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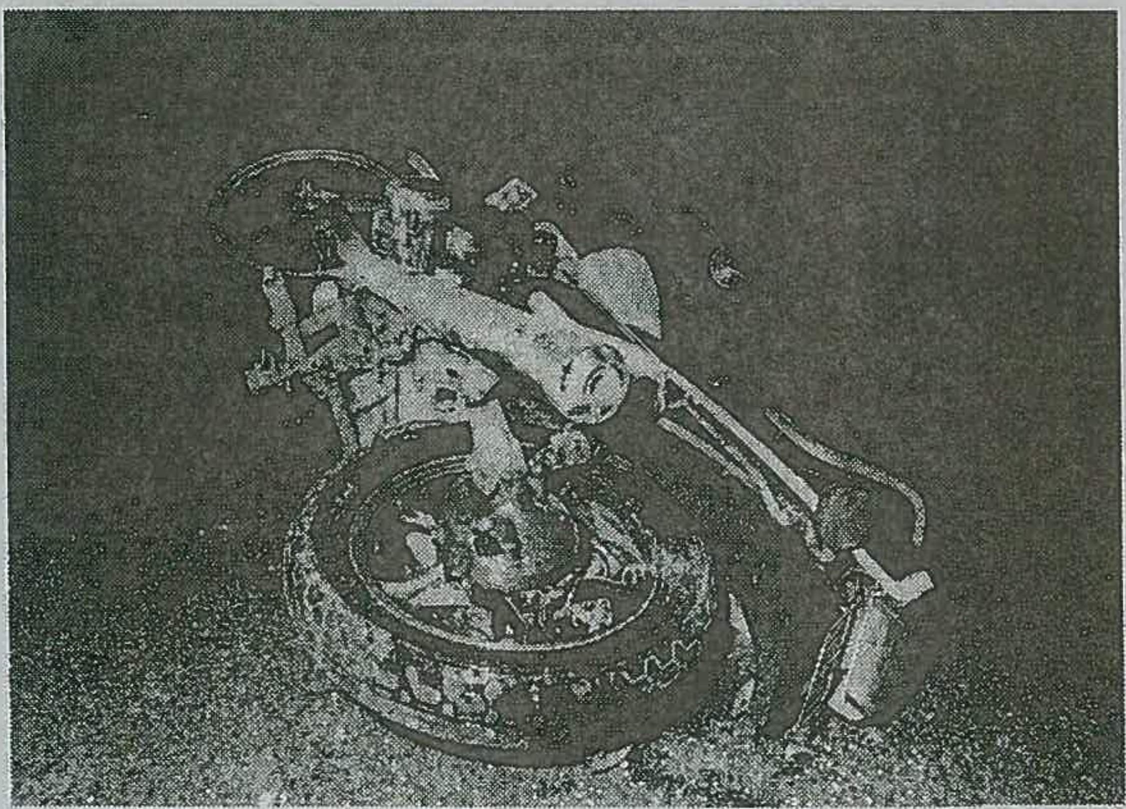
Road safety Bureau

Crashlab

A Study of Helmet Damage and Rider Head/Neck Injuries for Crash Involved Motorcyclists



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Research Note 5/88

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1.0 EXECUTIVE SUMMARY

Background

Helmets are currently the most effective countermeasure to serious injury available to motorcyclists. In New South Wales observational surveys of riders in city and rural towns have indicated that more than 97% of motorcyclists wear helmets. If the performance of motorcycle helmets can be improved than that can be fairly easily translated into reduced injuries to motorcyclists in road crashes. When the Australian Standard for motorcyclist's helmets was first implemented, it appeared to incorporate the best of all known Standards and as such, was probably the best in the world. Over the last ten years it has overgone little change. One of the main reasons given for this, has been the lack of Australian research data into the performance of currently available helmets and potential performance of helmets with improved protection. This study set out to resolve those criticisms by evaluating the in-crash performance of motorcycle helmets, with the particular aim of finding areas where there was potential for further protection from injury.

Method

During the study period, researchers at the Traffic Authority obtained notification from the Ambulance and the Police when a motorcycle crash occurred which was of sufficient severity to have the motorcyclist admitted to hospital. If the motorcyclist was wearing a helmet approved to the current Standard and if they consented to access to their helmet and injury data, they were included in the study. Fatal crashes were automatically included, if the helmet could be obtained. The helmets were inspected internally and externally to determine the types of contact and damage which had occurred. The motorcyclists injuries were evaluated and then coded by a medical officer using the 1985 version of the international abbreviated injury coding system (AIS). All of this data was then matched and analysed.

Results

- The study ended up with 200 cases, of which 72 were fatal and 128 non-fatal.
- 89% of the helmets were full face style whilst the remainder were open face style. Each helmet had received an average of two impacts.
- There were twice as many oblique impacts as radial.
- 35% of all impacts were outside the test area specified in the current Standard.
- 25% of all accidents appeared more severe than the prescribed Standard for radial impact.
- Of the very severe impacts, 50% were to the general frontal area of the helmet.
- Of the helmets with visors, 60% had received an impact.

- Only 13% of fatals received no head, neck or facial injuries, whereas 38% of non-fatal cases received no head, neck or facial injuries.

- In the cases where a head or neck injury occurred, 50% of impacts were to the general frontal area of the helmet and 40% of these impacts, or 20% overall resulted in base of skull fractures. In other words, these fractures were predominantly caused by forces transmitted from an impact remote from the injury site.

- Local skull fractures (vault fractures) were associated with impacts adjacent to the fracture site.

- 75% of the impacts which caused neck strain were oblique impacts.

- 60% of the cases involving neck strain had no radial impact at all.

- Minor oblique impacts were found to be capable of producing injuries ranging from minor unconsciousness to severe brain injuries.

Discussion

It appears that where the impact to the helmet was radial (that is impacts at right angles to the helmet shell), within the limited test areas specified in the Standard, then the helmets were relatively effective in providing protection. This protection was effective against either flat, blunt or irregular objects.

When the front of the helmet was struck, it was generally outside the test area and the most serious injuries associated with this were base of skull fractures or frontal skull vault fractures. Impacts to areas other than the front or test area of helmets were more likely to produce life threatening neck injuries than brain injuries.

It was concluded that the areas most needing attention are:

- Expansion of the zone of protection at the front of the helmet.

- The inclusion of a test to minimise the transmission of the impact force from frontal blows to the base of the skull.

- The inclusion of an oblique impact test to evaluate the helmets ability to minimise head and neck injuries from these impacts.

Recommendations

These recommendations have been assigned a priority based both on the technical difficulty of the laboratory investigations and development work, and the administrative feasibility of introducing further requirements. These were weighed against the expected reduction in the number and severity of injuries.

1. Increase the area of protection specified in AS1698.

The test area specified in the Australian Standard is not as extensive as that of other Standards. In this study frontal impact outside the test area was found to be frequent and severe. The brow aspect of the helmet needs to be considered on its own as an energy attenuator. The test area of the Standard should be extended to include this area. This recommendation will not produce as significant reduction of injuries as the following recommendations, but it is easier to achieve and can be quickly implemented.

2. Develop specifications for tests to measure the ability of a helmet to minimise the effect of oblique impacts.

Helmet Standards have traditionally tended to minimise translational acceleration but they have not tested the helmets ability to minimise rotational acceleration. The latter provides local accelerations equal to or greater than direct blows. Most Standards depend upon limitations on external projections by height, hardness or discontinuity, rather than an objective test of the helmet.

2.0 INTRODUCTION

The objective of the study was to improve head and neck protection to motorcyclists, by providing information on which to base a revision of the Australian Motorcycle Helmet Standard, AS1698 "Protective Helmets for Vehicle Users"`. It is known from in-depth crash studies and statistical studies that helmets reduce both the frequency and severity of injuries to motorcyclists. It appeared possible to gain further injury reduction by improvements in helmet design.

This study correlated helmet damage with head and/or neck injuries to motorcyclists injured in traffic crashes. Areas of interest in the study included the:-

- energy attenuation capabilities of helmets;
- location of impacts on helmets;
- frequency of impacts on visors;
- adequacy of the test area specified in AS1698;
- identification of the nature and cost, in terms of injury severity and frequency, of various injury mechanisms:

This report presents the data obtained from the examination of 200 motorcycle crashes. Data from fatal crashes was collected over a period of eighteen months from April, 1985 to September, 1986 and data from non-fatal crashes was collected over a four month period from June 1986 to September, 1986.

3.0 METHOD

Notification of prospective cases was obtained from the New South Wales Ambulance Service and New South Wales Police. Researchers from the Traffic Authority then made inquiries to determine if a case met the study criteria, which were:-

(i) that the motorcyclists was wearing a helmet approved to AS1698 and;

(ii) that the motorcyclist was killed or had received injuries sufficient to cause admission to hospital.

Once it was established that a case met the study criteria arrangements were made to obtain consent to gain access to injury data and to examine the helmets. Helmets which did not comply with AS1698 were not included in this analysis as the intention of this study was to improve the design of AS1698 approved helmets.

For the fatal cases post mortem reports were obtained from the Coroners Courts. Injuries described on these reports were then listed and coded by a Medical Officer using the 1985 version of the Abbreviated Injury Coding System (AIS) manual (see Appendix A)(Reference 1).

Non-fatal case injury data was obtained by the Medical Officer from Ambulance Service report forms, hospital medical records and interviews with subjects. The data was then collated and coded in the same manner as the fatal injury data.

Helmets from all fatalities and from some non-fatals were obtained by the Police. The remaining helmets were obtained by Traffic Authority researchers.

A general inspection of the helmets was made to determine the;

-brand, model, type, size, shell material;
-standards approval;
-presence of modifications.

An external inspection of the helmets determined the;

-number of impacts;
-impact locations;
-direction of impact relative to the surface of the helmet shell;
-severity of impact;
-type of shell damage;
-retention system damage;
-visor damage.

After dismantling each helmet an internal inspection was conducted to reveal the;

-location of liner damage;
-type of liner damage;
-area and extent of liner compression.

The data from this inspection was coded and entered into a computer for later analysis (see Appendix B for inspection form and procedure).

4.0 HELMET INSPECTION DATA

4.1 General

The total number of potential cases notified by the Police and Ambulance was 536, consisting of 123 fatal cases and 413 non-fatal cases. A number of these potential cases were omitted from the study, as detailed in Appendix C, leaving 86 fatal cases and 128 non-fatal cases for analysis.

A further 14 fatal cases were eliminated after a preliminary examination of the helmets and their associated user injuries. The injuries in these cases could not be related to the performance of helmets approved to AS1698 due to modifications to the helmets or to the absence of the helmet at impact.

In three of these cases the helmet's protective properties had been severely degraded by chemical attack to the shell and/or liner prior to the crash. In one of these cases a plastic shell had been painted and the shell had failed in a brittle manner when struck (Figure 1).

In eight cases the helmet had come off during the crash. In all except one of these eight cases there was doubt that the helmet had been worn correctly. In this case the visor mounting bolts had been replaced with steel bolts that projected from the helmet (Figure 2). The helmet had struck a light pole and one of the bolts became embedded in the pole causing the helmet to become dislodged. The riders unprotected head then struck a fence post.

In another three cases impacts to the head were outside the area of helmet coverage and there were no impacts to the helmets.

Thus the following analysis is concerned with 72 fatal cases and 128 non-fatal cases.

Helmet details are shown in Table 1. Eleven percent of the helmets examined were of the jet style and the remainder were full face. This distribution compares with that observed by the Traffic Authority during surveys of motorcyclists in 1984 (Reference 2), when, from a sample of 1,143 motorcyclists 87 percent wore full face helmets, 11 percent jet style and 2 percent no helmet.

The jet helmets examined in this study typically had plastic shells (56 percent). The majority of the full face helmets (74 percent) had fibreglass shells and the remainder were of plastic. Plastic shells are defined as those helmets with shells constructed from polycarbonate, ABS and other proprietary materials such as Ronfallin.

4.2 Helmet Approval

Of the 72 fatal cases, 41 helmets had no approval stamp other than that of AS1698 and 88 of the 128 non-fatal case helmets also had only one approval. The most common Standard's approvals other than AS1698 were Snell 80 and ANSI Z-90 with 25 cases each. Details of Standards approval other than AS1698 are shown in Table 2.

4.3 Helmet Impacts

4.3.1 Frequency of Impacts

Table 3 shows the impact frequency per case. Two impacts per helmet was the most common impact frequency. The 200 helmets examined received a total of 401 impacts (137 on the fatal case helmets and 264 on the non-fatal case helmets).

4.3.2 Severity of Impacts

The severity of impacts was assessed by comparing the damage caused by each impact with the damage to a similar helmet when tested to AS1698. Severity was defined as follows:

a) Minor -shell damage but no liner damage.

b) Moderate -usually some liner damage but not exceeding that of a similar helmet tested to AS1698.

c) Severe -shell and liner damage exceeding that of a similar helmet tested to AS1698.

The method of determining severity is discussed in Appendix D.

From Table 3 it can be seen that severe and moderate impacts occurred more often in the fatal cases while minor impacts predominated in the non-fatal cases. Twenty five percent of all impacts were considered to be more severe than the impact specified for testing to AS1698.

Impact severity and frequency for the different helmet types is shown in Table 4.

4.3.3 Type of Impact

Impact type was classified as radial (ie. normal to the surface of the helmet) or tangential (ie. an oblique impact).

Radial impacts had typical shell damage patterns (see Figure 3). An impact can have both radial and tangential components. Scoring of the helmet shell is associated with tangential impacts (see Figure 4). Liner crush beneath the impact site, or other shell damage, revealed the presence of a significant radial impact combined with a tangential impact. The degree of liner crush and shell damage determined the severity rating of tangential impacts.

Impact type by impact severity is shown in Table 5. There were twice as many tangential impacts as there were radial however most of the of severe impacts (73 percent) were classified as radial.

4.3.4 Impact Location and Frequency

Impact locations were recorded in relation to the areas of the helmet shown in Figure 5. These areas deliniate the top and areas inside and outside the AS1698 test area on the front, sides and back of the helmets.

The impact locations and frequencies are shown in Table 6 and in Figures 6 to 17. It was possible for an impact to be spread over more than one of the areas shown in Figure 5. In such a case a proportion of the impact was recorded in each of the areas contacted (for example, if two areas were contacted, half an impact was recorded for each area).

It should also be noted that no impacts are possible for jet helmets in areas 15 and 16 and that visor only impacts are not included (see Section 4.4).

The number impacts lying inside and outside the test area is shown in Table 7. Approximately two thirds of impacts occurred inside the test area. The largest proportion of impacts outside the test area was to areas 15 and 16, that is the area covered by the chinbar of a full face helmet.

4.4 Facial / Visor Impact

Visor fitment and damage are shown in Table 8. Almost 60 percent of the helmets received were fitted with visors or goggles. However, impacts to other helmets may have destroyed evidence of visor fitment. The majority of jet helmets were not received with eye protectors fitted. Observational surveys by the Traffic Authority (Reference 3) have found that over 80 percent of all helmet wearers also wear eye protectors.

Sixty percent of the visors received were damaged. Of the 28 fatal case helmets with visor damage 12 cases were not associated with impacts to the front of the helmet (ie. damage was due to impact to the visor alone). The remaining 16 cases of visor damage were associated with impacts to the helmet shell surrounding the visor. The comparable figures for the non-fatal cases were 8 impacts out of 40 solely to the visor and the remaining 32 associated with helmet shell damage.

4.5 Liner Damage

There were 4 penetration impacts and all were associated with extreme helmet damage.

The liner damage produced by the different impact types is given in Table 9 and the liner compression for the different impact types is shown in Table 10.

The information from Tables 9 and 10 can be summarised as follows:

-Of the 137 impacts recorded on helmets from fatal cases 59 were radial and 68 were tangential.

-Of the 264 impacts recorded on helmets from non-fatals; 70 were radial and 191 were tangential.

4.6 Retention System

The data collected does not allow conclusions to be drawn about the effectiveness of retention systems. Motorcyclists involved in the study crashes, or witnesses to these crashes, were not interviewed in respect of the effectiveness of helmet retention systems. Information supplied in Coroners reports, in conjunction with an assessment of helmet and injury data, allowed conclusions to be drawn about whether or not helmets were retained during some fatal crashes. If there was reason to believe a helmet had not been properly secured it was not included in the study.

In respect of retention system strength, there were three cases of retention system failure. Two cases involved broken straps and in the third the rivet attaching the strap to the helmet shell had been pulled out.

In six cases the retention straps had been cut, presumably to aid helmet removal after the crash.

4.7 Discussion

There are several points of interest regarding the location of impacts.

1. The was large proportion of severe blows to the front of the helmets. Almost 50 percent of all impacts were to this area and the ratio of severe to other impacts was much higher (70 percent) than for the sides (23 percent) or the back (22 percent).

2. There were few blows to the tops of the helmets. Only 10 percent of all impacts were to this area. The ratio of severe to other impacts was similar (25 percent) to that for the sides and backs of the helmets.

3. Minor impacts predominated on the sides and backs of the helmets.

4. The zone of protection (or area within which energy attenuation and penetration tests are to be conducted) specified in AS1698 is covered approximately by areas 1, 2, 5, 6, 7, 8, 9, 10, 13, 14, 17 and 18. Thirty five percent of all impacts were outside this area.

Given the conservative assumption that visors were not worn in the cases where no visor was received for inspection then 10 percent of all the cases received impacts to their visors that were not associated with helmet damage. This may be a conservative assumption as surveys have shown the wearing rates for eye protectors are much higher than 60 percent. It is therefore possible that many visors were destroyed by impacts or were subsequently lost. The alternative is that persons not wearing eye protectors were over-represented in the crashes studied.

Visors are required to meet an impact test which consists of firing a steel ball at a visor attached to a helmet. If the steel ball doesn't fracture or penetrate the visor then it passes the test. Visors are not considered part of the energy attenuation systems of a helmet.

AS1698 requires the helmet manufacturer to specify a "helmet positioning index". This index determines the relationship of the lowest point of the helmet brow opening at the lateral midpoint of the helmet to the "basic plane" of a test headform. The positioning index therefore determines the position of the test line on the front of a helmet. This test line marks the forward edge of the test area and is usually some distance above the brow opening of the helmet. The assumption has been made in this study however that impacts to areas 13 and 14 on Figure 5 are all within the AS1698 test area as it was not possible to determine the exact position of the test line for each helmet examined. This is again a conservative assumption when considering the proportion of frontal impacts outside the test area to those inside the test area. Many of the impacts to areas 13 and 14 were close to the edge of the helmet and may have been partly outside the test area.

Another factor to be considered when assessing the prevalence of frontal impacts is the fact that twenty three of the helmets were jet helmets for which no impacts could be recorded to areas 15 and 16 (ie.the chinbar region of a full face helmet). The frequency of impacts to the brow area of helmets was slightly higher than the frequency of impacts to the chinbar region (61.8 compared to 56.4). However the average number of impacts to each of the 177 chinbars in the study was greater than the average number of impacts to the brow areas of the 200 helmets.

5.0 INJURIES

5.1 General

5.1.1 Non-fatal Cases

There were 672 injuries recorded for the 128 non-fatal cases studied or over 5 injuries per case. Extremity injuries (ie. upper and lower limbs and the bony pelvis) were the most frequently occurring injury, followed by external injuries (ie. surface or integumentary for any body region). As the severity of injury increased thorax and abdomen injuries became relatively more important despite their low incidence (see Fig. 18 and Table 11). External injuries are not shown on Figure 18.

5.1.2 Fatal Cases

There were 682 injuries recorded from the 86 fatal cases studied or an average of almost 8 injuries per case. The most frequently recorded injuries were to the head closely followed by injuries to the chest. The serious (AIS3 or greater) injuries were predominantly head (thirty percent) and chest (eighteen percent). Table 12 and Figure 19 show the distribution of injuries for the fatal cases. Note that external injuries are not shown on Figure 19.

5.2 Head and Neck Injuries

5.2.1 Non-fatal Cases

Seventeen percent of all the injuries recorded in the non-fatal cases were to the head and/or neck and involved 79 cases. All of these injuries were, with one exception, of AIS 3 or less severity. The non-fatal head injuries typically related to loss of conciousness. In all of these cases the time of unconciousness was less than one hour.

There were two base of skull fractures and in both of these cases there were also facial fractures.

Cervical spine injuries comprised the majority (sixty two percent) of all the spinal injuries recorded. Twenty one of the 24 cervical spine injuries were classified as acute strain (AIS 1) and the other three injuries were fractures. Forty six percent of the cervical spine injuries were associated with loss of conciousness.

5.2.2 Fatal Cases

The 77 fatal cases with head and/or neck injuries received 186 injuries to these regions (ie. twenty seven percent of all recorded injuries in the fatal cases). As would be expected when injury data was obtained from post mortems the majority of the injuries were coded as AIS 3 or greater as this level of injury presents clinical signs that are obvious at post-mortem. The exceptions were AIS1 or 2 facial injuries.

Two thirds of the AIS3 head injuries were to the brain and the rest were base of skull and vault fractures.

Forty five percent of the 43 AIS4 head injuries were subdural hematomas and 95 percent of these were considered to be secondary deceleration induced injuries rather than primary injuries. Another forty two percent of the AIS4 injuries were to the brain and the remainder were cranium fractures.

The AIS5 head injuries all involved the brain stem as did five of the eleven AIS6 injuries (brain stem laceration). The remaining AIS6 head injuries were massive crush (ie. substantial deformation of the skull and the brain).

There were thirteen neck injury cases. Two of these involved spinal dislocations or fractures associated with massive crush head injuries and another two were associated with base of skull fractures. Of the remaining nine cases, seven involved cord contusions with fracture and/or dislocation. Neck injuries may have been under-reported in post mortems due to the absence of obvious clinical signs. The neck injuries in the fatal cases were mostly of AIS5 or 6 severity and were, with one exception, the result of moderate or severe impacts. The exception was a case where a minor tangential impact to a jet helmet resulted in an AIS6 severity neck injury.

5.3 No Head or Neck Injuries

In 9 fatal cases and 49 non-fatal cases there were no head or neck injuries. Six of the helmets in these fifty eight cases had not received impacts. The nature and distribution of the impacts to the remaining fifty two helmets is shown in Table 13. Table 14 contains similar data for the cases where head, neck or face injuries did occur.

As would be expected, the proportion of severe impacts to other impacts was lower in the cases which did not suffer head injuries, than in the cases where there was a head or neck injury. Six percent of the impacts in the non-head/neck injury cases were severe compared to thirty two percent in the head/neck injury cases. There was a contrasting increase in the number of minor impacts in the non-injury cases when compared with the cases where there was head/neck injury.

There were five cases with severe impacts but no head/neck injury.

6.0 INJURY MECHANISMS

6.1 General

After consideration of the injuries recorded and the location and severity of impacts to helmets, it was decided to group the cases under headings which related to the injury outcome. This grouping was done to assist in the identification of possible injury mechanisms. The classifications used were:-

a) massive crush
b) base of skull fractures
c) vault fractures
d) neck injuries
e) unconciousness

Each of these categories may include injuries from categories lower on the list. For example, brain injuries, vault fractures and neck injuries which occurred in cases where there was massive crush were not then included in their respective categories. Table 15 shows the frequency and severity of injuries in these categories.

Injuries were further classified as primary or secondary. Primary injuries were defined as those which were at or directly related to an impact and secondary injuries are those which resulted from an impact at a location remote from the site of injury.

6.2 Massive Crush

All of these six cases were either high energy crashes or impacts against unyielding objects. Two crashes were head on with cars, one rider hit the side of a moving train, there was one impact with a brick fence and another with a chain wire fence which resulted in penetration damage to the helmet shell and liner.

These impacts were considered unsurviveable.

6.3 Base of skull fractures

There were twenty five base of skull fractures. Table 16 lists the type and severity of associated injuries. Although a base of skull fracture is only rated as an AIS3 injury, it was often associated with other more serious injuries.

The most prevalent associated life threatening injuries were lacerations to, and bleeding in the brain stem directly associated with the fractures and spinal cord injuries. Injuries to the cerebellum, principally lacerations and hematomas, were more frequent but not as severe as brain stem injuries.

There were two cases where it was considered that the base of skull fractures were primary (ie. the injury was close to the point of impact on the helmet). One case involved a plastic full face helmet that received a severe radial impact to the side which resulted in a residual fifty percent crush of the helmet liner. In the other case the helmet appeared to have impacted a kerb, or similar object, on the side and back.

The remaining twenty three of the base of skull fractures were considered to be the result of forces transmitted from impacts remote from the fracture site. The impact site in two of these secondary injury cases was area "1" on the front left side of the helmet. In both of these cases there was only one severe radial impact. The impact in one case was sufficient to leave a large indentation in a polycarbonate helmet. In the remaining twenty one cases the impact was to the front of the helmet or to the face of the rider. The impacts were mostly radial (see Table 17) and were frequently severe single impacts (see Table 18).

Facial injuries were associated with eight of the twenty three secondary base of skull fractures. In all of these 8 cases full face helmets were worn.

Twelve vault fractures occurred in frontal impact/base of skull fracture cases. In five of these cases the fractured vaults were a continuation of the base of skull fractures.

Seven primary subdural hematomas occurred in cases where there was also a base of skull fracture. In three of these cases the subdural hematoma was directly associated with the fracture. Five cases had fractures of bones at or near the front of the head directly associated with the hematoma.

All, except two of the twenty five base of skull fractures, resulted from frontal impacts and transmission of the resulting forces to the base of the skull. Sixty percent of these frontal impacts were outside the test area specified in AS1698.

It was considered that the base of skull fractures, while not life threatening in themselves, are an indication of the type and severity of impact and are likely to be associated with other more severe injuries. Twenty seven percent of the fatal cases studied were included in this injury category.

6.4 Vault Fractures

There were only four vault fractures that were not associated with base of skull fractures. Three of these cases involved impacts to the front of fiberglass full face helmets and one to the back of a plastic helmet. In one of the frontal impact cases there was also a zygoma fracture. None of these cases had neck injuries and the most severe associated head injury recorded was of AIS4 severity.

These fractures were all considered to be primary injuries.

6.5 Neck Injuries

Seventy five percent of the helmet impacts in the 25 cases where acute neck strain was coded were tangential and seventy eight percent of these impacts were to the back and sides of the helmets (see Table 19). In eight cases the impact was to the back or sides of the helmet and all of these eight cases had tangential impacts. Only one of the acute neck strain cases received no tangential impact but there were in comparison 15 cases where no radial impact was noted. In 6 of these 15 cases, the most severe impact was of minor severity, it was of moderate severity in 3 cases and severe in the remainder.

In 11 cases the neck injury was associated with unconciousness. Table 20 shows the type and location of impacts in these cases. Seventy seven percent of these impacts were tangential and 7 of the 11 cases had tangential impacts only.

Nine fatal cases had neck injuries that were not associated with massive crush injuries or base of skull fractures and there were three non-fatal cases with neck injuries of AIS2 or greater severity. Almost all of these twelve neck injury cases also had head injuries. The associated life threatening head injuries were to the brain stem and the less serious AIS3 and 4 injuries were to the brain.

In one case a minor tangential impact to a jet helmet resulted in a fatal (AIS6) neck injury. This casualty was also reported as having contusions to the chin. The remaining cases with AIS5 and 6 injuries in this neck injury category all wore full face helmets which had received impacts to the back and sides but, with one exception, not to the front. Table 21 contains details of impact locations.

It is believed that spinal injuries were under-reported in the fatal cases particularly in cases where spinal cord damage may have occurred without obvious damage to the cervical spine.

6.6 Unconciousness

There were 42 cases, including 11 neck injury cases, in which the rider had become unconcious. More than two thirds of the impacts in these cases were tangential. In eighteen cases the impacts were tangential only, compared with eight cases of radial only impact. It was noted that tangential impacts of minor or moderate severity, without an associated radial or visor impact, were capable of producing unconciousness. When cases are considered which had either tangential or radial impacts only, the distribution of impact sites for each category is different. The tangential impacts were generally to the back or side of the helmet whereas the radial impacts were predominately to the front (see Table 22).

It would appear that unconciousness can be produced by two distinct mechanisms. It can result from a moderate or severe impact to the front of the helmet or it can be the result of a tangential impact to the sides or back of the helmet which impart a rotational acceleration to the brain. It is not known if the apparent relationship between unconciousness and neck injury is significant, but it should be noted that tangential impacts predominated in these cases.

7.0 IMPACT SEVERITY v. HEAD/NECK INJURY SEVERITY

As would be expected life threatening injuries predominately occurred in cases where there had been a severe or moderate impact. Similarly minor impacts were more likely to result in no injury than were moderate or severe impacts (see Table 23).

Helmets constructed to AS1698 should provide protection from impacts of moderate, or lesser, severity. There were 117 cases in which the most severe impact was of minor or moderate severity. In 17 percent of these cases the injury was of AIS3 (ie. a serious injury on the Abbreviated Injury Scale) or greater severity. In 55 percent of these moderate or minor impact cases there was no head/neck injury.

There were however 73 cases where the impacts were more severe than that allowed for in AS1698 and in 45 percent of these cases the injuries were of AIS3 or greater severity. Nineteen percent of the cases with severe impacts received no head/neck injury and another 26 percent received only moderate or minor injuries.

When Table 23 is considered in relation to the injury categories of Section 5 it is found that for severe impacts the "base of skull", "massive crush" and "neck injury" categories accounted for all of the 14 cases where the most severe injury was of AIS6 severity. The impacts which caused massive crush were considered unsurviveable. If these cases are excluded, then 71 percent of the remaining 24 cases, which received injuries of AIS4 or greater severity as the result of severe impacts, were in the "base of skull" or "fractured vault categories". Another 13 percent were neck injuries and the remainder were brain injuries.

8.0 SUMMARY OF RESULTS

- Seventy two fatal cases and one hundred and twenty eight non-fatal case were analysed.
- Eleven percent of the helmets were jet style and approximately half of these had plastic shells. The remainder of the helmets were full face and most (74 percent) had fibreglass shells.
- Almost forty percent of the helmets were approved to other Standards as well as to AS1698.
- The helmets received an average of two impacts each.
- There were more than twice as many tangential impacts as there were radial impacts.
- Thirty five percent of all impacts were outside the test area and forty percent of these impacts were to the chin bar region.
- Only ten percent of all impacts were to the tops of the helmets.
- Twenty five percent of all impacts were considered more severe than the impact specified for energy attenuation testing to AS1698.
- Almost 50 percent of severe impacts were frontal and almost half of these were outside the AS1698 test area.
- Forty percent of the helmets were received without visors but of the visors received almost 60 percent had received an impact.
- Five percent of the cases had received no impact to the helmet.
- Thirteen percent of the fatal cases and thirty eight percent of the non-fatal cases received no head neck or face injuries.
- Seventeen percent of all injuries to the non-fatal cases and twenty seven percent of injuries to the fatal cases were to the head, neck or face.
- Where head/neck injury occurred, almost fifty percent of the severe impacts were to the front of the helmet. Forty percent of these impacts resulted in base of skull fractures.
- Injuries were considered in the following categories to assist in the identification of injury mechanisms.

  a) massive crush
  b) base of skull fractures
  c) vault fractures
  d) neck injuries
  e) unconciousness

- Massive crush injuries resulted from either unsurviveable high energy impacts, or penetration or dislodgement of the helmet.
- Base of skull fractures were predominantly secondary injuries caused by forces transmitted from an impact site remote from the injury site. Almost all of the impacts that caused these secondary injuries were frontal. Frontal impacts to the chin alone, the brow alone, or to both were capable of producing this injury.
- Vault fractures that were not associated with base of skull fractures were primary impact injuries, that is they were located at the impact site.
- Acute neck strain was often (48 percent) associated with unconciousness.
- Seventy five percent of the impacts in cases where there was acute neck strain were tangential. In 60 percent of the neck strain cases there were no radial impacts, only tangential.
- Minor tangential impacts were found to be capable of producing injuries ranging from unconciousness to serious brain injuries.
- Fifty nine percent of all cases had an impact of moderate or less severity. In 55 percent of these cases there was no head/neck injury. Another 17 percent had head/neck injuries of AIS3 or greater severity.
- Thirty seven percent of all cases received a severe impact and 45 percent of these cases suffered injuries of AIS3 or greater severity.

9.0 DISCUSSION

9.1 Australian Standard 1698

This study was initiated following concern that the Australian Standard for motorcyclists helmets, AS1698, could be improved and thereby reduce the incidence and severity of injury to motorcyclists.

It would appear from the cases examined in this study that AS1698 is relatively effective at providing protection within its own terms of reference. That is, it specifies a zone of protection which covers the top and part of the front, back and sides of a full face helmet (see Figure 20). Within this zone of protection it specifies tests which are intended to produce helmets which will absorb or attenuate energy from radial impacts and thereby minimise translational decelerations of the brain. The helmets are also tested for their ability to resist penetration by sharp objects.

Impacts with sharp pointed objects were found to be almost non-existent. However it is not recommended that the penetration test be deleted from AS1698, as there were cases where severe local loading resulted in penetration of helmet shells. There were also several primary skull fractures which were the result of impacts with objects such as truck trays. In general, it appears that the present combination of penetration test and energy attenuation test is producing helmets that are capable of preventing skull damage in most circumstances when the helmet is struck on the top, back or sides. A more appropriate test for local loading is clearly desireable, but there are higher priorities for improvement of helmets. The current work on a replacement for the penetration test in the pedal cycle helmet Standard may eventually have direct application to the motorcycle helmet Standard.

With respect to the minimisation of decelerations on the brain, it would appear that impacts to areas of the helmet other than the front of the helmet are more likely to produce life threatening neck injuries than brain injuries. When the front of the helmet was struck the impacts were most likely to be outside the AS1698 zone of protection and the most serious resulting injuries were associated with base of skull fractures or frontal vault fractures.

After considering the results of the study it was concluded that the areas most in need of attention in AS1698 are:-

- the limited zone of protection on the front of the helmet;
- the lack of a test of the ability of the whole front (jawpiece, visor and brow) of a helmet to minimise the transmission of impact forces to the base of the skull;
- the absence of a tangential impact test that will evaluate the ability of a helmet to minimise the effect on the head and neck of tangential impacts;

9.2 Frontal Impacts

Frontal impacts were frequent and severe. Almost 50 percent of severe impacts to the front of helmets fell on the chinbars of the helmets, that is, outside the test area. Impacts to the visor alone occurred in 15 percent of cases. The base of skull injury category was the most significant injury category in terms of frequency and severity of associated injuries. In all except 2 of the 23 cases with this injury the impacts were to the face or to the front of the helmet.

9.3 Tangential Impacts

This study has shown that tangential (or oblique) impacts are a significant source of injury. Minor tangential impacts alone were found to be capable of producing unconciousness which was often associated with minor neck injuries. Tangential impacts, particularly to the back and sides of the helmets were found to result in serious or fatal neck injuries. Many of the brain injuries were of a type that is associated with translational or rotational accelerations that are produced by tangential impacts. Brain injuries of this type comprised over 40 percent of the AIS4 injuries.

9.4 Unmitigatable Injuries

In all of the 6 massive crush category injury cases, the impacts and resultant helmet damage were so severe it was considered that it would not be feasible for a helmet Standard to provide protection from impacts of this magnitude.

9.5 Mitigatable Injuries

Neck injury comprised 30 percent of the cases with life threatening AIS5 or 6 head/neck injuries. The hypothesis has been proposed that a helmet can protect the neck by off-loading impact forces to less critical areas such as the shoulders. In the medium term, this hypothesis needs to be tested in laboratory simulations using anthropometric dummies and various helmet designs. Given the relationship between neck injury and tangential impacts already shown by this study, the priority is to develop a tangential impact test suitable for inclusion in AS1698. Such a test should result in the production of helmets capable of reducing the frequency of life threatening neck injury.

This study confirmed the claim (Reference 5) that base of skull fractures can be produced by impacts to the front of the head. The study also found that the base of skull injury category was the most significant injury category in terms of frequency and severity of associated injuries. Mitigation of frontal impacts would reduce the frequency and severity of these injuries. The most effective way to mitigate these injuries is to introduce an energy attenuation test for the front of helmets (not to be confused with extension of the current test zone).

The neck and base of skull injury categories accounted for almost all of the life threatening injuries recorded in this study. When Table 24 is examined, it is found that of the 11 cases remaining in the AIS6 classification after discarding the massive crush group, there are 7 cases belonging to the neck injury category and 4 in the base of skull category. These categories also dominate the AIS5 classification with 4 base of skull and 1 neck injury category cases out of the 8 cases in this group. Countermeasures that are effective in reducing the frequency of base of skull or serious neck injuries, will therefore obviously result in a considerable reduction in the frequency of life threatening injuries. The countermeasures to these injuries are the introduction of a tangential impact test and an energy attenuation test for the front of helmets.

Countermeasures to neck injuries and base of skull fractures will also reduce the frequency and severity of brain injuries. Rotational and translational acceleration induced brain injuries accounted for approximately 40 percent of the AIS4 injuries recorded. Reducing the impulse provided by tangential impacts will minimise the rotational accceleration imparted to the brain. Improving the energy attenuation capability of the front of the helmet will reduce the incidence and severity of moderate severity, but often disabling, brain injuries. It is considered that this complementary approach is a more realistic and effective method of reducing the frequency of these injuries than attempting to improve the energy attenuation capabilities of the existing AS1698 test area.

It is considered that the implementation of the recommendations in Section 9.0 would be the most effective method of significantly upgrading the performance of the Standard and thereby reducing the severity and incidence of head injury to motorcyclists.

10.0 RECOMMENDATIONS

The neck injury and base of skull injury categories were found to produce 80 percent of the life threatening injuries, after discarding the unsurviveable massive crush injuries. There is no test in AS1698 that attempts to provide protection against neck injury. There is no test in AS1698 that attempts to maximise the energy absorption of impacts to the brow and/or chinbar of a helmet or to minimise the transmission of forces from these impacts to the base of the skull. The introduction of a tangential impact test to AS1698 coupled with new and expanded tests of the energy attenuation capability of the front of a helmet will provide effective countermeasures to these injuries. These countermeasures for neck and base of skull injuries will also reduce the incidence and severity of less serious but more frequent and often disabling brain injuries.

The following recommendations are given in descending order of priority. Priority has been assigned after consideration of the technical difficulty of laboratory investigations or development of a test. The technical difficulty of producing helmets to meet a particular test and the administrative feasibility of introducing a test was weighed against the expected reduction in the number and severity of injuries if a recommendation is adopted.

RECOMMENDATION 1: Increase the area of protection specified in AS1698.

The test area specified in AS1698 is not as extensive as that specified in other Standards. Frontal impact was found by this study to be frequent and severe. The brow of the helmet needs to be considered in isolation as an energy attenuator, because impacts to this region were often associated with brain injuries. It is recommended that this region be subject to the same energy attenuation tests as the those currently specified for the AS1698 zone of protection. Although this recommendation will not produce as significant a reduction of injuries, as either a tangential or total frontal impact test, it has been given the highest priority because it is readily achievable technically and can be quickly implemented.

The Standard which specifies the greatest area of protection on the front of the helmet is Snell 85.

It is both technically and administratively feasible to immediately increase the area of protection specified in AS1698 to match that specified in Snell 85 (see Figure 20). Such a test would provide some benefit in reducing the incidence of base of skull injuries and brain injuries. These two injury types account for the majority of the life threatening and serious injuries respectively.

RECOMMENDATION 2: Develop specifications for a test to measure the ability of a helmet to minimise the effect of tangential impacts.

Helmet Standards have traditionally tested the ability of helmets to minimise the translational deceleration of the brain during direct radial impact but have not directly tested a helmet's ability to minimise rotational decelerations of the brain. Most Standards depend upon the specification of limitations on features such as external projections or discontinuities of the helmet shell that may increase the likelihood of producing rotational accelerations on the brain. British Standard BS6658 (1987) is currently the only Standard to include a tangential impact test. In this test a helmeted headform is allowed to free-fall onto an inclined grid. The force imparted to the grid by this impact must not exceed a specified level. This is the first tangential impact test to be included in a motorcycle helmet Standard and as such is recognised as a valuable first step of development in this area. It has its limitations, especially the absence of any surrogate head-neck torso interaction. Officers from the British Standards Institute (BSI) (Reference4) stated that they were so concerned at the extent of injuries due to tangential impact that they felt a test must be specified, even if it had some limitations. They did not recommend that this test be incorporated in the Australian Standard as it stands. They hoped that it be used as the basis for an improved test. A tangential impact test has not been incorporated into AS1698 yet, because the development work for a new test has not been done. The need for such a test has been confirmed by this study.

Tangential impacts produce rotation of the head which result in angular accelerations in the brain and forces in the neck. An angular impact test must be based upon the results of angular impact tests on a human surrogate and measurements of its response to these impacts in terms of rotational head accelerations and forces at the head neck joint.

RECOMMENDATION 3: Develop specifications for a test to evaluate means of reducing the effect of frontal impacts by improving the energy absorption ability of the front of helmets.

Helmet Standards do not incorporate tests for the effectiveness of the chinbar of full face helmets in reducing forces transmitted to the base of the skull. Tests, such as those incorporated in Snell 85 and British Standard BS6658 are designed to test a helmets ability to protect the jaw, rather than its ability to lessen the transmission of forces to the base of the skull. There is a danger that in attempting to provide improved face protection, a Standard may result in helmets which may produce the more serious base of skull fracture in lieu of facial injuries. In the absence of better energy absorption, it is claimed by some (Reference 6) that facial fractures are an important protective mechanism for the brain. Therefore it is important to ensure that a chinbar offers equivalent or better energy absorption. It should not transfer the impact forces elsewhere and should provide additional energy and force attenuation. It is important when measuring this performance, that the test is conducted on a headform with a facial region whose strength models that of the human face.

The specification of tests designed to minimise the incidence of base of skull fractures needs to consider the helmet brow, visor and chinbar as a unit. The development of this test is technically relatively easy, in comparison with the development of a tangential impact test, but the development of helmets that could meet the test may take longer.

The test will involve mounting a helmet on a headform with a frangible face and impacting the front of the helmet with a pendulum. The pass criteria for the test will relate to the crush of the headform face and to the forces measured at the headform/neck/torso joints.

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APPENDIX A AIS SYSTEM OUTLINE

Injury severity was assessed using The Abbreviated Injury Scale 1985 Revision. In AIS 85 each injury description is assigned a unique 6-digit code of the form _ _ _ _ _ _ . _ to assist in data collection. The two numbers of most significance are the furthermost left number and the furthermost right number. The extreme left number designates the general body region as given below:

1 = External
2 = Head
3 = Face
4 = Neck
5 = Thorax
6 = Abdomen and Pelvic Contents
7 = Spine
8 = Upper Extremity
9 = Lower Extremity

The extreme right number represents the AIS severity code as given below:

1 Minor
2 Moderate
3 Serious
4 Severe
5 Critical
6 Maximum injury virtually unsurvivable in AIS 85

The AIS is a system for coding single injuries.

The AIS system divides the body into several regions. Head or neck injuries include injury to the brain or cervical spine, skull or cervical spine fractures, and ears.

Facial injuries include those involving mouth, eyes, nose and facial bones.

Chest injuries and injuries to abdominal or pelvic contents include all lesions to internal organs in the respective cavities. Chest injuries also include those to the diaphragm, rib cage and thoracic spine. Lumbar spine lesions are included in the abdominal or pelvic area.

Injuries to the extremities or to the pelvic or shoulder girdle include sprains, fractures, dislocations and amputations, except for the spinal column, skull and rib cage.

External injuries include lacerations, contusions, abrasions and burns, independent of their location on the body surface.

APPENDIX B HELMET INSPECTION

B.1 Inspection Form

CASE NO.		_ _ _ _
BRAND		_ _ _ _ _ _ _ _ _ _ _
MODEL		_ _ _ _ _ _ _ _ _ _ _
TYPE		_
SIZE		_ _ _ _
AS 1698 APPROVAL		_
SNELL 80 APPROVAL		_
Z-90 APPROVAL		_
OTHER		_
MAJOR COLOUR		_ _ _ _ _ _ _ _
OTHER COLOUR		_ _ _ _ _ _ _ _
OTHER COLOUR		_ _ _ _ _ _ _ _
REFLECTIVE TAPE		_
MASS (GM)		_ _ _ _
HELMET SHELL	-material	_ _ _ _ _ _ _ _ _ _ _
	-modified	_
	-painted	_
HELMET LINER	-material	_ _ _ _ _ _ _ _ _ _ _
	-modified	_
PREVIOUS DAMAGE		_
RETENTION SYSTEM	-modified	_
	-worn	_
	-damaged	_
	-velcro	_
VISOR	-fitted	_
	-damaged	_
	-pre crash damage	_

IMPACT NO.		_
IMPACT	-location	_ _ _ _
	-direction	_ _ _ _
	-type	_
	-severity	_
SHELL DAMAGE TYPE		_
LINER DAMAGE TYPE		_
PERCENTAGE CRUSH		_ _
AREA OF CRUSH (SQ. MM)		_ _ _ _
LENGTH OF CRACK (MM)		_ _ _
DEPTH OF PENETRATION (MM)		_ _

IMPACT NO.		_
IMPACT	-location	_ _ _ _
	-direction	_ _ _ _
	-type	_
	-severity	_
SHELL DAMAGE TYPE		_
LINER DAMAGE TYPE		_
PERCENTAGE CRUSH		_ _
AREA OF CRUSH (SQ. MM)		_ _ _ _
LENGTH OF CRACK (MM)		_ _ _
DEPTH OF PENETRATION (MM)		_ _

IMPACT NO.		_
IMPACT	-location	_ _ _ _
	-direction	_ _ _ _
	-type	_
	-severity	_
SHELL DAMAGE TYPE		_
LINER DAMAGE TYPE		_
PERCENTAGE CRUSH		_ _
AREA OF CRUSH (SQ. MM)		_ _ _ _
LENGTH OF CRACK (MM)		_ _ _
DEPTH OF PENETRATION (MM)		_ _

B.2 Inspection Procedure

Equipment Required :

1. Latex examination gloves
2. Photographic equipment
3. Steel rule
4. Outside calipers
5. Jigsaw

A. Helmet Specifications.

1. Photograph helmet ; 4 views - F, B, SL, SR.
2. Examine helmet for :
   (1) Brand
   (2) Model
   (3) Type - Full Face / Jet
   (4) Size (cm)
   (5) Colour scheme and use of reflective tape
3. Determine mass of helmet (gm).
4. Examine helmet for Type Approval labels.
5. Dismantle helmet :
   (1) Remove foam padding
   (2) Remove chin piece liner (if applicable)
   (3) Remove complete liner

Notes :

(1) It may be necessary to remove the retention system by grinding back the mounting rivets to enable liner removal.

(2) With some helmets having a glued in liner (notably Arai) it may be necessary to cut the helmet in two halves with a jigsaw.

6. Examine helmet shell for :
   (1) Material of construction -
       a) Fibreglass; including Kevlar or carbon fibre additives.
       b) Plastic; including Polycarbonate, ABS and Ronfallin.
   (2) Modifications -
       Modifications include the replacement of visor mounting screws.
   (3) Painting -
       Important with plastic helmets
   (4) Previous damage
7. Examine helmet liner for :
   (1) Material of construction -
       Usually polystyrene
   (2) Modifications
   (3) Previous damage -
       Common forms of damage result from placement of the helmet on handlebars, mirrors etc., the use of replacement visor mounting screws and liner hardening due to chemical attack.

8. Examine retention system for :
   (1) Wear / damage
   (2) Modifications
   (3) Velcro retention
9. Examine visor (if fitted) for :
   (1) Damage
   (2) Pre-crash damage

B. Crash Damage

1. Examine helmet shell and liner for evidence of crash damage.
2. For each impact :
   (1) Mark the area of damage on the diagram in the Inspection Sheet.
   (2) Note the impact location giving the helmet view and the impact areas covered by the damaged area.
   (3) Determine the type of impact :
      a) Tangential or sliding
      b) Radial or direct
      c) Unknown
   (4) For a tangential impact note the line of action of the impact using clockface notation.
   (5) Determine the impact severity -
      a) Minor - shell damage but no liner damage.
      b) Moderate - usually some liner damage but not exceeding that of a similar helmet tested to AS1698.
      c) Severe - damage exceeding that of a similar helmet tested to AS1698.
      d) Unknown

Note :

Fibreglass shells generally show noticable signs of impact damage whereas plastic shells may appear unmarked. For this reason plastic shells should be examined with particular care and the liner carefully examined for compression.

   (6) Determine the shell damage type
      a) Penetration
      b) Fracture
      c) Delamination
      d) Score
      e) Other eg. indentation
      f) Unknown
      g) None
   (7) Determine the liner damage type
      a) Penetration
      b) Fracture
      c) Compression
      d) Unknown
      e) None
   (8) If the impact caused liner crush determine the percentage crush of the liner at the point of severest impact, ie. the percentage reduction in the thickness of the liner.

(9) If the impact causes liner crush determine the total area of crush of the liner associated with the impact.
(10) If the liner has cracked determine the total crack length associated with the impact.
(11) If the liner has cracked determine the maximum depth of penetration of the crack.

3. Re-check Inspection Sheet paying particular attention to the size and location of the impact areas.

APPENDIX C **CASE OMISSIONS**

FATAL CASES

REASON FOR EXCLUSION	NO. CASES
DEATH NOT A RESULT OF ACCIDENT	2
ACCIDENT NOT FATAL	3
HELMET NOT WORN	1
POST MORTEM UNAVAILABLE	8
HELMET UNAVAILABLE	23
TOTAL	37

NON-FATAL CASES

REASON FOR EXCLUSION	NO. CASES
NOT A MOTORCYCLE ACCIDENT	11
INJURY NOT DUE TO ACCIDENT	1
HELMET NOT APPROVED	2
HELMET NOT WORN	23
HELMET UNAVAILABLE	82
INJURY DATA UNAVAILABLE	4
UNABLE TO CONTACT	158
DECLINED TO ENTER STUDY	4
TOTAL	285

APPENDIX D IMPACT SEVERITY RATING

The severity of impacts was assessed by comparing the damage to each helmet with the damage to a similar helmet when tested to AS1698.

Severity was defined as follows:

a) Minor -shell damage but no liner damage.

b) Moderate -usually some liner damage but not exceeding that of a similar helmet tested to AS1698.

c) Severe -shell and liner damage exceeding that of a similar helmet tested to AS1698.

Minor damage was typically associated with shell scratching from sliding contact with the road surface or with secondary impacts. Severe impacts were typically associated with gross shell and liner damage. Moderate impacts were then, those impacts not obviously fitting into the minor or severe categories, and consequently presented the greatest difficulty in severity rating.

Reference to helmets that had been through laboratory testing allowed reasonable consistency to be maintained in the rating of impact severity. It is recognised however that impacts against surface different to those used in impact testing will produce variations.A356

A tangential impact usually produces score damage whereas a radial impact results in different types of damage depending on the shell material.

Helmets with plastic shells provided greater difficulty in severity rating because of their tendency to mask minor to moderate impact damage. They do not mark as readily under minor radial impacts as do fibreglass helmets. Inspection of the liner revealed the presence of a significant impact.

Table 1 :Helmet brand, type and material

Table 1a :All Cases

BRAND	FULL FACE F'GLASS	FULL FACE PLASTIC	JET F'GLASS	JET PLASTIC
ARAI	43	0	6	0
AGV	28	5	0	0
SHOEI	23	0	2	0
OTHERS	36	41	1	13
UNKNOWN	1	0	1	0
TOTAL	131	46	10	13

Table 1b :Fatal Cases

BRAND	FULL FACE F'GLASS	FULL FACE PLASTIC	JET F'GLASS	JET PLASTIC
ARAI	19	0	3	0
AGV	6	2	0	0
SHOEI	12	0	0	0
OTHERS	9	16	1	3
UNKNOWN	1	0	0	0
TOTAL	47	18	4	3

Table 1c :Non-fatal Cases

BRAND	FULL FACE F'GLASS	FULL FACE PLASTIC	JET F'GLASS	JET PLASTIC
ARAI	24	0	3	0
AGV	22	3	0	0
SHOEI	11	0	2	0
OTHERS	27	25	0	10
UNKNOWN	0	0	1	0
TOTAL	84	28	6	10

Table 2 :Other standards approval

Table 2a :All Cases

HELMET TYPE	OTHER APPROVAL			
	SNELL 80	Z-90	SNELL 85	OTHER
FF GLASS	23	23	12	9
FF PLASTIC	0	0	0	0
JET GLASS	2	2	0	0
JET PLASTIC	0	0	0	0
TOTAL	25	25	12	9

Table 2b :Fatal Cases

HELMET TYPE	OTHER APPROVAL			
	SNELL 80	Z-90	SNELL 85	OTHER
FF GLASS	16	9	3	2
FF PLASTIC	0	0	0	0
JET GLASS	1	0	0	0
JET PLASTIC	0	0	0	0
TOTAL	17	9	3	2

Table 2c :Non-fatal Cases

HELMET TYPE	OTHER APPROVAL			
	SNELL 80	Z-90	SNELL 85	OTHER
FF GLASS	7	14	9	7
FF PLASTIC	0	0	0	0
JET GLASS	1	2	0	0
JET PLASTIC	0	0	0	0
TOTAL	8	16	9	7

Table 3 :Frequency of impacts per helmet

Table 3a :All Cases

NUMBER OF IMPACTS PER CASE	NUMBER OF HELMETS	IMPACT SEVERITY				ALL IMPACTS
		SEVERE	MODERATE	MINOR	UNKNOWN	
0	8	0	0	0	0	0
1	66	22	11	32	1	66
2	69	28	37	68	5	138
3	37	32	20	59	0	111
4	16	16	13	34	1	64
5	2	0	3	7	0	10
6	2	2	3	7	0	12
TOTAL	200	100	87	207	7	401

Table 3b :Fatal Cases

NUMBER OF IMPACTS PER CASE	NUMBER OF HELMETS	IMPACT SEVERITY				ALL IMPACTS
		SEVERE	MODERATE	MINOR	UNKNOWN	
0	0	0	0	0	0	0
1	29	16	3	10	0	29
2	26	16	19	14	3	52
3	12	20	5	11	0	36
4	5	9	5	6	0	20
5	0	0	0	0	0	0
6	0	0	0	0	0	0
TOTAL	72	61	32	41	3	137

Table 3c :Non-fatal

NUMBER OF IMPACTS PER CASE	NUMBER OF HELMETS	IMPACT SEVERITY				ALL IMPACTS
		SEVERE	MODERATE	MINOR	UNKNOWN	
0	8	0	0	0	0	0
1	37	6	8	22	1	37
2	43	12	18	54	2	86
3	25	12	15	48	0	75
4	11	7	8	28	1	44
5	2	0	3	7	0	10
6	2	2	3	7	0	12
TOTAL	128	39	55	166	4	264

Table 4 :Impact severity

Table 4a :All Cases

IMPACT SEVERITY	HELMET TYPE				TOTAL
	FF GLASS	FF PLASTIC	JET GLASS	JET PLASTIC	
SEVERE	77	16	5	2	100
MODERATE	68	11	4	4	87
MINOR	129	52	11	15	207
UNKNOWN	2	4	0	1	7
TOTAL	276	83	20	22	401

Table 4b :Fatal Cases

IMPACT SEVERITY	HELMET TYPE				TOTAL
	FF GLASS	FF PLASTIC	JET GLASS	JET PLASTIC	
SEVERE	47	8	4	2	61
MODERATE	28	3	0	1	32
MINOR	24	13	2	2	41
UNKNOWN	0	3	0	0	3
TOTAL	99	27	6	5	137

Table 4c :Non-fatal Cases

IMPACT SEVERITY	HELMET TYPE				TOTAL
	FF GLASS	FF PLASTIC	JET GLASS	JET PLASTIC	
SEVERE	30	8	1	0	39
MODERATE	40	8	4	3	55
MINOR	105	39	9	13	166
UNKNOWN	2	1	0	1	4
TOTAL	177	56	14	17	264

Table 5 :Impact type

Table 5a :All Cases

IMPACT SEVERITY	TYPE OF IMPACT			
	TANGENTIAL	RADIAL	UNKNOWN	TOTAL
SEVERE	24	73	3	100
MODERATE	58	25	4	87
MINOR	176	30	1	207
UNKNOWN	1	1	5	7
TOTAL	259	129	13	401

Table 5b :Fatal Cases

IMPACT SEVERITY	TYPE OF IMPACT			
	TANGENTIAL	RADIAL	UNKNOWN	TOTAL
SEVERE	11	47	3	61
MODERATE	18	10	4	32
MINOR	39	1	1	41
UNKNOWN	0	1	2	3
TOTAL	68	59	10	137

Table 5c :Non-fatal Cases

IMPACT SEVERITY	TYPE OF IMPACT			
	TANGENTIAL	RADIAL	UNKNOWN	TOTAL
SEVERE	13	26	0	39
MODERATE	40	15	0	55
MINOR	137	29	0	166
UNKNOWN	1	0	3	4
TOTAL	191	70	3	264

Table 6 :Impact location and frequency (excluding unknown impacts)

Table 6a :All Cases

IMPACT SEVERITY	FRONT		SIDES		TOP	BACK		ALL		TOTAL
	IN	OUT	IN	OUT		IN	OUT	IN	OUT	
SEVERE	25.5	23.2	16.8	9.0	8.0	8.8	8.8	59	41	100
MODERATE	17.3	12.7	20.7	8.9	4.5	15.5	7.3	58	29	87
MINOR	19.0	20.5	56.5	26.5	27.0	36.4	21.1	139	68	207
TOTAL	61.8	56.4	94.0	44.4	39.5	60.7	37.2	256	138	394

Table 6b :Fatal Cases

IMPACT SEVERITY	FRONT		SIDES		TOP	BACK		ALL		TOTAL
	IN	OUT	IN	OUT		IN	OUT	IN	OUT	
SEVERE	14.8	14.3	11.3	4.2	6.5	4.8	5.3	37.0	24.0	61
MODERATE	8.0	4.5	4.0	4.5	3.0	5.5	2.5	20.5	11.5	32
MINOR	2.0	3.0	16.5	3.0	4.5	7.5	4.5	30.5	10.5	41
TOTAL	24.8	21.8	31.8	11.7	14.0	17.8	12.3	88	46	134

Table 6c :Non-fatal Cases

IMPACT SEVERITY	FRONT		SIDES		TOP	BACK		ALL		TOTAL
	IN	OUT	IN	OUT		IN	OUT	IN	OUT	
SEVERE	10.8	8.9	5.5	4.8	1.5	4.0	3.5	22.0	17.0	39
MODERATE	9.3	8.2	16.7	4.4	1.5	10.0	4.8	37.5	17.5	55
MINOR	17.0	17.5	40.0	23.5	22.5	28.9	16.6	108.5	57.5	166
TOTAL	37.1	34.6	62.2	32.7	25.5	42.9	24.9	168	92	260

Table 7 :Impact location and Test Area.

CASE TYPE	INSIDE TEST AREA		OUTSIDE TEST AREA	
ALL	256	(65%)	138	(35%)
FATAL	88	(66%)	46	(34%)
NON-FATAL	168	(65%)	92	(35%)

Table 8 :Visor damage

Table 8a :All Helmets

CASE	VISOR FITTED		VISOR NOT FITTED	UNKNOWN	TOTAL
	DAMAGED	UNDAMAGED			
FATAL	28*	9	33	2	72
NON-FATAL	40	40	45	3	128
ALL CASES	68	49	78	5	200

* INCLUDES 2 CASES WHERE GOGGLES WERE WORN

Table 8b :Full Face Helmets

CASE	VISOR FITTED		VISOR NOT FITTED	UNKNOWN	TOTAL
	DAMAGED	UNDAMAGED			
FATAL	27*	9	27	2	65
NON-FATAL	39	40	31	2	112
ALL CASES	66	49	58	4	177

* INCLUDES 1 CASE WHERE GOGGLES WERE WORN

Table 8c :Jet Helmets

CASE	VISOR FITTED		VISOR NOT FITTED	UNKNOWN	TOTAL
	DAMAGED	UNDAMAGED			
FATAL	1 *	0	6	0	7
NON-FATAL	1	0	14	1	16
ALL CASES	2	0	20	1	23

* INCLUDES 1 CASE WHERE GOGGLES WERE WORN

Table 9 :Type of impact and shell damage

Table 9a :All Cases

IMPACT TYPE	FF GLASS							FF PLASTIC							JET GLASS							JET PLASTIC							TOTAL
	1	2	3	4	5	6	9	1	2	3	4	5	6	9	1	2	3	4	5	6	9	1	2	3	4	5	6	9	
TANGENTIAL	1	7	4	161	0	1	0	0	0	0	53	1	0	1	0	0	0	14	0	0	0	0	0	0	16	0	0	0	259
RADIAL	3	40	20	31	0	1	0	0	3	0	17	1	2	1	1	1	2	2	0	0	0	0	1	0	3	0	0	0	129
UNKNOWN	0	2	1	0	0	0	4	0	1	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	13
TOTAL	4	49	25	192	0	2	4	0	4	0	70	2	3	4	1	1	2	16	0	0	0	0	1	0	19	0	1	1	401

1 PENETRATION
2 FRACTURE
3 DELAMINATION
4 SCORE
5 OTHER
6 UNKNOWN
9 NONE

Table 9b :Fatal Cases

IMPACT TYPE	FF GLASS							FF PLASTIC							JET GLASS							JET PLASTIC							
	1	2	3	4	5	6	9	1	2	3	4	5	6	9	1	2	3	4	5	6	9	1	2	3	4	5	6	9	TOTAL
TANGENTIAL	1	3	0	45	0	0	0	0	0	0	14	1	0	0	0	0	0	3	0	0	0	0	0	0	1	0	0	0	68
RADIAL	2	25	11	6	0	0	0	0	3	0	3	1	1	1	1	1	1	0	0	0	0	0	1	0	2	0	0	0	59
UNKNOWN	0	2	1	0	0	0	3	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	10
TOTAL	3	30	12	51	0	0	3	0	4	0	17	2	1	3	1	1	1	3	0	0	0	0	1	0	3	0	0	1	137

1 PENETRATION
2 FRACTURE
3 DELAMINATION
4 SCORE
5 OTHER
6 UNKNOWN
9 NONE

Table 9c :Non-fatal Cases

IMPACT TYPE	FF GLASS							FF PLASTIC							JET GLASS							JET PLASTIC							TOTAL
	1	2	3	4	5	6	9	1	2	3	4	5	6	9	1	2	3	4	5	6	9	1	2	3	4	5	6	9	
TANGENTIAL	0	4	4	116	0	1	0	0	0	0	39	0	0	1	0	0	0	11	0	0	0	0	0	0	15	0	0	0	191
RADIAL	1	15	9	25	0	1	0	0	0	0	14	0	1	0	0	0	1	2	0	0	0	0	0	0	1	0	0	0	70
UNKNOWN	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3
TOTAL	1	19	13	141	0	2	1	0	0	0	53	0	2	1	0	0	1	13	0	0	0	0	0	0	16	0	1	0	264

1 PENETRATION
2 FRACTURE
3 DELAMINATION
4 SCORE
5 OTHER
6 UNKNOWN
9 NONE

Table 10 :Type of impact and liner damage

Table 10a :All Cases

IMPACT TYPE	FF GLASS					FF PLASTIC					JET GLASS					JET PLASTIC					TOTAL
	1	2	3	6	9	1	2	3	6	9	1	2	3	6	9	1	2	3	6	9	
TANGENTIAL	0	10	39	3	121	0	4	7	0	44	0	1	1	0	12	0	0	1	0	16	259
RADIAL	2	24	36	8	26	0	5	10	0	9	1	0	4	0	1	0	2	0	0	1	129
UNKNOWN	0	3	2	0	2	0	2	1	1	0	0	0	0	0	0	0	0	2	0	0	13
TOTAL	2	37	77	11	149	0	11	18	1	53	1	1	5	0	13	0	2	3	0	17	401

1 PENETRATION
2 FRACTURE
3 COMPRESSION
6 UNKNOWN
9 NONE

Table 10b :Fatal Cases

IMPACT TYPE	FF GLASS					FF PLASTIC					JET GLASS					JET PLASTIC					TOTAL
	1	2	3	6	9	1	2	3	6	9	1	2	3	6	9	1	2	3	6	9	
TANGENTIAL	0	6	16	0	26	0	1	1	0	13	0	1	0	0	2	0	0	0	0	2	68
RADIAL	2	16	24	2	1	0	3	6	0	0	1	0	2	0	0	0	2	0	0	0	59
UNKNOWN	0	2	2	0	2	0	2	1	0	0	0	0	0	0	0	0	0	1	0	0	10
TOTAL	2	24	42	2	29	0	6	8	0	13	1	1	2	0	2	0	2	1	0	2	137

1 PENETRATION
2 FRACTURE
3 COMPRESSION
6 UNKNOWN
9 NONE

Table 10c :Non-fatal Cases

IMPACT TYPE	FF GLASS 1	2	3	6	9	FF PLASTIC 1	2	3	6	9	JET GLASS 1	2	3	6	9	JET PLASTIC 1	2	3	6	9	TOTAL
TANGENTIAL	0	4	23	3	95	0	3	6	0	31	0	0	1	0	10	0	0	1	0	14	191
RADIAL	0	8	12	6	25	0	2	4	0	9	0	0	2	0	1	0	0	0	0	1	70
UNKNOWN	0	1	0	0	.0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	3
TOTAL	0	13	35	9	120	0	5	10	1	40	0	0	3	0	11	0	0	2	0	15	264

1 PENETRATION
2 FRACTURE
3 COMPRESSION
6 UNKNOWN
9 NONE

Table 11 :Liner compression vs. type of impact

Table 11a :All Cases

% LINER CRUSH	TYPE OF IMPACT			
	TANGENTIAL	RADIAL	UNKNOWN	TOTAL
1-5	31	6	1	38
6-10	3	11	0	14
11-15	4	12	1	17
16-20	4	4	1	9
21-25	3	5	2	10
26-30	1	2	0	3
31-35	1	2	0	3
36-40	0	5	0	5
41-45	0	1	0	1
46-50	1	2	0	3
TOTAL	48	50	5	103

Table 11b :Fatal Cases

% LINER CRUSH	TYPE OF IMPACT			
	TANGENTIAL	RADIAL	UNKNOWN	TOTAL
1-5	11	3	1	15
6-10	0	6	0	6
11-15	1	7	0	8
16-20	1	2	1	4
21-25	2	3	2	7
26-30	1	2	0	3
31-35	1	1	0	2
36-40	0	5	0	5
41-45	0	1	0	1
46-50	0	2	0	2
TOTAL	17	32	4	53

Table 11c :Non-Fatal Cases

% LINER CRUSH	TYPE OF IMPACT			
	TANGENTIAL	RADIAL	UNKNOWN	TOTAL
1-5	20	3	0	23
6-10	3	5	0	8
11-15	3	5	1	9
16-20	3	2	0	5
21-25	1	2	0	3
26-30	0	0	0	0
31-35	0	1	0	1
36-40	0	0	0	0
41-45	0	0	0	0
46-50	1	0	0	1
TOTAL	31	18	1	50

Table 12 :Non-fatal case injuries
:Region vs. injury severity

BODY REGION	CASES WITH INJURIES	NUMBER OF INJURIES	AIS INJURY SEVERITY			
			4	3	2	1
HEAD	58	61	0	5	46	10
NECK	25	25	1	1	2	21
FACE	15	28	0	0	14	14
CHEST	13	18	1	7	5	5
ABDOMEN	18	23	0	6	13	4
EXTREMITIES	110	265	1	132	119	13
EXTERNAL	127	252	0	0	12	240

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Table 13 :Fatal case injuries
:Region vs. injury severity

BODY REGION	CASES WITH INJURIES	NUMBER OF INJURIES	AIS INJURY SEVERITY					
			6	5	4	3	2	1
HEAD	58	143	11	11	43	68	10	0
NECK	16	18	8	2	0	3	3	2
FACE	17	25	0	0	0	1	8	16
CHEST	62	139	12	17	53	37	18	2
ABDOMEN	48	108	0	11	11	20	66	0
EXTREMITIES	47	113	0	0	3	46	61	3
EXTERNAL	69	136	0	0	0	0	20	116

Table 14 :No Head/Neck Injury Cases
:Impact Severity and Location

IMPACT SEVERITY	FRONT		SIDES		TOP	BACK		TOTAL		ALL IMPACTS
	IN	OUT	IN	OUT		IN	OUT	IN	OUT	
SEVERE	1.66	2.34	0.5	0.5	1.0	0	0	3.16	2.84	6
MODERATE	4.5	4.0	7.33	0.5	0	2.33	2.34	14.16	6.84	21
MINOR	11.0	5.5	20.25	4.25	11.0	15.75	5.25	58.0	15.0	73
TOTAL	17.16	11.84	28.08	5.25	12.0	18.08	7.59	75.32	24.7	100

Table 15 :Head/neck injury cases
:Impact Severity and Location

IMPACT SEVERITY	FRONT		SIDES		TOP	BACK		TOTAL		ALL IMPACTS
	IN	OUT	IN	OUT		IN	OUT	IN	OUT	
SEVERE	23.84	20.86	16.3	8.5	7.0	8.8	8.8	55.94	38.16	94.1
MODERATE	12.8	8.7	13.37	8.4	4.5	13.17	4.96	43.84	22.05	65.9
MINOR	8.0	15.0	36.25	22.25	16.0	20.65	15.85	80.9	53.1	134
TOTAL	44.64	44.56	65.92	35.15	27.5	42.62	29.61	180.68	113.31	294

Table 16 :Injury Categories
:Frequency and Severity of Head/Neck/Face Injuries

CATEGORY	NO. OF CASES	INJURY SEVERITY (AIS)					
		6	5	4	3	2	1
MASSIVE CRUSH	6	7	0	0	0	4	3
BASE OF SKULL FRACTURE	23	5	4	22	25	10	3
VAULT FRACTURE	4	0	0	5	5	4	0
NECK	34	6	4	3	4	6	26
UNCONSCIOUSNESS/BRAIN	52	0	4	5	15	0	45

Table 17 :Base of skull category
:Injury severity

Table 17a :Primary injury cases

REGION INJURED	NO. OF CASES WITH INJURY	INJURY SEVERITY (AIS)					
		6	5	4	3	2	1
HEAD	2	0	1	1	3	0	0

Table 17b :Secondary injury cases

REGION INJURED	NO. OF CASES WITH INJURY	INJURY SEVERITY (AIS)					
		6	5	4	3	2	1
HEAD	23	4	1	25	39	6	0
NECK	3	2	0	1	0	0	0
FACE	7	0	0	0	1	5	7

Table 18 :Base of skull category (excludes 2 unknown impact cases)
:Secondary injury cases (19 cases)
:Impact type, severity and location

IMPACT TYPE	IMPACT SEVERITY	FRONT		SIDES		TOP	BACK		TOTAL		ALL IMPACTS
		IN	OUT	IN	OUT		IN	OUT	IN	OUT	
ALL	SEVERE	6.5	9.0	3.5	0	0.5	0.5	0	11.0	9.0	20
	MODERATE	1.0	1.0	1.0	0	1.0	0.5	0.5	3.5	1.5	5
	MINOR	0	3.0	2.0	2.0	0	3.0	1.0	5.0	6.0	11
TOTAL		7.5	11.0	6.5	2.0	1.5	4.0	1.5	19.5	16.5	36

Table 19 :Base of skull category
: Secondary injury cases
:Impact Severity/case

NUMBER OF IMPACTS PER CASE	NUMBER OF HELMETS	IMPACT SEVERITY			ALL IMPACTS
		SEVERE	MODERATE	MINOR	
0	0	0	0	0	0
1	9	7	0	2	9
2	5	4	3	3	10
3	3	7	0	2	9
4	2	2	2	4	8
5	0	0	0	0	0
6	0	0	0	0	0
TOTAL	19	20	5	11	36

Table 20 :Neck injury category
:Acute strain (25 cases)

IMPACT TYPE	IMPACT SEVERITY	FRONT		SIDES		TOP	BACK		TOTAL		ALL IMPACTS
		IN	OUT	IN	OUT		IN	OUT	IN	OUT	
TANGENTIAL	SEVERE	1.25	1.25	0.5	0.5	0	1.25	2.25	3.0	4.0	7.0
	MODERATE	1.0	0.5	2.4	1.3	0.5	4.3	1.0	8.2	2.8	11.0
	MINOR	1.5	1.5	7.33	5.33	1.0	2.84	0.5	12.7	7.3	20.0
RADIAL	SEVERE	2.5	1.0	2.25	1.75	0	0.25	0.25	5.0	3.0	8.0
	MODERATE	0.33	0.67	0.5	0.5	0	0	0	0.83	1.17	2.0
	MINOR	0	1.0	0.5	0	0	0.5	0	1.0	1.0	2.0
ALL	SEVERE	3.75	2.25	2.75	2.25	0	1.5	2.5	8.0	7.0	15.0
	MODERATE	1.33	1.17	2.9	1.8	0.5	4.3	1.0	9.0	3.97	13.0
	MINOR	1.5	2.5	7.83	5.33	1.0	3.3	0.5	13.7	8.3	22.0
TOTAL		6.6	5.9	13.5	9.4	1.5	9.1	4.0	30.7	19.3	50.0

Table 21 :Neck injury category
:Unconcious cases (11 cases)
:Impact severity and location

IMPACT TYPE	IMPACT SEVERITY	FRONT		SIDES		TOP	BACK		TOTAL		ALL IMPACTS
		IN	OUT	IN	OUT		IN	OUT	IN	OUT	
TANGENTIAL	SEVERE	0.5	0.5	0.25	0.25	0	0.25	2.25	1.0	3.0	4
	MODERATE	0.5	0.5	1.4	0.9	0.5	1.2	0	3.6	1.4	5
	MINOR	0.5	1.0	2.0	3.5	0	1.0	0	3.5	4.5	8
RADIAL	SEVERE	1.0	1.0	0	0	0	0	0	1.0	1.0	2
	MODERATE	0.33	0.67	0	0	0	0	0	0.33	0.67	1
	MINOR	0.5	1.0	0.5	0	0	0	0	1.0	1.0	2
ALL	SEVERE	1.5	1.5	0.25	0.25	0	0.25	2.25	2.0	4.0	6
	MODERATE	0.83	1.17	1.4	0.9	0.5	1.2	0	3.93	2.07	6
	MINOR	1.0	2.0	2.5	3.5	0	1.0	0	4.5	5.5	8
TOTAL		3.33	4.67	4.15	4.65	0.5	2.45	2.25	10.43	11.57	22

Table 22 :Neck injury category
:Other injuries
:Impact type, severity and location

IMPACT TYPE	IMPACT SEVERITY	FRONT		SIDES		TOP	BACK		TOTAL		ALL IMPACTS
		IN	OUT	IN	OUT		IN	OUT	IN	OUT	
TANGENTIAL	SEVERE MODERATE MINOR	1.0 0 1.0	0 0 0	0 1.0 1.0	1.0 0 2.0	0 0 1.0	0 2.0 0	0 0 0	1.0 3.0 3.0	1.0 0 2.0	2 3 5
RADIAL	SEVERE MODERATE MINOR	0 0 0	2.0 0 1.0	1.33 0 0	0.67 1.0 0	1.0 0 0	0 2.0 0	1.0 0 0	2.33 2.0 0	3.67 1.0 1.0	6 3 1
ALL	SEVERE MODERATE MINOR	1.0 0 1.0	2.0 0 1.0	1.33 1.0 1.0	1.67 1.0 2.0	1.0 0 1.0	0 4.0 0	1.0 0 0	3.33 5.0 3.0	4.67 1.0 3.0	8 6 6
TOTAL		2.0	3.0	3.33	4.67	2.0	4.0	1.0	11.33	8.67	20

Table 23 :Unconcious category
:Impact type, severity and location

IMPACT TYPE	IMPACT SEVERITY	FRONT		SIDES		TOP	BACK		TOTAL		ALL IMPACTS
		IN	OUT	IN	OUT		IN	OUT	IN	OUT	
TANGENTIAL	SEVERE MODERATE MINOR	0.5 3.0 4.5	1.5 0.5 8.0	0.25 5.4 7.16	0.25 2.9 6.33	1.0 1.5 2.0	0.25 2.7 9.0	2.25 1.0 6.0	2.0 12.6 22.66	4.0 4.4 20.33	6 17 43
RADIAL	SEVERE MODERATE MINOR	5.33 0.83 1.0	3.33 3.13 2.0	1.5 1.0 1.0	1.33 0 1.0	0 0 1.5	2.0 1.5 2.0	0.5 0.5 0.5	8.83 3.33 5.5	5.16 3.63 3.5	14 7 9
ALL	SEVERE MODERATE MINOR	5.83 3.83 5.5	4.83 3.63 10.0	1.75 6.4 8.16	1.58 2.9 7.33	1.0 1.5 3.5	2.25 4.2 11.0	2.75 1.5 6.5	10.83 15.93 28.16	9.16 8.03 23.83	20 24 52
TOTAL		19.7	18.46	16.31	11.81	6.0	17.5	10.8	55.0	41.0	96

Table 24 :Most severe impact by most severe head/neck injury

MOST SEVERE IMPACT	MOST SEVERE INJURY							
	6	5	4	3	2	1	0	ALL
SEVERE	14	5	12	8	22	5	7	73
MODERATE	2	4	3	4	14	5	18	50
MINOR	2	1	5	3	10	7	38	66
NONE	0	0	0	0	1	0	8	9
UNKNOWN	0	0	1	0	0	0	1	2
TOTAL	18	10	21	15	47	17	71	200

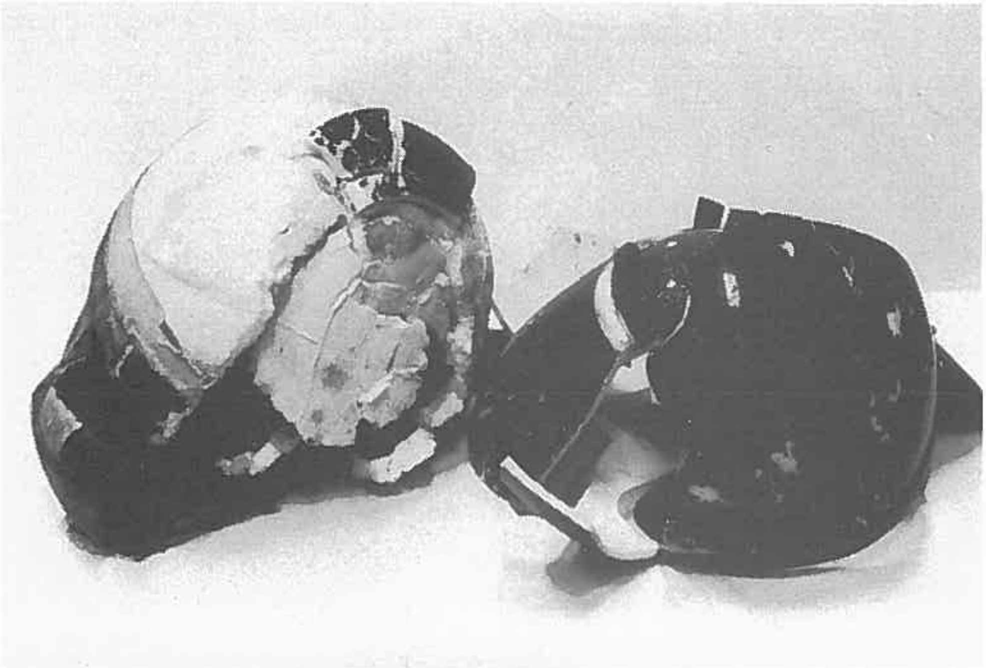

FIGURE 1 : BRITTLE FAILURE OF PLASTIC SHELL

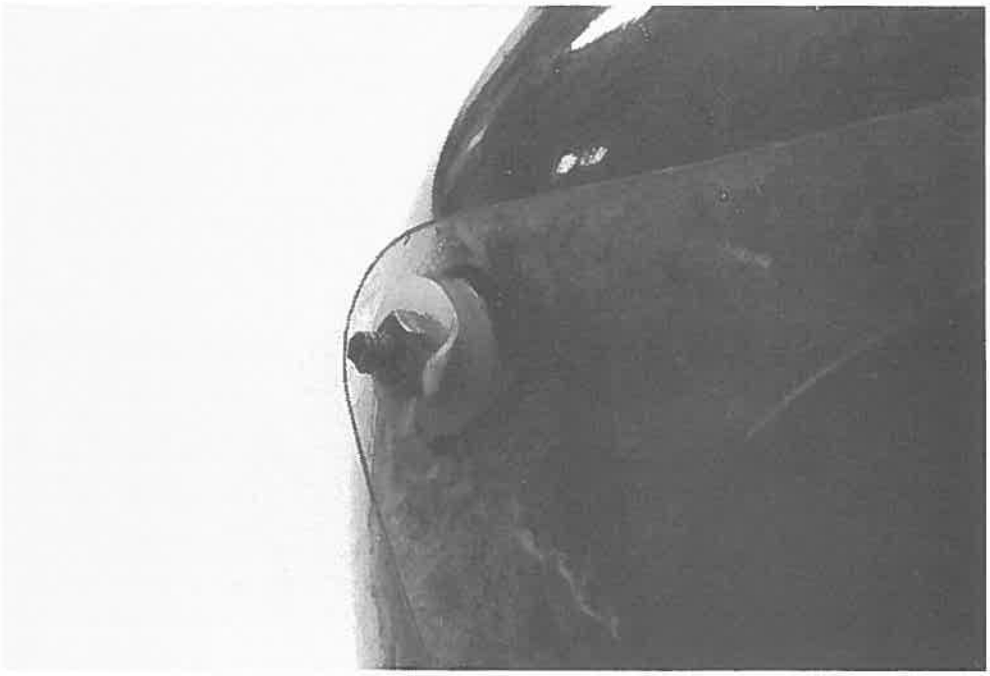

FIGURE 2 : MODIFICATION TO VISOR MOUNTING

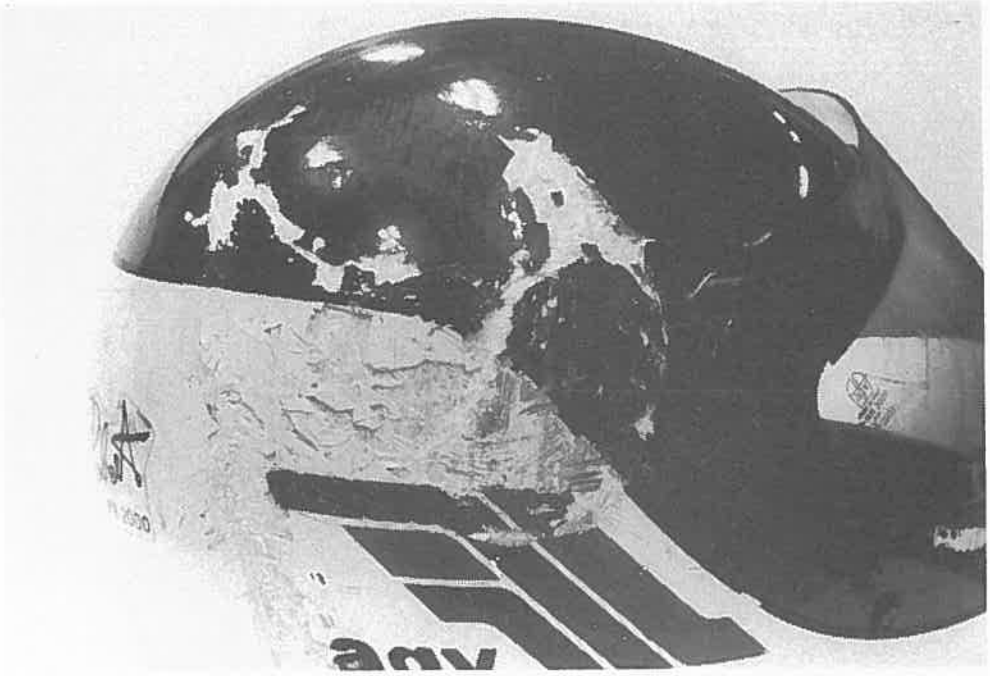

FIGURE 3 : TYPICAL RADIAL IMPACT

FIGURE 4 : TYPICAL TANGENTIAL IMPACT

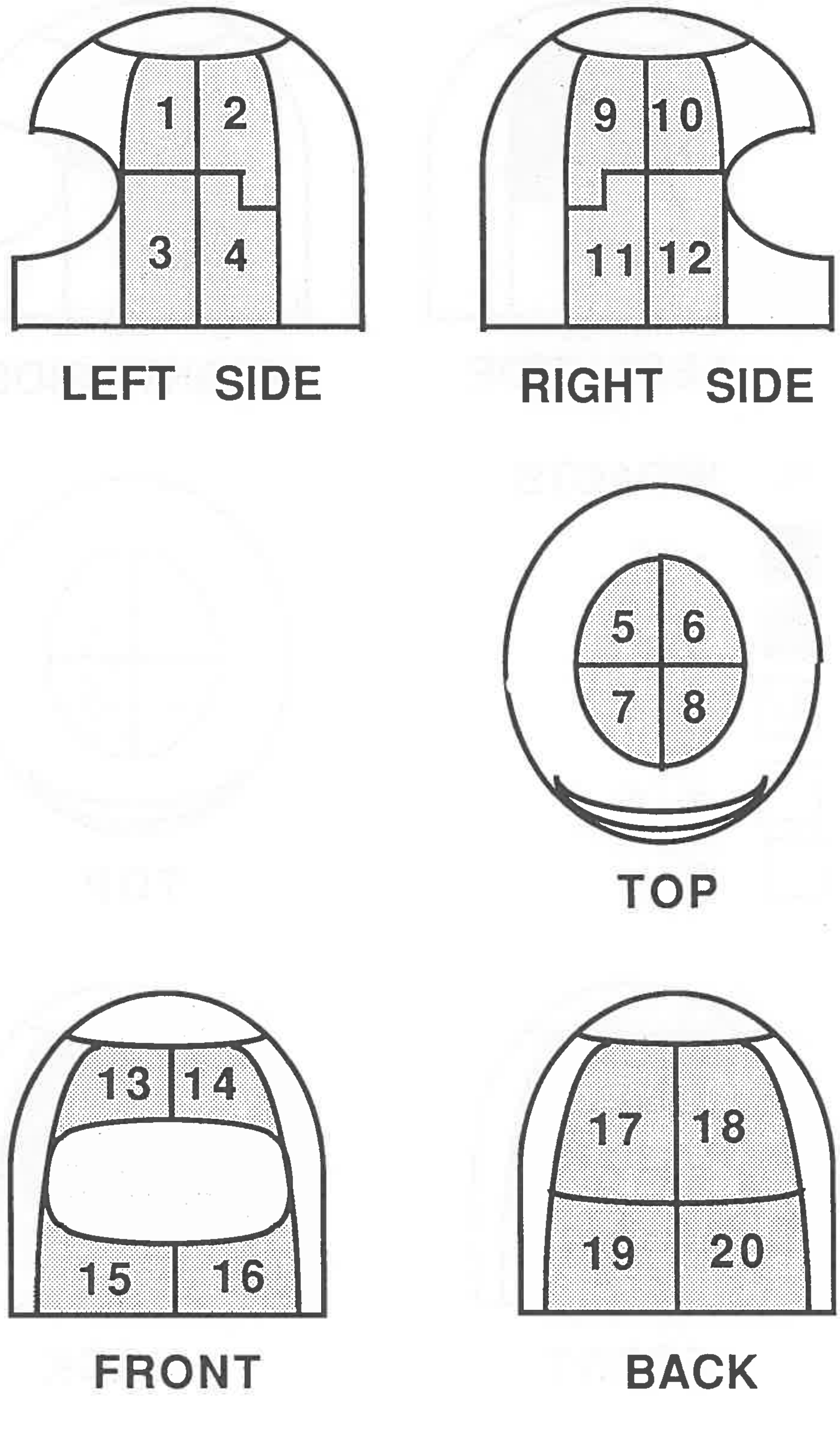

FIGURE 5 : KEY TO IMPACT AREAS

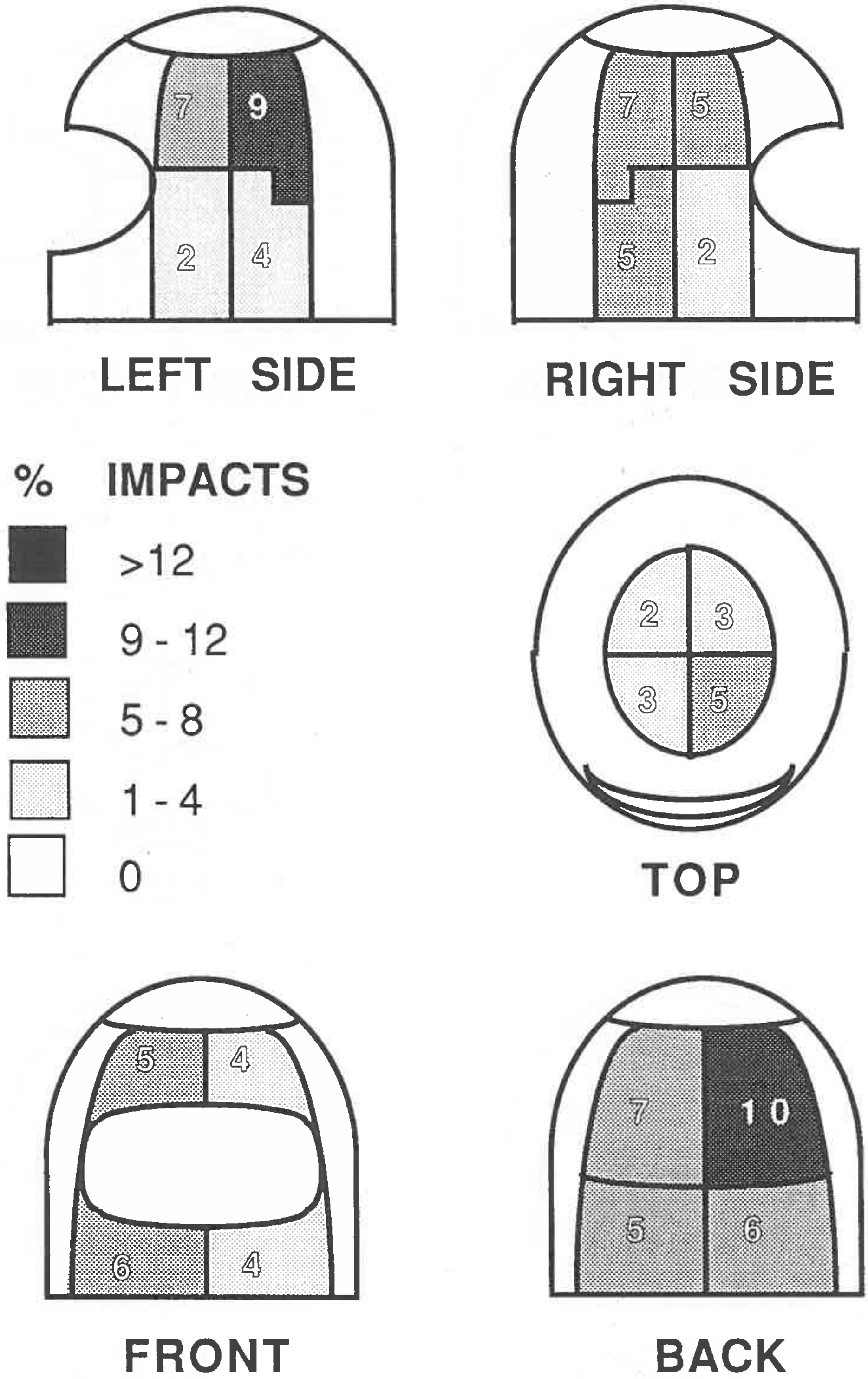

FIGURE 6 : ALL CASES
: MINOR IMPACTS

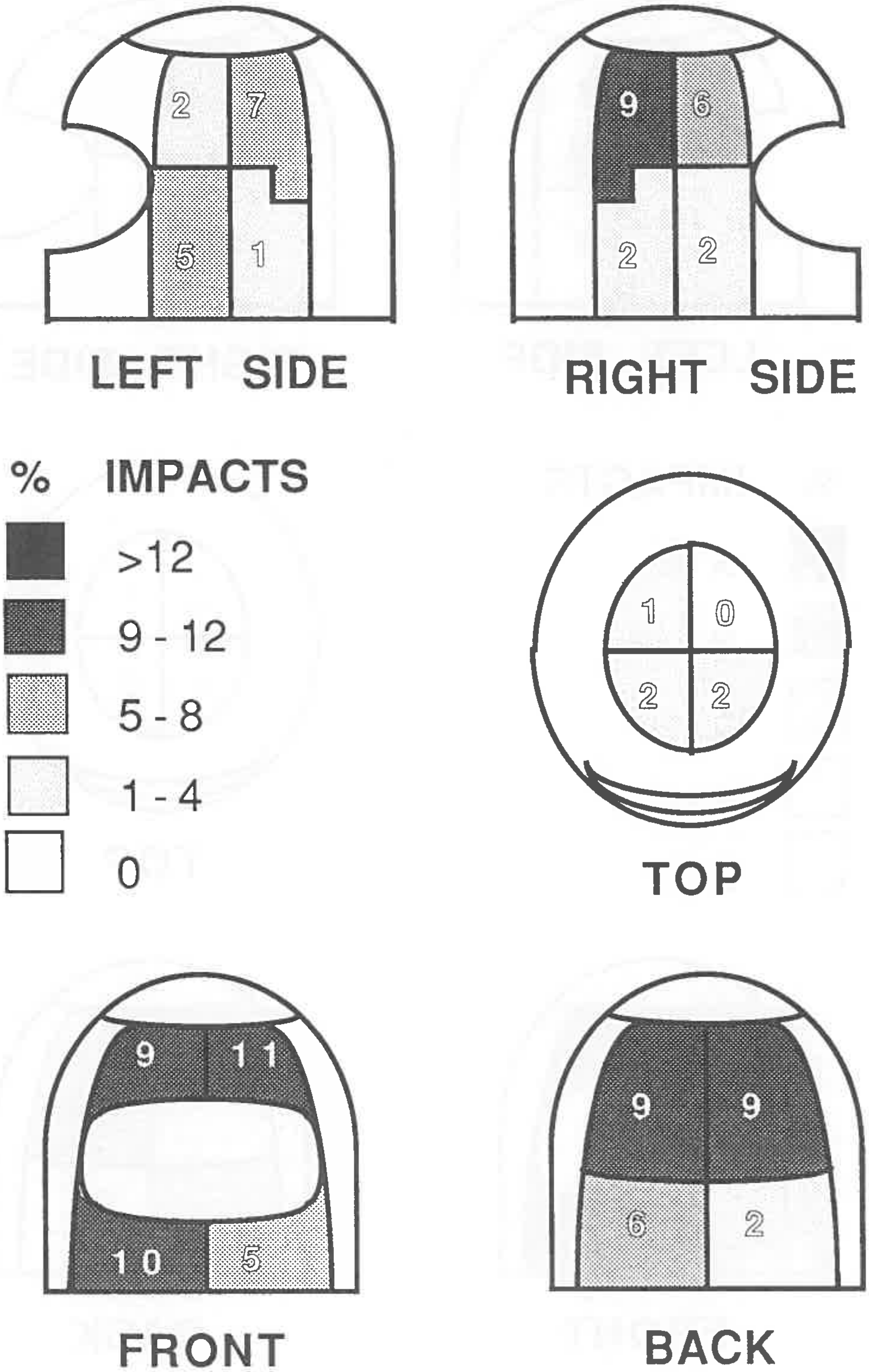

FIGURE 7 : ALL CASES
: MODERATE IMPACTS

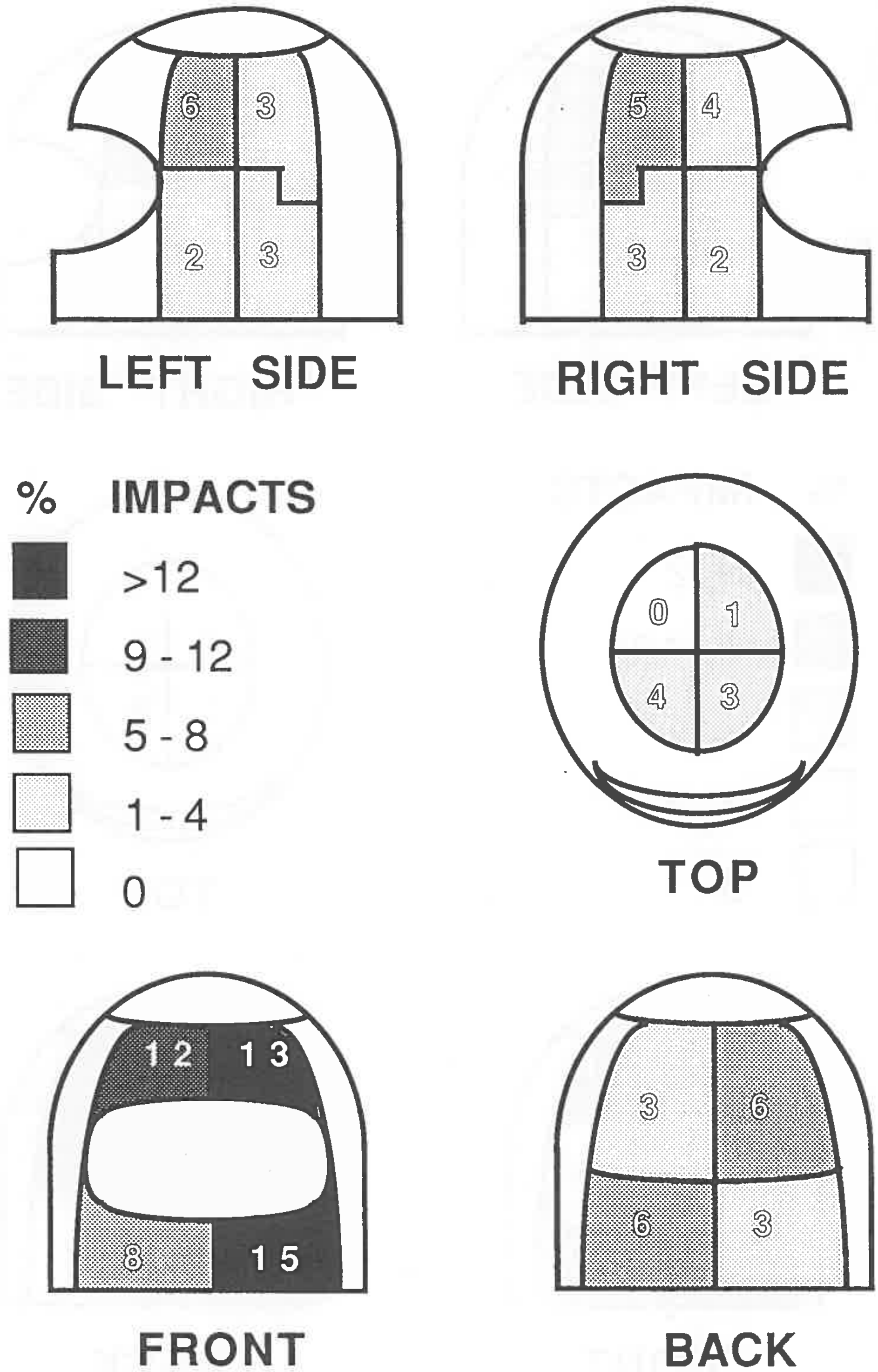

FIGURE 8 : ALL CASES
: SEVERE IMPACTS

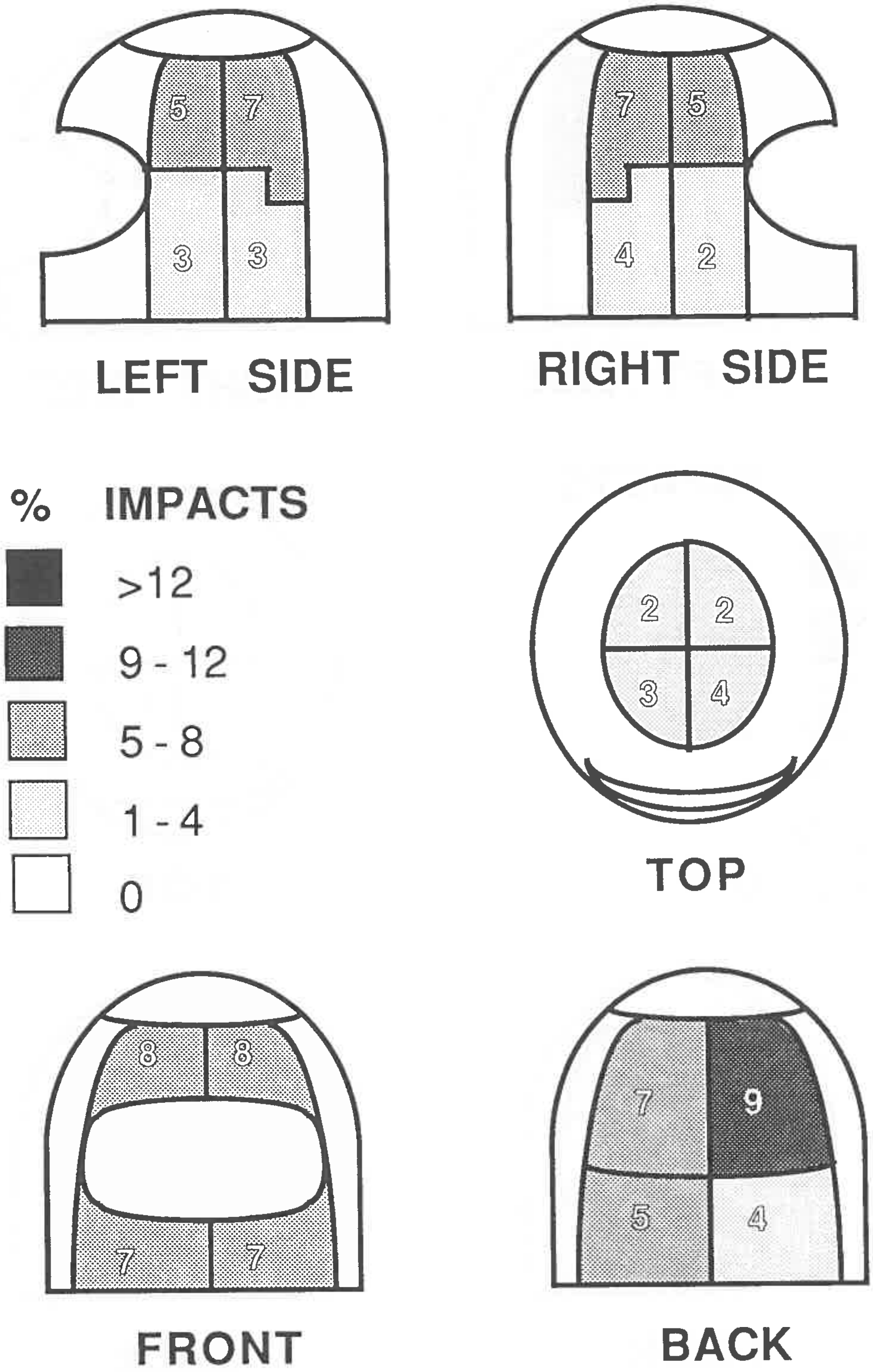

FIGURE 9 : ALL CASES
: ALL IMPACTS

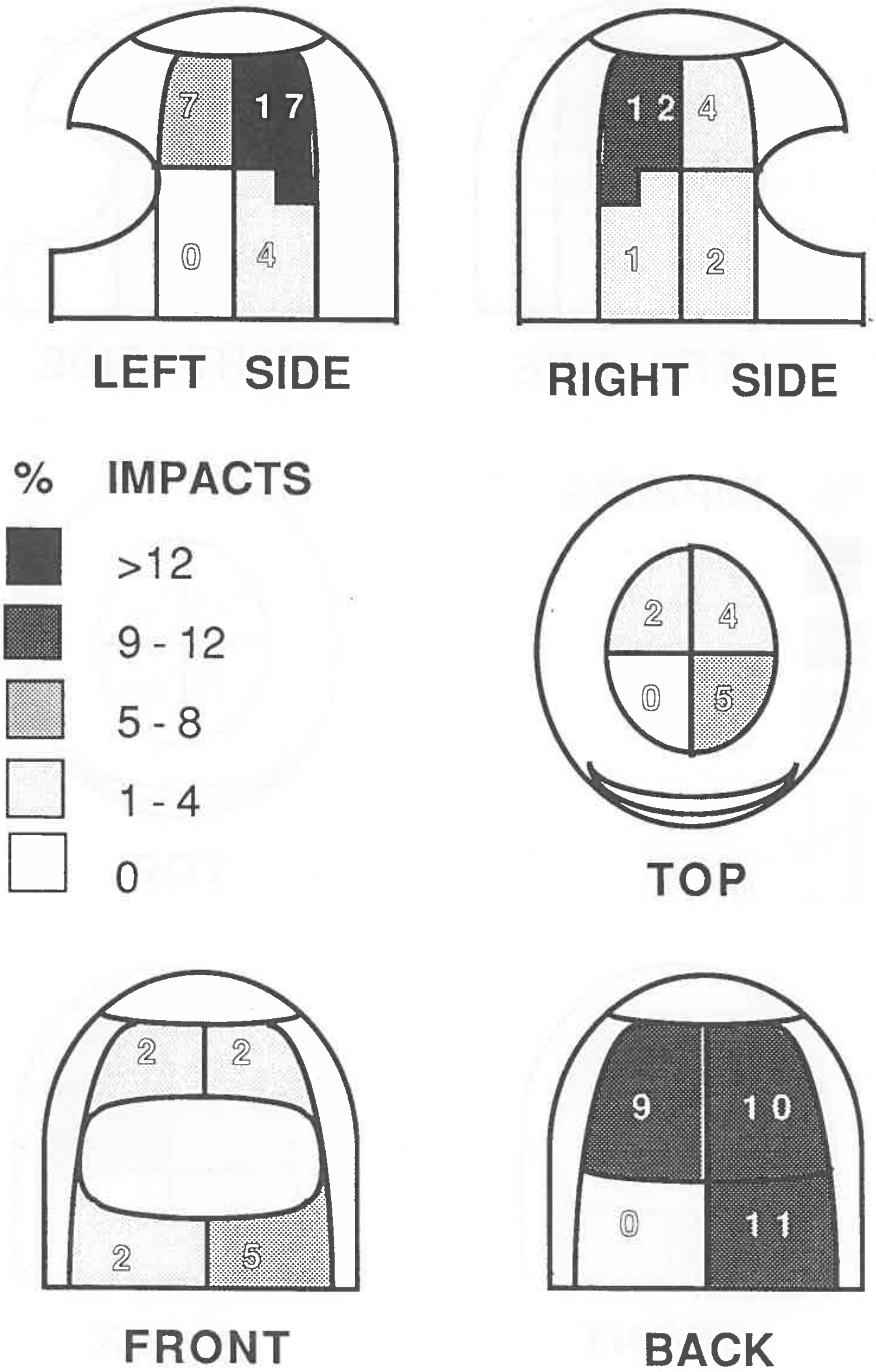

FIGURE 10 : FATAL CASES
: MINOR IMPACTS

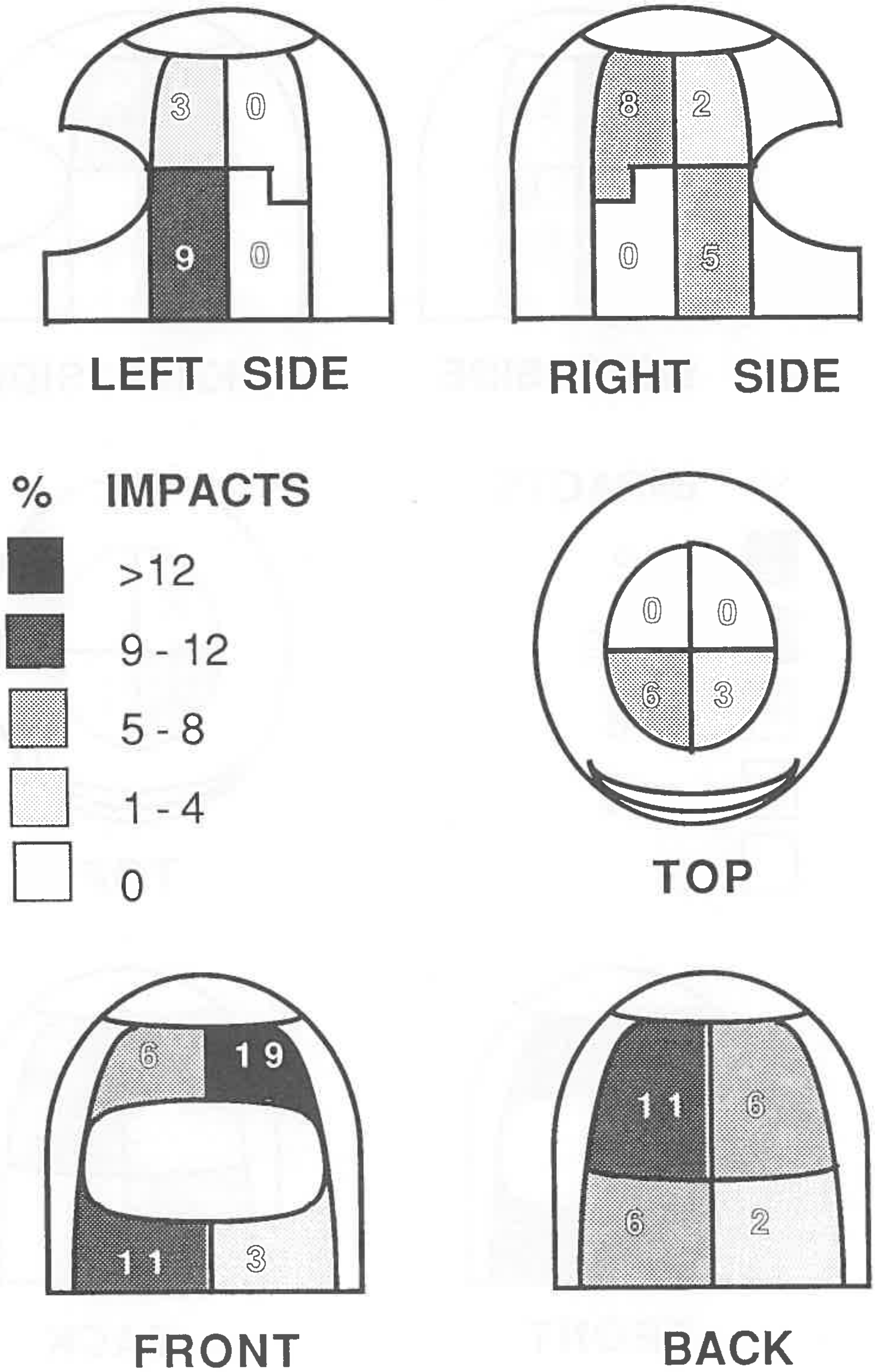

FIGURE 11 : FATAL CASES
: MODERATE IMPACTS

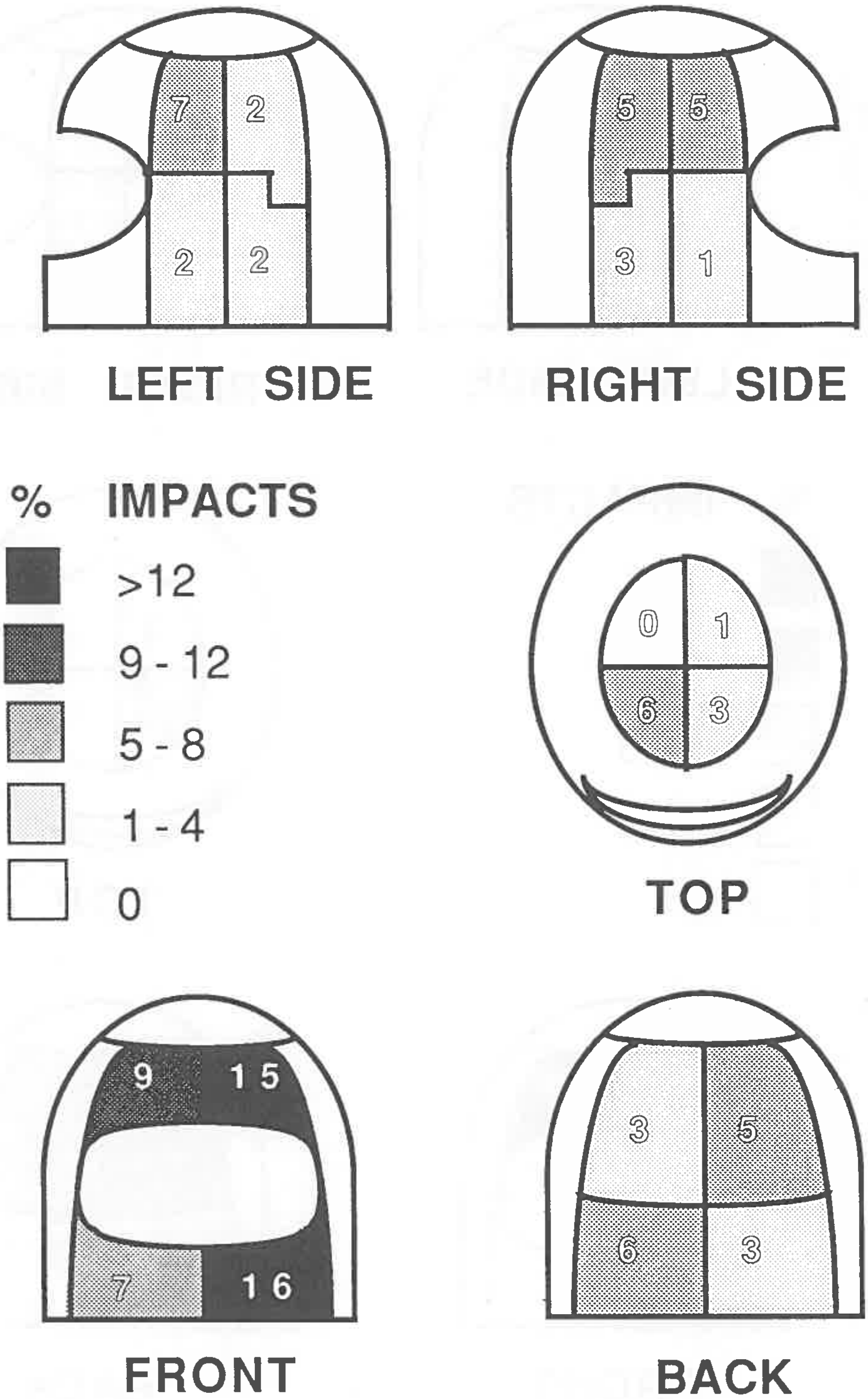

FIGURE 12 : FATAL CASES
: SEVERE IMPACTS

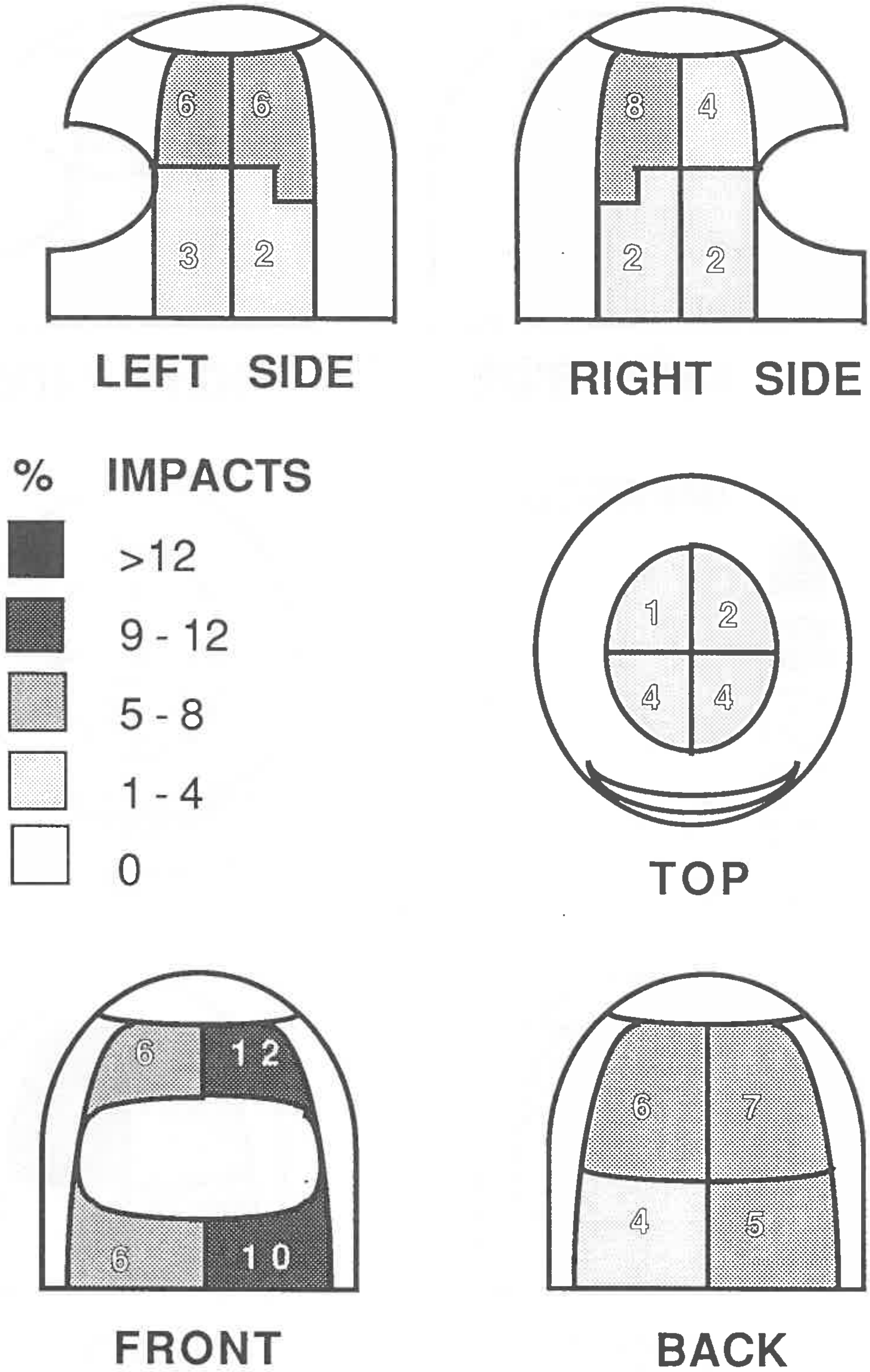

FIGURE 13 : FATAL CASES
: ALL IMPACTS

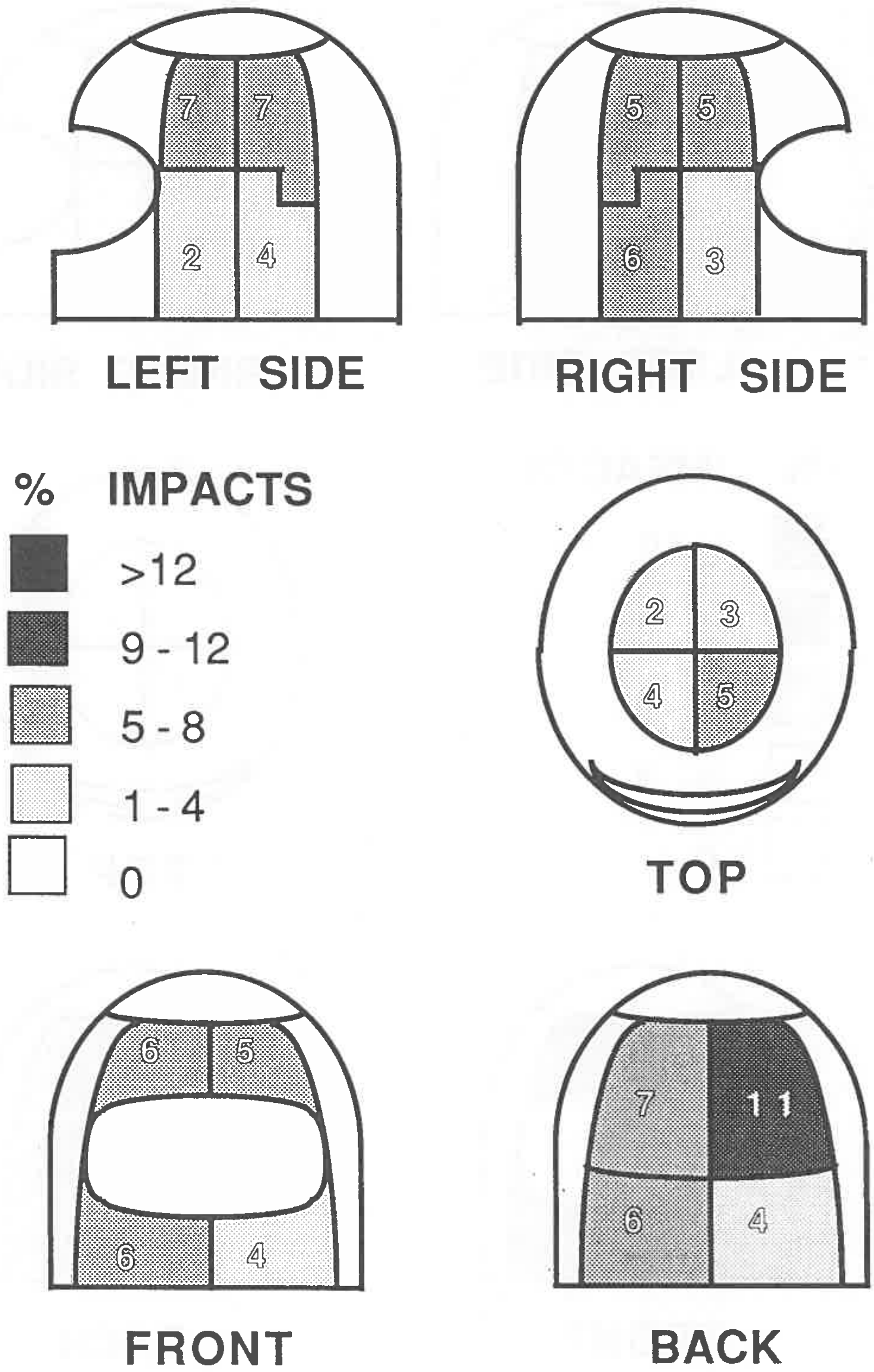

FIGURE 14 : NON-FATAL CASES
: MINOR IMPACTS

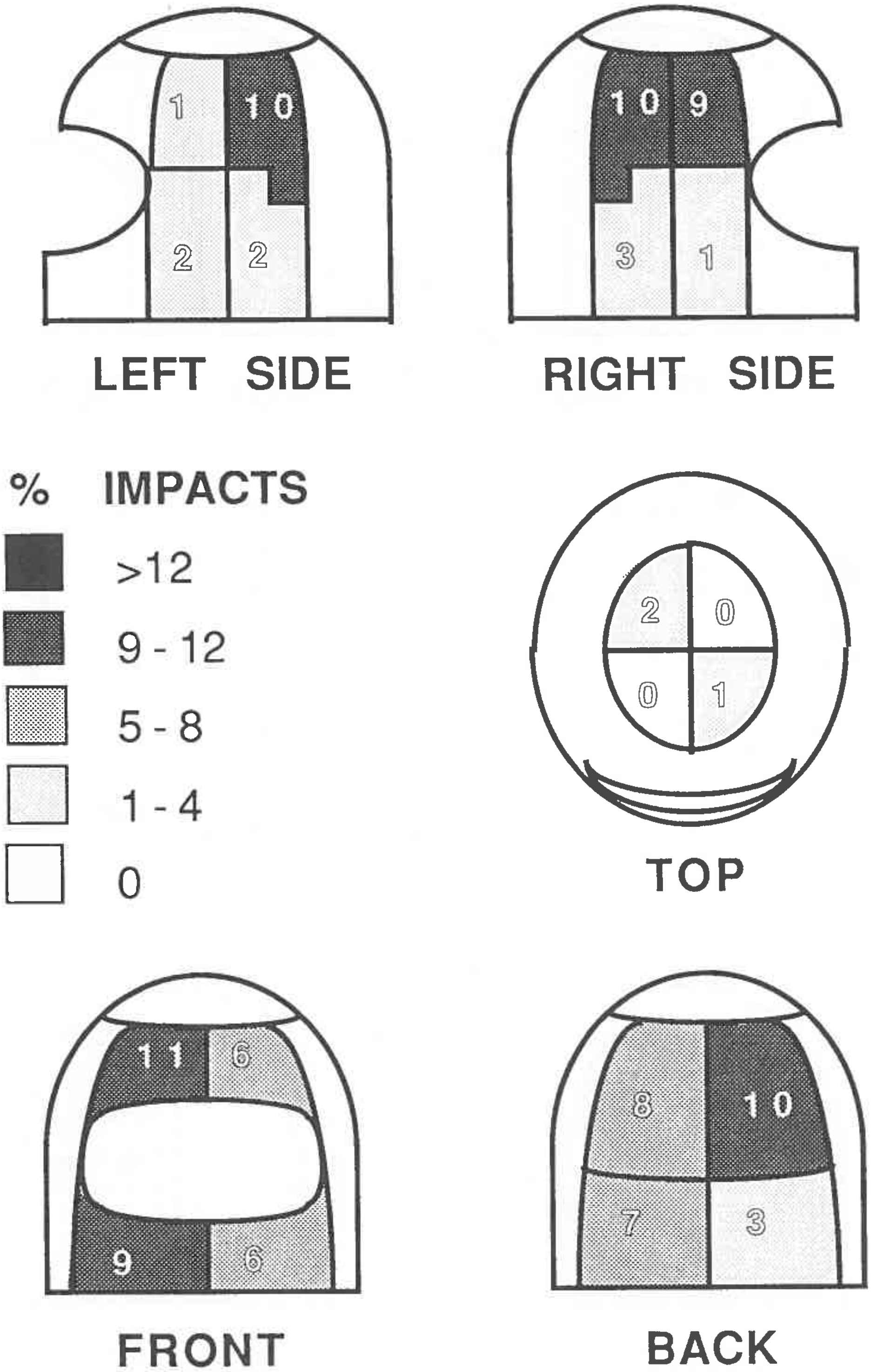

FIGURE 15 : NON-FATAL CASES
: MODERATE IMPACTS

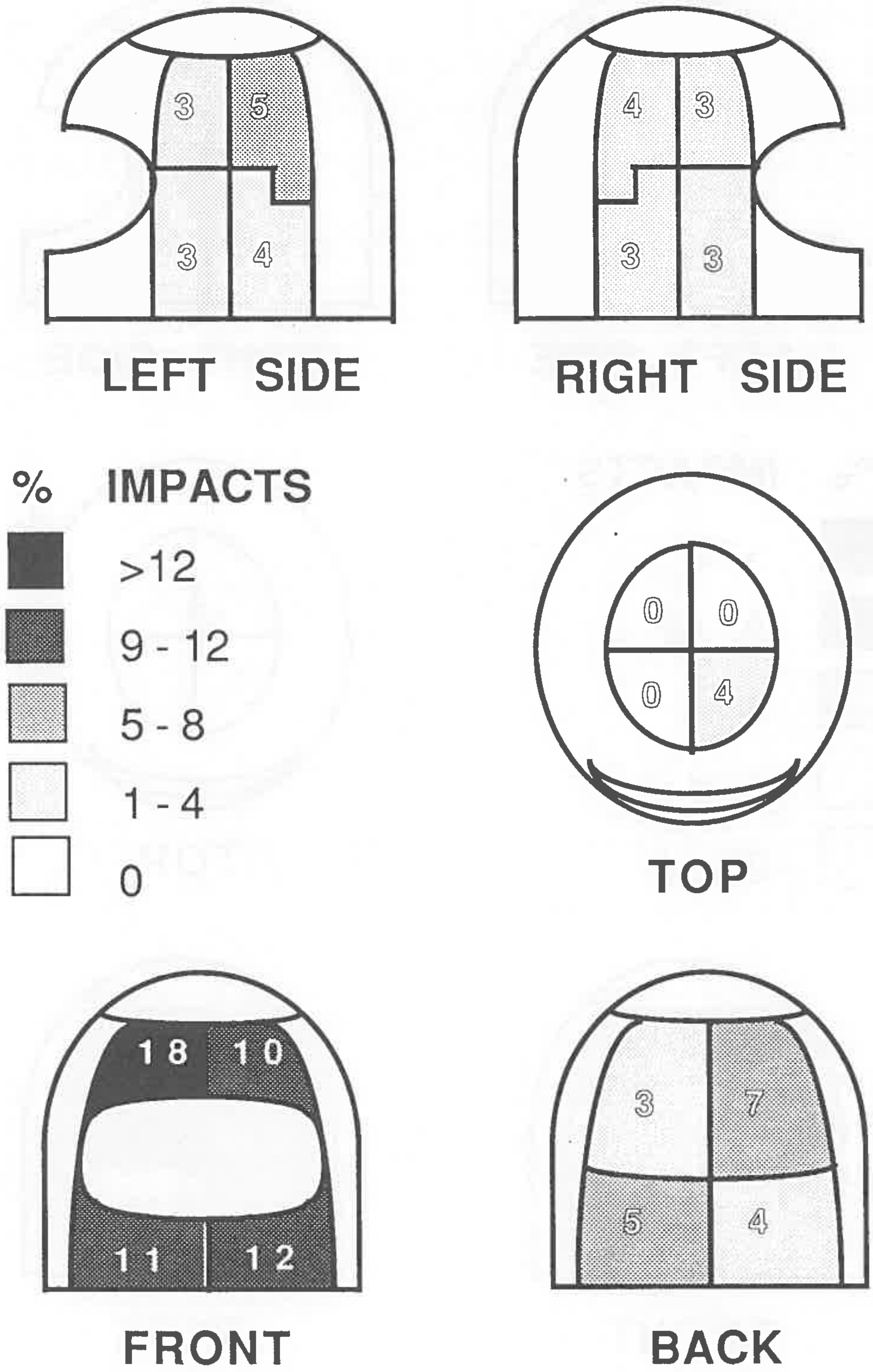

FIGURE 16 : NON-FATAL CASES
: SEVERE IMPACTS

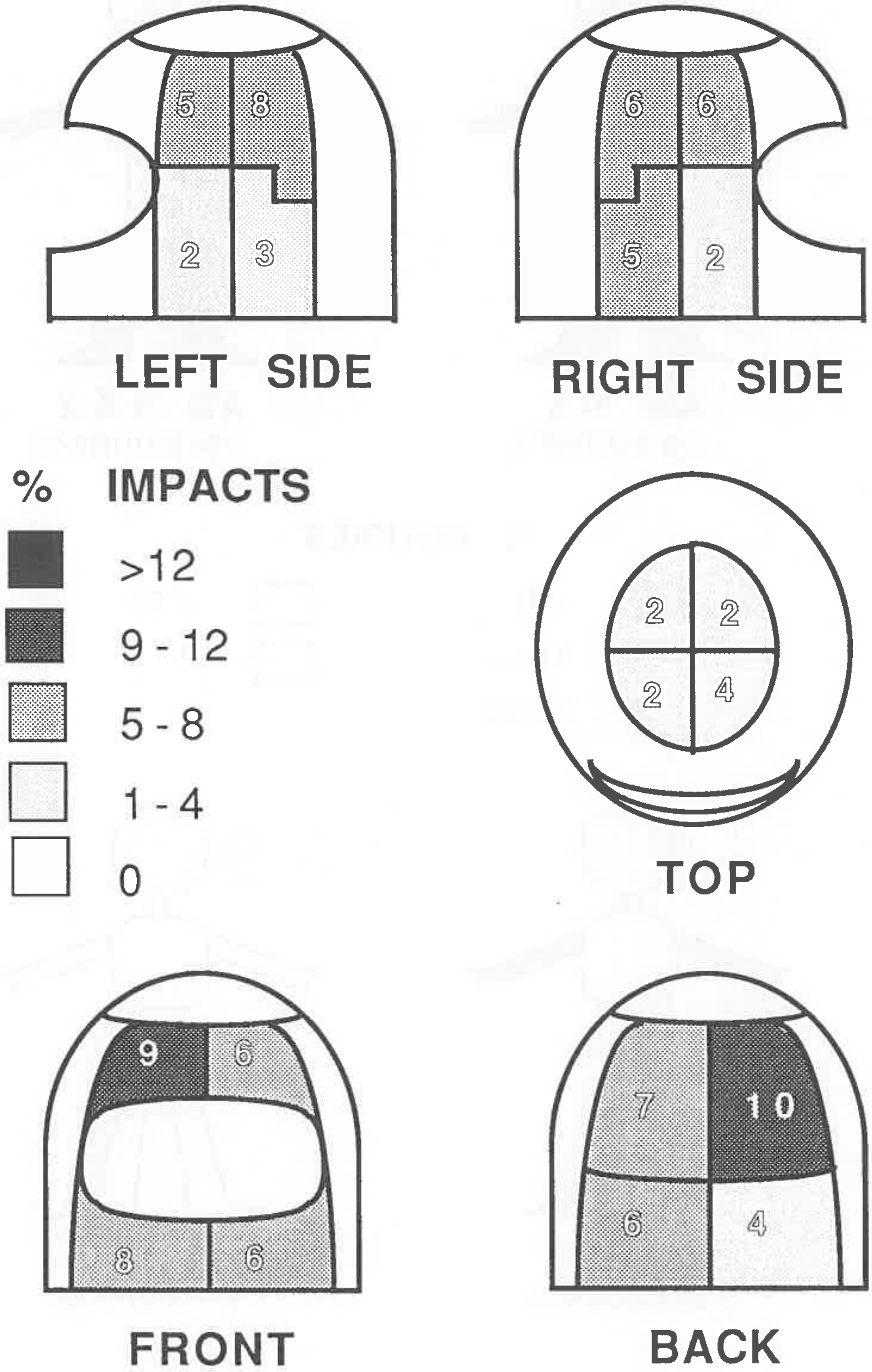

FIGURE 17 : NON-FATAL CASES
: ALL IMPACTS

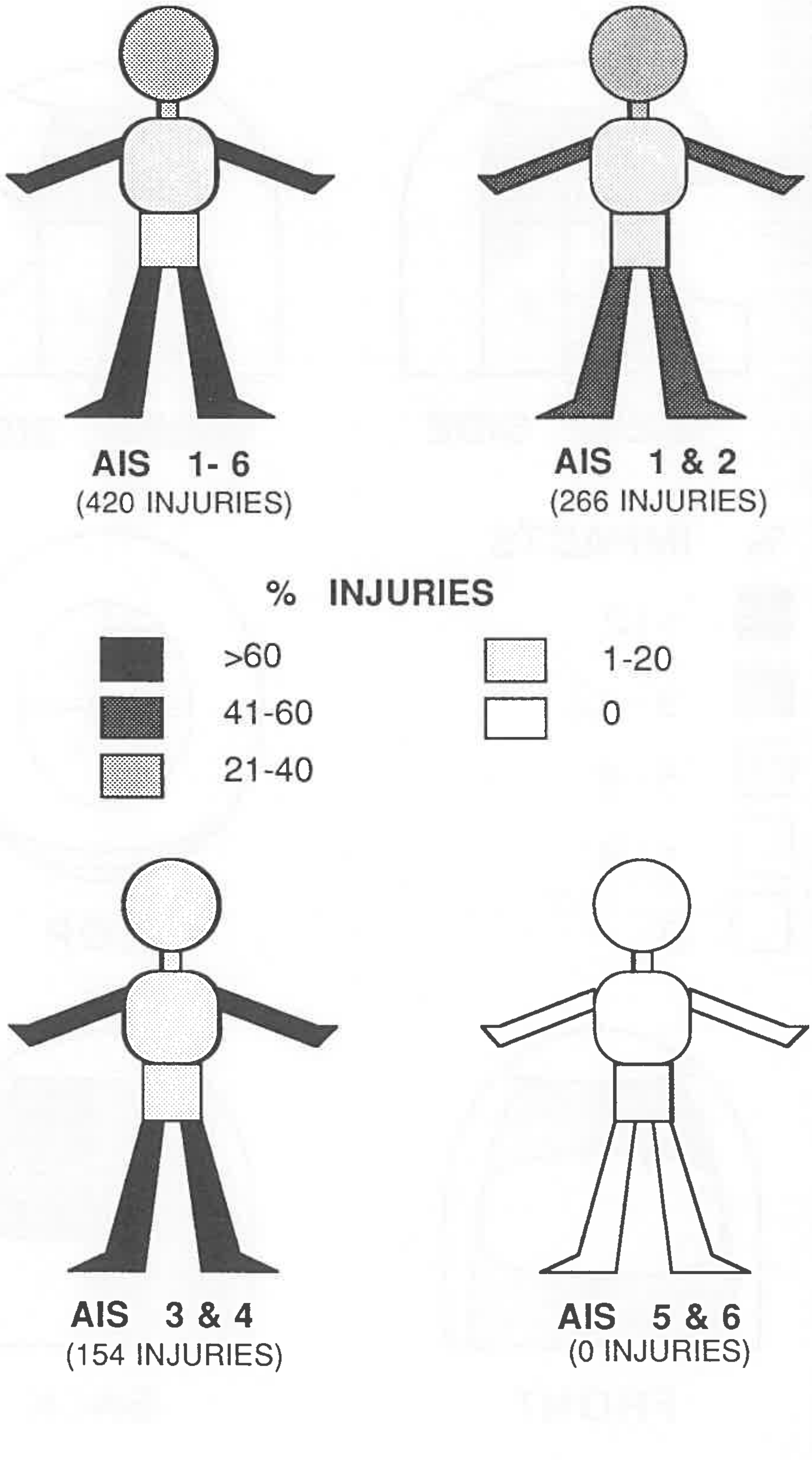

FIGURE 18 : NON-FATAL CASES
: PERCENT OF INJURIES BY INJURY LOCATION

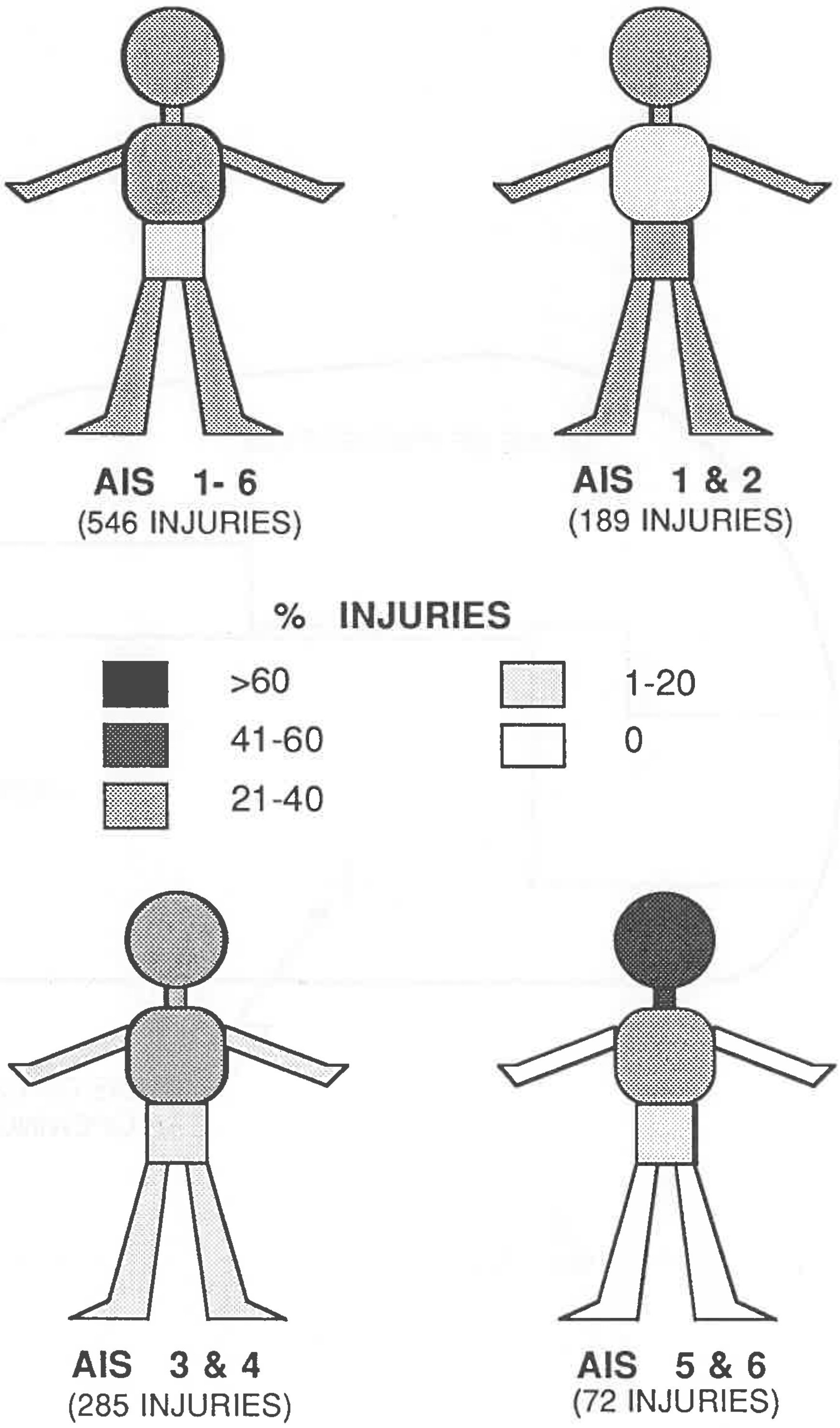

FIGURE 19: FATAL CASES
: PERCENT OF INJURIES BY INJURY LOCATION

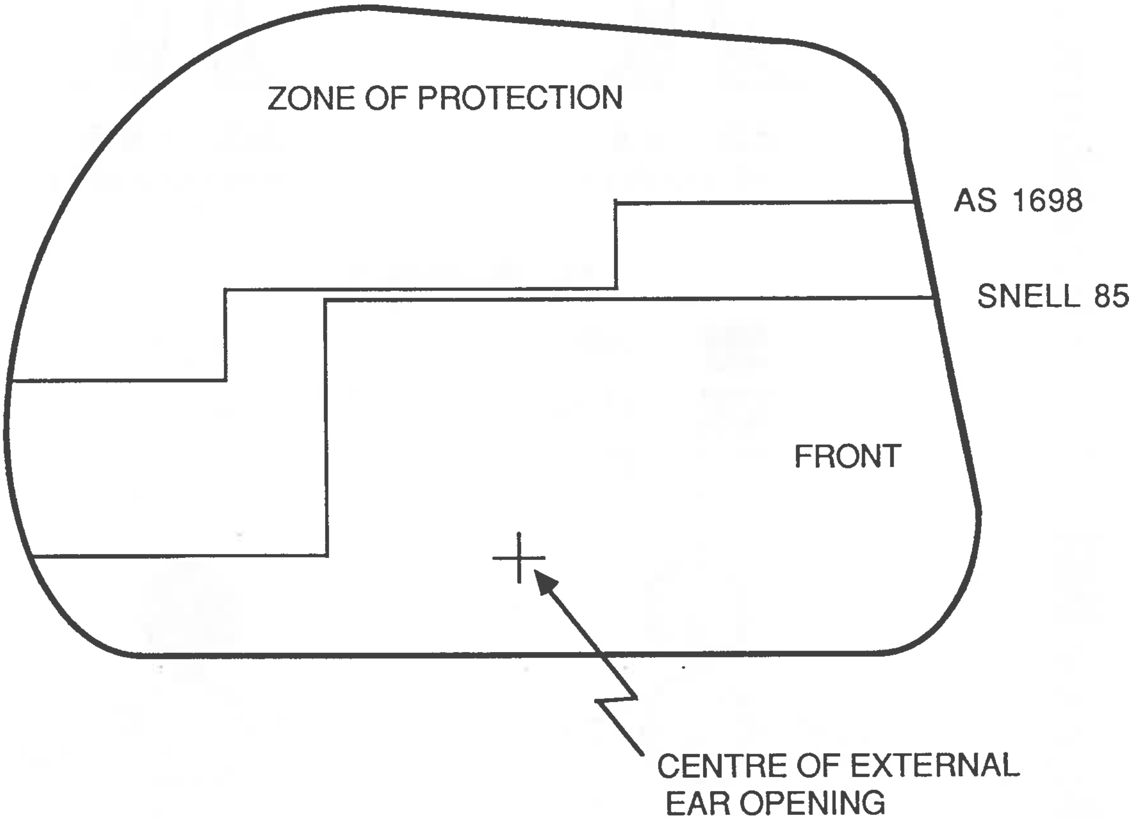

FIGURE 20: COMPARISON OF AS 1698 AND SNELL 85 TEST AREAS

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