THE ROLE OF IN-DEPTH INVESTIGATIONS IN INJURY RESEARCH AND PREVENTION

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ABSTRACT

Examples of five in-depth case studies ranging from pram-related infant fatalities to fatalities arising from falls from height involving fall-arrest devices and stuntmen airbags, are presented. These in-depth investigations clearly identify the injury causal factors and equipment design deficiencies. The discussion of these results and methodology are used to clarify the benefits to be gained from in-depth investigations incorporating experimental techniques together with analytical methods drawing on the laws of physics and engineering. In-depth investigations complement epidemiological and statistical studies, and are essential for gaining the insight needed to understand the accident and injury process, thus providing a robust basis for countermeasure development.

INTRODUCTION

Injury research and prevention activities are multifaceted and cross many disciplines, including epidemiology, medicine, statistics, human factors and engineering. Yet it is important to recognise that prevention is not just a statistical and policy issue but one of application[1]. Effective prevention requires, therefore, a robust understanding of the *accident process* and *injury process*.

Whereas epidemiological and statistical data analysis helps to tell us about incidence and risk factors as well as giving potentially useful signposts (associations) – they can not usually give us the detailed understanding of 'what went *wrong' and what is needed to remedy the situation.* This level of understanding and the needed level of *insight* into the accident and injury process require in-depth investigations and studies. These studies help provide both descriptive and quantitative information that engineers and designers need for improving product design. As Winston, Schwarz & Baker[2] (1996) note in contrasting the significantly different perspectives of epidemiologist and biomechanical engineers in assessing bicycle helmet performance: "*Without the input of bioengineers, the epidemiological approach identifies areas for further study but no new technologies are generated: the existing epidemiological results lack mechanical data needed by the engineer".* Winston et al go on to set out a methodology for combining the best of the multiple disciplines in injury studies.

Injury Process and The Laws Of physics and Engineering

In dealing with the *injury process* side of 'accidents', it is important to recognize that injury outcomes can be predictable (given sufficient knowledge) and are already *set in place* on the 'design drawing board'. Incident outcomes are not a random variation or response, but result from inherent characteristics and physical attributes of the system[3]. Such interactions are essentially repeatable, as they, of course, obey the laws of physics and engineering. An incident represents a "real world" experiment or 'crash' test - with the 'crash' performance characteristics revealed and ascertained from the detailed investigations. It is through in-depth investigations of incidents that we can obtain the feedback and insight into real-world system performance.

Databases

Injury databases are typically inadequate in being able to provide real understanding of the causal chain of events or the injury process itself. Injury databases describe an incident through selected and discreet variables - they in fact form an abstraction of reality. They thus provide a limited description of the 'universe', with any analysis of this data restricted accordingly. In-depth investigations are an essential complement to epidemiological and statistical analysis, and provide information that cannot be obtained from databases or in other ways.

Method for in-depth investigations

A very effective and powerful method for investigation of incidents in regard to the injury process, is the use of a three pronged strategy[3], which enables a very clear and robust understanding of "what went wrong"; how the injuries resulted; and principles for countermeasure development. This methodology is based on combining: (i) the insight gained from the in-depth investigation and testing; (ii) a critical examination of the design criteria and performance standards that the item must comply with, in the context of physics and engineering principles; (iii) combined with a review of the available research literature. Recognising that performance is the deterministic outcome of the regulation-design-manufacture environment and the laws of physics and engineering, this methodology therefore does not require large sample sizes needed for statistical power to determine correlations or to gain an understanding. The methodology is very direct and economical, enabling strategic assessment and homing-in on significant problem areas from the investigation of *individual* or small groups of similar incidents. The linking of these in-depth findings with appropriate epidemiological studies helps to form a robust basis for countermeasure development and implementation.

EXAMPLE STUDIES

To illustrate the above, examples of five in-depth case studies of fatalities involving pram-related infant fatalities to falls from height (and failure of associated safety equipment), are presented.

1. prams (3 fatalities)
2. stuntman airbags (2 fatalities)
3. fall-arrest device (1 fatality)

The results from these in-depth investigations clearly identify the injury causal factors and equipment design deficiencies. The discussion of these results and methodology are used to clarify the benefits to be gained from in-depth investigations incorporating experimental techniques together with analytical methods drawing on the laws of physics and engineering.

Fig. 1. Emmaljunga pram with backrest off frame and dropped down. Note inverted sleeve forming pocket.

1. PRAM FATALITIES

Fatal incidents involving young babies left sleeping in pramette type units, have been subject to Inquest[4],[5] both in Victoria and New Zealand. Although the actual design and features of the first two cases involving an Emmaljunga model stroller/pram are different to that of the third case involving a Burwood model pramette, the three incidents are related as they all involve key elements of the pram backrest which can be inappropriately removed, leading to instability of the unit, and subsequent asphyxiation of the infant.

The first two incidents relate to an Emmaljunga model pram/stroller in which the rear adjustable backrest is supported by a ‘loose’ fabric sleeve which fits over the frame of the unit. Careful examination and testing of the pram[6] identified that the sleeve fitting could, unknown to the user, progressively rolloff and come free of the supporting frame (Figure 1), allowing the backrest to drop down with the sleeping child sliding down and rearwards (Figure 2) into the pocket formed by the inverted fabric sleeve. Asphyxia
tion was determined as the cause of death in both of these cases.

Fig. 2. Emmaljunga pram with backrest off support frame and the head of the baby ‘dummy’ slid down into the pocket.

The third case involved a 7-month-old baby girl left sleeping in a pramette. In this case the pram was found tipped over backwards; the pram handle was set in the rear position and the backrest lowered into the pram position; the pram base was open at the rear due to the rear flap not being clipped onto the rear head bar.

A series of tests[7] were carried out on the Burwood unit using a standard TNO ‘child’ crash test dummy, borrowed from Autoliv’s Crash Test Facility in Campbellfield. The dummy is a 9kg unit with articulated limbs and head. Its mass is slightly higher than that of the infants in question (which was 7.6kg without clothes) and its length at 730 mm is close to that of the deceased infant’s length of 680 mm.

The back ‘head board of the pramette unit (Figure 3) is attached to the frame by means of a fabric sleeve with press studs. Although not intended by the manufacture, it can be removed and laid horizontal. An infant can fit under the rear white frame, and move rearwards sufficiently to cause instability of the pram. This is illustrated in

Figure 4, which shows the position of the child dummy after the pram was allowed to tip rearwards due to the mass of the 'baby'. In this case the frame forms a 'scissor action' across the stiff lower chest section of the dummy. Note that the pram's hood has been removed for clarity.

Fig. 3. Burwood model showing removable head board.

Under these circumstances the baby could either become trapped in the scissor action of the frame, or be loaded by the units handle or other parts of the frame, and/or be covered by the fabric of the hood – or combinations of these factors. Any of these circumstances could lead to "asphyxiation" directly or indirectly.

As a result of these incidents the standard for prams and strollers AS/NZS 2088 has been amended[8,9] to preclude the use of loose fittings, and require additional tests to help ensure designs which prevent entrapment and possible strangulation/ asphyxiation.

Fig. 4. Unit tipped rearwards, with 'baby' trapped by scissor action of frame.

In addition Emmulunga has issued a consumer advise and recall of the particular model for retrofit of a safety sleeve. The Burwood model has been replaced with the upgraded Richmond model in 1997, which has been modified by adding a fabric barrier (Figure 5) underneath the upholstery for protection in case the upholstery at the rear of the pram was unfastened and removed. It is important to note that an infant properly restrained by the safety harness could not move into a position to cause instability of the pramette.

However it is noted that, because the rear frame of the pram overhangs the rear wheels, instability can still arise if a sufficient load is applied to this cantilever overhang. The Stability tests required by AS/NZS2088:93 do not appear to address this issue, and need to be reviewed accordingly.

2. INVESTIGATION INVOLVING STUNTMAN AIRBAGS

Following the deaths of two stuntmen in separate incidents involving high falls onto stuntmen airbags, in-depth investigations[10] were conducted into the airbags performance, at the request of the Victorian State Coroner.

Fig. 5. New Richmond model with revised head board design with non-removal fabric sleeve.

In the first case the deceased was participating in an organised practice session for stuntmen, practicing high falls from a scissor lift onto an airbag. The platform was at a height of approximately 10m off the ground. The deceased had completed 14 jumps on the day, and in the jump in question had pushed off from the platform, landing near the far side of the bag. Following the jump the deceased was found unconscious on the bag, with no external injuries evident. The Hospital report showed the deceased to have suffered severe head injury with extensive skull fracture, brain swelling and traumatic subarachnoid haemorrhage.

In the second case the deceased was a professional stuntman, who jumped from the top of a wheat silo (25m high) as part of a jump for a movie being filmed. A practice jump was performed from the silo by Mr Dragsbaek, without incident. Empty cardboard boxes were added around two sides of the airbag, intended as an added safety precaution. The stunt was then performed for filming of the actual movie. In this case Mr Dragsbaek launched himself from behind and over the railing on top of the silo, and it appears launched himself out too far as he landed towards the edge of the bag with his feet hitting the cardboard boxes, but his head and torso on the bag. Mr Dragsbaek received severe head injuries and died that evening. The **autopsy** report noted cause of death as multiple fractures of the skull with lacerations of the brain. Signs of injury include a large contusion on top of the head.

In this case the investigation included a detailed test program for each airbag, to determine the *relative* performance of the airbags in terms of deceleration of a 'human surrogate' in high falls onto the bag in the following positions: (i) centre, (ii) off-centre, (iii) at the edge of the bag. The aim was to determine from the drop tests and the airbag's performance the likely cause of the head injuries of the two stuntmen.

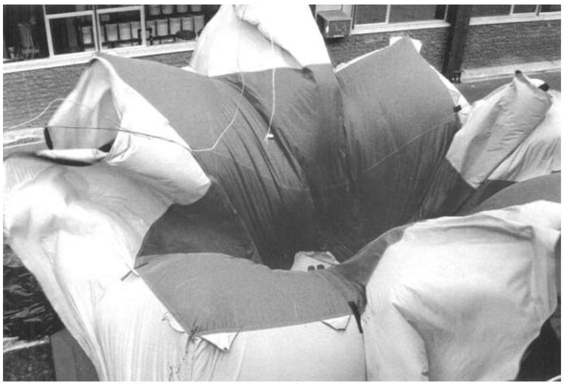

Fig. 6, Centre drop test, double chamber airbag.

Fig. 7, Edge drop test, double chamber airbag

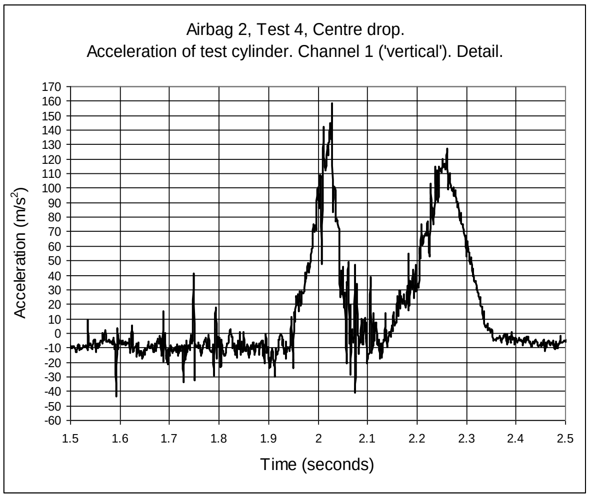

Fig. 8. Vertical accelerometer results for centre drop test, show the deceleration pulse for the upper and lower chamber.

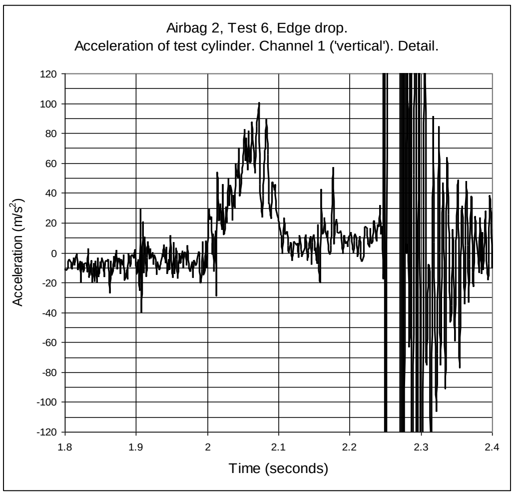

Fig. 9. Vertical accelerometer results for edge drop test, shows the deceleration pulse for the upper chamber, and ground impact.

The deceleration response of a 'mass' landing on an airbag can be determined by the use of accelerometres fixed to the falling mass. After careful consideration of the physical and logistic test requirements, a LPG gas cylinder (1.47m long by 0.3m diameter), weighted to 100kg, was used as the surrogate 'human'. The gas cylinder was selected as it was most likely to give reproducible results; could be readily instrumented; could be readily reused in each test; was similar in size (and mass) to a human torso so that its response would be sufficiently similar to that of a person landing on the airbag. Although the use of an anthropomorphic test dummy was considered, this was prohibitive from a cost point of view, as well as presenting significant handling difficulties in such a test.

A total of six drop test (3 per airbag) were carried out to determine the relative performance of the two airbags for falls of a 'human surrogate' mass on the centre, off center and edge of the airbags, respectively. The falls at the edge of the airbags were intended to simulate the impact position of the two deceased stuntmen on the respective airbags. The test cylinder and instrumentation performed satisfactorily in the tests and provided the results required to discriminate the airbag's performance.

The test results for the first airbag (drop height 9.2m), showed that for both the centered and off-centre falls (Tests 1 and 3) the airbag performed satisfactorily in that the LPG test cylinder (100kg) was decelerated by the airbag without contact with the ground surface. However for impact near the edge of the bag (Test 2), the bags' performance was not satisfactory as the cylinder was not adequately decelerated by the bag, and impacted the ground with a residual velocity of approximately 3.3m/s.

The test results for the second airbag (drop height 15.3m), for both the centered and off-centr**e** falls, the airbag performed satisfactorily in that the LPG test cylinder (100kg) was decelerated by the airbag without contact with the ground surface. Both the top and bottom chambers made significant contribution to decelerating the test mass (Figures 6 & 8). However for impact near the edge of the bag (Test 6), the bags' performance was not satisfactory as the cylinder was not adequately decelerated by either chamber of the bag, and impacted the ground (Figures 7 & 9) with a high residual velocity of approximately 7.4m/s.

Based on the Tests carried out it was evident that the severe head injuries received by the respective stuntmen can be attributed to the stuntmen impacting the airbags near the edge, with consequent bottoming out of the airbag. This study, which also included a literature review and a review of the industry codes of practice, identified a number of clear deficiencies with the performance of the airbag and the safety approach of the industry.

The State Coroner has recently presented his Inquest findings[11] with recommendation for major improvements for safety for stunt activities in the movie industry.

3. INVESTIGATION OF FALL ARREST DEVICE PEFORMANCE

A fatal accident occurred in September 1996 in which a person fell to the ground while working at a height of some 10m, on a demolition site, despite the use of an inertia reel fall-arrest device. The steel rope of the fall-arrest device (Figure 10) broke during the fall of the deceased. A fall-arrest device is a small portable unit which provides a link between someone working above the ground and a suitable anchorage point, and is designed to slow down and stop the person in case of a fall. In this incident, a significant aspect of the operation of the Fall Arrest device, according to investigations carried out by the WorkCover Authority, is that wire rope most probably acted over the edge of some steel work (refer Figure 11). The unit was anchored at the same level as the deceased - though contrary to the manufacturer's requirement of overhead anchorage – it was apparently in keeping with some industry practice and knowledge.

This study[12] involved the detailed investigation of the performance of the fall arrest device to assist in the determination of the cause of failure and conditions for this to occur. Testing included metallurgical examination and static and dynamic testing. Two load cells were used at the fall arrest device end and the falling mass end to determine the loads in the wire cable and the energy absorption performance of the fall-arrest device (Figure 12).

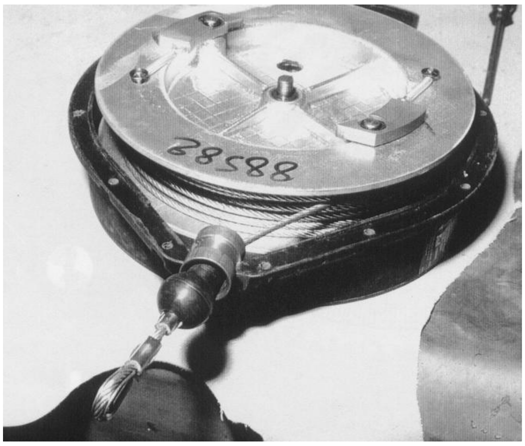

Fig. 10. Inertia reel Fall-arrest device showing the 4mm steel cable.

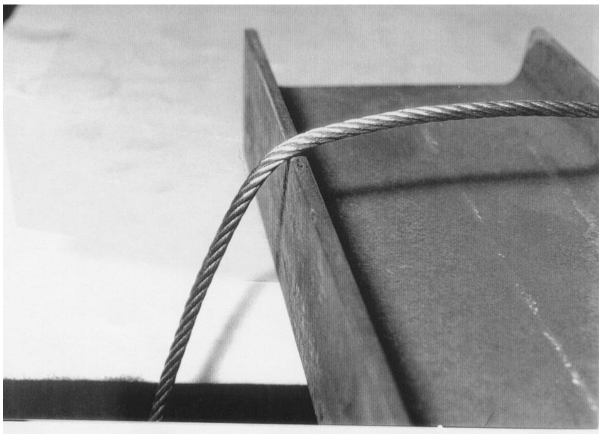

Fig. 11. Wire rope over edge of steel beam used for tests.

A 100kg test mass was used for the dynamic drop tests.

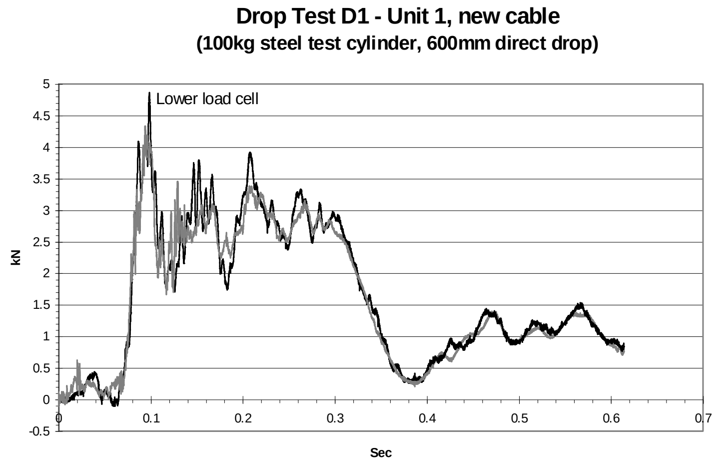

Fig. 12. Energy absorption response characteristic of the fall arrest device - load vs time measured in the straight drop test with the fall arrest device.

The test program carried out by this project has demonstrated the severe degradation in load capacity of the wire rope (up to 50%) and the degradation in energy absorption function, if it is forced to act over small radius corners. The wire rope failed in the three tests conducted over a 'sharp' edged beam. The full tensile capacity of the wire rope/ Fall Arrest device system and associated factors of safety can only be achieved if the wire rope from the unit acts in a straight line between the supported person and unit. Use of the unit in circumstances where this condition can not be assured may render the unit ineffective and offer no assurance of fall protection. Recommendations have been made for significant changes in industry practice in the proper use of these safety devices.

CONCLUSIONS

The examples of in-depth investigations presented related to six fatalities: the findings for five of these cases were used as evidence in Inquests, and in the sixth case for a prosecution involving occupational health and safety breaches.

These case studies illustrate three key components of in-depth investigations:

i) Detailed examination, and analysis of the product/ equipment or process involved;
ii) Reconstruction of the incident, including appropriate scientific testing
iii) Critical review of the design criteria and performance standards that the item must comply with, in the context of physics and engineering principles;

The investigation of the three incidents involving asphyxia of infants left sleeping in pramettes identified problems with the design of the units which could lead to inadvertent instability. As a result of these incidents the standard for prams and strollers AS/NZS 2088 has been amended to preclude the use of loose fittings, and require additional tests to help ensure designs which prevent entrapment and possible strangulation/ asphyxiation. In one case the manufacturer issued a consumer advise and recall of the particular model for retrofit of a safety sleeve. In the second case the manufacturer installed a safety sleeve on the revised model.

In the separate cases of the two stuntmen fatalities involving high falls onto airbags, reconstructing the falls and testing the performance envelope of the airbags, enabled the determination of the causes of the fatal head injuries, and limitations of the airbags' performance. A review of the industry codes of practice also identified a number of clear deficiencies with the safety approach of the industry. The Victorian State Coroner has recently presented his Inquest findings, recommending major improvements to safety practices for stunt activities in the film industry.

The final case related to the use of energy absorbing fall arrest device, which failed to protect a demolition worker who slipped and fell 10m onto a concrete slab. Testing conducted in this investigation identified the severe degradation in load capacity of the wire rope (up to 50%) and the degradation in energy absorption function, if it is forced to act over an edge, such as a beam. Despite manufacturers' instructions to the contrary, industry practice, in many cases, has involved the use of fall arrest devices anchored at the same level as the user, rather than overhead. The tests have demonstrated that such usage provides no real assurance of fall protection.

As a result of these investigations the Victorian WorkCover Authority has issued industry notices for significant changes in industry practice in the proper use of these safety devices.

It is concluded that the role of in-depth investigations is to provide the detailed understanding of injury mechanisms and underlying causal factors, thereby complementing the more general information gained from epidemiological and statistical methods used in injury research. In-depth investigations are essential for gaining the insight needed to understand the accident and injury process, thus providing a robust basis for countermeasure development.

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