

Injury Outcomes in Pole/Tree Crashes

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Abstract

This study examines a sample of real-world frontal and side impact crashes with poles and trees in which the crash-speed and injury outcomes were determined. The data were obtained from individual crash investigations that were conducted as part of an on-going study of vehicle crash performance and occupant injury. A total of 316 single vehicle crashes were available for analysis. The most commonly injured body regions in both frontal and side impacts included the head, chest and lower extremity.

Recent refinements in the EuroNCAP test programme have led to the development of an optional pole test, which can be conducted at the manufacturers' discretion. This study demonstrates the representativeness of this additional NCAP requirement in terms of real-world outcomes. This study also highlights the need for the introduction of available injury countermeasures (such as side airbags and side curtains), particularly for protection of occupants in side impact crashes with trees and poles.

Keywords

Pole/Tree Crashes; Injury Outcomes; New Car Assessment Programme; Australian design Rules (ADR's)

Introduction

A recent report by the Australian Bureau of Transportation Economics concluded that road crashes in Australia cost the society some \$15billion per annum, equaling approximately 1.4% of Australia's gross national product (BTE; 2000). The high cost of road crashes makes it desirable that the Australian government establishes and enforces motor vehicle design and construction standards, which represent the reality of crashes.

Currently, vehicles manufactured for Australian roads are required to satisfy requirements as specified by the Australian design Rules (ADR's) formulated by the Australian government. Three ADR's (ADR 69, ADR 72 and ADR 73) involve single point crash testing;

- ?? ADR69 for full frontal crash protection. In this test, the vehicle is impacted into a rigid barrier, which is fixed perpendicular to the vehicle. The crash speed is approximately 48km/h.
- ?? ADR 72 is for side impact crash protection. This test involves compliance with either US regulation FMVSS214 or European regulation ECE95 and involves a Moving Deformable Barrier (MDB) striking the vehicle at between 50 to 54km/h (depending upon which test is used).
- ?? ADR73 is for offset frontal crash protection. In this test, approximately 40% of the front of the vehicle strikes a rigid crash barrier in a head-on crash at 56km/h.

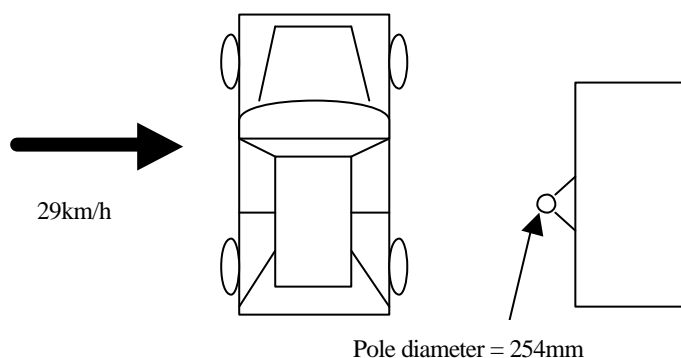
It has been suggested in recent times that these ADR's perhaps do not extend to crashes with fixed objects such as poles and trees. Yet these types of crashes often result in disastrous consequences for the occupants of the vehicles involved. This paper aims to explore the injury outcomes and other characteristics of such crashes.

Currently, the European New Car Assessment Programme (EuroNCAP) includes a side impact pole crash-test as an option for manufacturers if they choose to obtain a higher score in the EuroNCAP system of rating the safety performance of vehicles. Australia chose to adopt the EuroNCAP test protocol in 2000 therefore the side impact pole crash-test is now an option for vehicle manufacturers. The test has been

specifically developed to encourage manufacturers to fit head protection devices for pole impacts. Side impact airbags are now expected to help make this kind of crash survivable. In the new test, the car tested is propelled sideways at 29km/h (18mph) into a rigid pole. The pole is relatively narrow, so there is considerable penetration into the side of the car. In an impact without the head protecting airbag, a head injury criterion (HIC) of 5000 is possible, five times that which indicates the likelihood of serious brain injury. In contrast, the head injury criterion in crash tests with vehicles that are fitted with a head protection airbag is around 100 to 300, well below the injury reference value. Therefore, it is suggested that a side impact airbag with head protection can help to make this kind of crash survivable despite the severity.

The test format is as shown in figure 1. In practice, most manufactures would only opt for their vehicles to undergo this test providing that the vehicle itself is equipped with in-vehicle safety technology that is designed for head injury mitigation in pole/tree crashes.

Figure 1 – EuroNCAP Pole Test Procedure



In addition to the NCAP test procedure (which is only for side impact crashes), there has been some international debate over whether the introduction of a pole test should be included as part of the regulatory compliance test programmes that manufacturers will need to conform to in future years. Some indication of the nature and circumstances of pole/tree crashes in Australia is therefore necessary since such tests would need to be representative of real-world crashes.

Literature Review on Pole and Tree Crashes

Pole Crashes

In Australia, Good, Fox and Joubert (1987) found that pole crashes resulted in approximately 45 fatalities and 785 injured occupants annually, representing approximately 9.4% and 5.9% respectively of all fatal and injury crashes. In a study of fatal single vehicle crashes, Haworth et al (1997) found that poles were involved in 29% of the crashes in the Melbourne metropolitan area and 10% in other study areas. However, when single vehicle fatalities alone were studied, they observed that of 127 fatal crashes, almost 75% involved an impact with a tree, a pole or both. Kloeden et al (1999) found that 22% of the total number of fatalities in road crashes in South Australia between 1994 and 1996 involved poles.

Internationally, Pilkington (1998) found that pole crashes were six times more likely than other crashes to lead to a fatality and three times more likely to lead to an injury when compared with car-to-car crashes. A Swedish study by Nilsson and Wenall (1998) found that pole crashes accounted for 12% of single vehicle crash fatalities.

Tree Crashes

Ray, Toxel and Carney (1991) found that tree crashes represented 25% of side impact crashes and produced 48% of side impact fatalities from collisions with roadside objects.

Kloeden et al (1999) found that trees were the most commonly struck roadside hazard in South Australia and some 30% of occupants were fatally injured in tree-crashes. Internationally, Tignor et al (1982) found that 21% of fatal crashes in the US in 1981 involved trees.

In summary, tree and pole crashes are the object struck in approximately 30-50% of fatal crashes in Australia. Injury outcomes in tree/pole crashes are typically worse than in car-to-car crashes. This is because in a typical pole/tree crash, the vehicle has to absorb all of the impact energy, which is applied to a relatively small area on the length or width of the vehicle such that substantial deformation is inevitable. In a car-to-car crash, both vehicles in the crash absorb the crash energy and the impact energy is typically distributed over a wider area, when compared with a pole/tree crash. Therefore, there is scope for prevention of such crashes through highway engineering design but this is not always practical. In addition, the design of vehicles should be such that the crash performance takes into account the nature and cause of injuries in a typical pole/tree crash.

The aims of this study were as follows;

- (a) to study the risk of injury to different body regions in tree/pole crashes in a sample of real-world tow-away crashes that were investigated by the Monash University Accident Research Centre (MUARC); and
- (b) to determine priorities for countermeasure development in such crashes.

Methodology

The data in this were obtained from a sample of tow-away crashes that have been investigated as part of an on-going study of driver injury and vehicle crash performance currently on-going at the Accident Research Centre at Monash University. This study examines injuries that were sustained by a sample of drivers and passengers involved in crashes with poles and trees only. Vehicles were examined at recovery-garages, scrap-yards and panel-beating shops in Victoria, New South Wales, Queensland and Tasmania (depending on accident location) within a few days of the accident. An inspection was performed on each vehicle in accordance with the National Accident Sampling System procedure for retrospective examination of crash-damaged vehicles (NHTSA, 1989;). Determination of seat-belt usage was achieved with a high degree of certainty.

Injury details on each injured occupant were obtained from participating hospitals in the study area. Injury details were only included in the study if their presence had been verified by an Accident and Emergency Consultant or Surgeon. Injury severity was assessed according to the Abbreviated Injury Scale (AIS) 1998 revision. This scale classifies injuries on a threat-to-life scale from 1 to 6 where;

1	=	minor (e.g. bruise, abrasion)
2	=	moderate (e.g. simple limb fracture)
3	=	serious (e.g. base of skull fracture)
4	=	severe (e.g. major liver laceration)
5	=	critical (e.g. major aortic tear)
6	=	maximum (e.g. decapitation)

To assess collision severity in this study, Delta-V was calculated where appropriate.

In all, some 316 single vehicle crashes with poles/trees were available for analysis. Of these, 150 involved crashes with trees and 166 involved crashes with poles (comprising lamp-posts, telegraph posts, power poles etc).

Results

1. Occupant and Impact Details

Table 1 shows details of the occupants in the sample. The majority of the crashes (55%) were frontal crashes whilst 45% involved a left-side or right-side impact. Table 2 shows that right-side crashes were slightly more frequent than left-side crashes. Table 3 shows the distribution of injuries according to impact type. As would be intuitively expected, side impact crashes with poles/trees represent the highest risk in terms of injury outcomes. Of the crashes investigated, the risk of sustaining life-threatening injury (i.e. injury at the MAIS 4+ level) was 28%. Injury risk to specific body regions is investigated more fully below.

Table 1: Details of Occupants

	Males (65%)	Females (35%)
Mean Age	33 years	37 years
Mean Weight	77.4kgs	63kgs
Mean Height	1.80metres	1.63metres
Belt use	86%	92%

Table 2: Impact Classifications for Study Vehicles

	Number of Vehicles	% Vehicles In Impact Classification
Frontal	175	55.4
Left-side	59	18.9
Right-side	82	25.9
Total	316	100

Table 3: Injury Outcomes by Impact Type

Impact Type	MAIS 0-1	MAIS 2-3	MAIS 4-6
Frontal	50%	36.6%	13.1%
Side	37.6%	34%	28.4%

2. Frontal Impacts

Although there are no procedures under development (either regulatory compliance or as part of the Australian NCAP programme) to assess the crash performance of vehicles in frontal impacts, it is still interesting to assess the performance of vehicles in such crashes with poles and trees.

Table 4 shows the Principle Direction of Force (PDOF) for vehicles involved in frontal crashes with poles. As can be seen from the table, the majority of frontal crashes (73%) in the sample involved a Principle Direction of Force of within 30-degrees of head-on

Table 4: Principle Direction of Force for Frontal Crashes with Poles (N=175)

Principle Direction of Force	N	%
30-degrees	41	23.6
60-degrees	7	4
0-degrees	127	72.6

Frontal impact crashes were studied in more detail in order to establish injury outcomes in such crashes. Table 5 shows the distribution of the impact damage in crashes where the principle direction of force was within 30-degrees of head on. In order to sub-classify the frontal crashes, analysis was performed according to whether there was damage to the right, left or centre of the vehicle. It should be noted that this analysis includes drivers only because of limited numbers of passengers in the study.

Table 5; Injury Outcomes to Drivers According to Crash Type in Frontal Impacts

Driver Details	Damage to Right 1/3 of Vehicle (N=28)	Damage involving Centre of Vehicle (N=52)	Damage to Left 1/3 of Vehicle (N=22)
Confirmed belt use	89%	87%	80%
Mean Delta-V	50km/h	47km/h	49km/h
% with AIS2+ Head Injury	36%	29%	23%
% with AIS2+ Face Injury	21%	13%	14%
% with AIS2+ Neck/spine	7%	17%	9%
% with AIS2+ Chest Injury	11%	31%	14%
% with AIS2+ Abdomen Injury	0%	8%	9%
% with AIS2+ Pelvis Injury	0%	4%	5%
% with AIS2+ Upper Extremity Injury	18%	15%	14%
% with AIS2+ Lower Extremity Injury	43%	23%	18%

Table 5 contains some interesting results. Firstly, the frequency of injury at the AIS2+ differs somewhat according to the location of damage to the vehicle front. When the damage is located at the front right of the vehicle, head, face and lower extremity injuries are higher than when compared to situations where the damage is concentrated to the centre or left of the vehicle. This would suggest two things; firstly that when the impact is concentrated on the right-side of the vehicle, intrusion of the steering column and steering wheel is more likely leading to an enhanced risk of head and face injuries through direct contact with the steering wheel. Secondly, intrusion of the footwell is also more likely leading to an enhanced risk of lower extremity injuries through loading applied to the lower extremity.

When the location of the damage is applied to the centre of the vehicle, the injury distribution changes in that the chest is the most common body region injured and neck/spine injuries also assume a greater prominence. Given that the crash severities as indicated by Delta-V are roughly equal in both sub-groups, the explanation may be that crashes to the centre of the vehicle engage the engine such that energy absorption through 'crumple' of the front structure of the vehicle is relatively low. However, when the impact is focused to the left or right of centre, it is probable that a 'softer' crash-pulse may be experienced in the occupant compartment, as there is reduced likelihood of engagement of the engine and increased probability of engagement and 'crumple' of the energy-absorbing longitudinals. It should be noted that the majority of the vehicles in the sample contained a longitudinal rather than transverse engine configuration. Unfortunately, Delta-V calculation will not provide any useful indications of the validity of this conclusion since this measure does not allow discrimination between crash-pulses.

3. Side Impacts

Table 6 shows the Principle Direction of Force for side impact crashes with poles. The direction of force for side impact crashes is more widely distributed than is the case with frontal crashes. A 90-degree test would only be representative of some 35% of real-world situations but overall this is the most frequent impact configuration. However, it was necessary to determine exactly what this crash condition represents in terms of injury outcomes when compared to other crash conditions. Table 7 shows the results of this analysis.

Table 6; Principle Direction of Force for Side Impact Crashes with Poles (Struck-side Occupants Only - N=141)

Principle Direction Of Force	N	%
0-degrees	5	3.5
30-degrees	42	29.8
60-degrees	29	20.6
90-degrees	49	34.7
120-degrees	14	10.0
150-degrees	2	1.4

Table 7; Injuries in Side Impact Crashes with Poles/Trees

	60-90 degree crash involving passenger compartment (N=42)	0-60 degree crash involving passenger compartment (N=54)	All other side impact pole crashes (N=27)
Mean delta-V	30km/h	41km/h	31km/h
AIS2+ Head Injury*	45%	46%	19%
AIS2+ Face Injury*	7%	19%	7%
AIS2+ Neck/spine*	12%	17%	15%
AIS2+ Chest Injury*	40%	43%	7%
AIS2+ Abdomen Injury*	14%	24%	0%
AIS2+ Pelvis Injury*	24%	17%	0%
AIS2+ Upper Extremity Injury*	12%	19%	4%
AIS2+ Lower Extremity Injury*	33%	11%	33%

* to occupants on the struck-side of the vehicle (i.e drivers in right-side crashes and passengers in left-side crashes)

When the location of impact is adjacent to the passenger compartment, there is an intuitive enhanced risk of direct contact between the occupant and the striking object. In the table shown above, it can be seen that when the passenger compartment is directly contacted in a perpendicular side impact with a pole (as defined in figure 2 below) there is risk of AIS2+ injury particularly to the head, chest and lower extremity.

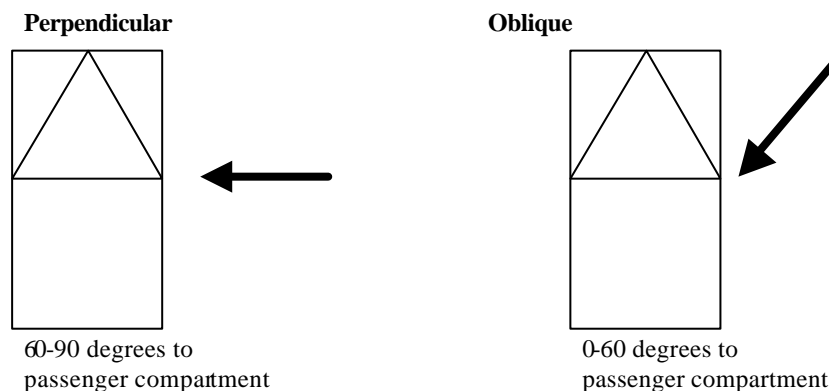


Figure 2; Perpendicular and Oblique Impacts to Passenger Compartments

In perpendicular impacts (as defined in figure 2 above) whereby the occupant compartment is not contacted, the outcomes are generally good since there is reduced risk of injury from intrusion of the survival cell or from the effects of the restraint system. However, oblique crashes (as defined in figure 2 above) such as those with a Principle Direction of Force (PdoF) of between 0-60 degrees represents an overlap of crash types that considerably amplifies the injury risk. Firstly there is a risk of direct contact on the pole/tree as in purely perpendicular impacts. However, in addition for oblique impacts, occupant kinematics would determine that there is also an enhanced risk of contact with the forward structure of the vehicle such as the A-pillar and/or facia region that may lead to injury outcomes, particularly to the head. Furthermore the restraining effects of the seat-belt, although obviously beneficial in the vast majority of cases can occasionally cause serious injury particularly to the chest and abdomen. The steering wheel can be a factor in injury causation to the driver.

Discussion

Pole/tree impacts represent a challenge to the vehicle designer. As indicated earlier, they are a relatively common event in crashes but by and large, most modern vehicles are designed for optimum crash performance in a car-to-car impact. Not surprisingly therefore, outcomes in car-to-pole/tree crashes at the

same level of severity as car-to-car crashes are often more severe. In such events, it is the car that absorbs the impact energy and such energy is generally concentrated over a narrow area of the vehicle and hence intrusion of the survival cell is common, as is direct interaction between the object struck and the occupant, particularly in side impacts.

For 'head-on' frontal impacts with a Delta-V crash of around 48-50km/h (which is approximately the speed of an ADR69 regulatory compliance test), there is a difference in injury outcomes which appears to be related to the location of damage to the vehicle. Damage to the front right of the vehicle appears to be associated with greater risk of head, face and lower extremity injuries whilst damage to the centre of the vehicle appears to be related to risk of neck/spine and chest injury. It is suggested that this may in part be related to differences in crash-pulse that are experienced by the vehicle according to the location of the vehicle damage. This in turn, could be influenced by the geometry of the engine (according to whether the vehicle is rear-wheel or front wheel drive). There were unfortunately insufficient cases within the sample to allow discrimination between front and rear-wheel drive vehicles. Another factor is that the crash-pulse in the vehicles studied could not be calculated by assessment of vehicle damage. Moreover, whilst Delta-V is a useful measure of crash severity, it does not provide an indication of crash-pulse either.

Side impact crashes with poles and trees represent probably the greatest challenge to vehicle designers. When the passenger compartment is contacted in a pole-tree crash, the head and the chest are particularly vulnerable body regions in both perpendicular and oblique crashes. The pelvis and lower extremity are also at risk in perpendicular impacts whilst the abdomen is vulnerable during more oblique impacts. It will be interesting to examine how successfully side airbags designed for protection of the head in a pole/tree crash perform in the real world. As yet there are only limited data that do not allow any real insight. However, given that the EuroNCAP pole crash-test protocol measures predominantly the risk of head injury, the importance of injury to other body regions, particularly the chest, should not be overlooked.

There are limitations of this present study, which should be addressed in a follow-up study. Firstly, there have been several expressions about the accuracy of CRASH3 as an instrument for measurement of crash severity. Whilst many of these issues have been addressed in a study by Lenard et al (1999), CRASH3 calculations are still prone to underestimation. One other limitation is that inherently, retrospective studies such as the study undertaken here are prone to concerns about the accuracy of the understanding of the crash and injury circumstances. The only means of improving data quality and reliability and accuracy is to undertake full in-depth at-scene crash investigations but unfortunately, the costs associated with such studies prove prohibitive in the majority of cases.

In conclusion, it is well understood that pole/tree crashes are a common and serious problem in Australia (Wilson et al, 1999). Future vehicles may well be designed that provide enhanced protection to occupants in such crashes and the only means of fully evaluating design effectiveness is for continued collection of in-depth data.

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