1. OVERVIEW OF THE EPIDEMIOLOGY OF ALL TERRAIN VEHICLE INJURIES AND DEATHS

1.1 Patterns and trends of All Terrain Vehicle injuries in Australia

In order to present a profile of all terrain vehicle (ATV) injuries and to put the profile into context, a range of data is required. Firstly, for quantification of the size of the problem, all terrain vehicle cases need to be identifiable in fatal and serious injury (i.e., requiring hospital treatment) data bases. Secondly, information regarding the injured person and the circumstances in which the injury occurred is required for each case. Finally, information regarding the population of ATV riders and the number of ATVs in use is needed to generate fatality and injury rates which take into account the numbers of riders and the number of vehicles. Further, this information is required over time so that increases or decreases in the frequency and rate of ATV injury can be determined.

Unfortunately, in Australia, much of this information is not available at all, or is limited in detail or the years for which it is available. Fatality data is available from the new National Coronial Information System (NCIS), although this is likely to underestimate the frequency (see fatality section below). Details of the injured person and the circumstances of injury are included. Trends over time cannot yet be determined as the NCIS is a relatively new data base.

Serious injury data is even more limited. Until relatively recently, case enumeration has not been possible from the state hospital admissions databases as the coding system used did not distinguish between two wheel or four wheel motorcycles. This situation will improve over the coming years as the impact of the implementation of Version 10 of the International Classification of Diseases coding becomes apparent. Cases may also be identified using free text included in some local emergency department surveillance systems. However, the number of wheels on the motorcycle is not systematically recorded.

Some stand alone research projects have conducted surveys of ATV riders and follow-up surveys of injured ATV riders. However, the nature of participation in these surveys means that the information may not necessarily be representative.

Information regarding the population of ATV riders and the number of ATVs in use is even more limited.

Therefore, the profile presented here represents the best readily available information, but the limitations should be recognised.

1.1.1 Fatalities

The following profile of fatal events involving all terrain vehicles has been produced from data provided by the Victorian Coroner's Office, and data provided by Keith Ferguson of the Division of Workplace Health and Safety, Queensland Department of Industrial Relations (DIR). Data provided by the Victorian Coroner's Office was extracted from the National Coronial Information System (NCIS) for the period 1st July 2000 to 5th December 2002, which was all the data available on the NCIS at the time. Cases were identified by text search of Police Summary of Circumstances and Coronial Findings, and by field searches of both the "object" and "mechanism" fields. All age groups are included as are events occurring during both occupational and recreational activities. All states were included in the NCIS data, except Queensland.

Consequently, the NCIS data was supplemented with that provided by the QLD DIR for the same time period. This data includes all cases identified by DIR as occurring on farms, and either formally notified to DIR or identified in press clippings. All age groups are included, as are events occurring during both occupational and recreational activities. Events occurring in non-farm settings would not be included.

Complete case enumeration has therefore not been achieved due to incomplete information in the data fields of the NCIS, and incomplete case identification in the DIR data set. Due to the limitations of the data to hand, the numbers should be regarded as an under-estimate of the actual number of cases.

1.1.1.1 Overview

There were 22 cases in total identified in the NCIS, one of which involved a death by natural causes, and a second involved the death of a person riding a 2 wheel bike which collided with an ATV. These two cases have been excluded from the analysis below. There were 4 cases identified by the QLD DIR, giving a total of 24 cases for the profile. This is an average of 10 cases per year. There are approximately 150,000 to 200,000 ATVs in Australia (personal communication, Ray Newland, Federated Chamber of Automotive Industries). Therefore, an estimated annual rate of ATV deaths in Australia is 5-7 per 100,000 all terrain vehicles. This is equivalent to about half the motor vehicle crash death rate of 13.9 per 100,000 vehicles in 2001 (Australian Transport Safety Bureau, 2002).

Due to the relatively short period of time for which the data was available, robust trends over time could not be determined. There were 8 deaths in the first year of data (2000/01) and 10 in the second year (2001/02). However, in Victoria, there had been an average of 1 ATV death on a farm since 1997 until 2002 when there was a sudden increase to 5 deaths associated with ATVs (personal communication, Eric Young, Victorian WorkCover Authority). An increase in the number of ATVs in operation could partly explain this increase in fatalities. The Tractor and Machinery Association of Australia has reported a 12% increase in sales for 2002 compared with 2001 (Tractor and Machinery Association of Australia, 2003).

The majority of cases in the Australian data were male (22 cases). Close to one third (7 cases) were under 16 years of age, and just under half (11 cases) were 50 years of age or over. (Table 1). The two females were in the 50-59 year age group. In the absence of nationally representative data on the age and gender profile of ATV users, conclusions regarding age and gender related risk cannot be determined. The word "risk" in this context is a technical term referring to the probability of being killed or injured. If for example, 90% of the ATV fatalities were male and 90% of ATV riders were male, then males are not actually of increased risk of ATV related death, even though the majority of fatalities are male. In comparison, if 90% of the ATV fatalities were male and 70% of ATV riders were male, then males could be said to be at increased risk of ATV related death. The estimation of risk could be further refined by adjusting for hours of ATV riding (eg., some of the increased risk could be explained by greater use of ATVs).

Location was specified in 23 cases, the majority of which occurred on a farm (17 cases). Activity was specified in 21 cases. Twelve cases were working at the time of injury, six of whom were spraying. Seven were engaged in sport or leisure, and two were travelling.

Table 1: Age distribution and incident mechanism, all terrain vehicle fatalities, Australia, 1.7.2000-5.12.2002

Age group	Overturns	Collisions	Other	Total
0-4		1		1
5-9	1			1
10-15		4	1	5
16-19	1		1	2
20-29				
30-39	2			2
40-49	1	1		2
50-59	3	1	2	6
60-69		1	1	2
70+	2		1	3
Total	10	8	6	24

1.1.1.2 Mechanism of incident

Overturn

There were 10 cases in which an overturn of the ATV was the primary incident mechanism. The most common overturn scenario (8 cases) involved either a slope (6) or surface irregularity (1 rock, 1 hollow in ground) as the initiating factor. A further overturn involved a tyre puncture as the initiator. There was one overturn for which the initiator was unclear.

Among the cases involving overturns on slopes (8 cases), four ATVs were carrying a load in addition to the rider. Two of these involved spraying gear, one involved steel and one involved a pillion passenger. Gradient was specifically mentioned as steep in 3 out of the 8 cases, one of which was noted as also uneven, and a second was noted as also muddy. One case involved a load and a steep gradient (which was also muddy).

One of the cases involving an overturn due to surface irregularity also occurred on steep, bumpy terrain.

All the overturn cases were male, half of whom were 50 years or over (Table 1).

Collision

There were 7 incidents (resulting in 8 fatalities) in which a collision was the primary incident mechanism. Collisions occurred into a range of objects: trees (2), rock (1), fence (1), haul out bin (1), trailer (1 incident, 2 cases), creek (1). Loss of control was specifically noted in two incidents. Other factors each noted in one incident include inadvertent reversing (1 incident, 2 cases), alcohol, a pillion, and mustering cattle at the time (possibly distracted by the cattle).
All the collision cases were male, except 1, and five of the eight cases were under 16 years of age (Table 1).

Other

There were 2 cases in which the ATV went over a slope and the riders were ejected from the ATV. One of these involved a pillion.

There was one case in which the ATV ran into the deceased.

There were three cases for which there was insufficient information to determine the incident mechanism.

1.1.1.3 Mechanisms of injury

The most common mechanism of injury was the ATV falling onto the deceased (12 cases). Body regions injured included chest (5 cases), head (3), and cervical spine (1). Injury data was missing for three cases. More than one injury could be recorded per case.

There were a further 7 cases (plus one possible) in which the deceased person was thrown from the ATV and impacted with an object or the ground. Body regions injured included: head (6), cervical spine (1), aspiration (1), crush (1), and multiple injuries (1). More than one injury could be recorded per case.

There was a mix of mechanisms among the remaining 4 cases.

1.1.2 Serious injury

In an overview of hospital admissions due to farm injury, motorcycle incidents were identified as the leading cause of admission for all three states examined (New South Wales, Victoria and South Australia) (Fragar and Franklin, 2000). Detail on ATV related hospital admissions for Australia is not readily available. However, in Victoria for the three financial years from July 1998 to June 2001, there were 178 cases of ATV injuries admitted to hospital (personal communication, Karen Murdoch, Victorian Injury Surveillance and Applied Research Program). These data include all admissions to Victorian hospitals, covering all age groups and all locations of injury event. This is an annual average of 59 hospital admissions per year for Victoria. Over this time period, there was an average of 1 death per year in Victoria. If we assume a ratio of 59 hospital admissions for each death, then there are approximately, 590 hospital admissions of ATV related injury in Australia each year.

In the Victorian data, a total of 169 (95%) were injured in a non-traffic incident, and 151 of these were riders (as opposed to passengers). The majority (89%) were male. Age groups most commonly injured were 15-19 years (16%), 20-24 years (16%), 25-29 years (11%). The under 15 year age group accounted for 15% of the admissions, while the 65 years and over accounted for 7%. The lower extremities were the most frequent body part injured (33%), followed by the upper extremity (25%). Just over half the injuries were fractures (52%). Length of stay in hospital was between 2 and 7 days for 43% of the patients. As with the fatality data, robust trends over time can not yet be determined. There were 44 admissions in the first year of data (1998/99), 73 in the second year (1999/00), and 61 in the third year (2000/01).

Some stand alone studies of motorcycle injury on farms have identified ATV injuries separately. In a project involving several convenience samples of farm motorcycle riders, 552 riders who had been injured were identified (Schalk and Fragar, 2000). Forty-seven of these were injured while riding at ATV. Using data from a range of sources, the study concluded that while injuries associated with ATVs may occur less frequently than those associated with two-wheel motorcycles, ATV related injuries tended to be more severe involving fractures and sprains most commonly to the upper body. Hitting a stationary object and rolling was a common scenario associated with ATV injury. The majority of incidents involving both two-wheel motorcycles and ATVs on farms were estimated to occur at speeds less than 30 km/h.

1.1.3 Summary

There is an average of 10 deaths at least, and an estimated 590 hospital admissions due to ATV related injury each year in Australia. The rate of ATV deaths per 100,000 vehicles is equivalent to about half the motor vehicle crash death rate. Trends over time are difficult to establish at this stage, but it appears that the numbers of both deaths and hospital admissions are not decreasing. ATV sales have reportedly increased between 2001 and 2002, and if this trend continues, then the numbers of deaths and hospital admissions are also likely to continue, in the absence of any substantial preventive efforts.

Males comprise the majority of killed and seriously injured people. Most incidents occur in off road locations, with an agricultural setting being particularly common. Under 16 year olds and those over 50 years feature in the fatalities, while those between 15 and 29 years feature in the serious injury data. Overturns and collisions are the predominant event mechanisms. Injury patterns are different for fatalities and serious injuries, with the chest and head being most frequently injured in fatal events, compared with upper and lower extremities for serious injury events.

1.2 Patterns and trends of ATV injuries in other countries

Comparisons with other countries are not as informative as would be hoped due to differences in the reporting systems, the types of ATVs on the market and the ways in which ATVs are used in different countries. For example, until recently, a greater proportion of ATVs in the United States where three-wheeled, in contrast to Australia where four-wheeled have been more common. Further, recreational riding seems to be more prevalent in the United States (Schalk and Fragar, 2000). Within the agricultural sector, ATVs seem to be used more frequently in New Zealand than Australia. For this reason, limited details are provided in the overview below. Countries include the United States of America, New Zealand and the United Kingdom. Data for ATV injury was not readily available for Canada.

1.2.1 United States of America

Fatalities

Trends in ATV deaths and death rate are available for the United States of America for the period 1985-2000 (Ingle, 2002). These data include deaths in all locations. Data for 1999 and 2000 are not as comparable to the previous years due to a change in reporting. The actual number of deaths involving 4-wheel ATVs increased over the period from 1985 to 1998 (Figure 1), although there was a period of relative stability in numbers from 1988 to 1992. In comparison, the fatality rate per 10,000 4-wheel ATVs decreased from 1985 to 1993, after which it began to increase (Figure 2).

A profile of fatalities for the period 1985-1996, which included three- and four-wheel ATVs, indicated that males (87%) and drivers (86%) made up the majority of cases (David, 1998). Over 35% of the deaths involved children under 16 years of age. The two most frequently reported incident mechanisms were collisions (56%) and overturns (28%). Over half the incidents occurred on roadways. More than 90% of the child-driver fatalities involved an adult sized ATV.

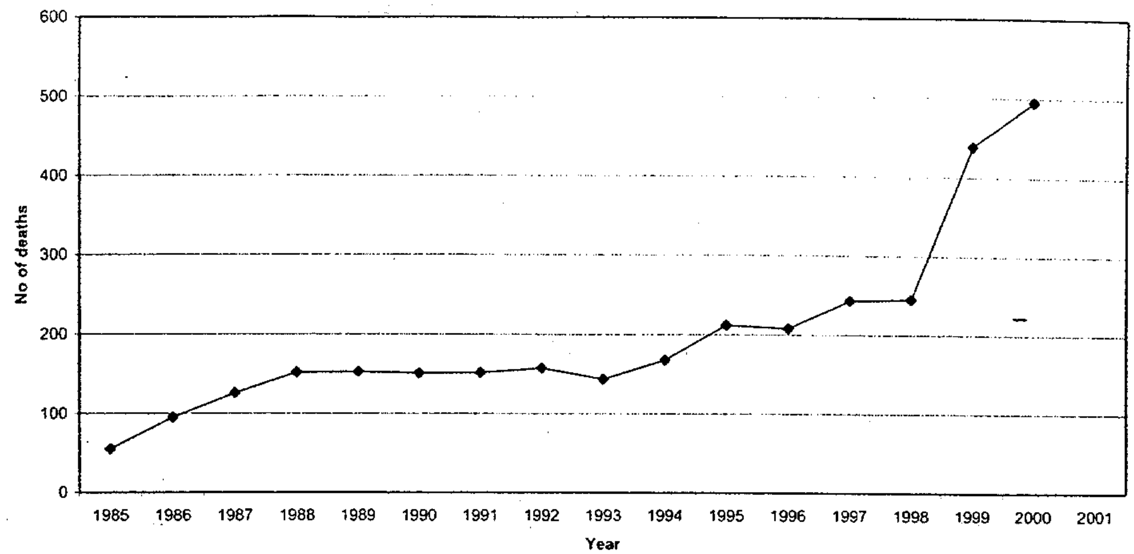


Figure 1: Estimated deaths involving 4-wheel all terrain vehicles, United States. Data source: Ingle, 2002

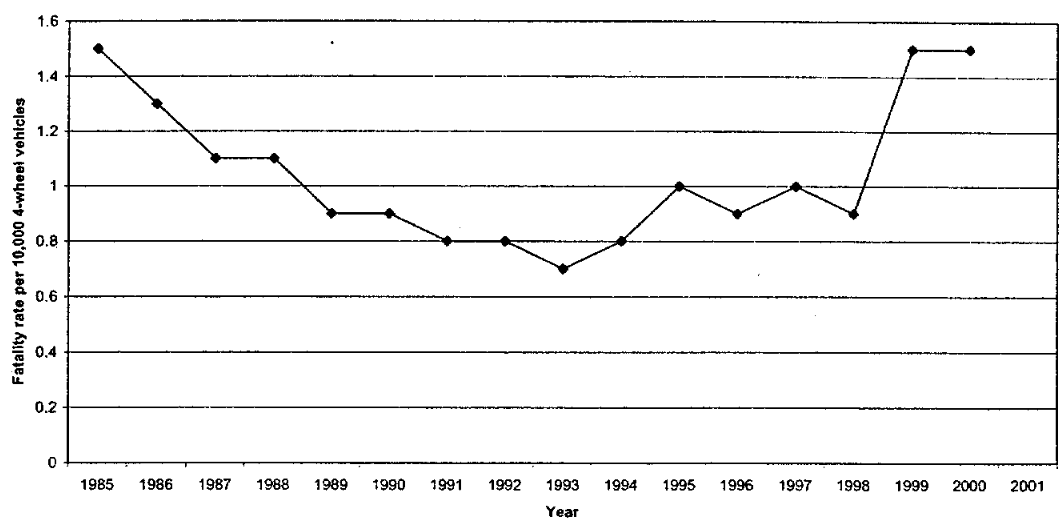


Figure 2: Fatality rate, 4-wheel all terrain vehicles, United States. Data source: Ingle, 2002

Serious injuries

Annual estimates of 4-wheel ATV related injuries treated in hospital emergency departments in the United States show a dramatic increase since 1997 (Figure 3). The serious injury rate per 10,000 4-wheel ATVs decreased from 1985 to 1997, after which the rate has increased steadily every year until 2001 (Figure 4).

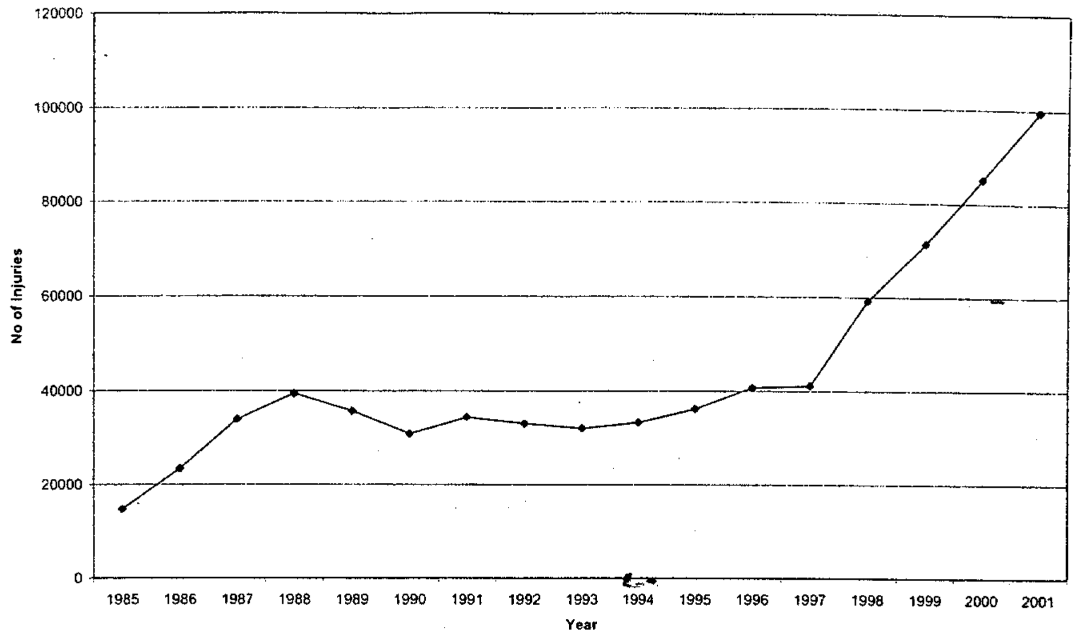


Figure 3: Estimated serious injuries involving 4-wheel all terrain vehicles, United States. Data source: Ingle, 2002

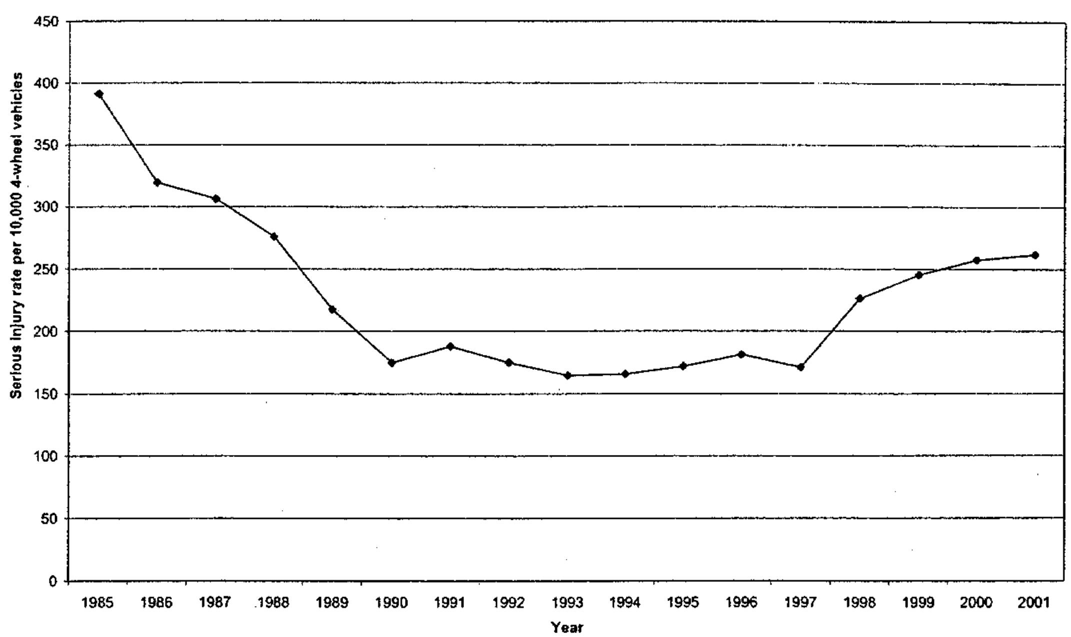


Figure 4: Serious injury rate, 4-wheel all terrain vehicles, United States. Data source: Ingle, 2002

A follow up survey of 319 ATV related injuries presenting to hospital emergency departments during May and August, 1997 showed that males (75%) and drivers (75%) made up the majority of cases (Consumer Product Safety Commission, 1998). Forty-seven percent were children under 16 years of age. The arms (37%), legs (28%) and head (22%)

were the most frequently injured body parts, and bruises and abrasions (27%) and fractures and dislocations (26%) were the most frequent injuries. Thirteen percent of cases were admitted to hospital, compared with 4% for emergency department presentations for all types of injuries.

1.2.2 New Zealand

Fatalities

In New Zealand, ATVs are the second most common cause of work-related fatalities, following motor-vehicles (Occupational Safety and Health Service, 2002).
Of 15 total deaths during 2000/01 to 2001/02, the Occupational Health and Safety Service classified 8 as from being crushed or pinned by the ATV, and an additional four were defined as roll-overs (Moore, 2002). The average annual rate of deaths per 100,000 ATVs over the five years since 1997/98 is 9.3 (Table 2).

Table 2: Work-related fatality rate, all terrain vehicles, New Zealand

Year	ATV work related fatalities[1]	Estimate of ATVs in use[2]	Rate per 100,000 ATVs
1997/98	3	55,000	5.5
1998/99	6	55,000	10.9
1999/00	5	62,500	8.0
2000/01	8	70,000	11.4
2001/02	7	70,000	10.0
Annual average	5.8	62,500	9.3

1 From Moore, 2002; and Occupational Safety and Health Service, 2002.

2 Data for 1998 and 2001 from Occupational Safety and Health Service, 1998 and 2002; Figure for 1999/00 estimated as half way between 1998 and 2002.

Injuries

Due to difficulties in distinguishing all terrain vehicles from motorcycles in most data bases (Langley et al., 1995), there has only been one study to date in New Zealand of injuries due to ATVs (Moore, 2002). The Accident Compensation Commission escalated claims data (i.e., those claims which are estimated to be in the third most costly) indicated a total of 850 claims over the 13 month period from July 2000-July 2001. Six of these were fatalities, and four were classified as serious. Males comprised 83% of the injured persons. A large proportion of injured persons were aged 31-50 years (44%), and a smaller proportion were aged up to 20 years (12%). The most common injury sustained was soft tissue injury (57%), followed by fractures or dislocations (19%) and lacerations (12%). The knee (10%) and lower back (9%) were the most frequently injured regions, followed by shoulder (9%) and chest (8%).

A follow-up study of 156 loss of control events, identified a large range of factors associated with the event (Moore, 2002). Overall, unpredicted surface changes (36%), use of marginal routes (35%), loads (26%), and equipment-task mismatch (24%) were the most common. Among the more serious injuries (37 in total), use of marginal routes (35%), unpredicted surface changes (30%), and haste (27%) were identified. Among the more serious events, 26 involved roll-over of the ATV and 14 involved being entrapped by the ATV (note: these two categories were not mutually exclusive).

Among the 156 total loss of control events, 31 (20%) had ROPS (Moore, 2002). Among the 37 most serious events, 4 involved a machine equipped with ROPS. In three of these cases, the rider was thrown forwards. In the fourth case, the ATV flipped backwards and the rider sustained a head injury. The object causing the head injury was unknown.

1.2.3 United Kingdom

A limited profile of ATV related injury for the United Kingdom has been published by Allinson (1996). Ninety incidents involving four and six wheeled ATVs were investigated by the Health and Safety Executive between June 1986 and February 1995. It was not clear whether these included both fatalities and serious injuries. Sixty-four percent (58) involved vehicle overturn or roll, and of these 46 (79%) overturned sideways and 12 (22%) resulted in the rider being trapped under the ATV. Rider error was judged by the HSE inspectors to be the most probable cause of almost half of the overturns. Further details as to how cause was assigned, or the actual nature of the error were not available. The most frequently injured body parts were the head (21%), chest (15%), and legs (14%).

1.2.4 Summary

Some common observations apply to Australia and the other countries examined with respect to ATV deaths and injury. Males are more frequently killed or injured, which may reflect the predominance of males among ATV riders. Riders under 16 years of age make up substantial proportions of those killed or seriously injured. Overturns and collisions are consistently reported, and generally overturns are the most common event scenario. The chest and head are commonly injured in fatalities whereas other body areas (arms and legs) are also involved in serious injuries. The fatality rate per 100,000 vehicles for Australia (5-7) is a little lower than for New Zealand (9), and substantially lower than that for the United States (15). However, the data on which these estimates were made for Australia and New Zealand, particularly the number of ATVs in use, is not as robust as that for the United States.

2. PREVENTIVE STRATEGIES FOR ALL TERRAIN VEHICLES

2.0 Overview of current preventive strategies in Australia

Most of the preventive activity related to ATV deaths and injuries has taken place within the agricultural setting, given that a large proportion of ATV related deaths and injuries occur in that setting. Farmsafe Australia takes a lead role in defining the nature and size of the farm injury problem, setting agreed goals and targets, and developing an agreed strategy for achievement of these targets. ATV related injury is included in the Farmsafe Australia Goals, Targets and Strategy (Fragar and Franklin, 1999), although not explicitly. Both vehicles in general (for deaths) and motorcycles more specifically (for serious injury) are targeted and ATVs would be incorporated under both these categories.

A research project on injuries associated with farm motorcycles (2 and 4-wheel) was undertaken by the Australian Centre for Agricultural Health and Safety which set some directions for prevention of motorcycle related deaths and injuries (Schalk and Fragar, 2000). The following were recommendations related specifically to ATVs:

- Competency based ATV farm motorcycle training courses should be developed with the aim of improving both rider knowledge and skills.
- Information regarding carrying of passengers and recommended driver age should be made available to all riders and their guardians.
- Advice for Australian suppliers, farmers and farm managers on the fitment of ROPS to ATVs should be prepared on the basis of research information regarding the benefits and risks of fitment.

Note that the recommendation regarding training was made in the absence of any robust research evidence that such training would actually reduce deaths and injury.

A series of recommendations were also made regarding the evidence base for ROPS on ATVs (Stephenson, in Schalk and Fragar, 2000). These recommendations were developed by a qualified engineer following a review and analysis of available material on previous attempts at designing ROPS for ATVs. These recommendations indicated that there was not yet sufficient data to recommend or condemn the two ROPS designs evaluated, and identified a need to continue to develop better ROPS. It was also noted that if adverse statistics continue and there are no significant safety improvements (such as ROPS), then consideration should be given to issuing warnings to consumers and possibly restricting the sale of ATVs.

ATV related fatality and injury prevention initiatives in Australia have until recently primarily focussed on provision of information and on training programs. Competencies for motorcycle and ATV riding have been incorporated into the Australian Rural Training Framework. Some ATV manufacturers provide ATV training as a service, however the extent to which the manufacturer provided training meets the formal competencies has not yet been determined (personal communication, John Temperly, Australian Centre for Agricultural Health and Safety).

The development of an all-purpose protective helmet (for horse and motorcycle riding) is also being pursued. The fitment of ROPS is being officially discouraged, although individual farmers may continue to fit their own. Anecdotal evidence from a Victorian ROPS manufacturer and supplier indicates that demand for ATV ROPS is relatively low (personal communication, Frank Ford, Casey Cab and Frame).

The Australian Centre for Agricultural Health and Safety is currently developing an ATV safety strategy for Farmsafe Australia.

2.1 Overview of current preventive strategies in other countries

Apart from the provision of information to users, the two countries which appear to have applied the most significant preventive effort are the United States of America and New Zealand.

2.1.1 United States of America

Serious concerns arose in the USA during the early to mid 1980s when the numbers of fatalities and serious injuries associated with ATVs increased significantly. The United States Consumer Product Safety Commission (CPSC) initiated regulatory proceedings which culminated in a decree which was in effect for ten years, from April 1988. The decree required:

- Withdrawal of three-wheel ATVs from the market.
- Implementation of a national training program and provision of free training to all future purchasers of ATVs and their immediate families.
- Implementation of a public awareness campaign costing US$8.5 million.
- Development and implementation of improved labelling, owners manuals and point of sale purchase materials.
- Implementation of a toll-free ATV hotline service.
- Implementation of an outreach program to disseminate safety materials to consumer groups.
- Agreed age recommendations for operating ATVs to prevent young children from operating the wrong size ATVs.

The CPSC has monitored fatality and injury rates, and conducted a number of national surveys, to determine the impact of the consent decrees (Ingle 2002, Rodgers 1999).
The number of deaths had been decreasing from 1986 to 1988 when the consent decree was instituted (Figure 5). The numbers continued to decline until 1993 after which deaths increased until 1998 when the consent decree expired. The numbers of deaths in 1997 and 1998 were equal to or greater than the number in 1988. Deaths have continued to increase from 1998 to 2000, although some of this increase is due to changes in reporting processes. Most of the decrease in deaths appeared to be due to the withdrawal of the three wheel ATVs, as there was little decline in deaths associated with four wheel ATVs (Figure 1).

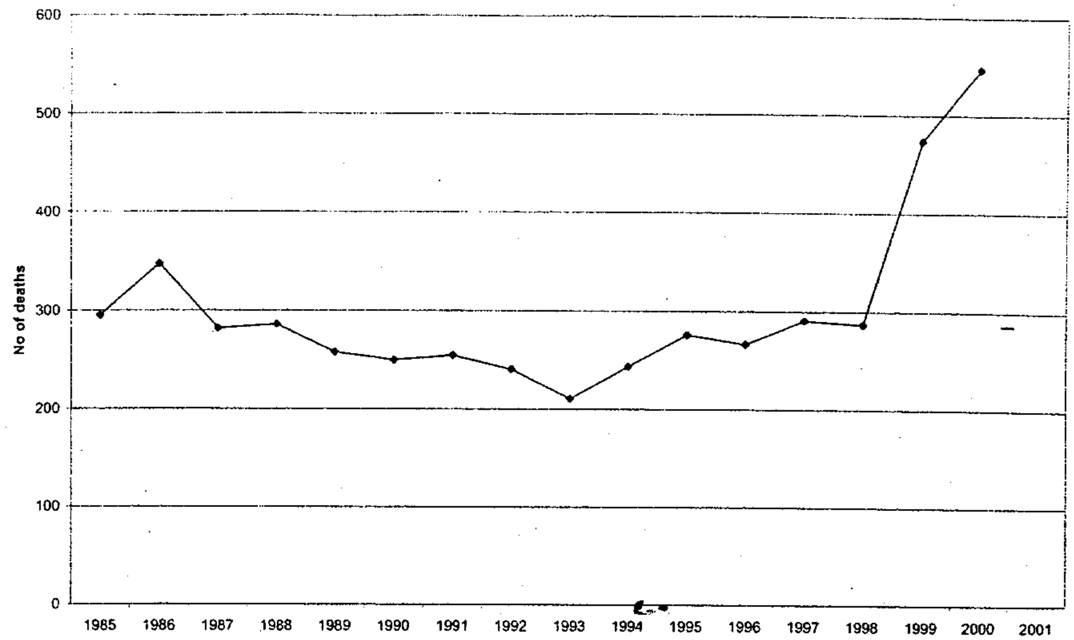


Figure 5: Estimated deaths, all terrain vehicles, United States. Data source: Ingle, 2002

Rates were not available for all ATV related deaths, but were available for four wheel ATVs. The rates per 10,000 for four wheel vehicles in use decreased from 1985 to 1993, after which an increase was observed. The fatality rate for 1998 was only marginally lower than that for 1988 (Figure 2).

The same pattern was seen for the number of ATV injuries treated in hospital emergency departments, as for deaths. The increase in serious injuries has been particularly pronounced since 1998 when the decrees expired. As with the deaths, most of the decrease in serious injuries appears to be associated with the withdrawal of the three wheel ATVs from the market.

Serious injury rates per 10,000 for four wheel vehicles decreased from 1985 until 1991. The rate was then stable until 1997 after which it increased. Unlike the fatality rate, the serious injury rate for 2001 remained below that for 1998 (Figure 4).

It would certainly appear from the deaths data that the main effect of the decree had been the withdrawal of three wheel ATVs from the market.

National surveys of ATV riders conducted in 1989 and 1997 revealed that the other aspects of the decree appeared to have had little effect. In 1997, just over a half of riders (53.7%) reported that they carry passengers frequently or sometimes, despite clear warnings discouraging this practice.

Between 1989 and 1997 there was a decrease in the proportion of ATV drivers who were under 16 years of age (23.2%, 14.3%). However, in 1997, 95.9% of drivers under 16 years of age rode adult sized ATVs.

An increased proportion of riders had undertaken an organized training program (2% in 1989, compared with 11% in 1997). Although a relatively large increase, there were still

89% of riders who had not undertaken formal training by 1997, the year before the expiry of the decree. Close to one third of respondents (32.6%) rode ATVs which were subject to the training requirements of the decree, but had not undertaken the free training provided. This is despite the offer of a $50 rebate on the vehicle purchase, a $100 US Savings Bond, or a merchandise voucher worth at least $50. The most common reason for not taking the training was that the respondent already knew how to ride. Other reasons included inconvenient time or location, or that a friend or relative provided the training.

The United States example confirms one of the general principles of injury prevention: that removal or modification of a hazard will usually be more effective than encouraging protective behaviours that need to be repeated on each occasion of exposure to the hazard (National Committee for Injury Prevention and Control, 1989).

2.1.2 New Zealand

The Departments of Labour and Agriculture, and the Accident Compensation Commission have released a guideline on the Safe use of ATVs on New Zealand Farms which sets out agreed industry best practice (Occupational Health and Safety Service, 2002). The guidelines cover recommendations for training, age related restrictions, helmets, ROPS, and management practices. Standards New Zealand has developed a standard for an approved ATV helmet that is designed for low speed off road use, which is recommended in the industry guidelines. Further, while ROPS are neither recommended or advised against in the guidelines, the Department of Labour has published guidelines for the design, construction and installation of ROPS for ATVs. The guidelines were issued in 1998 with an intention of a 12 month trial (Department of Labour, 1998). The guidelines were issued following the recognition of a moderate level of demand from farmers for ATV ROPS.

3. OVERVIEW OF ATV HANDLING AND DESIGN SOLUTIONS FOR THE PREVENTION OF ALL TERRAIN VEHICLE INJURY AND DEATH

3.1 Literature Review

The following section briefly reviews some of the main literature regarding the design, handling and proposed engineering solutions to reduce injury risk with ATVs. The key publications were identified by searching electronic literature databases of engineering literature, and the American Society of Agricultural Engineers publication collection. References were also obtained from experts working in the field.

1. Weir D.H & Zellner J.W., (1986), An introduction to the Operational Characteristics of All-terrain Vehicles, SAE paper 860225

The paper discusses rider control techniques and the handling qualities of all terrain vehicles (ATVs). It notes that although they are easy to ride, their configuration and goal of high mobility makes them somewhat different from other commonplace vehicles such as motorcycles, automobiles and off road buggies. In particular the rider sits on top of the vehicle and is free to position himself to modify the vehicle's inertial properties when appropriate.

The paper states that in considering rider body movements it is important to recognise that the movement of the rider's centre of gravity (cg) is what counts.

Overall the paper discuses at length the characteristics of ATV handling and compares these with other vehicles, but all of this is done on a general basis without any quantification of these properties or the magnitude of the effect of rider body movements.

The paper concludes with noting that the effectives of body movement on changing the handling response of ATVs is greatest with three wheelers but that '*it also applies to 4-wheelers but to a lesser extent*".

It goes onto say that:

> "*The handling characteristics of a four-wheeler in some situations maybe determined more by basic configuration of the vehicle, and there maybe somewhat less opportunity for rider movement to influence the dynamic response.*
>
> *Overall the requirement for stability and manoeuvrability depend on the particular vehicle designs, the rider's size, weight and skill; and of course, the terrain contour and the soil characteristics as they further define the riding task.* "

2. Dahle J., (1987) Occupant protection for all terrain vehicles, SAE paper 871920.

The paper notes the steadily increased growth of sales of ATVs and their user in a wide variety of environment ranging from dry desert to wet hilly wooded areas. The author Dahle notes that:

"The design of the ATV and its intended purpose make it an attractive vehicle for the general public. The general appearance of the vehicle suggests a relatively safe means of transportation, even in environments which have heretofore had limited accessibility.

However, it appears that the design and operational characteristics of these vehicles require more of a driver than he may initially assume as evidenced by the number of injuries and deaths that have occurred."

In regard to injury causation Dahl states that though the accident investigated by the CPSC have many causes associated with them, regardless of the specific factors that may initiate an accident, *"most accidents result in the driver being injured or killed because the vehicle rolls over onto the driver or the driver is thrown from the vehicle or both."*

In regard to the ATVs stability characteristics Dahl states that:

It is clear that the stability and manoeuvrability of the ATVs are not only dependent on vehicle design but on the driver's body movements or location of his centre of gravity. From an engineering and safety standpoint, if the driver is required to provide such critical input in order to control the vehicle and the consequence of error is injury or death, then he should be provided with a system that offers him a measure of protection. This is particularly true when considering the wide range of characteristics of the user population and driver's purposes for which these vehicles are purchased.

Dahle also notes that *"Of course it may be possible to redesign the vehicle to reduce the influence of the driver on the vehicles stability and manoeuvrability"*.

Figure 6 Mock up of ROPS and rider restraint using tethered waist belt (from Figure 1 of Dahle (1987))

Dahle proposes a ROPS (Figure 6) with a seat restraint system which allows the driver to move around on the vehicle consistent with 'active driving'. The ROPS is a 4-post design, with Dahl presenting suggested design criteria in terms of force, while also recommending that specific criteria be developed for ATVs. The seat restrain system comprises a belt worn by the driver with a non-slip buckle and three tethers attached to the vehicle.

Although Dahle presents an insightful understanding of ATVs from a safety perspective, his suggestion of a restraint system based on effectively a lap only belt, would not provide upper torso restraint and would not prove effective, and indeed could increase injury risk.

3. **Kvalseth, T. O., 1987, "All-Terrain Vehicles: A Human Factors and Safety Analysis", Proceedings of the Human Factors Society – 31st Annual Meeting, Department of Mechanical Engineering, University of Minnesota, Minneapolis, USA**

This paper examines the human factors and safety of 3-wheeler ATVs and as such is not considered further.

4. **Allen, R. W., Szostak, H. T., Rosenthal, T. J. and Klyde, D. H., August 1988, "Man Machine Systems Analysis of ATV Stability and Control Problems", Technical Report No. 1253-1, Systems Technology, INC., California, USA**

This 1998 report examines in detail the various vehicle characteristics and accident contributing factors in regard to both 3-wheel and 4-wheel ATVs in sprung and un-sprung models. The generic properties of the ATVs are discussed in relation to their short wheelbase and tyre suspension systems. Lateral and longitudinal dynamics and stability are examined quantitatively.

The aim of the study was to obtain an overall assessment of ATV stability and handling. Computer simulation models and field-testing was used to demonstrate both stability and handling problems.

The first section of the report considers the ATV's dynamics and its significance in regard to rider performance. The main points noted are:

- In regard to longitudinal dynamics, the short wheelbase of ATVs relative to the speeds at which they can travel makes them sensitive to pitch-over accidents in certain terrain and speeds.
- In regard to lateral and directional dynamics, the rider steering action provides the primary input (to change direction). Because of a solid rear axle (no differential), the rider must shift their body weight to overcome resistance to sharp turns. [The solid rear axle forces both rear wheels to rotate at the same speed, which should not be the case in a turn, as the outside wheel would normally want to turn faster.]
- After considering various complexities in the design of ATVs from a handling viewpoint the authors state "*These considerations point out the complex compromises that are involved in ATV design, which manufacturers have probably evolved empirically over the years*".
- Conditions of rollover depend on terrain slope, vehicle lateral acceleration, and the centre of gravity of the combined vehicle rider systems as illustrated in Figure 4 of their report (reproduced here as Figure 7).
- Rider weight shifts can significantly affect vehicle lateral/directional response, and in fact, are required under sharp turning and hard cornering conditions. A theoretical rider 'weight shift' strategy is developed and

presented in Figure 8. Allen et al state that for sharp turns a rider must position his C of G outside in order to "*unload them inside rear wheel so as to reduce the opposing yaw torque caused by the solid rear axle. For a give turn radius as speed increases, the increased lateral acceleration provides the load transfer which unloads the inside wheel, reducing the need for the rider to shift outwards. At higher lateral accelerations the rider must avoid rollover by weight shift to the inside of the corner.*"

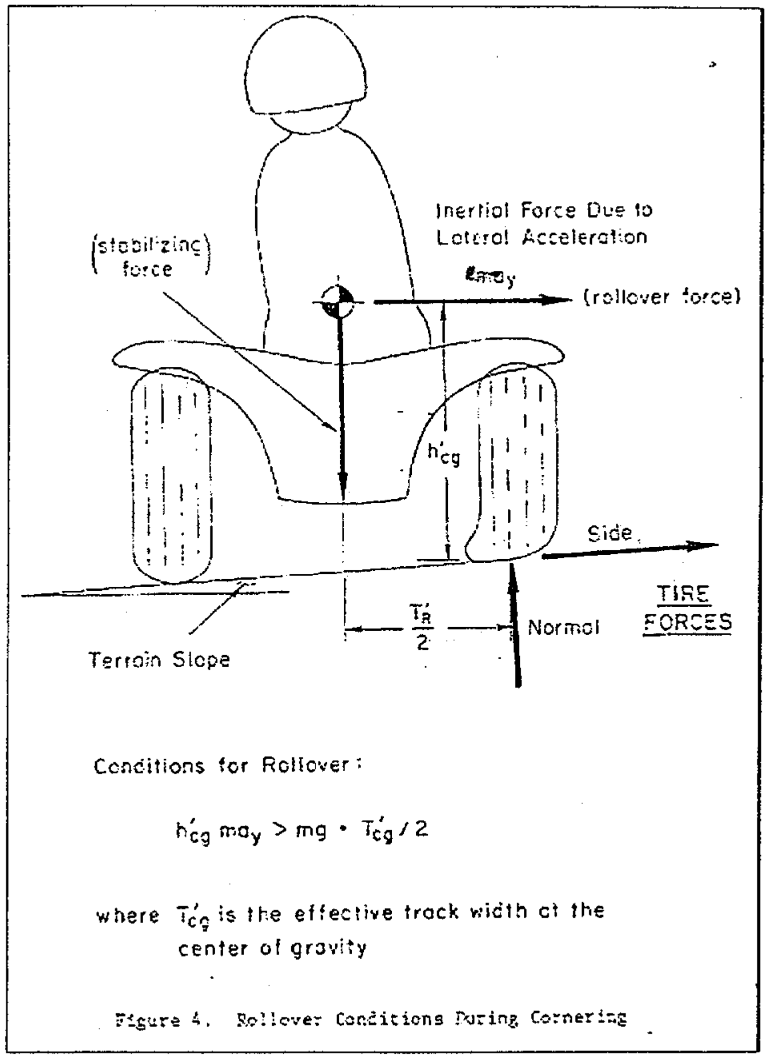


Figure 7 ATV rollover conditions during cornering (from Figure 4, Allen et al, 1988)

It is interesting to note that Allen et al describes a counterintuitive action on the part of the driver to move outwards when doing sharp turns, followed by a transition for higher speed turns into moving in the opposite direction to the inside of the ATV, relative to the turn.

A close examination of this theoretical rider weight shift strategy given in Figure 8 shows that for a maximum CG shift of around 9 inches (225mm), the lateral acceleration level to cause rollover (in their example) increases from 0.3g to 0.38g, an increase of about 25% in lateral stability. The authors do not state the assumptions made in such an analysis in terms of the rider's weight, height nor that of the ATVs weight etc.

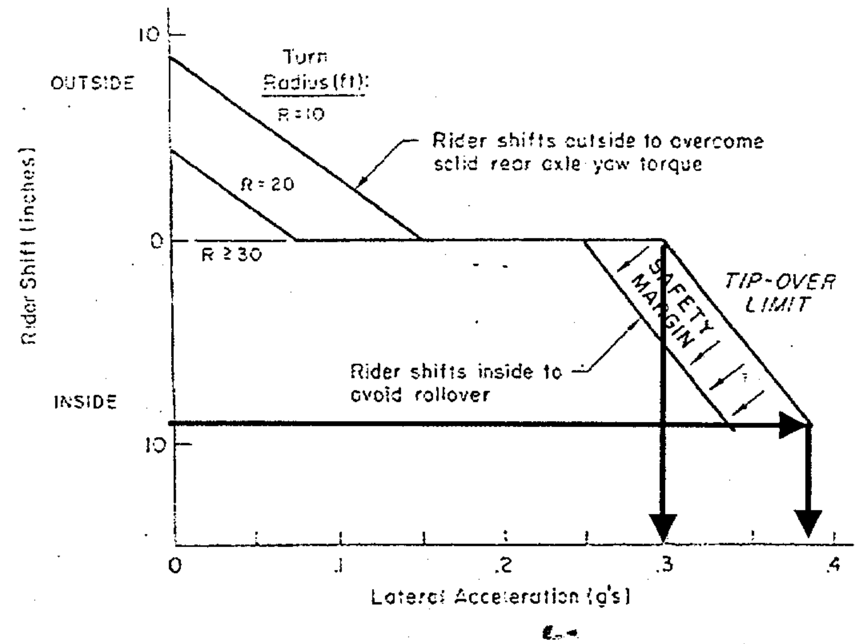


Figure 5. Rider Weight Shift Strategy Based on Lateral Dynamics Analysis

Figure 8 Rider weight shift strategy (from Figure 5 from Allen et al, 1988) The red arrows point to the lateral level of acceleration to cause rollover, which (in their example) varies from 0.3g to 0.38g when the rider's CG moves to the inside by 9 inches (225mm)

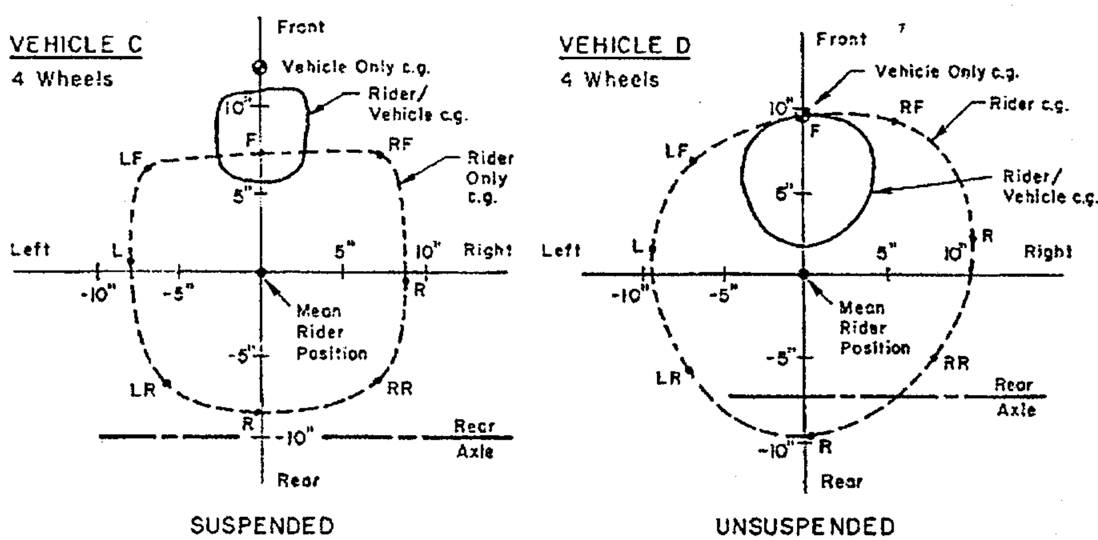


Figure 8. Influence of Rider Weight on Center of Gravity Location

Figure 9 influence of rider weight on Centre of Gravity location (from Figure 8 Allen et al, 1988)

However examination of Figure 9 for the example of a 4-wheel ATV with suspension shows that movement of the rider's CG laterally by around 9 inches (225mm) results in a shift of the CG of the combined ATV and rider by about 3 inches (75mm) laterally. Such a shift may result in an increase in the lateral acceleration limit of about 18%. Thus, from this particular analysis, the effect of 'active riding' would appear to provide at most, an increase of only 18% in lateral stability.

Allen et al in their analysis of "Accident Contributing Factors", state that due to their short wheel-base ATVs are vulnerable to small terrain generated disturbances such as a depression, rock, or mound which can result in longitudinal instability and an end over end pitch. They continue to state that "*Unfortunately, such potentially disastrous disturbance induced control instabilities are not rare.*"

They note that the characteristics of the rider population at risk in terms of weight, size and age is important because of the dynamic coupling between the ATV and its driver. They quote accident data, which shows that (around 1988 or earlier) the majority of accidents involved riders between 100 to 200 lbs (45kg-91kg). They note that the statistics also show that young riders are particularly at risk. It is notable of course that the lighter and or shorter rider, the less effect they will have on being able to influence the stability of the ATV through so called 'active riding' techniques.

They quote data from other sources, which show that 57% of accidents occurred on level terrain, while 47% occurred on slope or grades. Whilst qualifying that speed estimates are difficult, it would appear that about half the accidents occurred at constant speeds, distributed as:

<8km/h	10-40km/h	>40km/h
17%	55%	18%

In the authors' concluding remarks they state that: *"Because of their short wheel base entire suspension system characteristics, ATVs tend to be vulnerable to modest terrain disturbances. ATV longitudinal dynamics are characterised by 3 basic modes, associated with heave or vertical motion, pitch motion and speed."* Given the right terrain input ATVs can suffer severe vehicle motion and lead to a downward pitching motion, which can result in pitch-over accidents. They also go on to say that the ATVs lateral/direction response characteristics tend to define the vehicle's rollover stability.

The authors conclude that *"The counter measures to the above problems would seem to be to increase rider skill and prudence in undertaking risks. Certainly speed must be controlled diligently relatively to terrain conditions, and lateral/directional manoeuvres should be performed cautiously ... ".*

It is rather surprising and somewhat baffling that in such a technically oriented analysis of ATV handling stability characteristics which has identified significant vulnerability of the ATV to terrain 'disturbances' the authors consider that the solution lies not with engineering design changes but rather with driver training.

5. Cabaniss, J. C. and Gaddy, J. D., 1989, "All Terrain Vehicle (ATV) Litigation", The New Mexico Trial Lawyer

Following the introduction in the USA in 1971 of the Honda 90 ATC (ALL TERRAIN CYCLE), this 3-wheeler with low inflation balloon tyres and solid rear axle was noted, according to this article, by regular reports received by Honda through its 'early warning system' of ATC accidents. In June 1976, American Honda was apparently informed by one of its Sales Representatives, of the need to provide users with special training to operate ATVs.

In the late 1970s the recreational market for ATVs began to take off with other Japanese manufacturers moving quickly to enter the market. Yamaha for example bought in the Yamaha 125 in the USA in 1980 and was followed by the ATV market entrance by Kawasaki and Suzuki. According to this article, information regarding ATV hazards continued to accumulate. The authors state that Yamaha test riders experienced numerous injuries whilst testing their ATV products.

In the USA the CPSC (Consumer Products Safety Commission) notified the ATV manufacturers of *"a dramatic rise in ATV related injuries"*. A subcommittee of the Committee on Government Operations, House of Representatives held a hearing on the CPSCs response to ATV injuries on 21 May 1985 and issued a report on 16 July 1985. The report is quoted as stating amongst other things *"use of ATVs presents an unreasonable and imminent risk of death and serious injury. It recommended that the manufacturers immediately halt ATV sale and production; the manufacturers warn all ATV owners of the hazards; and the manufacturers should make training courses available to all ATV owners."*

In September 1986 a report by the CPSC Task Force on ATV Safety noted that by the end of 1986 it was estimated that there were approximately 2.3 to 2.4 million ATVs in use and that there had been 559 ATV fatalities and 239,200 injuries. The report found that 74% of 3-wheeled ATV accidents involved tripping or overturning. In 1987 the manufacturers agreed to requests by the United States Department of Justice to halt marketing and sales of 3-wheeled ATVs and to develop specified boarding labels for 4-wheeled ATVs and to make hands-on training available to all ATV purchasers.

In litigation, the authors of this paper note that various aspects of ATV design have glaring deficiencies; the geometric configuration of the ATV renders it prone to roll-over during a turn and prone to flip-over whilst ascending a hill; the lack of a differential makes turning the ATV difficult and requires an operator to perform counter intuitive manoeuvres in order to effect the turn. The geometric configuration of ATVs coupled with their weight distribution and lack of differential render the vehicle prone to plow-forward rather than turn under certain conditions. At the time of this article, the authors also state that a major design deficiency for many ATV models is a lack of mechanical suspension. They note further that the manufacturers can also be criticised for failing to evaluate and incorporate a rollover protection system (ROPS) into ATV design. The authors also claim that ATV sales were dramatically increased through an aggressive advertising campaign undertaken by the manufacturers beginning in the early 1980s by showing ATVs as safe, fun vehicles for the entire family.

6. Delisle, A., Laberge-Nadeau, C. and Brown, B., February 1989, "Les Trimotos et les Quadrimotos: des Véhicules Instables et Dangereux", Canadian Journal of Public Health

This paper is in French and the abstract of the paper states the following:

> *"This paper presents the results of a questionnaire completed by 526 victims of accidents involving 3 and 4-wheeled all-terrain vehicles. All victims were treated in the emergency departments of 10 regional hospitals in Quebec. In 70% of the cases*

the vehicles overturned. Two thirds of the victims were injured in accidents without collision, typically involving overturns on level or hills. We suggested accident reconstruction research as a means of identifying engineering solutions as one element in the injury control approach."

7. **Johnson FH, Wright RR, Carpenter TG & Nelson R; A Safer ATV SAE paper 911945, Passenger Car Meeting and Exposition, Nashville Tennessee, September 16-19, 1991**

In recognition of the dramatic increase in serious injuries and deaths associated with ATVs during the 1980s, the authors decided that a "*safer, more stable ATV should be and could be built.*"

Both 3-wheel and 4-wheel ATVs were modified as prototypes. The 4-wheel ATV was denoted as RCX 250 (roll cage experimental vehicle with 250cc engine, see Figure 10), and Johnson et al state that this prototype demonstrated feasibility with clear improvements in safety.

The paper lists the basic ATV hazards as:

1. ATV rollover causing injury or death:
    a. Forward pitch
    b. Lateral or pitch roll
    c. Rearward pitch
2. Objects strike the operator such as overhangs or branches.
3. Operator's or passenger's foot or leg is caught in rear tyre, chain, etc.
4. ATV strikes bystander due to loss of control.
5. ATV strikes subject due to loss of control.

In regard to the ATV's stability characteristics, the paper notes that the basic geometric characteristics of an ATV with a rider, including centre of gravity height, results in stability to be low, and makes overturn of the vehicle very likely and quite probable. The paper goes on to state that:

> *"While the intention of operation is that the operator shifts his/her weight to positively affect the handling characteristics, it is also likely that the operator cannot shift enough weight quickly enough or in a favourable manner to positively affect the handling characteristics."*

Modifications included widening of the track width, lengthening the wheelbase, and the seat reconfigured and lowered, and sheet metal installed under the machine for better foot and leg protection. The results of these modifications to the 4-wheel ATVs were reported to have significantly increased lateral and longitudinally stability characteristics. The personal protection system of the RCX 250 "*worked extremely well and without failure. In all overturns (dozens of lateral overturns to date), the operator was fully protected and received no injuries.*"

The study concluded that modifications to the 4–wheel ATV demonstrated feasibility with clear improvements in stability and safety, with the results justifying continued study to improve the stability, manoeuvrability, ease of operation, and safety of this class of vehicle, including study into the use of a differential.

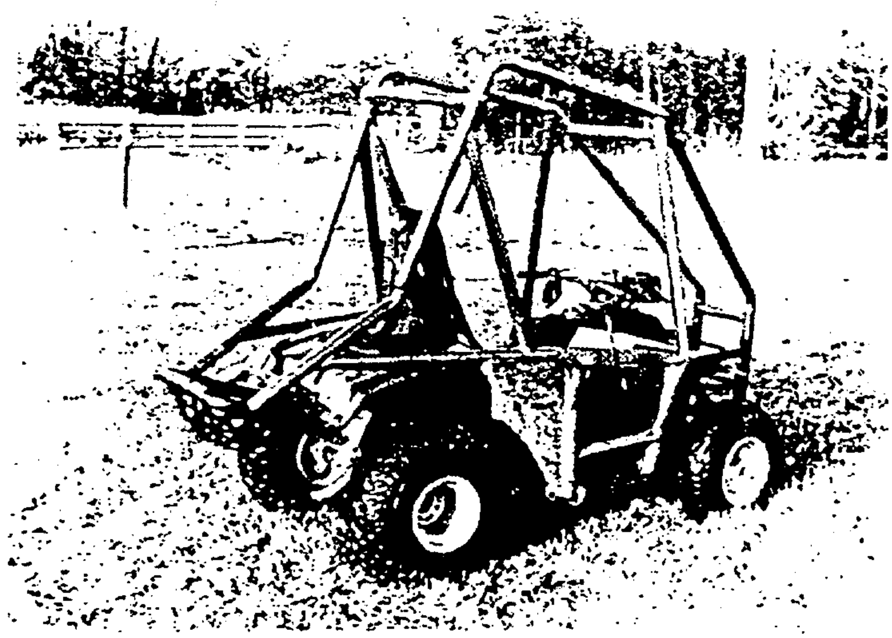


Figure 5. RCX 250 4-Wheel ATV - Rear Quarter View

Figure 6. RCX 250 4-Wheel ATV - Side View

Figure 10: View of the modified ATV - RCX 250 with ROPS (from Johnson et al, 1991)

It should be noted that a key feature of the protective structure in Figure 10 are the bars running down either side of the rider's shoulder. These bars provide lateral support for the rider during rollover.

8. **Piziali, R. L., Ayres T.J, Paver J.G, Fowler, G. and McCarthy, R. L., "Investigation Of The Net Safety Impact Of An Occupant Protection System From All Terrain Vehicle", SAE Technical Paper 930208, International Congress & Exposition, Detroit, Michigan, USA, March 1-5, 1993**

This paper critically reviews the Rollover Protective System proposed by Dahle (1987). Firstly, crash tests were conducted on ATVs fitted with the Dahle style ROPS (called D-ROPS, see Figure 6) to determine the resultant level of protection and injuries arising in various accident scenarios. Secondly, the ATV associated fatal accidents in 1986, which were considered by Dahle were reviewed to assess the likely safety benefits of the D-ROPS. Thirdly, accident reports from the CPSC's 1985 Injury Survey were examined to explore net safety costs of the D-ROPS.

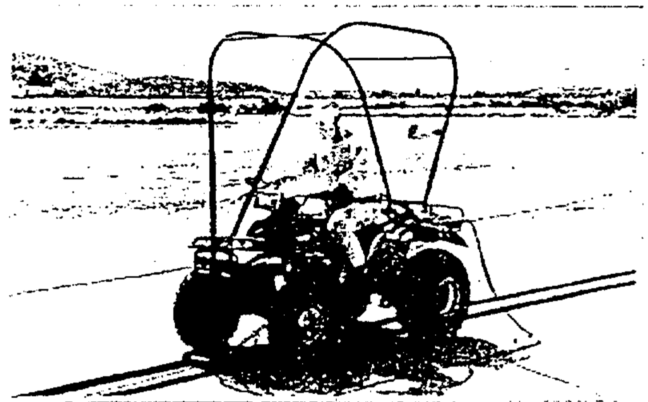


Figure 1. Instrumented Hybrid III Dummy on Test Vehicle

Figure 11 View of test ATV with 'Dahle' style ROPS with Hybrid 111 ATD (from Piziali et al, 1993)

The crash test comprised:

- Lateral rollovers at 18-24 km/h onto soil and rocks.
- 90 degree and 360 degree rearward pitchovers at 13-14 km/h.
- Low barrier, pole, and oblique frontal impact tests at 46-47kph.

Piziali et al stated that based on their tests of specific accident scenarios, they found no evidence that the D-ROPS would offer protection to a passive ATV operator.

Similarly, the authors conclude, "*The review of 'several hundred' ATV-associated injury and fatality reports suggest that it is unlikely that fatalities would be prevented or overall injury severity reduced if the vehicles involved had been equipped with the prototype system studies. Many of the accidents would have produced more severe injuries with D-ROPS equipped ATVs due to the introduction of alternate accident and injury modes.*"

Piziali et al, go on to state that:

> *"Our findings are also consistent with the result of research on motorcycle injuries, which suggest that the crashworthiness strategy of placing a protection system (e.g helmet) on the operator and allowing separation from the vehicle is a more viable form of protection than adding more structure and restraints to lightweight, ride active vehicles."*

Two major deficiencies exist with Piziali et al's research and conclusions as set out in this paper. The first relates to generalising conclusions regarding the effectiveness of a Rollover Protective System *in principle* to that determined by testing of the Dahle's proposed design. The most glaring anomaly in the Dahle system is that it does not comply with the fundamental principle of an effective ROPS design. An effective Rollover Protective System requires apart from the ROPS structure, an occupant restraint system which comprises a seat with a backrest and a three point or 4-point seatbelt system. The Dahle design does not offer an effective restraint to the occupant (no seatback and the restraint is only a tethered waist belt) and thus it is not at all surprising that the crash tests show the Dahle system to be ineffective or even hazardous.

The second point to note is the suggestion that motorcycle safety strategies are applicable to ATVs. This does not appear to be a considered suggestion. How does personal protection equipment as suggested by Piziali et al prevent, for example, one of the common mechanisms for fatal injuries - crushing arising from an ATV rolling onto the rider? In addition, the terrain and functional use of ATVs is significantly different to most motorcycle use, as is the accident mechanism. Whereas rollover of ATVs is the most common mechanism associated with serious or fatal injuries, motorcycles do not typically rollover.

The third point to note is the suggestion of a crashworthiness strategy for motorcycles. At best what can be stated is a risk reduction strategy for a motorcyclist as they are still inherently vulnerable to serious injuries in collisions or falls from the motorcycle, depending on the circumstances or environment.

9. Piziali, R. L., Fowler, G. F., Merala, R., Grewal, D. S. and McCarthy, R. L., "Evaluation of a Proposed ATV Design Modification", SAE Technical Paper 940276, International Congress & Exposition, Detroit, Michigan, USA, February 28 - March 3, 1994

This paper notes that *"successful development of a product requires the consideration and balancing of many design parameters. Proposals to modify designs that have been fully implemented and put into production are often made by people who were not involved in the original design process... a design change may improve performance in one area but compromise performance in another, or even introduce new problem areas."*

The authors in this paper carried out full scale operating model tests of proposed 4-wheel ATVs with the addition of Rollover Protection Systems (ROPS). They found that the proposed vehicle modifications in fact produced a new vehicle type with significantly reduced utility and performance compared to unmodified ATVs, without the likelihood of reducing the accident and injury risk. They claim that the modified design does not appear to be a viable approach to balancing utility and safety and that this outcome is consistent with other analyses and general conclusions reached by the CPSC.

The authors describe ATVs as vehicles which are generally less than 50 inches in overall width (127 cm), weigh less than 600 lbs (272 kg[1]), travel on low pressure tyres (2.2-5 psi) and the single operator sits on a straddle type seat and uses handlebars for steering. The authors state that these vehicles *"are light enough that the weight of the single operator*

[1] This weight estimate appears to be not applicable to today's ATVs as the weight of the most common ATVs is around 270 kg, but quite a few models are over this weight.

can influence the vehicle's handling properties. The last 3 qualities (straddle seat, handlebars, and rider activity) allow for movement of the operator, relative to the vehicle, which significantly enhances the off-road mobility and utility of the vehicle."

In considering the above description of ATVs by the authors of the paper, their reference to movement of the operator (active riding) as being able to significantly enhance the handling of the vehicle is stated without providing any basis for such an assertion. Indeed, it would be most pertinent for such a statement to be supported by quantitative data showing the difference in handling characteristics based on changes in operator movement.

An example of a commercially available, single operator, off-road vehicle with a ROPS is the Honda Pilot which includes an adjustable seat, a four point restraint and a rectangular steering wheel. The paper notes that the operator is essentially fixed in the vehicle and the operator's body motion does not affect handling and stability, the authors state that the vehicle has reduced mobility and utility relative to the ATV and is primarily used for recreation riding in open terrains such as sand dunes and deserts. The authors do not provide any explanation for how and why this Honda vehicle has reduced mobility and utility.

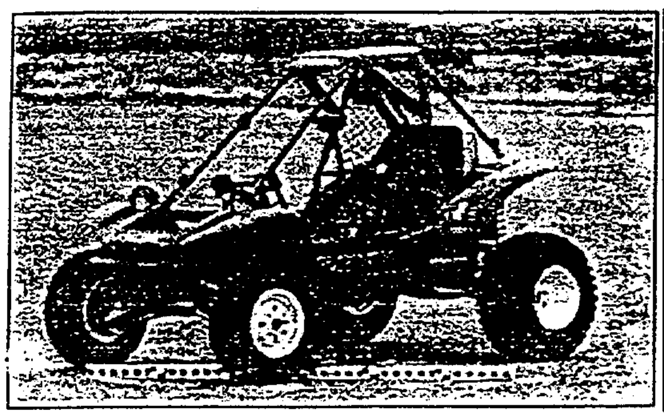


Figure 12: Honda Pilot (from Figure 3, Piziali et al, 1994)

The paper discusses a design of a modified Honda TRX 250 ATV by Johnson which incorporates a substantial roll frame, increased wheel base and track width, lower seating position, seatback added, slack in restraint system for limited rider active inputs, foot pegs replaced by floorboards and foot guards. The mass of the Johnson vehicle is 347 kg compared to the original 1985 Honda TRX 250 of 224 kg.

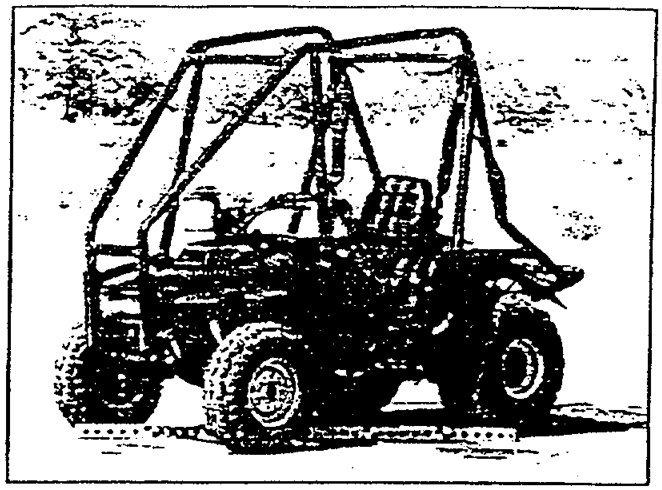


Figure 13: view of the Johnson vehicle (from Figure 4, Piziali et al, 1994)

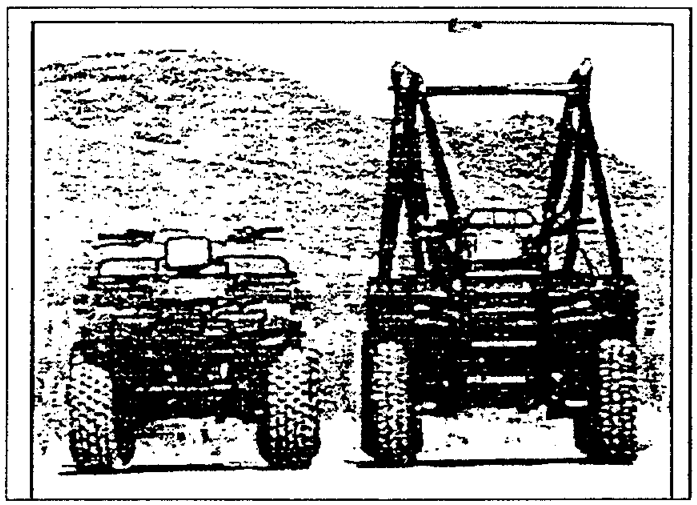


Figure 14: Front view of the Johnson vehicle and ATV from which it was built (Honda TRX250) (from Figure 5, Piziali et al, 1994)

The authors Piziali et al then proceed to analyse the Johnson vehicle and identify a series of what they regard as deficiencies with this model. They describe new injury modes associated with this vehicle as the 'mousetrap', the 'fly swatter' and 'submarining'. These injury modes are related to partial or full ejection of the occupant resulting from, in the first case, slack in the restraints, and in the latter case, from non-wearing of the restraints.

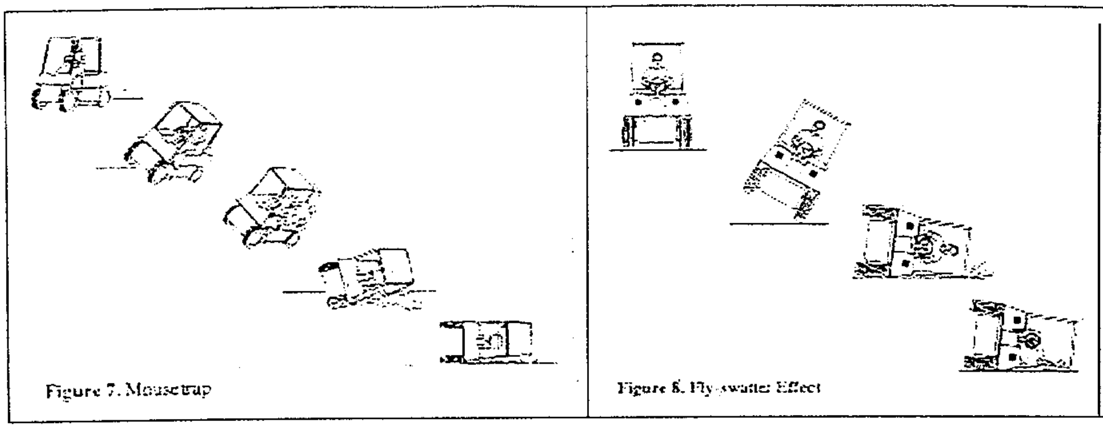


Figure 15: injury modes described by Piziali as the 'mousetrap' and 'fly-swatter effect'. Note in the first case, the occupant is unrestrained and ejected, followed by crush; in the second case, the occupant has poor or no lateral restraint and impacts the ground.

They quote studies by Woodward (1980), IASS (1985) and Bowman (1988) that restraint usage in ROPS equipped vehicles can be expected to be low. As much has changed since the 1980s in regard to seatbelt usage in general, it is unreasonable for the authors to quote such early works in regard to supporting the view that seatbelt usage in ROPS equipped vehicles would continue to be low. Indeed, it is rather fallacious to use ROPS as the characteristic which defines whether seatbelts will be used or not. ROPS equipped vehicles range from tractors to earth-moving equipment to, forklifts and the like, none of which are really similar to ATVs in their usage or design.

In summary, the authors Piziali, et al have identified a number of problems with the Johnson design based on the Honda TRX 250 ATV. Such criticisms of this design are not surprising as it is a major change to the original vehicle with a weight increase of some 123 kg. In their criticisms, the authors have made a number of unsupported generalisations the most important of which has not been explicitly stated by them. This relates to the presumption that the ATV product as currently developed by the manufacturers is 'just right' and that the manufacturers and designers have properly taken into account all the competing considerations including safety. Such a gross assumption is certainly not borne out when considering safety in regard to many products (e.g., consider the history of development of automobile safety). What is quite evident from these historic examples is the lack of balancing and including safety as a prime design criteria in products. It often requires consumer or other pressures (regulatory, litigation) to help ensure that a true balance between product utility and safety eventuates.

Although the Piziali, et al analysis of the Johnson vehicle may be justified in many areas, it certainly cannot be generalised into an overall critique of equipping ATVs with ROPS. It is no doubt, however, a justifiable critique of *poorly designed ROPs and restraint systems* for ATVs.

10. Allinson D, Rollover protection for Agricultural All Terrain Vehicles, Health and Safety Laboratory, HSE, UK, Report FE/96/01. 28th February 1996

The objectives of the study were to assess the feasibility in terms of operational, ergonomic, dynamic and mechanical consideration, of fitting roll over protection structures (ROPS) to the range of ATVs that were available in the UK.

The study's review of the accident statistics for the period 1986 to 1995 identified 90 incidents involving 4 and 6 wheel ATVs. 64% of the incidents involved overturn or roll, of which 79% were overturned sideways. According to the report, the largest proportion of incidents was caused by rider error: "The most common injuries were to the head, chest or legs as the rider is crushed or struck by the vehicle".

For the purpose of the study, a ROPS was defined as a structure attached to an ATV which will, in the event of a vehicle overturn accident, minimise the possibility of injury by:

a. providing a safe volume for containment of the rider
b. preventing complete overturn and continuous roll

The report examined different ROPS designs and the advantages and disadvantages of each. It considers the ergonomics of ROPS and defines a '*clearance zone*' as the volume into which a rider would be pressed but not crushed, under an ATV on a flat surface (Figure 16). It bases the requirements on a 95% percentile adult male.

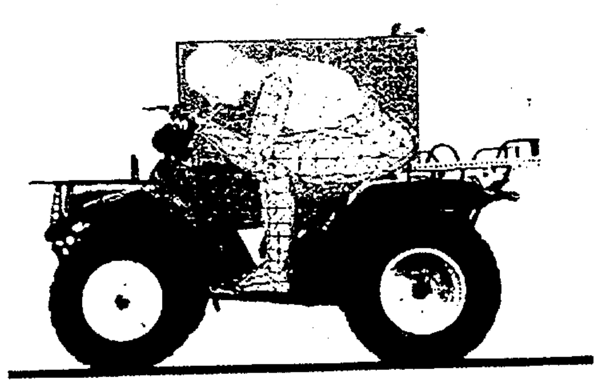


Figure 16: Minimum clearance zone (from Figure 3, Allinson, 1996)

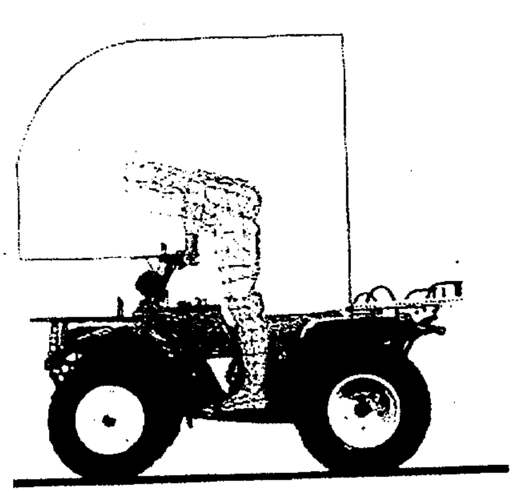


Figure 17: Riding Posture Envelope (from Figure 4, Allinson, 1996)

The *riding posture envelope* (Figure 17) represents the limits of the rider's body restrained by maintaining feet on the foot pegs and hands on the handle bars. Allinson et al notes that any ROPS should not intrude into this space as rider body movement is an important factor in ATV handling and stability, and that ROPS in this envelope may be more likely to strike the riders body during overturn.

In assessing the performance of the ROPS certain criteria based on the ECE Directives are considered:

- The non-continuous rolling test to ensure that ROPS prevents continuous rollover on a slope with a gradient of 1: 1.5 (this represents a slope of 34 degrees).
- Structural strength. Reference is made to British Standards for tractors which specify lateral, longitudinal and vertical force (and energy criteria).

The studies carried out an assessment of ATVs in the UK in regard to the feasibility of fitting ROPS.

From the assessment of '*Ergonomics*' it was found that the height of rear mounted ROPS required to provide an adequate clearance zone would have required the rollbar to extend above head height (Figure 18). The study notes that "*This would restrict the vehicles operational usefulness in areas of low head room (e.g in forestry) and considerably increase the force on the attachment points and frame during overturn.*" On this basis, the study concludes that "*Therefore it is not deemed practical to fit ROPS providing a 'safe' area for rider containment on current ATV designs. It may be practical to fit a single pole or roll bar at the rear of the ATV for preventing complete overturn or continuos roll.*"

In regard to preventing *continuous roll*, the study estimates that a single pole or roll bar behind the rider of a height of 0.6m to 1.0m should prevent continuous roll.

In regard to *structural strength* of the ROPS, the study found that ATV frames are generally narrow and lightweight with no provision for additional structural attachment, although some possible attachment points were identified. Overall the study found difficulty in establishing a practical pole or frame structure that would withstand the required forces. It advises that further work is required to analyse such structures and devise a practical solution.

The study concludes that the use of ROPS to provide a 'safe' volume for rider containment in the event of an overturn is not practical due to the design of the ATVs and the ergonomics of the various rider positions.

The report suggests that ROPS structures must be designed to suit the particular structure of the particular model ATVs and selecting a particular model and to test the ROPS structure to the British Standard for tractors.

Two major concerns are raised in regard to this study. The first is that it violates its own principles for the design of an effective Rollover Protective System, by the ready dismissal of providing an effective rider clearance zone for the ROPS due to possible problems with clearance in some applications (e.g forestry). The obvious and preferable approach is to define a ROPS which provides the required clearance which can be accommodated in most applications, and then to separately consider the exceptional cases. The other reason given for not providing a ROPS of the necessary height is that this would result in too high a load on the connections and structure. This later reasoning is puzzling, as it prejudges any possible solutions as being impossible, a clearly untenable approach to engineering design to achieve safe systems for rollover protection.

The second deficiency with the study is that it fails to mention or recognise the role of occupant restraint systems as being integral to an effective Rollover Protective System.

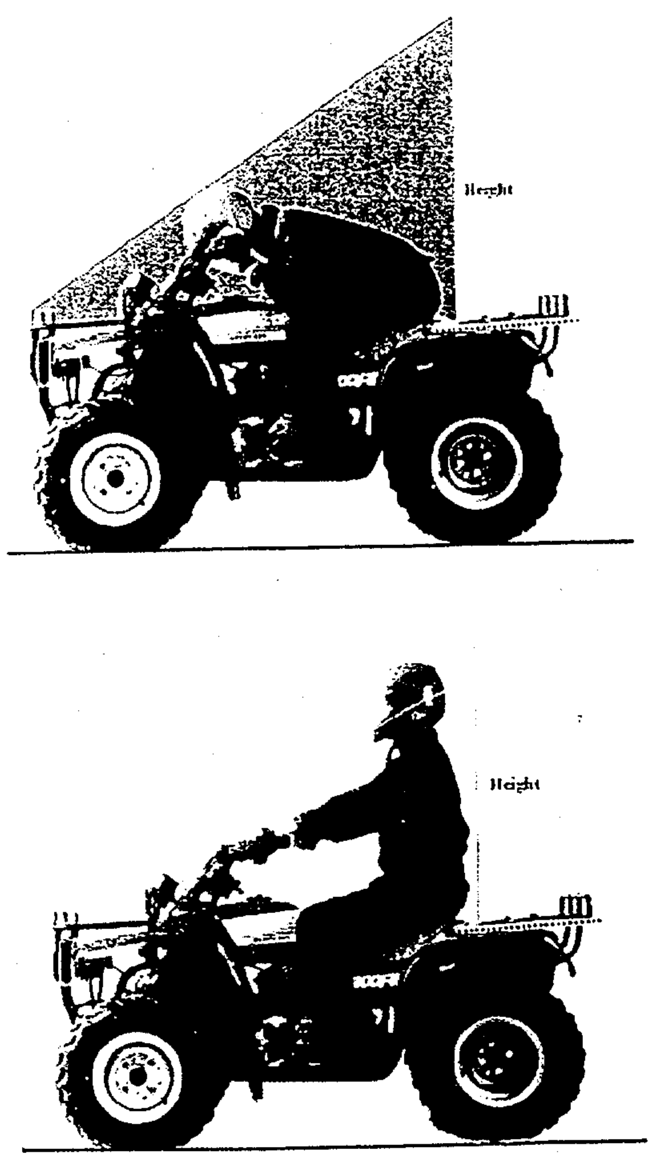


Figure 18: Clearance zone for ATV with Rear mounted ROPS (from Allinson, 1996, Figure 6)

11. , "Go Anywhere Bikes Show their Versatility", Farming Ahead No. 61, January 1997

The article notes that these 4-wheel bikes are an increasingly popular farm tool due to their versatility and ability to operate in country unsuitable for other vehicles. These vehicles, which were originally designed as recreation vehicles, have several advantages over 2-wheel motorcycles and other 4-wheel vehicles. The article states that stability at low speeds and ease of use make them suitable for a wide range of people. Large balloon tyres operating at inflation pressures of about 24-34 kpa allow these vehicles to be driven over muddy or boggy ground without sinking into the soil and without loosing traction. These ATVs also have front and rear racks, which can be used to carry various items.

The article notes that safety remains an important issue for 4-wheel bikes, which can be dangerous in the hands of inexperienced riders or those that use them beyond their limitations. The authors note that some ATVs loaded with 120 litre spray packs can result in exceeding the maximum weight limits and towing limits are also being exceeded which can severely affect braking and stability. The Kondinin Group carried out a survey of its farm members in 1996 with more than 500 replies, which suggested that the owners were generally happy with the performance of their 4-wheel motorbikes.

In Australia, Yamaha and Honda are the market leaders followed by Suzuki and Kawasaki with the US made Polaris also featuring in the market.

Criticisms of the bikes included punctures with tyres and complaints about the thumb throttle controls with many owners apparently converting to a twist type throttle. Many farmers apparently wanted the throttle shifted from the right to left hand side of the handlebars and to have a foot throttle control, with the main call for these changes being applications requiring a constant set speed such as during spraying by farmers. The article notes that manufacturers use thumb operated throttles as twist grips, which were implicated in accidents in the United States. Rider safety was considered important with requests for wider mudguards and more foot protection as well as differentials for easier turning.

In regard to safety the article notes that the size of the operator has a major influence on safe bike operation due to the *"rider active"* nature of these machines. Because these machines do not lean when turning as much as 2-wheel bikes, the whole body movement is more critical to influence the centre of gravity. It states that *"4-wheel bikes are not designed to fit small people...as 4-wheel bikes are non-adjustable good body fit is an important criteria in terms of who should ride them."*.

12. "Rollover Protection Structures for All Terrain Vehicles, A Preliminary Report", Australian Agricultural Health Unit, 14 January 1997

The paper notes that the 'agbike' has adopted the role of both horse and farm utility (ute) on many Australian farms and is generally thought of as the workhorse and has become an integral part of Australian farms. As ATVs are being associated with increasing causes of farm deaths particularly where ATVs rollover, consideration is being given to development of ROPS which can be fitted to all models of ATVs.

The paper considers the different possible ROPS configurations and their operational advantages and disadvantages. These ROPS structures range from a full cab, 4 post ROPS roll cage, roll bar 2 posts, pole (single post) through to a 2-post centre mounted. A survey in New Zealand indicated that out of 273 ATV users, 17% had fitted ROPS to their ATVs, with the major reason for fitting ROPS being that the respondent had been previously involved in an accident.

In Australia, the report notes that there is very little information concerning ROPS and that although there have been a number of engineering companies designing ROPS due to litigation concerns, these ROPS have not been sold. They note that it appears that the majority of ROPS fitted to ATVs in Australia have been designed by farmers for a specific use on their own farm.

The report notes that although initially the attachment of ROPS to ATVs appeared to be a simple solution to protect riders in rollover accidents, after viewing a computer simulation by Dynamic Research Inc. (Zellner, J. W (1996) ATV Rollover Computer Simulation, Torrance, California, USA) it is evident that a number of questions need to be addressed before ROPS can be considered a safety feature on ATVs. Questions that need to be addressed in regard to the fitting of ROPS are:

- What shape should a ROPS be and where should it be fitted?
- Will the ROPS alter the centre of gravity of the ATV?
- Will ROPS affect the attachment of spray tanks, etc or the loading specification of the ATV?
- What safety factors would be used in the design? The weight of an ATV design for agricultural use can range between 160 and 390 kg.
- What materials should be used for construction?
- Where and how should the ROPS be attached to the frame of the ATV?
- Is it likely that ROPS will increase the incidence and severity of injuries, particularly head, neck, chest and leg injuries?

The following figures (Figure 19) are from the report and show different types of ROPS structures for ATVs and the 'protective zone' for a restrained occupant.

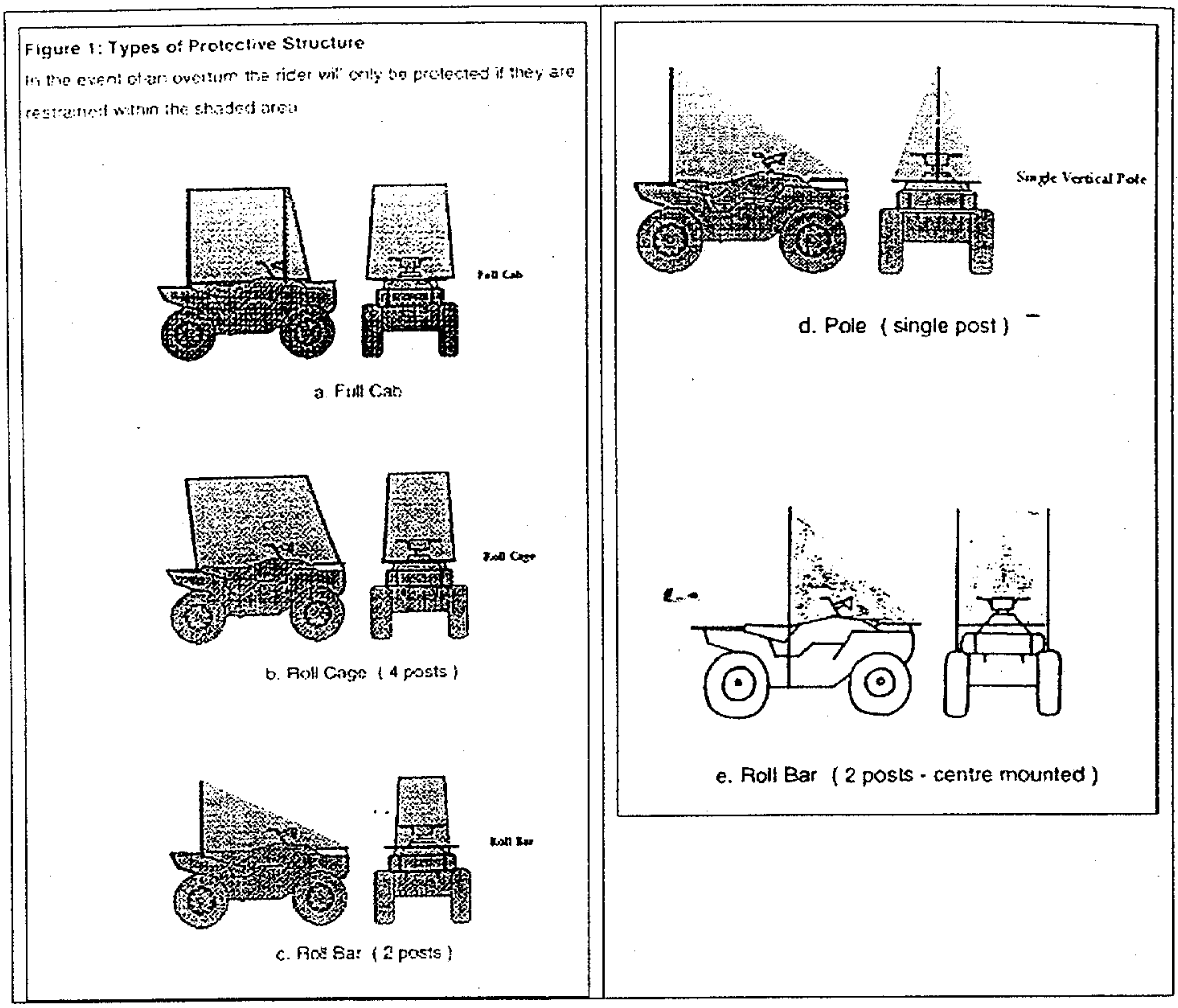


Figure 19: Types of Rollover structures (from 14 January 1997, "Rollover Protection Structures for All Terrain Vehicles, A Preliminary Report", Australian Agricultural Health Unit.)

13. Van Auken, R. M. and Zellner, J. W., "Preliminary Analysis of the Effects of ATV ROPS on Rider Injury Potential, Volume 1: Technical Report, DRI-TR-96-4B", October 1996, Second Revision Issued February 1997, Dynamic Research, Inc., California, USA

The Executive summary of this report states:

> *"This report describes results of preliminary analyses of the effects on rider injury potential of fitting two types of rollover prevention structures (ROPS) to an all terrain vehicle. The analyses involved the computer simulation of 43 ATV rollover accident configurations (based on 105 UK HSE accident summaries); standardised calibrated simulation procedures defined by ISO 13232-7 (1996) for models of ATV, ROPS., terrain and helmet and unhelmeted riders; risk/benefit analyses and injury indices defined in ISO 13232-5 for motorcycle riders. Results indicated that fitment of the example ROPS devices would reduce the potential for chest compression and abdominal penetration injuries; but would also significantly increase potential for head (closed skull brain) injuries, and cervical, thoracic and*

lumbar spinal injuries due to contact with the ROPS, and other effects. Therefore such devices are not recommended for fitment to ATVs at this time."

The dynamic computer simulation was done using the Articulated Total Body (ATB) program[2]. Computer modelling used for the ATV rider was an ISO Motorcycle Anthropometric Test device (MATD) representing a 50th percentile adult male. The MATD is based on the Hybrid III 50th percentile male.

The vehicle modelled was a Honda Foreman 400 4x4, 1995 (Model No. TRX400FWS) with the following dimensions:

- Wheelbase 1227mm;
- Front track 869mm;
- Rear track 848mm;
- CG height =420mm;
- Total vehicle mass = 258.6kg.

Two different protective structures were modelled. The first was a HSE style ROPS comprising a rectangular shaped bar located behind the rider as shown in 'Figure 2' of Figure 20. The second style ROPS was a NZ style Quad ROPS consisting of a T shaped bar shown in 'Figure 3' of Figure 20.

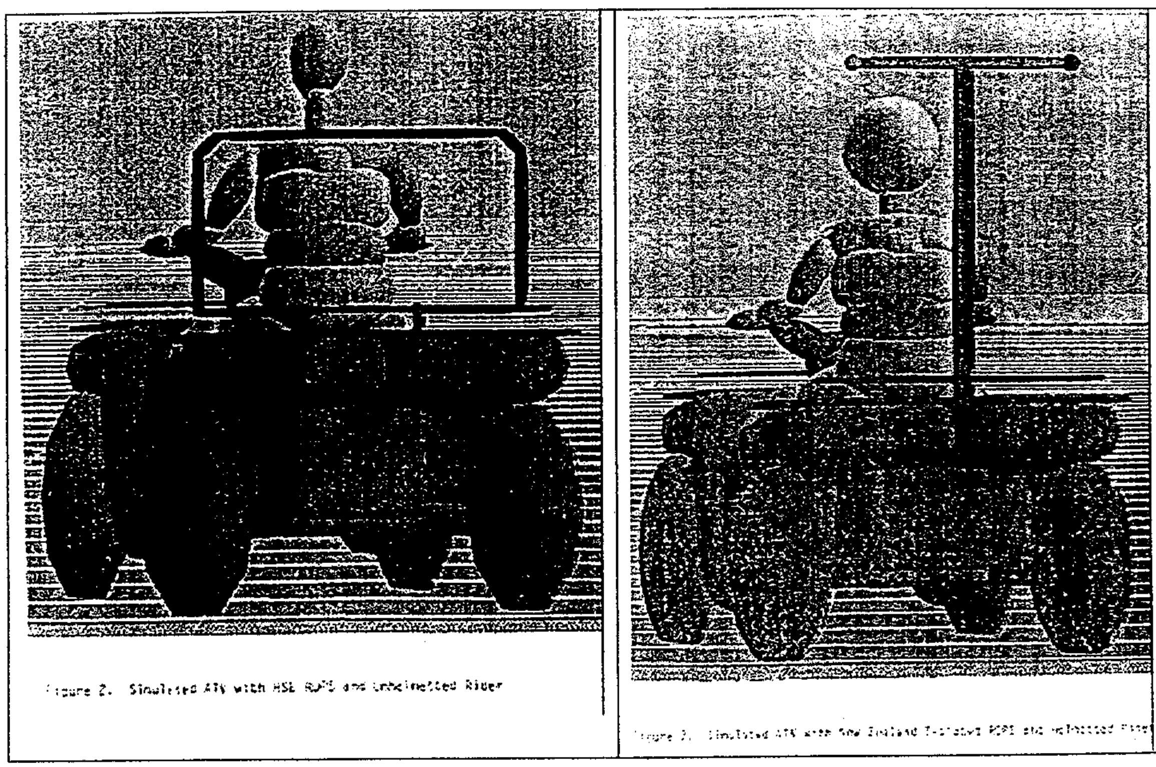


Figure 20: Views of the two ROPS types modelled by Zelner et al

The mass of the HSE ROPS hoop frame was 7.3kg; and the NZ T frame was 7.3kg.

A range of ground terrains and surface characteristics were modelled.

[2] This is similar to the multibody program MADYMO.

Of the 105 HSE accident case summaries, 59 involved rollover of 4 wheel ATVs. These cases were approximated in terms of initial speed, terrain geometry and slope angle, initial heading angle, and applied brake or drive torque from the verbal descriptions provided in the case summaries, and resulted in 43 different accident scenarios.

An example of HSE Case 42 is given as follows:

> *"DP asphyxiated riding ATV chain harrowing grassland down 15' slope with 19' cross slope. Fell from bike which landed across chest. BAC 121 mg."*

For this case the model used the following parameters:

- Ground slope 30 degrees
- Initial forward speed 2mph (3.2km/h)

Rider injuries were assessed using both Injury Assessment Variables (IAV's) and Injury Indices (II's). The IAVs included head accelerations, neck forces, chest injury criteria, leg fractures etc. The Injury Indicies (II's) related to peak force, acceleration etc. A risk /benefit was then calculated for each case based on the IAV's and II's for the ATV with the ROPS fitted and without a ROPS fitted.

From this risk/benefit analysis, Zellner et al concluded:

> *"Overall, it was observed that the increased injuries with ROPS fitted were caused by ROPS rider contact, and also rider trapping and dragging. In addition some of the changes (both increases and decreases) in injury due to ROPS fitment were due to changes in dynamic motion of the vehicle and resulting rider ejection, due to changes in the mass, CG location and vehicle inertia."*

The Zellner report concluded that based on their analyses, *"ATV rollover prevention systems (ROPS) of the types analysed should not be fitted to ATVs as the current time, as it is predicted that this would result in substantially increased injury potential...."*

We would agree with such a conclusion. Simply put, the two types of protective structures modelled are totally inappropriate and do not form an effective Rollover Protective System for ATVs irrespective of whether restraints would have been fitted or not. This report and analyses conducted convincingly demonstrate that a poorly designed Rollover Protective System is probably worse than not having a ROPS. The paper does not show, however, the benefits of a well-engineered Rollover Protective System (with proper occupant restraints).

The Zellner video

The Zellner video is based on the report considered above. Essentially, the video shows the outcomes of using poorly designed ROPS or ROPS without proper seating and restraint systems. It presents what may appear as a biased view of the effectiveness of Rollover Protective Systems by only showing systems which *a-priori violate the very first principles* of good rollover protection set out at the start of the video. What is not shown is how a well designed Rollover Protective System would look for ATVs and how this would perform. The intended implication could be that no such system is possible? The video further gives the impression of setting out a 'scare campaign' against ROPS on ATVs and instead promotes the so-called 'active –riding' method of reducing risk with ATVs.

Perhaps the intention of this video is to simply make a strong campaign against the fitment of inappropriate ROPS structures, while still leaving open the possibility for a future design of an ATV with an integrated Rollover Protective System which results in a significantly positive risk/benefit ratio.

One aspect of the video, which could be considered as misleading, is the idea that separation of the rider from the ATV is an advisable manoeuvre and one that the average rider can accomplish. Indeed any notion that an *average* ATV rider can in some way control their ejection from the ATV and how they land in order to reduce injury risk is quite unlikely.

The idea of rider separation is one that is used with *motorcycles*, but would appear to be quite inappropriate for ATVs which are a 4x4 *vehicle based* system. It is well known in car rollovers that occupant ejection from the vehicle is a major cause of serious injuries, and that proper restraint of the occupant within the vehicle reduces injury risk (Rechnitzer & Lane, 1994). Clearly with an ATV with a properly designed ROPS keeping the occupant within a protective zone would significantly reduce injury risk. The advent of the BMW C1 motorcycle which includes a full occupant restraint with a ROPS type structure, radically redefined what was considered feasible with occupant protection on motorcycles: for such a vehicle the general notions of separation applied to motorcycle riding are no longer valid or applicable.

14. February 1997, "Review of ATV Characteristics and Rollover Protection Systems" – Power Point presentation

The exact source of this Power Point presentation is not known, but it would appear to be a presentation of the work of Van Auken & Zellner and their 1996 and 1997 report on the Effects of ATV ROPS on Rider Injury Potential, by Dynamic Research, Inc., California, USA.

Comments on this presentation are as for the preceding review Number 13.

15. Van Auken, R. M. and Zellner J. W., February 1997, "Initial Analysis of the Effects of ATV Flexible ROPS on Rider Injury Potential, Volume I: Technical Report DRI-TR-97-1", Dynamic Research, Inc., California, USA

This report is an extension of the 1996/1997 report cited above with the objectives 'to analyse further the effects of various ATV flexible ROPS on rider injury, taking into account the NZ draft performance standard. The simulated ROPS designs included elastic and plastic bending degrees of freedom in accordance with the NZ standard.

Two ROPS styles are analysed. The first is the HSE hoop style (mass = 7.3kg) and the second is the NZ T-bar (mass = 9.5kg).

The section Results and Initial Observations from this report state that "*The flexible ROPS tends to remove the extremes in Risk/Benefit ratios compared with the previous results with a rigidly attached ROPS, however most of the trends remain the same.*"

As this report is very similar to their previous report cited above, the earlier comments made in regard to their first report are similarly applicable.

16. Allinson D & Crichton O, ATV Rollover Protection Feasibility And Development, Health and Safety Laboratory, HSE, UK, 31th March 1997

This report examines the feasibility of installing a ROPS which will reduce the potential for continuous sideways overturn, and determines if it is feasible to fit such a ROPS (Figure 21) and one that meets existing ROPS tractor standards.

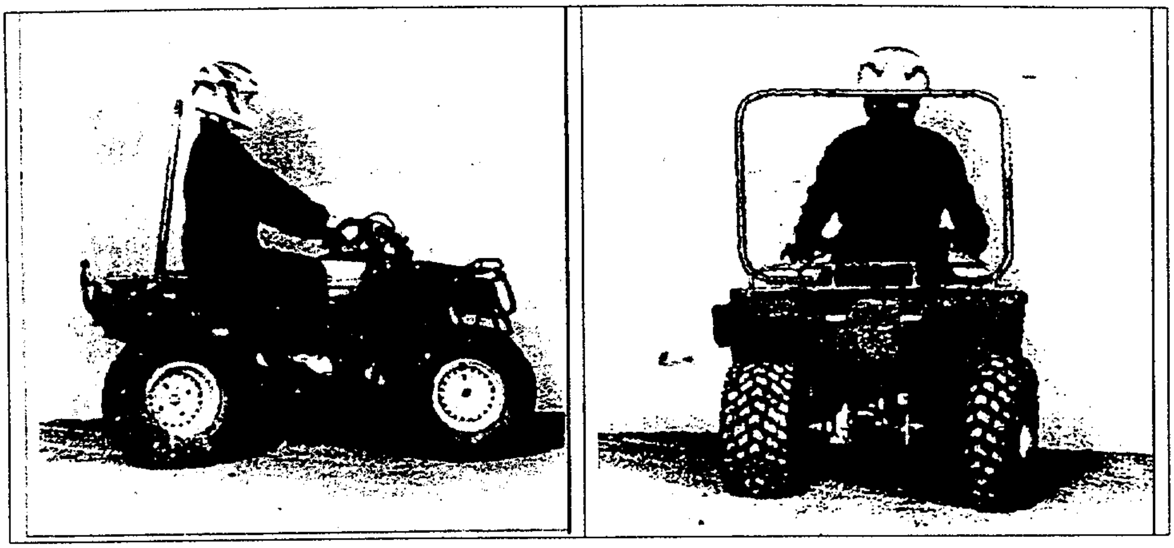


Figure 21: Honda ATV with the ROPS (from Figure 2, Allinson & Crichton, 1997)

The report recommends that further assessment is required of the risk to the rider from the ROPS.

17. Forouhar, F. A., 5-7 October 1997, "All-Terrain Vehicles Frequency Domain Response Analysis and Rider Behaviour", Proceedings of the 1997 IEEE International Conference on Control Applications, Hartford, USA

This paper presents the results of experimental and analytical studies looking at the lateral and directional response and handling characteristics of ATVs. Both 'circle turn' and 'J turn' tests were conducted which showed understeer at low levels of lateral acceleration and oversteer at high lateral accelerations (transition at 0.1g to 0.15g). This property of ATVs is mainly attributed to their solid (no-differential) rear axle and the load transfer from the inside to the outside tyres at higher levels of lateral acceleration.

The paper reported that no evidence of directional instability was found during subjective testing and normal riding of ATVs at speeds above the 'critical speed' predicted by theory. This relative stability of ATVs when compared to theory is attributed to the fact that the ATV rider can influence the understeer/oversteer of the ATV through their body movements, throttle control and compensatory steering actions.

The paper is essentially supporting the view that 'active riding' can significantly affect the handling performance of ATVs. What the paper omits to present or quantify is:

- Any scientific evidence of this claim.

- What relative change in ATV handling occurs due to rider control?
- What level of riding skill is necessary to achieve the level of rider control tested and how does this vary based on different levels of skill?
- What is the affect of the weight of the rider on these results?
- What is the affect of carrying loads on the front or rear of the ATV?

As none of these questions are evidently answered in this paper, the paper could be considered as quite misleading in terms of its conclusion.

18. Occupational Safety Health Service, September 1998, "Guidelines for the Design, Construction and installation of Rollover Protective Structures (ROPS) for All Terrain Vehicles", Department of Labour, Wellington, New Zealand

The Guidelines were introduced in NZ on a voluntary basis to be trialed for one year. The guidelines provide guidance "*for the safe design, construction and installation*" of ROPS for ATVs.

The guidelines describe four different ROPS configurations (see Figure 23):

- **Full cab with enclosure** – not recommended due to greater risk of being trapped by the frame of the ROPS during a rollover.
- **Full roll cage with four post** frame - not recommended due to greater risk of being trapped by the frame of the ROPS during a rollover.
- **Roll bar with two post frame.**
- **Single pole frame.**

The guideline sets out structural performance requirements for the ROPS to ensure that the ROPS is capable of withstanding ten loadings likely to arise from a rollover. These load requirements are set out in terms of lateral force and energy; vertical force and longitudinal force and energy. The guidelines state that the loading requirements are expected to provide crush protection under the following conditions (at least):

- Forward velocity between 0 – 16km/h on hard clay surface of 30 degree slope.
- Roll angle of 360 degrees about the ATVs longitudinal axis.
- 180 degree backward roll about the rear axle.

The height of the ROPS is defined indirectly by defining a 'deflection limiting volume' (DLV) (see Figure 22) the top of which is approximately 1.0m above the riders' seat cushion.

Other than setting out the structural and some basic geometric requirements for the rollover protective structure, the NZ guidelines do not specify (or mention) restraint systems or seat configurations. As such, these guidelines would appear to be totally inadequate in terms of specifying a proper and safe Rollover Protective Systems.

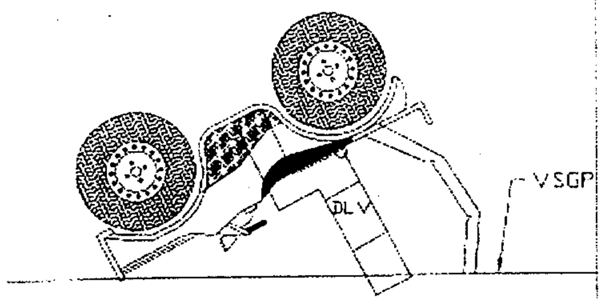


Fig. 2 Intrusion of vertical simulated ground plane (VSGP) into the DLV

Fig. 3 Allowable rotation of upper portion of DLV about the locating axis (LA)

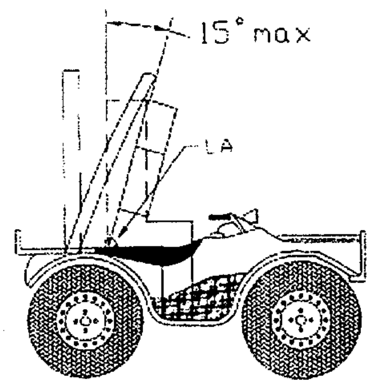


Figure 22: Figures 2 & 3 from the NZ Guidelines, showing the allowable deflection of the ROPS in terms of the Deflection Limiting Volume (DLV)

APPENDIX D: Types of Rollover Protective Structure

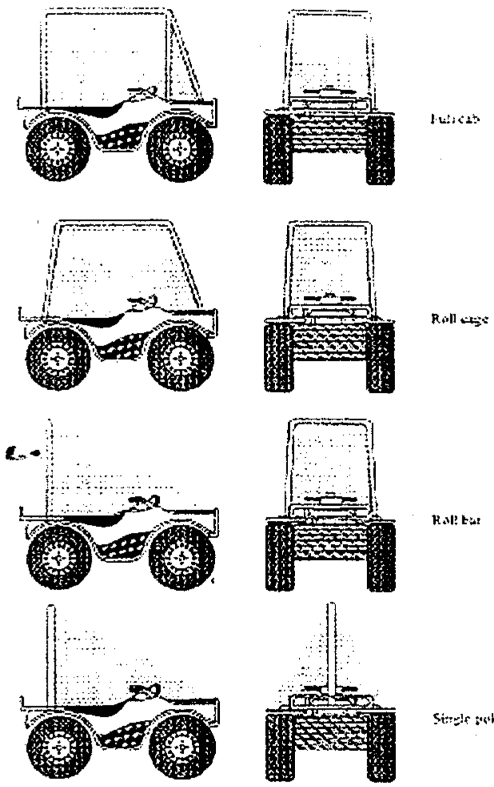


Figure 23: Different types of ROPS structures described in the NZ Guidelines

19. Tyler-Street, M. D., 1999, "Mathematical Modelling of an ATV and Rider in an Overturn", Contract Research Report 222/1999, Health and Safety Executive, The Motor Industry Research Association, Warwickshire, United Kingdom

This report presents the results of modelling of an ATV in a rollover to evaluate the risks verses benefits of fitting a roll over protection structure to an ATV. The report states that a new European Directive will require employers and self employed to fit a ROPS or equivalent to protect a person on any 'ride on' equipment.

The study was carried out in three phases:

1. ADAMS simulation package to assess the stability of the ATV for each of 5 overturn scenarios.
2. Use of the finite element program LS-DYNA3D to investigate the transient response of the ATV and rider during the rollover.

3. Examine the effects of rider lean to simulate an active riding position.

The study concluded that based on the result there was not a strong case at the moment to support the provision of ROPS on ATVs of the sit-astride type.

The study compared injury risk outcomes qualitatively, that is by assessing whether the rider was thrown clear of the ATV or whether the rider was contacted by the ROPS and/or ATV (Figure 19). The basic weakness with the analysis is this qualitative approach rather than quantitative and that in the ROPS model the occupant was not restrained at all.

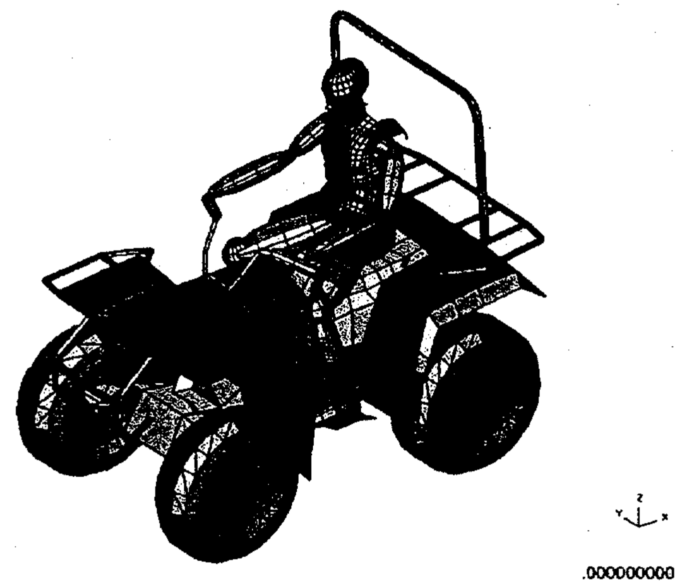


Figure 3: Finite Element Model of ATV, ROPS and Rider

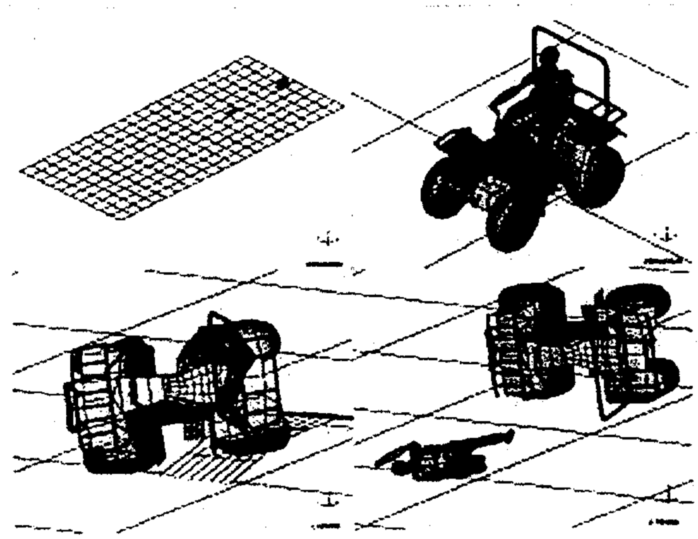


Figure 12: Scenario 3 - sideways overturn over bump - with ROPS -no lean

Figure 24: View of the ATV and ROPS finite element model and example of rollover scenario (Figures 3 & 12 from HSE Report 222/1999 Mathematical modelling of an ATV and rider in an overturn)

20. **Schalk, T. and Fragar, L. J., "Injury Associated with Farm Motorcycles on Farms in Australia", August 2000, Australian Centre for Agricultural Health and Safety, University of Sydney**

The report states that the study was directed primarily at the identification of preventable injury risk factors with a view to making recommendations for reducing risk of injury and death associated with riding 2 wheel and 4 wheel motorcycles on Australian farms.

The study was undertaken by a survey of farm motorcycle riders approached at field days, a mail survey of farm women, a survey of Emergency Departments in a small number of rural hospitals, collations of information on head injuries associated with farm motorcycle riding, and a collation of data available regarding deaths associated with motorcycle riding.

Of the respondents, 505 riders were injured on 2-wheel motorcycles (62.5% of 2-wheel motorcycles riders) and 47 riders on ATVs (9% of ATV riders) in the previous 2 years. There were 24 farm motorcycle fatalities in the coroner's files between 1989-1992 of which 5 deaths were attributed to ATVs and 19 to motorcycles. The majority of accidents occurred at speeds less than 30km/h.

The study notes that rollover was the main cause of deaths with ATVs, with multiple crush injury as the predominate injury mechanism in these cases (60%).

Regarding ROPS for ATVs, the report recommends:

> *"Research information regarding the benefits and risks of the fitment of ROPS to ATVs should be referred to an expert panel to prepare advice for Australian suppliers, farmers and farm managers."*

In Section 4 of the Schalk & Fragar report, reference is made to the Van Auken & Zellner (1997) report. The project went on to commission an independent consultant MG Stevenson to advise regarding the validity of the Van Auken & Zellner study and findings. Overall Stevenson appears to have been satisfied with the Auken & Zellner work, with a few provisos.

21. **Becker, W. J. and Stephenson, W. C., 16 May 2001, "Tractors and Roll-Over Protective Structures (ROPS) and Seat Belts: Standard 1928.51", University of Florida, USA**

This paper is intended to advise owners and managers of agricultural businesses of requirements for ROPS and seatbelts for tractors under Standard 1928.51 of the Occupational Safety and Health Act. Specifically the Act states that:

1. A roll-over protective structure (ROPS) shall be provided by the employer for each tractor operated by an employee.
2. Where ROPS are required by this section, the employers shall:
    a. Provide each tractor with a seatbelt that meets the requirements of SAE standard J4C.
    b. Ensure that each employee uses the seatbelt and tightens the belt sufficiently to confine the employee.

22. Ayers, P., Conger, J., Troutt, P. and Comer, R., "ROPS Design and Testing for Off-Road Utility Vehicles and Lawnmowers", University of Tennessee, Knoxville, USA

This paper presents the results of tests carried out determining the critical lateral and longitudinal stability angles for 4 ATVs, 5 ORUVS (off road utility vehicle) and 8 lawn mowers. Critical stability angles were calculated for loaded and unloaded conditions. It was found that some of the vehicles had critical stability angles lower than 40 degrees recommended by ANSI 71.4- 1999 for installation of ROPS for commercial turf care equipment.

Table 3 is taken from the Ayers et al paper and summarises the critical overturn angles. For the ATVs in their loaded condition, the critical lateral angles vary from 31.1 degrees to 32.7 degrees, with an average of 32.3 degrees. These values compare to those for the off-road utility vehicles, which range from 37.4 degrees` to 42.2 degrees (average 39.4 degrees) in a loaded condition. The average longitudinal critical angle is 39.1 degrees for the ATV compared with 37.3 degrees for the off-road utility vehicle.

The authors note that all 4 of the loaded ATVs had critical lateral stability angles of less than 40 degrees and similarly the critical longitudinal stability angles were typically less than 40 degrees. These results suggest that Rollover Protective Systems should be used on ATVs.

Table 3 Summary of test results showing the critical longitudinal and lateral overturn angles for 4 different model ATVs, 5 off-road utility vehicles and 8 lawn tractors - mowers (from Ayers et al)

	Vehicle Weight (N)		Lateral Critical Angles		Longitudinal Critical Angles	
All Terrain Vehicles	Unloaded	Loaded	Unloaded	Loaded	Unloaded	Loaded
Honda Rubicon TRX 500	2823	4631	41.3	33.7	51.1	40.4
Yamaha Grizzly Ultramatic 660	2809	4970	38.6	31.1	49.7	38.0
Polaris 700 Sportsman	3483	5662	36.9	31.8	45.3	38.3
Kawasaki Prairie 650	2911	4974	39.4	32.6	51.6	39.8
		Average	39.0	32.3	49.4	39.1
		% Change	17.2		20.8	
Off Road Utility Vehicles						
Polaris Ranger 4x4	5382	12508	46.2	37.7	56.9	38.6
John Deere Gator 4x2	4085	8093	47.4	41.6	47.7	37.8
John Deere Gator 6x4	5444	11681	49.3	42.2	54.0	41.1
Kawasaki Mule 4x2 3000	5663	11022	43.1	37.4	54.3	39.8
Toro Workman 2110	4464	11802	39.9	37.8	45.2	29.0
		Average	45.2	39.4	51.6	37.3
		% Change	12.9		27.8	
Lawn Tractors						
Kubota BX2200	6930	7819	40.0	36.4	50.3	44.3
John Deere X485	4878	5767	45.0	38.9	54.9	45.7
Murray Garden	2122	3011	42.2	32.6	53.4	37.5
Cub Cadet HDS 3205	4039	4928	50.7	40.9	62.6	50.2
		Average	44.5	37.2	55.3	44.4
		% Change	16.4		19.6	
Zero Turning Radius Mowers						
Kubota ZD21	6382	7271	55.7	50.5	37.9	34.4
Ferris IS 3000	5618	6507	46.7	42.9	34.3	30.7
Cub Cadet 3654 Comm.	4395	5284	53.2	46.0	38.6	34.3
Toro Z-master	5881	6770	50.2	37.4	39.6	33.5
		Average	51.5	44.2	37.6	33.2
		% Change	14.1		11.6	

4. ATV STABILITY FACTORS AND OVERTURN ANGLE

The following section examines the stability characteristics for the ATV in terms of stability factors and overturn angle. The stability factor is a fundamental geometric characteristic of a vehicle and is a function of the track width and centre of gravity (COG) height.

A Honda TRX350 (4x4) was provided to Monash University on loan for the purposes of establishing some fundamental characteristics necessary for the modelling of an ATV without and then with ROPS (see Chapter 6). The impact of the interactive riding style was also examined, although these results should be considered as preliminary. The ATV was examined in the Structural Laboratories in the Department of Civil Engineering.

4.1 Centre of gravity position of the ATV

The lateral and longitudinal Centre of Gravity (CofG) of the ATV was determined by measuring the reaction force of the ATV at each wheel.

Mass measurements were taken of the Honda TRX360FM FOURTRAX350. The spring damper combination's were removed and replaced by rigid links during these measurements.

During the measurement of each wheel, the opposite wheel was packed to the same height as the scales and a lift jack centrally supported the other axle. The vehicle was then supported on 3 points enabling an accurate mass measurement to be made. The unladen mass of the vehicle was determined to be 241kg.

1. The front right wheel 68kg.
2. The front left wheel 60kg.
3. The rear right wheel 63kg.
4. The rear left wheel 50kg.

The wheelbase (distance between the front and rear axles) was measured at 1.260m. The front track width (distance between front tyre centrelines) was 0.820m and the rear track width was 0.860m. The width of the tyres was measured at 0.200m. The effective overall width and length of the vehicle is estimated at 1.2 metres and 2.0 metres respectively.

The handlebars were secured in position to lock the steering wheels in a forward direction. The vehicle was pivoted onto its right side and supported on both right tyres and the right handle bar. This was done so that the vehicle would be supported on 3 points and to enable an accurate mass measurement to be made. The unladen mass of the vehicle was 240.5kg. The following were the masses under each wheel and are used to determine the vertical height of the C of G.

1. The front right wheel 69kg.
2. The right handle bar 80kg.
3. The rear right wheel 91.5kg.

The vehicle was placed back on all four tyres and the following vertical offsets were measured to each of the load points:

1. The front right wheel 0.060m.

2. The right handle bar 1.100m.
3. The rear right wheel 0.075m.

Based on the measurements taken the unladen C of G is defined as follows:

1. The lateral C of G is 0.060m to the right of the centreline.
2. The longitudinal C of G is 0.100m behind the front axle.
3. The vertical C of G height is 0.412m above ground level.

4.2 ATV stability factor

The Stability Factor is considered to be a first order estimator of propensity for a vehicle to rollover. Stability Factor is determined from the following (see Figure 25):

Stability Factor = Vertical C of G height xTrack width/2

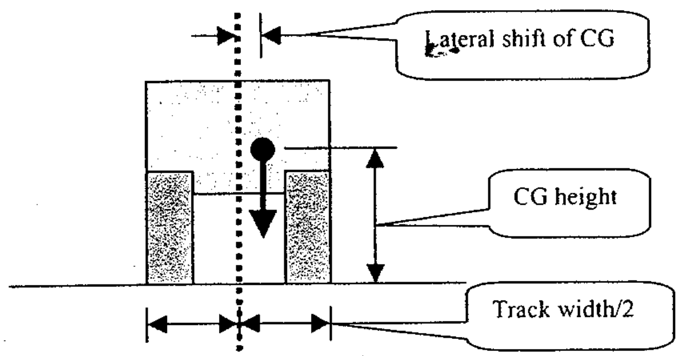


Figure 25 Diagram showing basic vehicle geometry in relation to stability factor

The lateral position of the COG is offset from the centreline of this ATV and results in this ATV having a different Stability Factor for the left and right. The lateral displacement of the COG to the right means that it is harder to overturn this ATV to the left than the right.

This ATV does not have a symmetrical handling characteristic, so an operator could turn to the left and not roll the ATV. However if the operator duplicated the manoeuvre to the right this could cause the rollover of the ATV.

A spreadsheet was developed to enable calculation of the position of the CG of the ATV with different weight riders, and the change in the position of the CG due to the rider adopting an active riding style. The results are summarised in Table 4 & Table 5. This shows the variation in SF (and overturn angles) for variation in rider weight, left and right side of the ATV; active riding and with and without ROPS, and with increased track width.

Table 4: Summary of Stability factor for the ATV for varying conditions

Function	Left side			Right side		
1. Rider weight	100kg	80kg	60kg	100kg	80kg	60kg
2. Rider CG shift for "active riding".	0	0	0	0.2m	0.18m	0.15m
3. Stability Factor (track 0.84m)	0.73	0.78	0.85	0.64	0.68	0.74
4. Stability Factor <u>with Active riding</u> (track 0.84m)	0.82	0.86	0.91	0.74	0.76	0.80
5. ATV with ROPS (track 0.84m)	0.69	0.73	0.79	0.61	0.64	0.68
6. ATV with ROPs with increased track to 1.1m	0.82	0.87	0.94	0.74	0.78	0.83

Table 5: Summary of the estimated overturn angles for the Honda TXR350 ATV for varying conditions

Stability Function	Left side			Right side		
Rider weight	100kg	80kg	60kg	100kg	80kg	60kg
Rider CG shift for "active riding".	0	0	0	0.2m	0.18m	0.15m
Tilt angle (track 0.84m)	36	38	40.3	32.7	34.4	36.5
Tilt angle (track 0.84m) <u>with Active riding</u>	39.4	40.7	42.2	36.4	37.3	38.5
Tilt angle for ATV with ROPS (track 0.84m)	34.6	36.3	38.2	31.3	32.7	34.3
Tilt angle for ATV with ROPs with increased track to 1.1m	39.4	41.0	43.2	36.5	37.9	39.7

Row 3 of Table 4 shows the left and right side stability factor (SF) for riders of mass 100kg, 80kg and 60kg. Hence, the Stability Factor for a seated 100kg operator is calculated at 0.73 (left) and 0.64 (right). These Stability Factors equate to an approximate overturn angle of 32° (left) and 30° (right). The SF varies from 0.73 for a 100kg rider to 0.85 for a 60kg rider. These calculations show that the Stability Factor (SF) for the right side is less than for the left side by up to 14%.

4.3 Affects on Stability Factor by active riding

If the operator adopted the '**active riding style**' (row 4 of Table 4) it is estimated that the operators CG could move ±0.200m laterally, without any change in the height of the rider's CG. The Stability Factor for a 100kg operator adopting an 'active style' is estimated as 0.82 (left) and 0.74 (right). These Stability Factors approximate to overturn angles of 39° (left) and 36° (right). It is noted that for overturing to the right (the least stable direction), the 'active riding style' SF is only increased back up to the 'normal' level for overturning to the left (0.74 vs 0.73).

The benefit gained by an active riding style also varies depending on the rider's weight [see Table 6]. Thus the increase is the highest for the heavier rider (12-16%) and lowest for the lighter rider (7 to 8%). This effect is simply due to the lighter rider having a smaller effect on changing the position of the CG of the ATV plus rider.

Table 6: Percentage increase in stability factor due to an "active riding" style

	Left side			Right side		
Rider weight (kg)	100	80	60	100	80	60
Percentage increase in Stability Factor with Active riding	12%	11%	7%	16%	12%	8%

With a 19kg ROPS added, this reduces the SF by around 17% for a 100kg 'active- rider'. (with a ROPS the rider would no longer be 'active').

To regain the same stability factor for a 100kg active rider for an ATV[3] with ROPS, would require the track width to be increased from 840mm to 1100 mm, an increase of 130mm to each side (260mm total). Alternatively, the stability factor could be regained by lowering the COG of the rider (different seating arrangement) and a lesser increase in track width.

As a comparison to the ATV with a stability Factor of around 0.65 to 0.8, a Holden Rodeo 4x4 has a Stability Factor of 1.07 (unladen) and 0.91 (laden) - the measured tilt table overturn angles for the Holden Rodeo 4x4 were 44° (unladen) and 37° (laden). Stability Factors for small farm tractors are around 0.59, with the measured overturn angle for a small tractor was 31°. The Stability Factors for a medium tractor is estimated to be around 1.07 based on approximate overturn angles of 47°. The Stability Factor of the tested ATV is less than that of a medium farm tractor, and less than a 4WD motor vehicle.

4.4 Measurements of the Honda TRX 350 ATV stability

The following measurements were determined from the tilt table tests carried out in the structural laboratories of the Department of Civil Engineering. Tests were conducted using 2 different weight and height riders. These test are preliminary and are indicative only. A much larger range of riders would need to be tested to clearly establish the effects on stability of an 'active riding style'. In addition handling tests would also need to be conducted to determine the dynamic response.

The tilt tests were carried out with different riders positioned with and without active riding as shown in Figure 26 and Figure 27. The angle of inclination (see Figure 40) are summarised as follows:

Roll to the left:

No rider:	H = 745mm,	$\alpha = 39.15$ deg
Peter, straight:	H = 640mm,	$\alpha = 32.85$ deg
Peter, leaning to the right:	H= 710 mm,	$\alpha = 37.0$ deg
Andrew, straight:	H = 630mm,	$\alpha = 32.27$ deg
Andrew, leaning to the right:	H = 670 mm,	$\alpha = 34.60$ deg

Roll to the right:

No rider:	H = 740mm,	$\alpha = 38.84$ deg
Peter, straight:	H = 620mm,	$\alpha = 31.70$ deg
Peter, leaning to the left:	H = 700 mm,	$\alpha = 36.39$ deg

[3] This example is based on the Honda TX350 ATV

Peter:	173cm, 76kg;
Andrew:	172cm, 104kg;

It is clear the differences resulting from active riding (moving one's posterior to the high side: bottom photos in Figure 26 and Figure 27) to non-active riding (maintaining a seated position perpendicular to the wheel base plane (top photos in Figure 26 and Figure 27) is minimal. This is particularly the case for the shorter, heavier set person where the angular difference is only 7% compared to a 50th % person where the difference is around 11%.

Using 'active riding', these results show a change in SF from 0.65 to 0.75, a 15% increase for the left side, for the 76kg rider (Peter); and a 10% increase for the 105kg rider (Andrew). For the right side the SF changed from 0.62 to 0.74, a 19% increase for the 76kg rider.

These values are a little lower than the theoretically calculated values presented in Table 4 and Table 5. This is probably due to the suspension and tyre compliance, which acts to reduce the SF.

A full stability analysis would require instrumented handling tests as well, using arrange of riders (refer Rechnitzer et al, 2002).

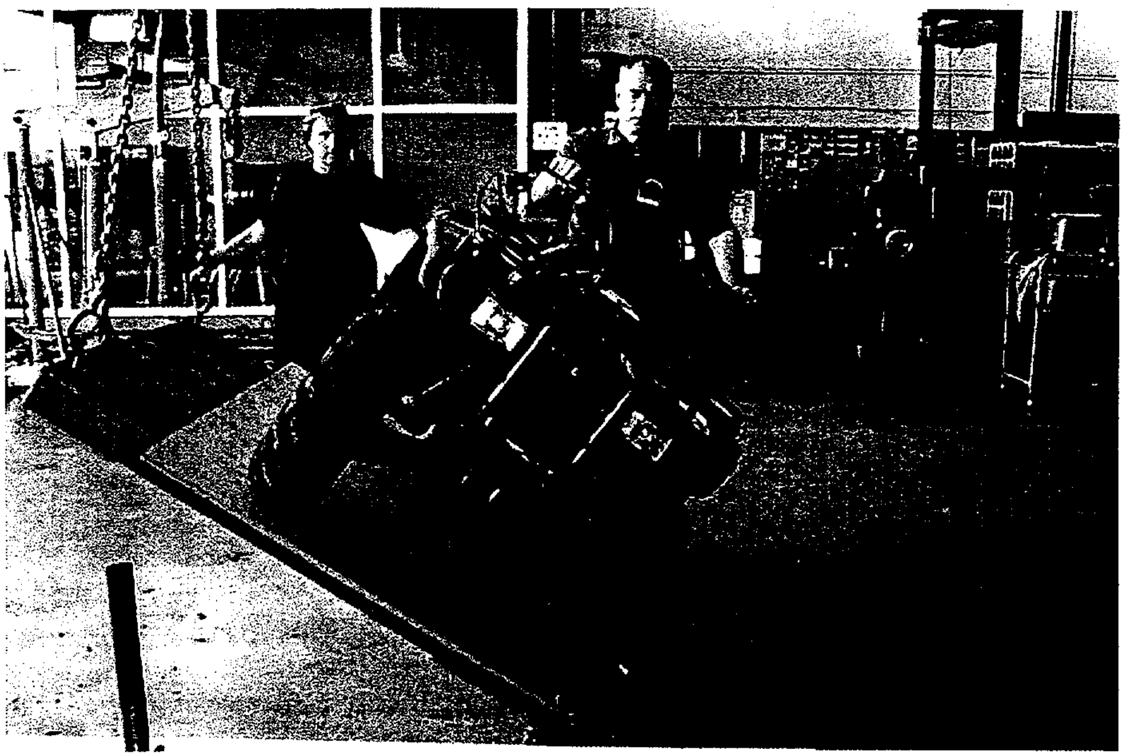


Figure 26 Tilt test with Mr Peter Dunbar as non-active rider (top) and active rider (bottom).

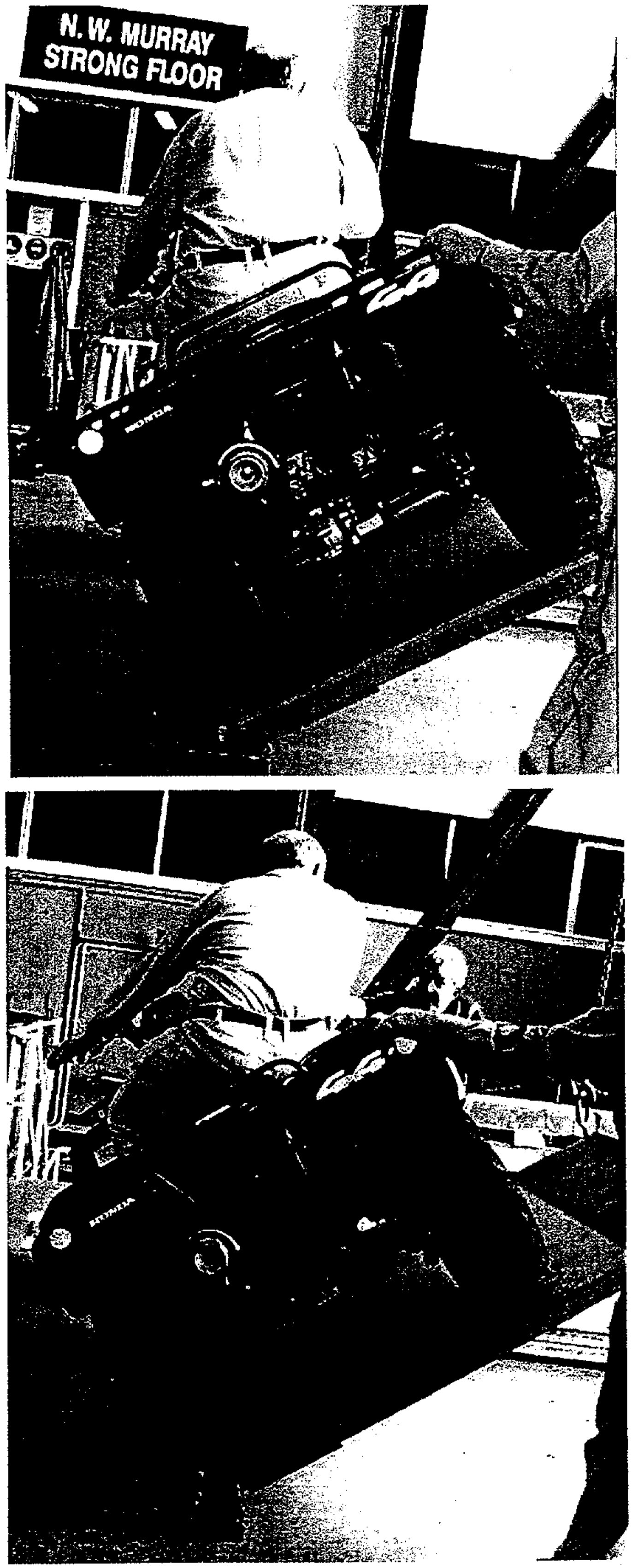


Figure 27 Tilt test with Mr Andrew Haines as non-active rider (top) and active rider (bottom).

5. STRUCTURAL ANALYSIS OF PROPOSED ATV ROLLOVER PROTECTIVE STRUCTURE

5.1 Different Rollover Protective Systems

To properly satisfy occupant protection requirements in both a forward impact and rollover in any direction, the *rollover protection system* (ROPS) must provide:

- Structure to prevent intrusion and maintain occupant survival space
- Occupant restraint system which maintains the occupants position relative to the structure and prevents excursion of the torso and head thereby preventing harmful external or internal contacts

To achieve this requires a rollover protective structure together with appropriate seatbelt and seat system.

In terms of a rollover protective structure the Honda Pilot shown in Figure 23 below has a good rollcage in this regard.

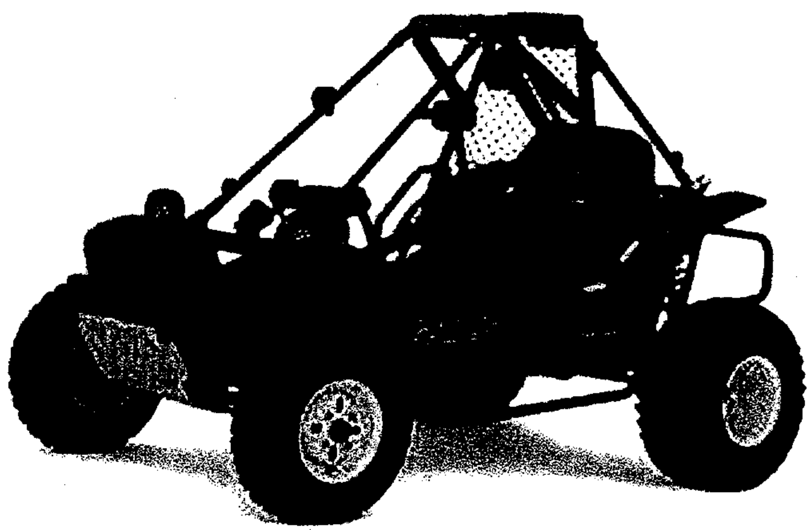


Figure 28: Honda Pilot 'dune buggy'.

Another vehicle, which shows what is possible with good design in regard to occupant protection, is the BMW C1 motorcycle which has full rollover protection and cross-over seatbelt system (see Figure 24).

Figure 29: BMW C1 motorcycle with full Rollover Protective System

The Polaris range of ATVs includes vehicles based on ATV design but which appear to be modified (designed) specifically for farm type activities, but with full off road capabilities. The Polaris Ranger vehicles have what appears to be a rollover protective structure, but apparently is not (see Figure 30).

Figure 30 Polaris 4x4 Ranger with ROPS like frame and lap belts (from the Polaris product catalogue). Apparently the Polaris Ranger has a warning label on the frame which states "this cab frame is not designed or intended to provide rollover protection in the event of vehicle overturning (Ayers et al).

5.2 Different Seatbelt systems

Although the seatbelt used in the modelling (Chapter 6) was based on the BMW C1 motorcycle crossover system with lap belt because of its effectiveness for rollover, and frontal impacts, other systems may also be possible. These would of course require evaluation and testing with users.

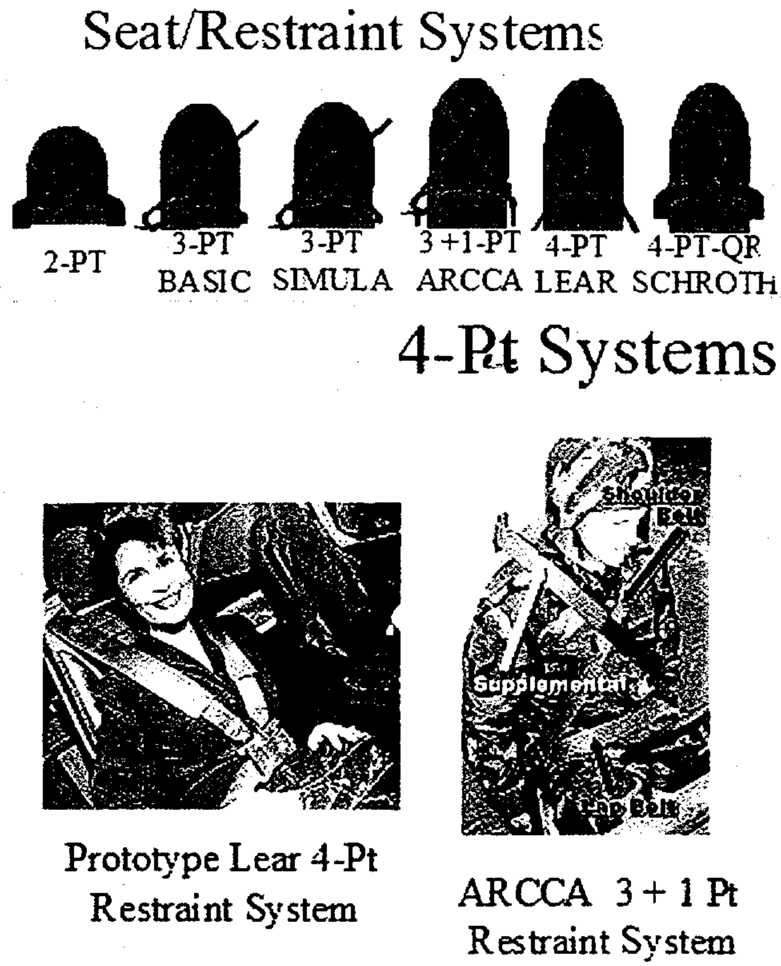


Figure 31: Different seatbelt systems, from lap belt through to 4-point (from the US Army TACOM).

The most effective seatbelt system for rollover is a 4-point belt. The least effective is a lap belt, which should *not be used at all as they do not provide any restraint for the upper torso.*

5.3 Analysis and Design of the proposed Rollover Protective structure for the ATV

This section sets out the design and analysis of the ROPs used in the MADYMO simulation presented in Chapter 6.

The structural adequacy of the ROPS structure was based on satisfying the load criteria from the New Zealand Department of Labour Guidelines for Roll Over Protective

Structures, and those developed by Mr Shane Richardson for the Australian Army (Richardson et al, 2002).

(1) The New Zealand Department of Labour Guidelines for Roll Over Protective Structures on ATV's was evaluated and the following points are made:

1. In the absence of other information the guidelines provide reasonable design criteria (at least as a starting point).

2. However the guidelines are based on and have similarity to Australian Standard AS2294 Earth-moving Machinery – Protective Structures. This is not surprising as the Roll Over Protective Structure manufacturers are identified as having helped to prepare the guideline. Based on the information contained in the forward it would appear that no other researchers or research organisations contributed to the development of the NZ ATV ROPS guideline.

3. The fundamental difficulty in basing the guideline on AS:2294 is that AS:2294 is intended for equipment of much greater mass, of 16 tonne or more, whereas an ATV is typically less than 0.5 tonne. The main rollover mode for this type of heavy equipment is falling on their side and possibly rotating onto their roofs - different to that for ATVs.

4. The rollover mode for ATV's can be as simple as falling onto their sides or onto their backs or as complex as a dynamic multi directional tumble. Since AS:2294 itself was not intended for tumbling vehicles, it is therefore considered that the guideline was not written for a tumbling ATV. A review of the guideline indicates that the loading conditions considered define the rollover modes evaluated, that is:

   a. Lateral loading
   b. Vertical loading and
   c. Longitudinal loading.

5. Based on a vehicle mass of 241kg the structural loading arising from the guidelines are:

   a. Lateral loading: 2520N and absorb energy in excess 525J.
   b. Vertical loading: 8236N and
   c. Longitudinal loading: 2016N and absorb energy in excess 588J.

6. A fundamental premise of the guideline is that the structure will distort under impact loading and that the occupant survival space can distort under loading.

(2) Richardson developed ROPS loading requirements

Roll Over Protection Structural Requirements have been developed, tested and validated by Richardson et al [2002]. Currently these standards are being used by the Australian Army to modify the Perentie and Unimog 4x4 and Mack 6x6 vehicle fleets operated by the Army. The requirements are based on the application of loading conditions and non-infringement of occupant survival spaces. These criteria are most comprehensive developed for rollover protection systems.

Applying the Richardson et al loading requirements to the tested ATV would result in the following structural criteria:

1. Loading Condition 1 would apply 577J to the upper forward corner of the structure. The loading would be applied at 21° to the horizontal and 21° to the longitudinal centre line of the vehicle so that the loading was directed into the structure.

2. Loading Condition 2 would apply 8236N to the forward top of the structure. The loading would be applied 7° to the vertical so that the loading was directed into the structure.

3. Loading Condition 3 would apply 445J to the upper rear corner of the structure (to the opposite side that Loading Condition 1 was applied). The loading would be applied at 21° to the horizontal and 21° to the longitudinal centre line of the vehicle so that the loading was directed into the structure.

Richardson et al's requirements use a pendulum mass of 33% of the vehicle mass. Results of previous tests indicate that under Loading Conditions 1 and 3, the peak acceleration of the impacting mass is 8g's and 6g's respectively. Therefore the peak forces applied to the structure would be 10,877N, 8236N and 8,160N during Loading Conditions 1, 2 and 3.

5.3.1 Proposed ROPS model

Based on consideration of the occupant protection requirements for a ROPS structure for an ATV, the following conceptual structure was developed designed to ensure maintenance of survival space in a rollover in any direction. Integral to the ROPS is a seating back with side bolsters and proper restraint configuration. The ROPS Structure was analysed using the Finite element method with loading applied as noted in the above criteria.

A quasi-static analysis of this simple ATV Roll Over Protective Structure has been developed and analysed using Finite Element Methods. The simple ATV structure is based on four hard points (attachment points to the ATV chassis) on the supplied vehicle and using 25x50x2.5mm steel tube[4] rectangular hollow section, grade 450MPa.

[4] Subsequent to this analysis, in the MADYMO modelling presented in Chapter 6, it is noted that the effective section properties for this tube were doubled for the model, in light of the high stresses noted from the analysis. However other design changes to the structure such as the use of bracing could achieve the same increase in structural capacity and stiffness. In addition it is considered that the soil stiffness used in the analyses may have been overly stiff, resulting in unrealistically high stress levels in the structure.

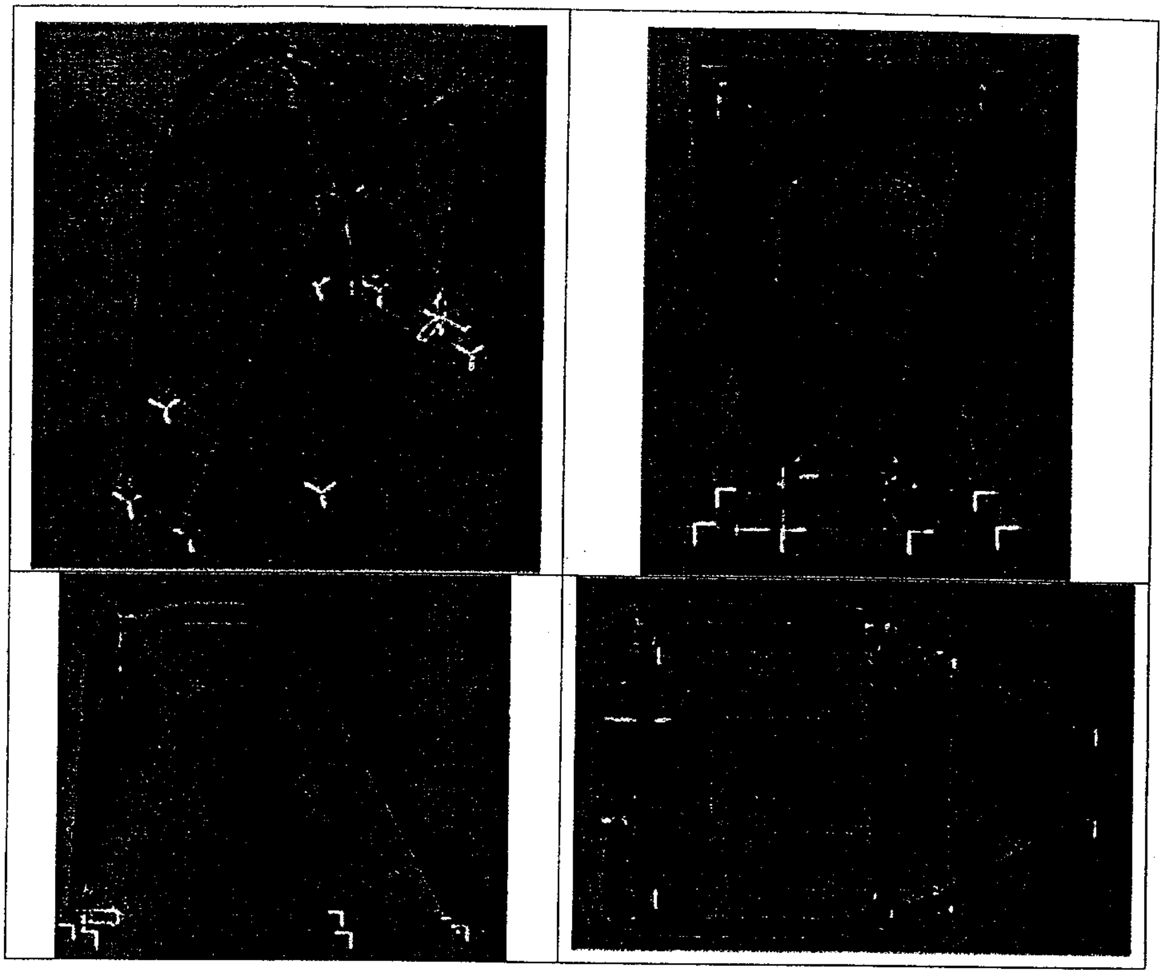


Figure 32: Different Views of the proposed ROPS structure

The following 3 figures (Figure 33, Figure 34, Figure 35) illustrate the stresses derived in the Finite Element Model of the simple ATV structure, the Survival Space after the application of the above Loading Condition's 1, 2 and 3 respectively.

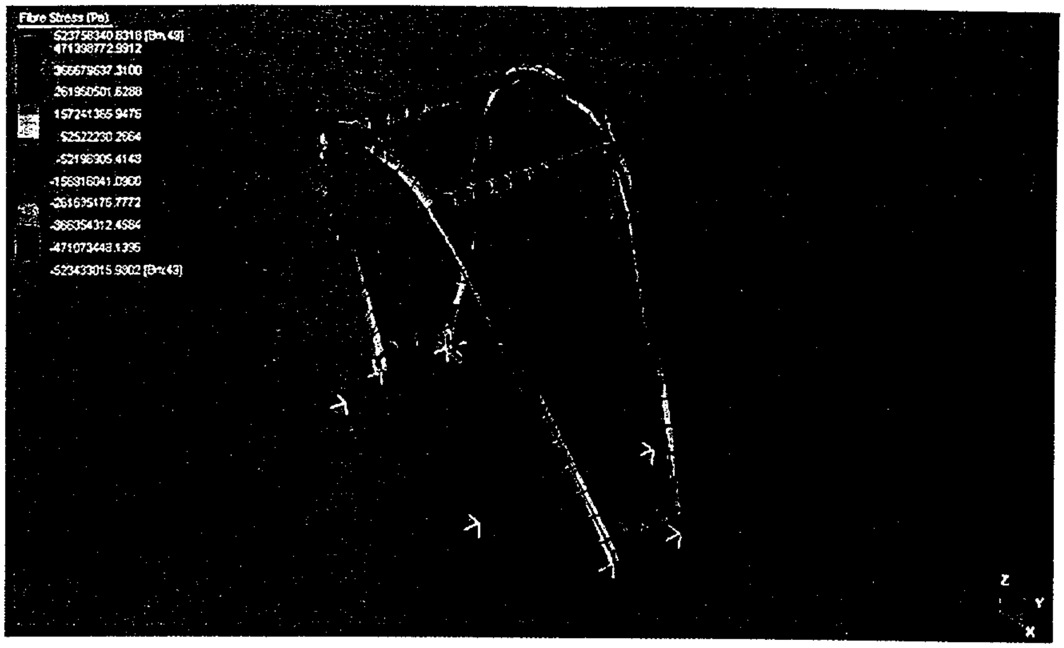


Figure 33: Stresses in the ROPS structure for the Loading Condition 1

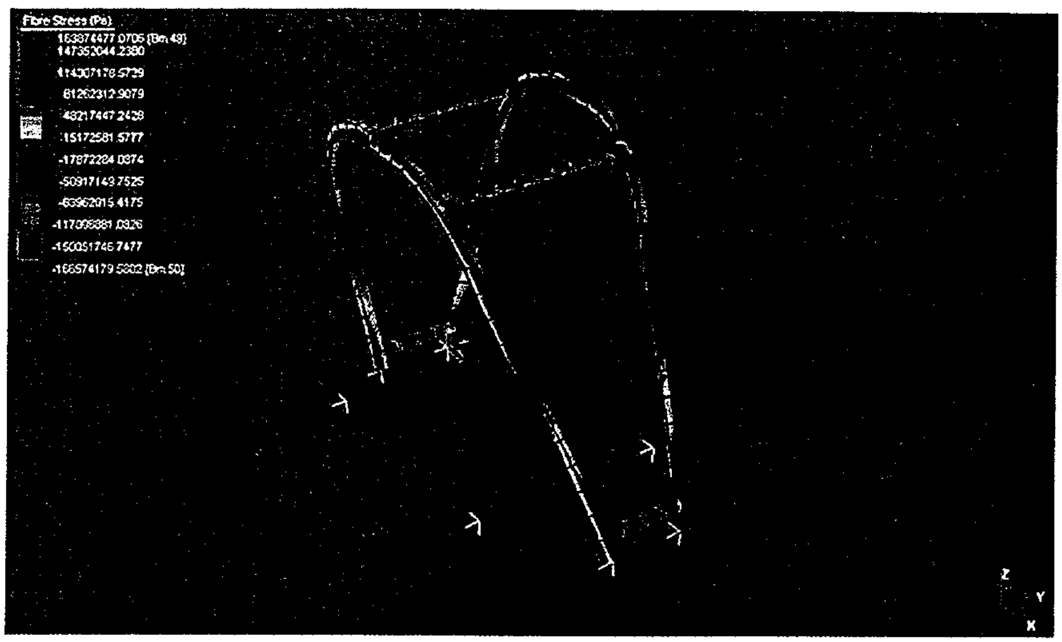


Figure 34: Stresses in the ROPS structure for Loading Condition 2

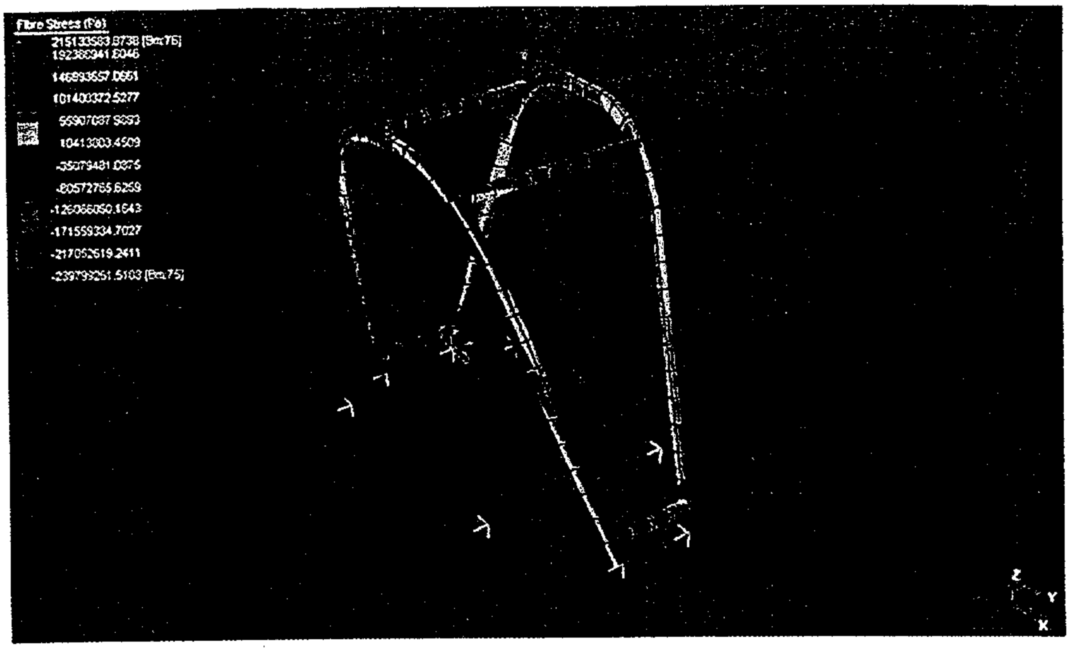


Figure 35: Stresses in the ROPS structure for Loading Condition 3

The mass of the simple structure is 19kg and it is estimated that the addition of the simple structure would decrease the Stability Factor for a seated operator to 0.69 (left) and 0.61(right). The decrease in Stability Factor approximates to overturn angles of 32° (left) and 30° (right). The simple structure is based on 50 x 25 x 2mm rectangular hollow section (Duragal 400) and Ø32 x 2mm circular hollow section (Galtube plus 300).

The addition of the simple structure and the use of an effective occupant restraint to prevent complete or partial ejection will dramatically reduce the risk of injury or fatality for the operator, as demonstrated in the following section (Chapter 6) of this report.

It is noted that the ROPS presented here is a simplified structure and that refinements in both shape and design would occur for final design, particularly one that is integrated with the design of the ATV from the beginning.

6. MODELLING OF ROLL-OVER PROTECTIVE SYSTEM FOR ALL TERRAIN VEHICLES

6.1 Introduction

The computer program MADYMO was used to assess the roll-over protective system proposed in this report. A Honda TRX350 ATV was modelled as it was deemed typical of the range of ATV's used on farms.[5] The ATV's geometric dimensions were obtained from a demonstration model provided to the Department of Civil-Engineering from Honda Australia. Figure 36 shows a view of the ATV.

Figure 36 View of Honda ATV used for dimensioning the MADYMO model.

The Roll-Over Protective System includes the roll-over protective structure, a seat back with side bolsters and seat belts. The computer reconstruction of the ATV, the Rollover Protective System, the rider and slope terrain is based on information gathered from various sources as detailed in previous chapters.

Because of the time and development cost constraints, only six cases (scenarios) were modelled (see the CDROM enclosed). In all cases the ATV was travelling along a 30° slope with the downward side of the slope on the rider's right side (as seen by the rider looking forward). A large rock was used to trip the ATV into a rollover in all six cases. While it is understood that roll-overs have occurred in a number of different scenarios, the cases used were selected with due regard to the epidemiological profile as illustrations of typical fatal and serious injury scenarios. Moreover it is highly likely that the design of the

[5] As advised by Mr Ray Newland, Federal Chamber of Automotive Industries.

Rollover Protective System would cater for other roll-over and impact situations such as forward and rear impact and subsequent pitching rollover. The six cases modelled were:

Case 1: ATV moving at 7 km/hr - No Protective Structure or seat belts

Case 2: ATV moving at 7 km/hr with Rollover Protective System

Case 3: ATV moving at 30 km/hr – No Protective Structure or seat belts

Case 4: ATV moving at 30 km/hr with Rollover Protective System

Case 5: ATV moving at 20 km/hr – No Protective Structure or seat belts

Case 6: ATV moving at 20 km/hr – with Rollover Protective System

The ATV's Rollover Protective System was designed using, for guidance, the BMW C1 motorcycle shown in Figure 37 as an example of a tested protective system. This motorcycle has a rollover protective structure, a safety seat with side bolsters and cross over inertia reel seat belt system.

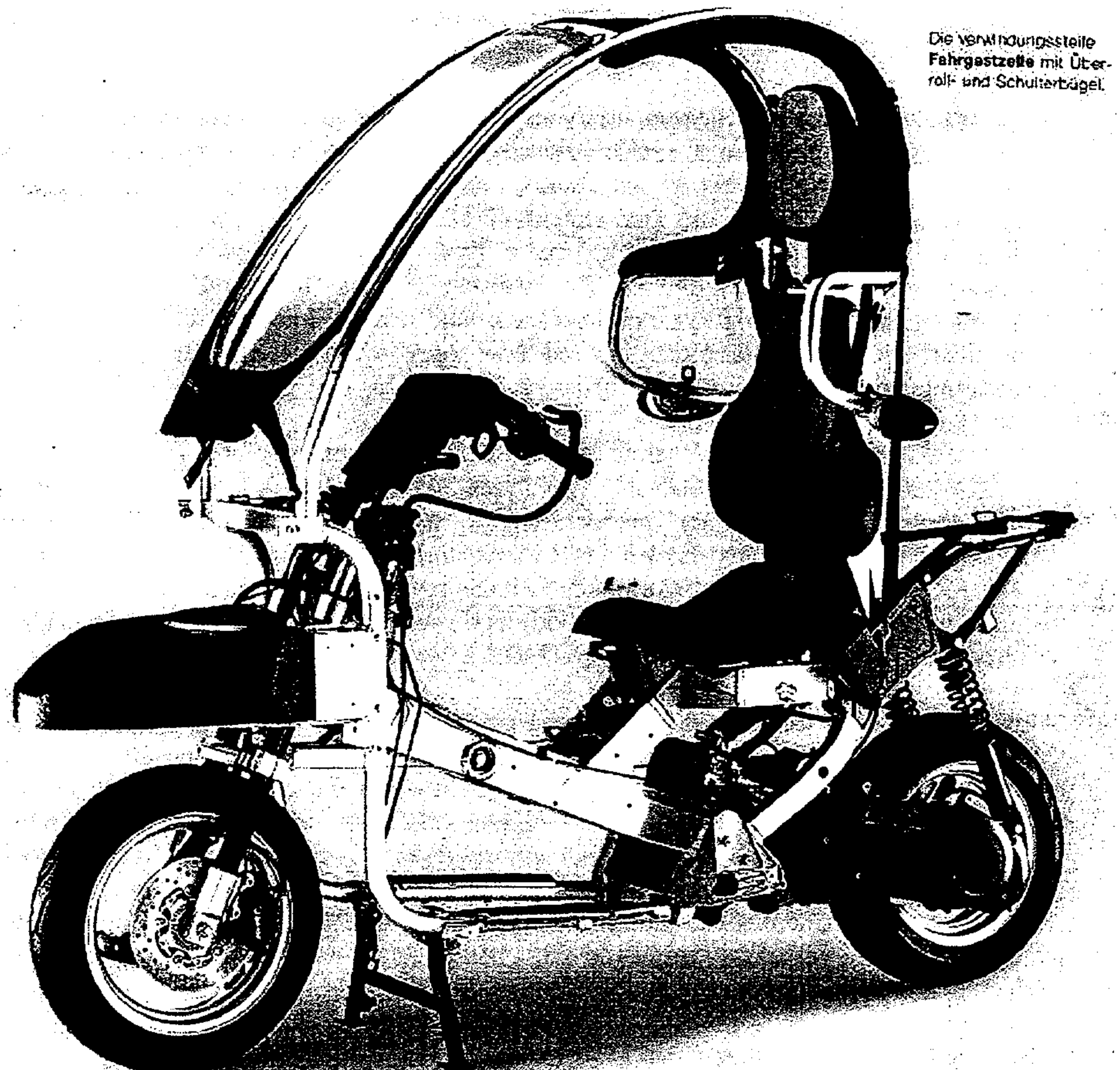


Figure 37: BMW's C1 crashworthy motorcycle

A number of supplementary tests were also carried out to provide information for the MADYMO modelling process. Tilt tests were carried out on the Honda ATV (without a rider) to ascertain the ATV's centre of gravity (COG) and with an "active" and "non-active" rider to ascertain the angle at which rollover is imminent (see Chapter 4). A compression test on the ATV's suspension strut was carried out to ascertain the strut's load displacement response. A head form drop test onto bare ground was also used to assess ground compliance.

6.2 Methods

Computer model

As mentioned above MADYMO was used to model the ATV shown in Figure 36. The two MADYMO models of the ATV; with a rider and no ROPS and with a rider with the ROPS, are shown in Figure 38. The ATV's dimensions for the Models shown in Figure 38 were measured from the vehicle shown Figure 36. It should be noted that the seat belt crossover restraints have been modelled even though they are not clearly visible in the bottom image shown in Figure 38.

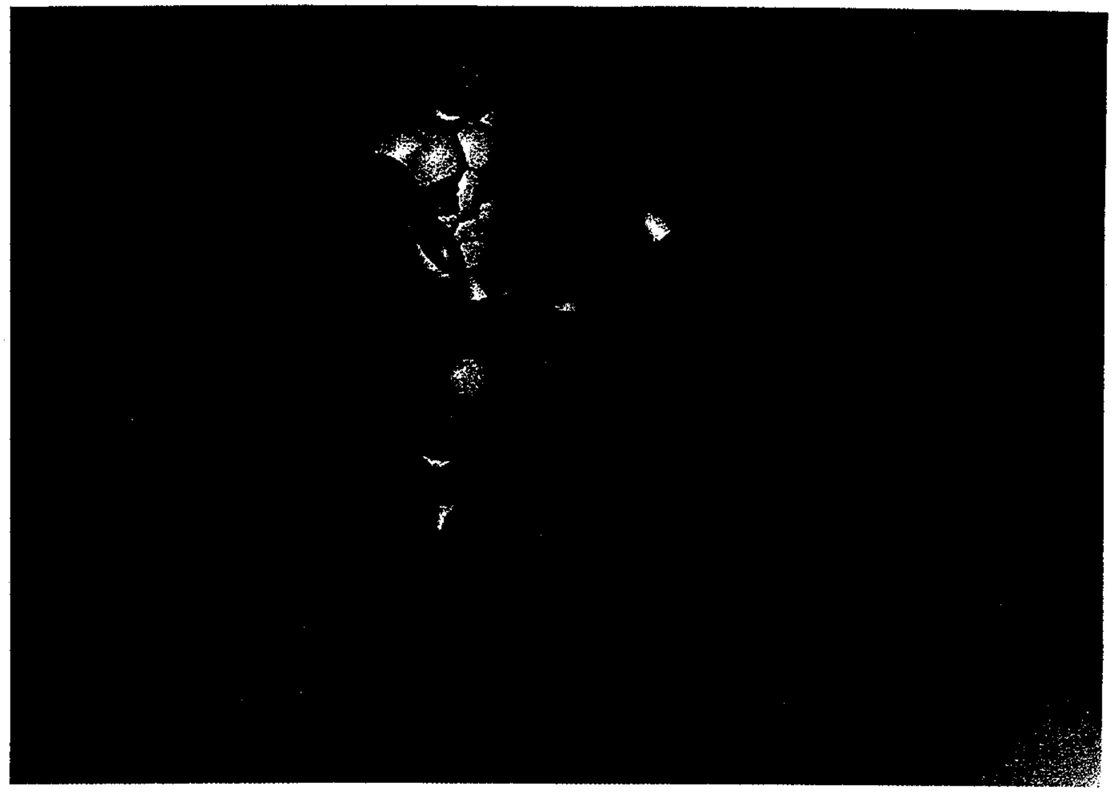
While MADYMO can be programmed by any engineer competent in computer modelling, accurate modelling requires a senior research engineer that specialises in MADYMO analyses and who has access to test results for validation purposes. Dr. Roger Zou (a Senior Research Fellow in the Department of Civil Engineering, Monash University), carried out the MADYMO modelling under Prof. Raphael Grzebieta's (an Associate Professor in the Department of Civil Engineering, Monash University) supervision. Dr. Zou has approximately 10 years experience and Prof. Grzebieta around 20 years experience in such computer modelling and have access to engineering data from the Civil Engineering Department.

MADYMO (MAthematical DYnamic MOdel) is a general-purpose engineering computer program using multibody analysis techniques. MADYMO is commonly used by manufacturers and regulatory authorities for assessing occupant protection and crashworthiness of vehicles as well as to investigate numerous other safety systems. MADYMO is extensively used worldwide in industry and research for the analysis of non-linear dynamic responses of the human body and mechanical systems to impact loads. It has been developed in the Netherlands by TNO.[6]

Although originally developed for studying occupant behaviour during vehicle crashes, MADYMO is a sufficiently flexible code that can be used for modelling and analysing collisions, vehicle crashworthiness, crash victim safety, vehicle dynamics, and accident reconstruction involving many other vehicles such as trains, aeroplanes, ATVs, motorcycles and even bicycles. Various restraint systems including seatbelts and airbags can also be assessed using this program. The MADYMO program has been extensively validated against numerous laboratory crash tests worldwide using crash test dummies and cadavers, and against real world crashes. A selected number of paper references concerning model validation can be located at the web site:

http://www.automotive.tno.nl/smartsite.dws?id=1002.

[6] See http://www.automotive.tno.nl/madymo/



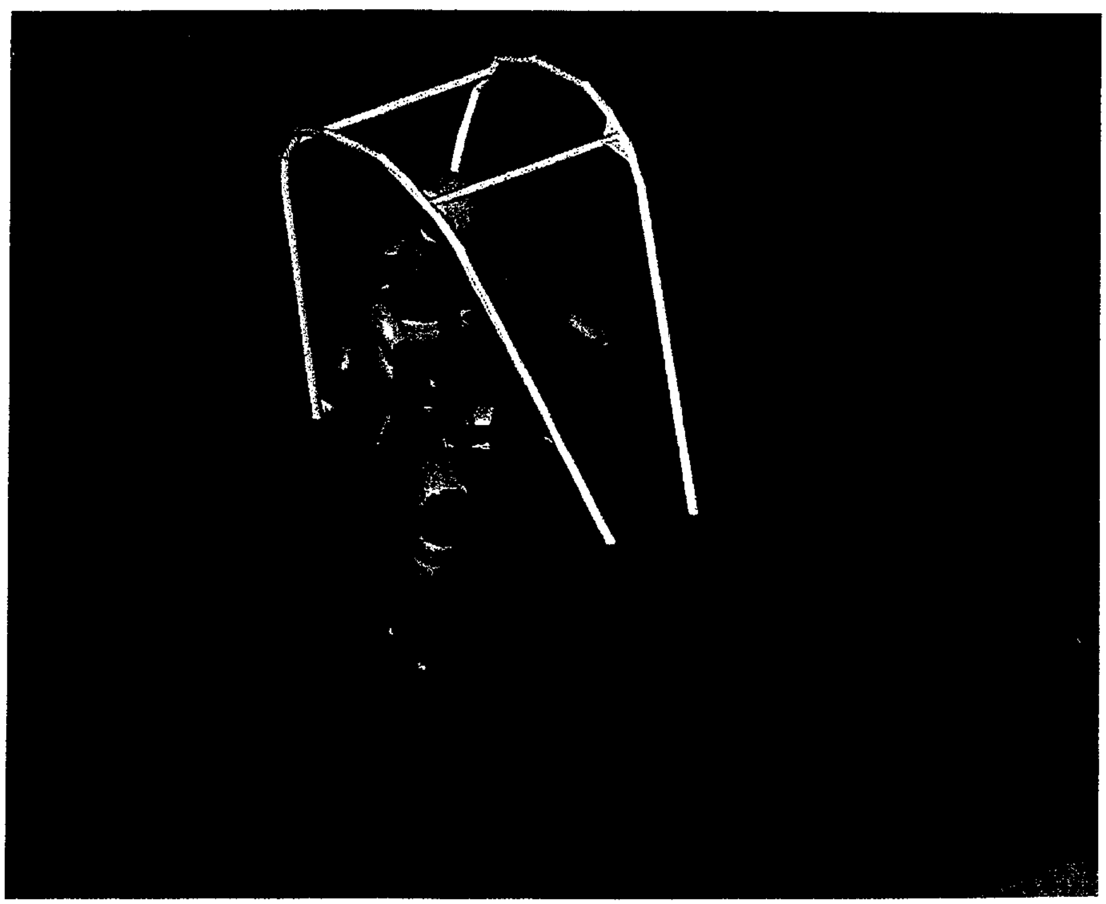


Figure 38: MADYMO models used for simulation. Top: normal configuration, bottom: with Rollover Protective System.

In Australia, MADYMO simulations have also been used in evidence for two Coronial Inquests in Australia – Death of Nicole Franks in a Go Kart fatality in Wollongong (by Grzebieta) in February 2002 and Death of Ernest Bowd, an elderly pedestrian struck by a van with a bull bar in Melbourne in 1992 (Case No. 2967).

Equations of motion, derived from Newtonian laws of physics, are used to determine the movement and interactions of the ellipsoids and planes that model the rider, the ATV vehicle, the rollover protective system, the seatbelts and the rock and sloping terrain.

Computer dummy model and injury criteria

A 50th % male dummy model (representative of a 50^{th} % adult male) was used as a surrogate human rider. The weight of each dummy is 78 kg and has a height of 175 cm. The movement and deformation/response of each of the surrogate's body parts has been validated against cadaver and crash dummy laboratory tests. MADYMO can also calculate the impact forces and deflections imposed to the surrogate and associate these forces with injury criteria established from cadaver testing and epidemiological studies. The Hybrid III 50^{th} % ellipsoid dummy model used in the analysis is also described the MADYMO Database Manual (Version 6) in Appendix E. References are also made in this Appendix to seminal papers where model configuration and validation is described in more detail.

For Cases 2 and 4 the dummy was restrained using a cross over seat belt system as sketched in Figure 39. The seat belt is made up of a lap sash system with a second sash only crossover belt, i.e. two buckles need to be fastened[7].

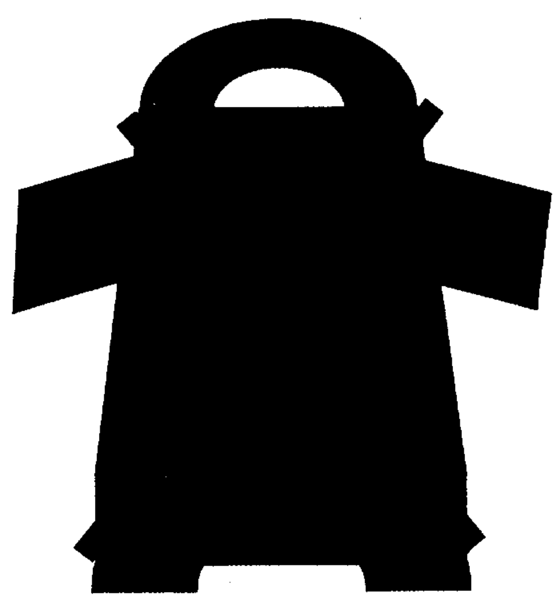


Figure 39 Cross-over seat belt system.

MADYMO can also calculate injury values based on impact force and displacements. The threshold values quoted in this report were obtained from the USA's National Highway Safety and Transport Administration (NHTSA) documentation that is available on the world wide web [Kleinburger et al (1998), Eppinger et al (1999), Eppinger et al. (2000)].

[7] This seatbelt system is intended to be indicative of what is needed, but other systems may also be effective subject to evaluation.

The NHTSA documentation also provides an excellent overview of how the relationship between injuries sustained, injury threshold values and impact loads was obtained. In summary, the injury thresholds were developed on the basis of experimental tests of human surrogates (human volunteers, cadavers, animals such as pigs, computer simulations, accident reconstructions, and crash test dummies) where both measurable engineering parameters and injury consequences have been observed and the most meaningful relationships between forces/motions and resulting injuries are determined using statistical techniques.

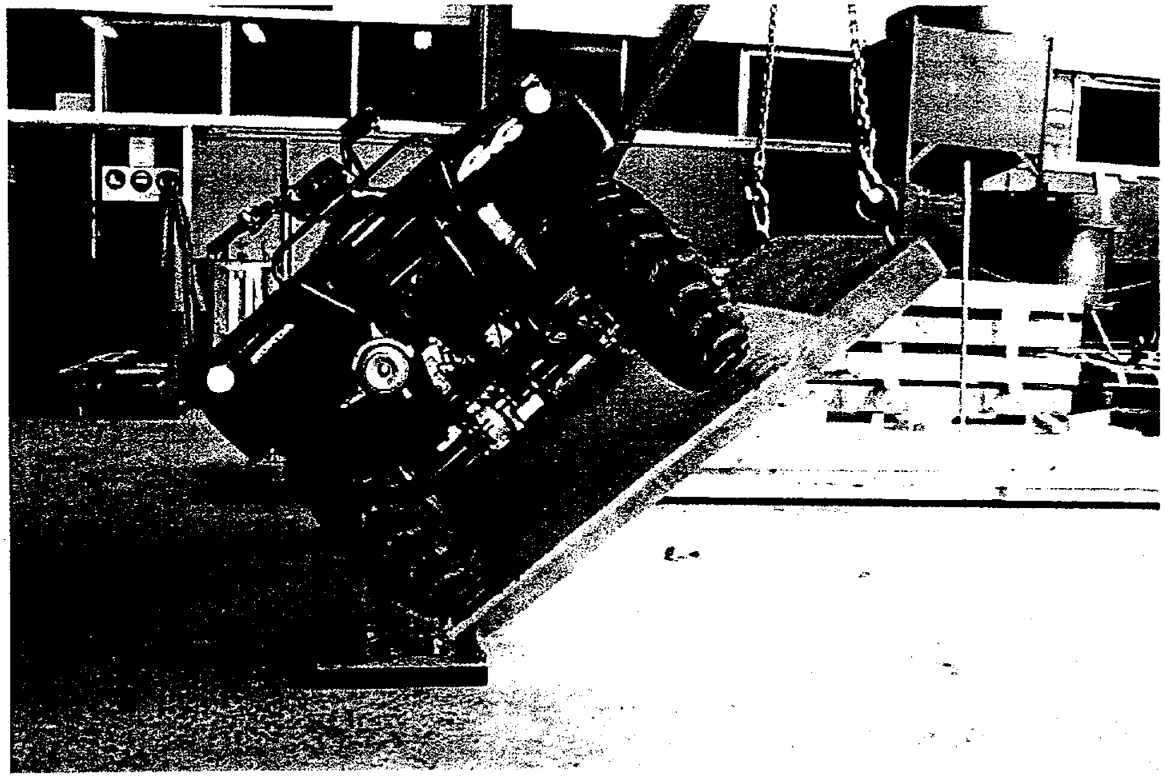
Vehicle characteristics

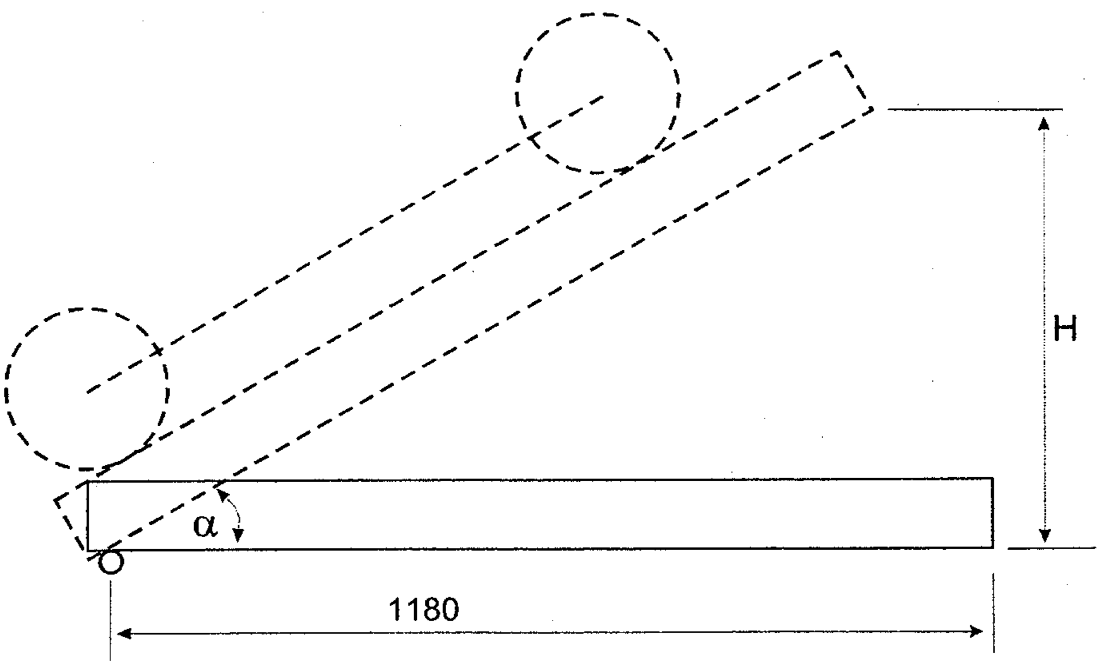
In order to model the vehicle it was necessary to determine its centre of gravity (COG) and rotational inertias. The rotational inertia's provided by Tyler-Street (1999) were adopted as an adequately close approximation. To determine the ATV's COG the vehicle was tilted on a flat board as shown in Figure 40. The key dimensions including the vehicle's COG and wheel mass values are provided in Figure 41. The methodology used to determine the COG is explained in Chapter 5. The value of mass in brackets in the top diagram is the mass of each wheel.

Tyre, Suspension and terrain compliance

One of the tyres was also compressed in a Baldwin universal compression testing machine set to a 10 kN range in order to obtain its elastic characteristics. The load deformation plot is shown in Figure 42.

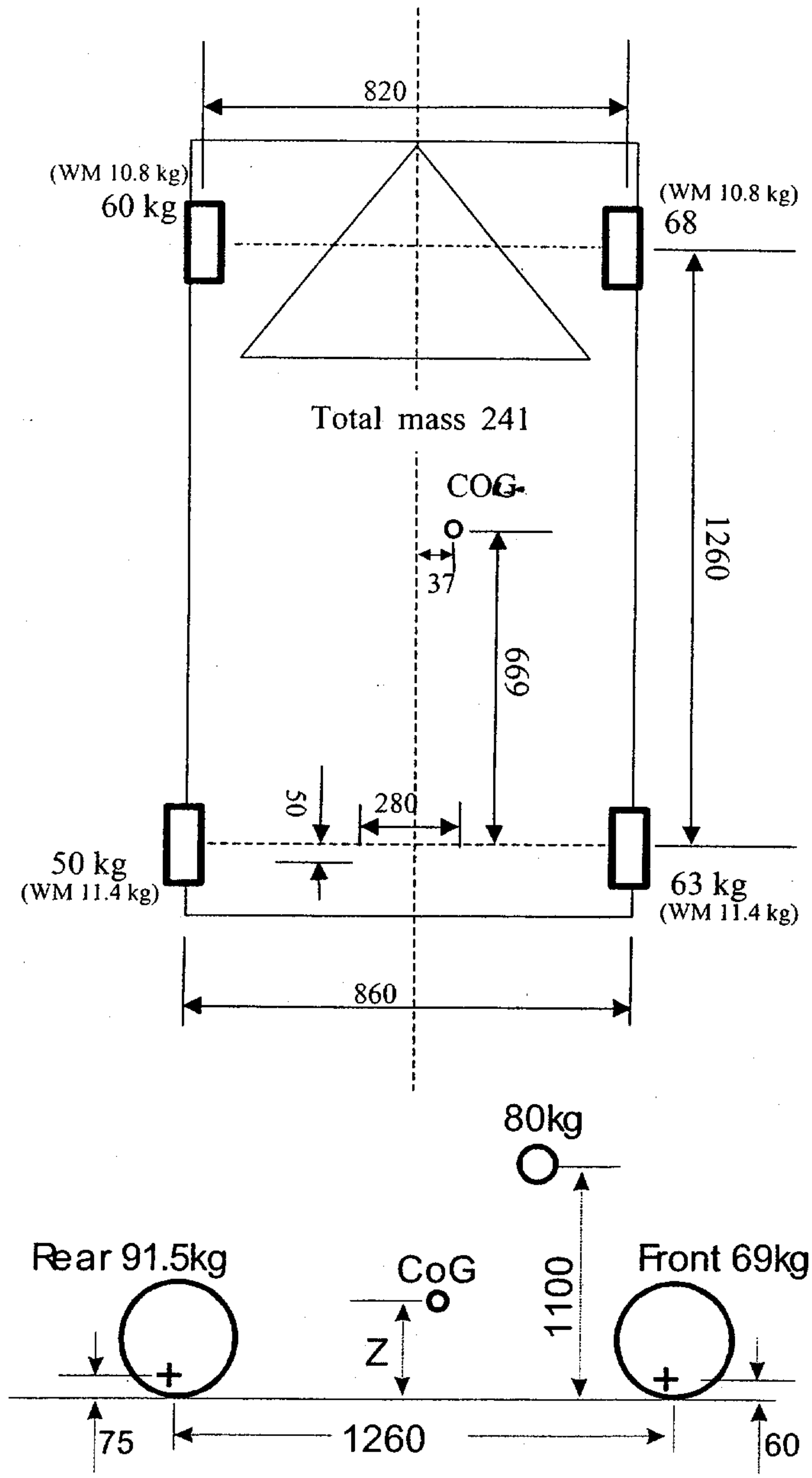
The ATV's suspension characteristics were obtained by dissembling one of the vehicle's shock absorbers and placing it into an Instron testing machine as shown in Figure 43 and measuring it's load-deformation behaviour. The strut was tested in a vertical position. However it is fixed into the vehicle at an angle as shown in Figure 46. The deflection used to model the suspension's load-deformation behaviour in the model was a resolved displacement as shown in Figure 45.





Roll to the left:	No rider:	H = 745mm,	$\alpha = 39.15$ deg
Roll to the right:	No rider:	H = 740mm,	$\alpha = 38.84$ deg

Figure 40 Tilt test to determine ATV's COG.



The center of gravity height, Z= 410.8mm
(see Chapter 4 for explanation of how COG and mass was determined)

Figure 41: Key dimensions, wheel loads, mass distribution and position of COG.

Table 7 **Honda TRX350FM ATV Vehicle characteristics.**

Mass	
Total mass	241 kg
Front wheels	10.8 kg
Rear wheels	11.4 kg
Location of Centre of Gravity	
X with respect to rear axle center line	0.669 m
Y with respect to vehicle center line	-0.027 m
Z with respect to ground	0.410 m
Suspension ride height	
Wheel base	1.26 m
Track front	0.82 m
Track rear	0.86 m
Moment of Inertia (Calculated based on Tyler-Street, 1999)	
Ixx	25.19 kgm^2
Iyy	68.46 kgm^2
Izz	78.05 kgm^2

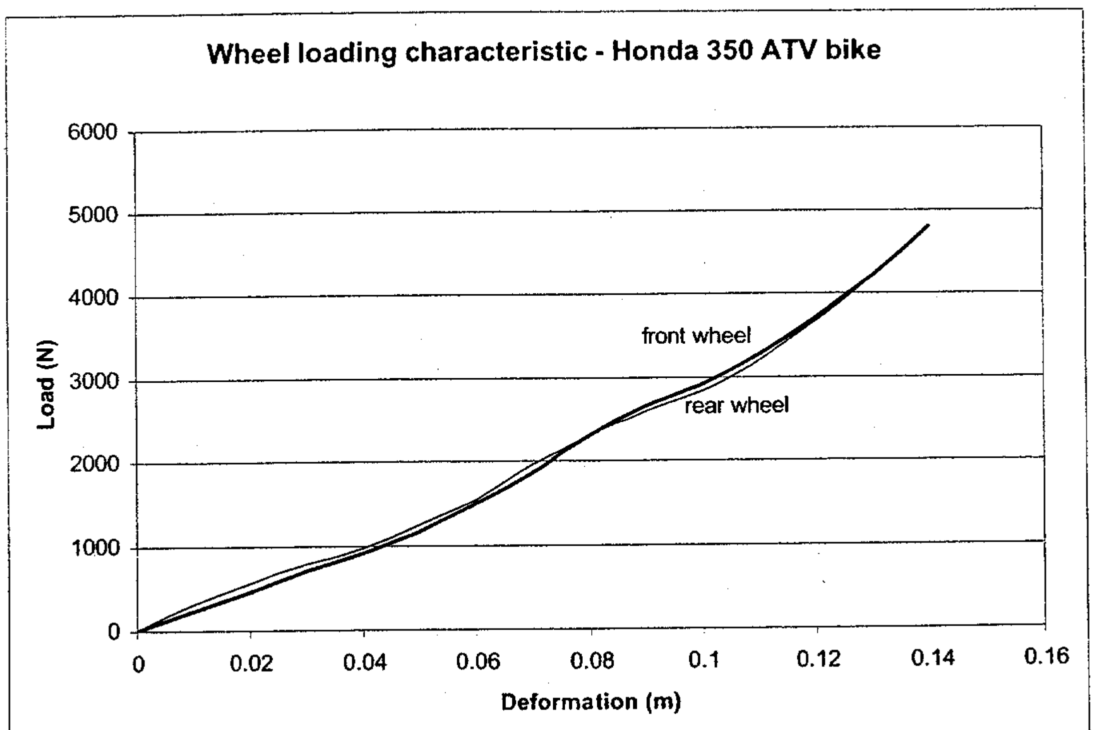


Figure 42: Wheel loading deformation plot (tyre pressure 3.7 psi, wheel diameter 590mm).

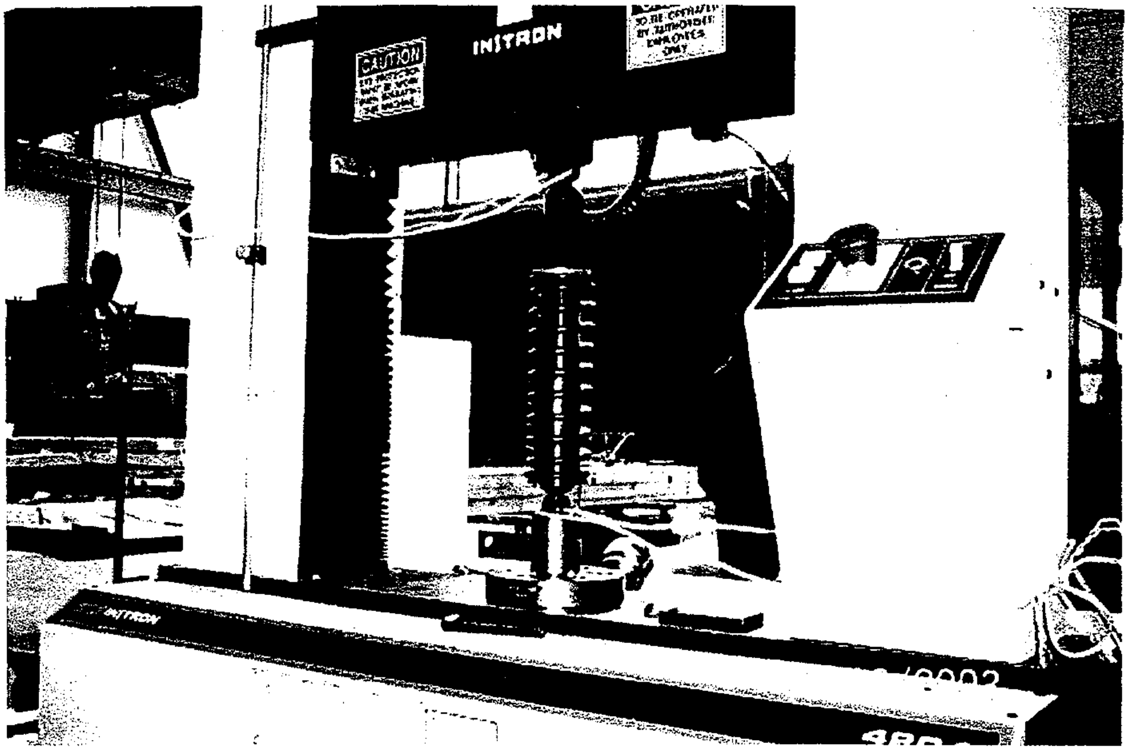


Figure 43: One of the ATV's struts being tested in the Instron compression testing machine.

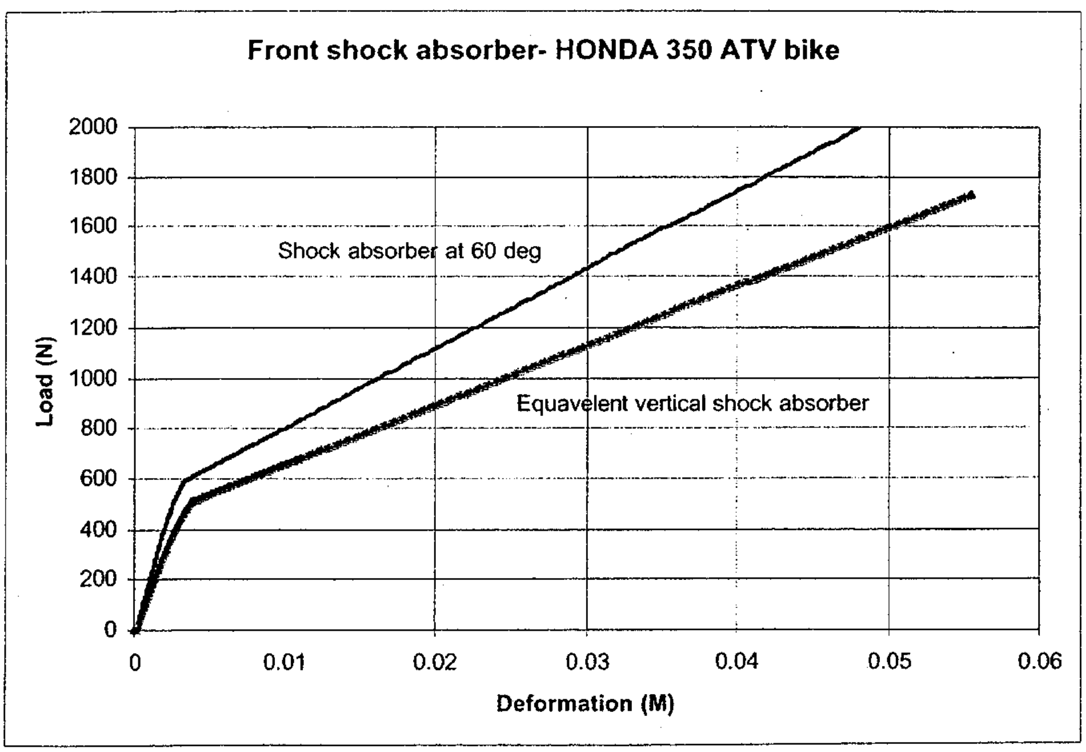


Figure 44: Load deformation plot from compression test of shock absorber (see Figure 43 above)

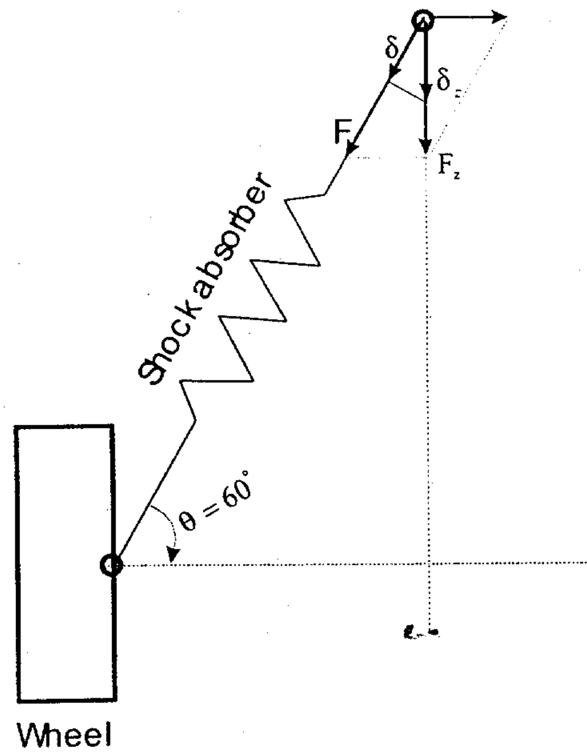


Figure 45 Diagram showing how response force from (Instron) compression test of shock absorber was resolved and used in MADYMO model.

Figure 46: Front view of ATV. Suspension struts are inclined to vertical dierection.

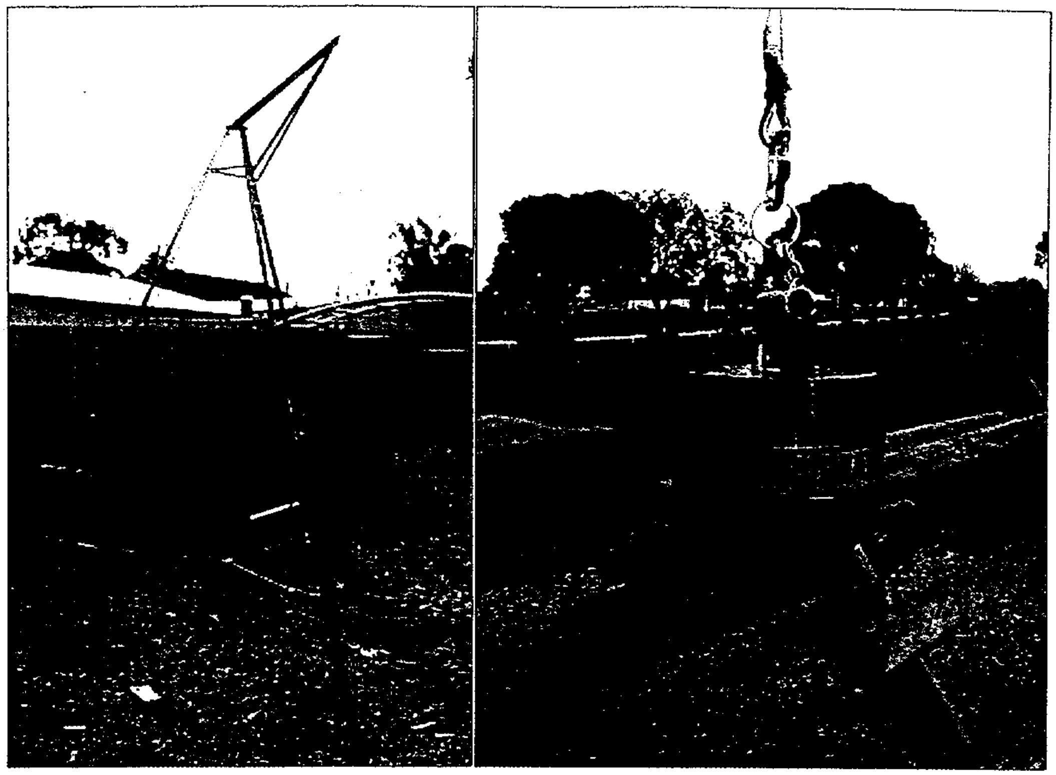


Figure 47: Drop rig and head form used to determine compliance of ground surface shown in Figure 48.

Figure 48: Ground surface where head form test was carried out.