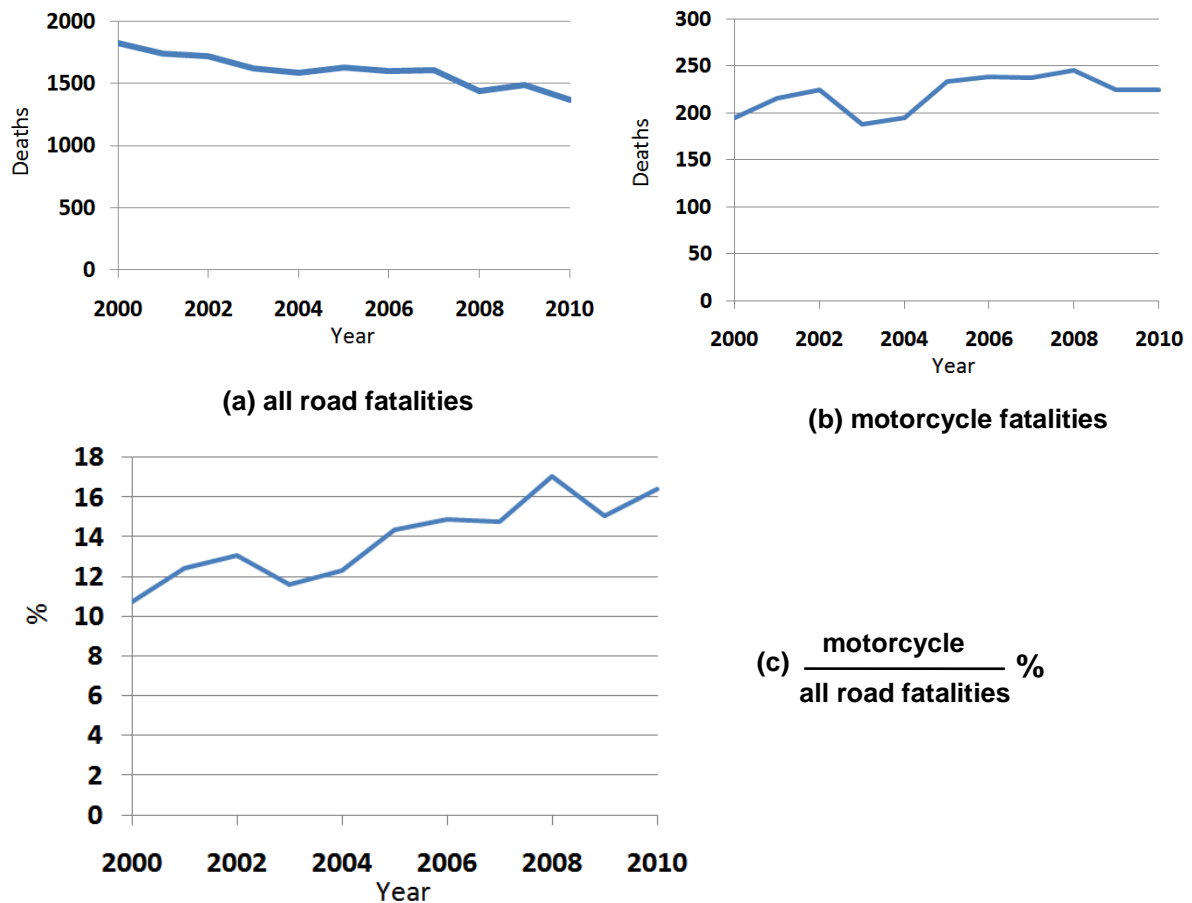
Motorcyclists contribute significantly to road trauma in Australia and New Zealand because of their high incidence of serious injuries and fatalities. The role of roadside safety barriers in such trauma has been an area of concern amongst motorcyclists, road authorities and road safety researchers and advocates despite the number of barrier-related deaths being relatively small (less than 0.01% of all road fatalities, 6% of all motorcycle fatalities in Australia and 2% of New Zealand crashes for the period 2001 to 2006). Roadside barriers include safety barriers positioned either at road edges or within medians, and are typically steel W beam, concrete, and wire-rope.

This paper presents an overview of key findings of a research project investigating motorcycle crashes into roadside safety barriers carried out at the University of New South Wales. Investigation and analyses were completed in three stages. Stage 1 focused on the characteristics of the human, vehicle and environmental crash characteristics and causal factors associated with fatal motorcycle-barrier collisions in Australia and New Zealand between 2001 and 2006. Stage 2 focussed on the crash mechanics and injury causation in such crashes. Stage 3 focussed on a survivability of motorcyclists colliding with roadside barriers, and other types of fixed roadside objects. A summary of the results from all three stages is presented.

## INTRODUCTION

Motorcycle registrations account for less than less than 4% of the Australian fleet and less than 2% of the New Zealand fleet but account for around 15-16% of all road deaths. While fatalities for all road users has been consistently falling, motorcycle fatalities have been steadily increasing over the past decade [1]. The Australian Transport Council in their recent National Road Safety Strategy [2] highlight that *“Motorcycle riders make up 22 per cent of serious casualties, yet motorcycle usage accounts for one per cent of vehicle-kilometres travelled.”*

Figure 1 shows the past decade in terms of motorcycle fatalities, all road fatalities, and the percentage of motorcycle fatalities to all fatalities. Data were extracted from the Australian Federal Government Department of Infrastructure and Transport’s statistical publications [3]. It is clear that there is a marked rise in motorcycle related fatalities. Any suggestion that this rise is due solely to the rise in motorcycle registrations is weakened when one considers that there was also a rise in this period in other vehicle registrations and, probably, numbers of pedestrians and cyclists. In contrast to motorcyclists, the numbers of fatalities for all road users fell. It is clear that much more attention needs to be given to reducing and reversing this rise in motorcycle casualties, and as soon as possible.



**Figure 1: Comparison of motorcycle fatalities to all road fatalities**

During the last decade significant action had occurred around the installation of wire-rope barriers in order to reduce fatalities and serious injuries resulting from median cross-over and run-off-the-road crashes. This was driven by the success of the Swedish 2+1 system and the related significant reductions in road trauma [4]. Where ever these barriers are installed there is an associated sudden and permanent reduction in both fatalities and serious injuries ranging from 50 to 90% depending on the location, as discussed in Grzebieta et al and Marsh and Pilgrim [5,6].

Fearing that wire-rope barriers may be more hazardous to motorcyclists than the impacts the barriers prevented, a number of rider and motorcycling organisations lobbied for their removal [7]. The term ‘cheese cutter’ was used as an emotive description of the potential harm a wire rope barrier could inflict. The little available research, however, suggested that these concerns were misplaced [8,9].

The authors decided to carry out a retrospective case series study of Australian and New Zealand coronial files of motorcycle into barrier impacts to provide scientific evidence on the impact of wire-rope barrier systems on fatalities and serious injuries among motorcyclists. The study was carried out at the University of New South Wales with funding provided by the Office of Road Safety Main Roads West Australia, NSW RTA’s Centre for Road Safety, NZ Transit road authority, the Australian Automobile Association and NSW Motor Accidents Authority.

Investigation and analysis have been completed in three stages so far. Stage 1 focused on the human, vehicle and environmental crash characteristics and causal factors associated with fatal motorcycle-barrier collisions in both Australia and New Zealand [5,10]. Stage 2 focused on the crash mechanics and injury causation in such crashes [11]. Stage 3 focused on a survivability analysis of motorcyclists colliding with roadside barriers, and other types of fixed roadside objects. A summary of the results from all three stages is presented in the following sections. A fourth Stage is planned focusing on injury mitigation and carry validation testing.

## **METHODOLOGY**

For the Stage 1 analysis, information was extracted about motorcycle-into-barrier crashes from the Australian National Coroners Information System (NCIS) and from the New Zealand Crash Analysis System (CAS) for the years 2001 to 2006. Details of that process have been published in earlier papers [5,10].

The following information was extracted with regards to the human factors: demographics; riding license status; the primary purpose of the journey; the wearing of a helmet; and riding behaviour including an estimate of the riding speed prior to the crash were obtained from the police briefs. Other human factors examined included the presence of alcohol and other drugs in the deceased's blood which were obtained from toxicology reports.

The environmental factors considered included the road surface condition, road type and road horizontal alignment. The barrier factors examined included the barrier type and the hazard being protected against. The weather and temporal factors were also examined. The vehicle factors examined included the motorcycle registration and the mechanical condition of the motorcycle prior to the crash.

Once the cases potentially involving roadside safety barriers were identified in the NCIS and CAS, a request was made to the coroner in each state in Australia and New Zealand for permission to view the police reports. The level of detail included in the police briefs prepared for the coroners varied within and between states and New Zealand but was usually of sufficient quality to enable a basic reconstruction of the crash events. Information extracted for the study of injury causation was; autopsy report, type of barrier, pre-crash speed, impact angle, contacts with barrier posts, crash posture (sliding or upright) and type of motorcycle (sports, touring or off-road).

For the Stage 2 analysis, the crash mechanisms and injury causation of barrier crashes was interrogated. Scene photographs were included in 66 cases and measurements of the crash scene were documented in 62 cases (skid/scrape mark lengths, impact point location, rest positions of motorcycle and motorcyclist and any parts thereof, etc). In 54 cases the pre-crash speed of the motorcycle was estimated and in 14 cases scene diagrams produced from a surveying instrument were included. Many cases also included witness accounts and statements from police attending the scene. Some results have been published from that study as well [11].

Injuries were coded according to the Abbreviated Injury Scale (AIS) [12] from the autopsy reports, and only AIS3+ injuries were coded. The injury producing the

maximum AIS score (MAIS) was determined, as were injury severity scores (ISS) calculated as per AAAM (2005). The three most severely injured body regions have their maximum AIS score squared and added together to produce the ISS score. Logistic regression was used to provide odds ratios and 95% confidence intervals for establishing any relationships between injuries, crash mechanisms and injury causation. Statistical significance was measured at the level  $p < 0.05$ .

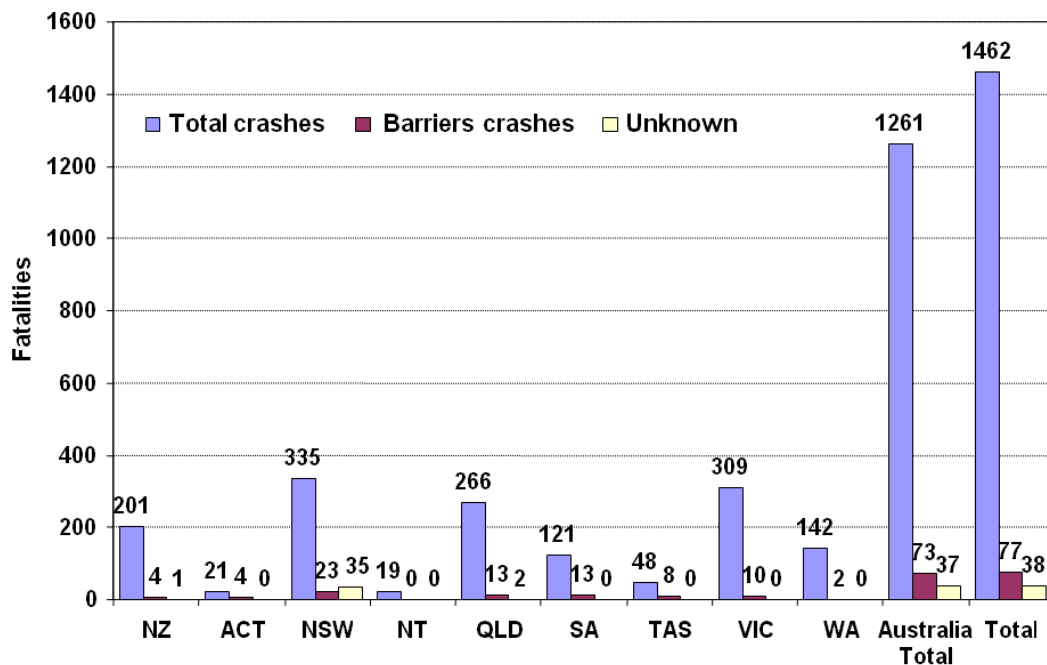
For the Stage 3 analysis, survivability of motorcyclists colliding with roadside barriers, and other types of fixed roadside objects was studied. Survivability analysis depends on two factors: firstly, the data must involve all types of injury outcomes, from no injury to fatal injury; and secondly, the travel speed of the motorcyclist must be known for each case. From these two data items, a relationship between the travel speed and the likelihood of fatality may be established, and fatality risk curves may be generated to establish survivability. Unfortunately no data in Australia or New Zealand presently exists that contains these two pre-requisite items. The data were thus extracted from a database of crash data in the United States [13]. Since the roadway, motorcycle and roadside barrier conditions are similar between the United States and Australia and New Zealand, the results are nominally valid for use in these countries (and indeed many other countries). Unfortunately, wire rope barriers are completely excluded from the database used, thus no conclusions regarding wire rope barriers could be drawn from the analysis.

## RESULTS

A total 1462 cases of a roadside fatality involving a motorcycle were identified to have occurred in Australia and New Zealand. Of these, 77 were positively identified as involving a roadside safety barrier. A further 38 cases could not be categorised due to insufficient information in the NCIS. Of the 77 coronial files collected, 72 contained police reports, 56 contained mechanical inspections, 77 contained autopsy reports and 74 contained toxicology reports. Figure 2 shows the final distribution of motorcycle crashes for each of the Australian states, Australia and New Zealand.

It is important to note that the numbers of fatalities resulting from such crashes is small at around 6% of all motorcycle fatalities for Australia and only 2% for New Zealand. This in turn constitutes less than 0.01% of all road fatalities. It is clear that any proposed retrofit changes or removing road safety barriers systems would have very little effect on reducing motorcycle fatalities, let alone a proportion of all road fatalities in either countries. Road safety stakeholders need to focus their attention and limited resources in other areas related to motorcycle behavior and crashes in order to have any significant effect on reducing motorcycle fatalities.

The main factors isolated from the police reports were speeding, alcohol and drugs [5,10]. Indeed the highest single factor that contributed to the crash was speeding or inappropriate speed, following by speed combined with alcohol, alcohol by itself, alcohol and drugs, speed and drugs and speed combined with both alcohol and drugs. Approximately 74% or approximately three in every four crashes involved speed, alcohol or drugs or a combination of the three.



**Figure 2: Fatal motorcycle crashes in Australia & New Zealand (2001 to 2006)**

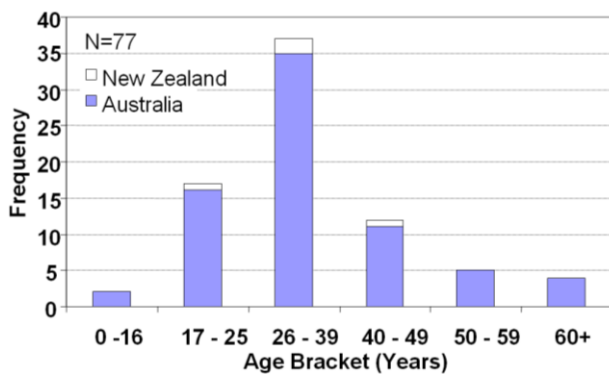
The Stage 1 analysis showed that a roadside barrier predominantly involved in such crashes was W-beams (72.7%), which is representative of exposure. Concrete and wire rope barriers accounted for 10.4% and 7.8%, respectively. An additional 3.9% of impacts involved steel guardrails, but there was insufficient information available to determine whether these guardrails refer to W-beams, tubular or Thrie beam steel barriers. This was similar to the findings by Gabler [14] and Berg et al [15]. These fatality proportions were compared to the proportions of barriers installed, which shows that: W beam comprises 71.5% of the barriers and results in 72.7% of the fatalities; concrete comprises 8.6% of the barriers and results in 10.4 % of the fatalities; and wire rope comprises 15.9% of the barriers and results in 7.8% of the fatalities. Therefore assuming the probability of a fatality occurring across the network of barriers is similar, wire rope barriers have around half the fatality rate of W beam barriers and concrete barriers.

Figure 3 shows the breakdown into age groups of motorcyclist fatalities involving a roadside safety barrier in Australia and New Zealand. The youngest and oldest persons killed were 11 and 70 years old respectively. The mean age was 34.2 years and the median was 31 years and 72.3% are aged less than 40 years. The largest group of motorcyclists killed as a result of a collision with a roadside barrier are aged between 26 and 39 years (48.4%). The 17 to 25 years age group was second highest consisting of 22.1%. The fact that riders in the 26 to 39 years age bracket are involved in the majority of the fatalities may be related to their crash risk and possible lack of experience but it also may be a reflection of the distribution of the motorcycle riding population [16]. Unfortunately the national age distribution of the Australian motorcycling population was not available.

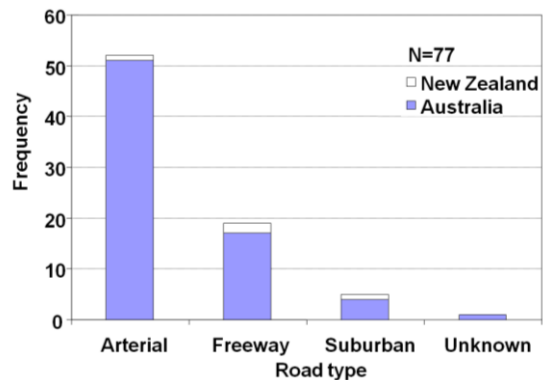
More males than females were killed in motorcycle crashes into roadside safety barriers. Out of the 77 fatalities, 92.2% were male. The majority (4 out of 6) of the females killed were pillion passengers. In all the four cases where a female pillion was killed, a male was in control of the motorcycle and survived the crash. Although

the percentage of females killed in a crash into a roadside barrier was relatively small (7.8%), it is comparable to the overall number of females killed as a result of riding a motorcycle. According to ABS data, between 2001 and 2006, 5.0% of all riders (including pillion passengers) killed in a motorcycle crash were female. The low number of female fatalities is likely to be a reflection of exposure. For example, in the state of New South Wales, 89.3% of motorcycle licence holders are male.

Fatalities involving a motorcycle impacting a roadside safety barrier mostly occurred on roads with speed limits above 60 km/h. This is consistent with Gibson and Benatatos [17]. Figure 4 shows the majority of the crashes occurred on arterial roads. Arterial roads were categorised as roads with speed limits ranging from 60km/h to 100km/h which consist of one or more lanes of traffic travelling in each direction with junctions. Arterials accounted for 69.8% of the fatalities. Freeways with speed limits of between 100 and 110 km/h accounted for 23.3% of cases. Freeways were categorised as roads which have 2 or more lanes travelling in the same direction with the traffic travelling in the opposite direction separated by a median barrier and no junctions but instead with exit ramps. Suburban roads with speed limits of between 50 and 60km/h accounted for only 5.5% of the fatalities.



**Figure 3: Age distribution**



**Figure 4**

Figure 5 shows the impact site's horizontal road alignment where a motorcyclist died hitting a roadside barrier. 80.8% of fatal crash sites involved a bend in the road. Nearly an equal number of cases involved a left hand and right hand bend with 28 and 26 cases involved respectively. A further 8 cases were described only as a bend. Unfortunately, there was insufficient information in the records to determine the radius of the curvature of the bends involved. Only 14.1% of cases occurred on a straight section of the road and 3.8% occurred at an intersection.

The predominance of fatalities on bends is not surprising. It is harder to control a motorcycle on a bend than it is on a straight part of the road. This was exacerbated by inappropriate speed in 17 out of the 72 cases where it was observed that the posted advisory speed was ignored on a bend. It is also likely that the driving/riding challenges posed by bends make them more suitable candidates for barrier installation, so that exposure to barriers is probably greater for curves.

Figure 6 shows that 53.6% of motorcycle fatalities involving a roadside safety barrier occurred on a weekend with 21 fatalities associated with each day. The rest of the week witnessed 35 fatalities with an average of 7 deaths for each day. In 46 cases motorcyclists were on a recreational ride, which explains the high frequency of

fatalities on a weekend. Driving as a recreational activity is generally known to be a predictor of crashes [18,19].

Figure 7 shows barrier crashes primarily occurred during daylight hours, particularly in the afternoon. This pattern likely reflects exposure, with riders more likely to engage in recreational riding in the afternoon, but it may also be related to fatigue as the riders are likely to be returning tired from such a ride later in the day.

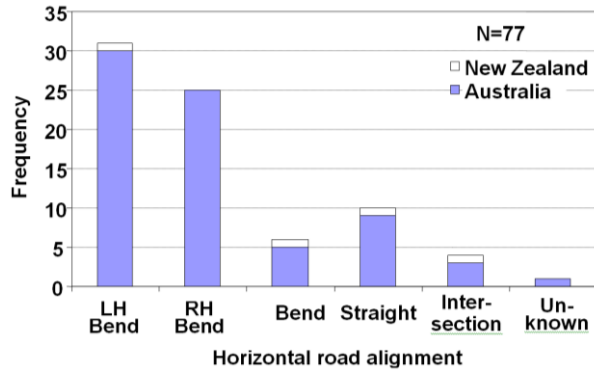


Figure 5

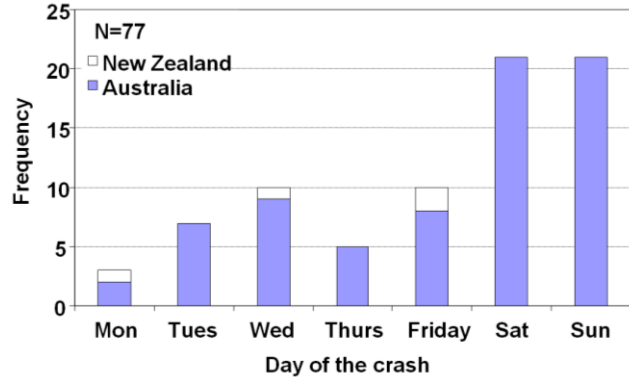


Figure 6

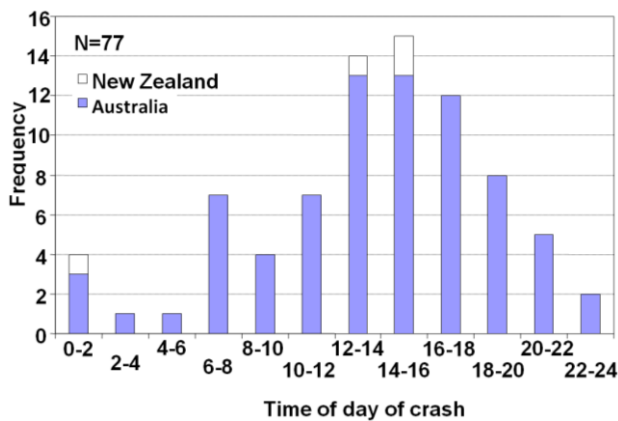


Figure 7

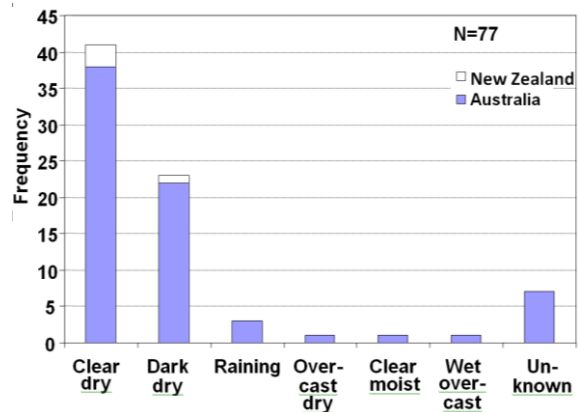


Figure 8: Weather condition

Night time crashes were not associated with any day of the week. Night time crashes were often associated with speed or alcohol with 10 out of the 15 cases registering blood alcohol level above the legal limit. Speeding was suspected in 8 out of the 15 crashes that occurred at night while in 3 out of the 15 cases speeding was suspected plus alcohol was found in the blood of the deceased.

In 71 out of the 77 fatalities the road surface was described by the police as in good condition. In three cases, the road surface was described by the police as poor and in two cases the road surface had corrugations.

In nearly half of the cases, the weather was described as “clear and dry” or “fine day” and the road surface condition was dry (Figure 8). This was followed by dark conditions with dry road surface in which 28.2% of the fatalities occurred. In 16.7% the description of the weather was insufficient. These results are not surprising as dry conditions are conducive to riding a motorcycle. The authors suspect that the

lower numbers for wet conditions reflect exposure, i.e. riders chose not to ride in wet or rainy conditions.

In 55 out of the 77 cases, there was an examination of the mechanical condition of the motorcycle after the collision. In 47 of these cases, the inspection reports conclude that there was no mechanical defect that could have contributed or caused the crash. In the remaining cases, the motorcycle was found to be in poor condition; five with worn out tyres. These data suggest that mechanical problems do not play a major role in motorcycle-barrier impacts.

In the majority (77.9%) of cases, the motorcycles were registered. In four cases the motorcycles were unregistered. In all these four cases, the rider had also consumed alcohol. In the remaining 13 cases, there was insufficient information to determine if the motorcycle was registered or not.

In summary, the the Stage 2 study [11] revealed that both sliding and upright crash postures were approximately equally represented, i.e. in 47% of cases the motorcyclist impacted the barrier in the upright mode, and in 44% of cases the motorcyclist slid into the barrier. This is similar to Berg et al's findings [15]. Around half of the crashes in the upright mode resulted in the motorcyclist scraping/tumbling/skidding along the top of the barrier. The mean pre-crash speeds and impact angles were found to be 100.8 km/hr and 15.4° respectively.

The thorax region was found to have the highest incidence of injury and the highest incidence of maximum injury in fatal motorcycle-barrier crashes, followed by the head region. This is in contrast to motorcycle fatalities in all single- and multi-vehicle crash modes, where head injury occurs with greater frequency than thorax injury. As existing motorcycle-barrier crash testing protocols based on the Spanish standard [20] do not specify a thorax injury criterion, there appears to be a need to determine and implement such criteria. Likewise both a sliding and an upright test needs to be implemented considering that these appear to be the two crash mechanisms identified. Also it was found that 97% of motorcyclists were helmeted. This indicates that the crash severity exceeded the functional range of the helmets in many cases, thus efforts to improve helmet design should continue.

Nearly half of the fatally injured motorcyclists received untreatable injuries, including aorta, heart, brain stem, upper cervical cord and dismemberment injuries. 81% of motorcyclists died at the crash scene. These results suggest that the potential to reduce fatalities by improving hospital or pre-hospital treatment may be limited, and efforts should therefore be focussed on measures to prevent injuries.

Analysis of motorcyclist pre-crash speeds in the sliding posture, and entry and exit sliding distances, determined that typically 30-80% of the motorcyclists' pre-crash kinetic energy is dissipated during the contact with the barrier. This suggests that there is significant scope for reducing motorcyclist injuries with barrier design. This could be achieved by either reducing the magnitude of kinetic energy dissipated on the barrier (redirecting the motorcyclist), or by ensuring that the kinetic energy is dissipated in a more controlled manner (barrier impact attenuators/protective devices), etc.



Finally the Stage 2 analysis revealed that from the variables investigated of barrier type, crash posture and barrier post impacts, and within the limitations of the small dataset of fatal only motorcyclists, no statistically significant association between these variables and injury severity could be established. It appears that the strongest association with injury severity is pre-crash speed (crash severity), and a strongly linear relationship was determined between these two.

In regards to the Stage 3 investigation, it was mentioned earlier that Australian data was not available to estimate risk survivability curves and that US data would need to be used. The assumption being that the road environment (surface, barriers, lighting, rural roads, etc) closely approximates Australian conditions. The United States National Automotive Sampling System (NASS) General Estimates System (GES) was accessed. The GES obtains its data from 400 police jurisdictions in 60 areas that reflect the geography, roadway mileage, population, and traffic density in the US. Around 50,000 police accident reports (PARs) are sampled each year, from the estimated 5.8 million police-reported crashes which occur annually. These crashes include those that result in a fatality or injury, and those involving property damage only.

A multiple variable logistic regression model was developed to determine which factors associated with fatalities occurring from fixed object collisions would enable safer roadway infrastructure design for motorcyclists. A nationally representative weighted sample of around 30,000 single-vehicle fixed object motorcycle collisions which occurred in the United States over the ten year period between 2000 and 2009 were analysed. Additionally, a single variable logistic regression model was developed for motorcyclist fatality risk from fixed object collisions as a function of travel speed. Details of the analysis will be presented elsewhere.

The following key outcomes were identified from the Stage 3 analysis

- increased travel speed, older motorcyclists, speed related crashes, late model motorcycles, darkness, interchange locations, non-level roadway profiles and roadside departure to the right-side (in the USA), are all associated with an increase in the likelihood of a motorcyclist fatality;
- fatality risk remains relatively low below a pre-braking pre-crash travel speed of 100 km/h, however above this speed the risk rises sharply (note that travel speed is not the impact speed at which the motorcyclist struck the fixed object);
- the serious injury risk is significantly greater than the fatality risk, and is above 20% even for low speed crashes;
- motorcyclists with a pre-crash pre-braking travel speed less than about 55 km/h, could be expected to survive a collision with a fixed object;
- trees and poles were found to be a greater fatality risk than roadside barriers, which indicates that the deployment of a barrier to protect road users from trees and poles reduces motorcyclists' risk of being killed;
- departures from the roadway on the same side as the travel lane are nearly four times more likely to result in fatality, due to the reduced distance over which the motorcyclist may decelerate as a result of braking, skidding or sliding;

## CONCLUSIONS

The following major conclusions were drawn from the three stages of the project:

- The number of motorcycle fatalities involving road side barriers is small at around 15 per annum compared to about 230 motorcycle fatalities and around 1400 road fatalities each year in Australia. Thus any alterations to roadside safety barriers will have a minor effect on motorcycle fatalities in general;
- Fatalities of motorcyclists involving impact with a roadside barrier predominantly involved steel W beams;
- Wire rope barriers were found to have around half the fatality rate of W beam and concrete barriers.
- Half of the fatalities involving a roadside safety barrier usually occurred on a weekend and around 60% of all barrier impact fatalities are during recreational riding and mostly in the afternoons;
- A total of 74% of fatalities were found to involve either speed, alcohol or drugs, or a combination thereof, i.e. 3 in 4 fatalities;
- There is a strong linear association between injury severity and pre-crash speed (crash severity);
- Both sliding and upright crash postures were approximately equally represented, and mean pre-crash speeds and impact angles were found to be 100.8 km/h and 15.4° respectively. The thorax region was found to have the highest incidence of injury and the highest incidence of maximum injury in fatal motorcycle-barrier crashes, followed by the head region;
- Nearly half of the fatally injured motorcyclists received untreatable injuries, including aorta, heart, brain stem, upper cervical cord and dismemberment injuries and 81% of motorcyclists died at the crash scene;
- No statistically significant association between barrier type, crash posture and barrier post impacts, and injury severity within the limitations of the small dataset of fatal only motorcyclists, could be established;
- In a single-vehicle motorcycle collision with a fixed object, trees and poles were found to be particularly hazardous, and more so than barriers. Fatality risk increased sharply above a 'travel' speed of about 100 km/h, while serious injury risk was greater than 20% even at the lowest travel speeds. The tool developed from fatality risk as a function of travel speed from the Stage 3 analysis predicts that motorcyclists travelling less than about 55 km/h, could be expected to survive a collision with a fixed object.

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