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CRASH PERFORMANCE OF EMERGENCY LOCKING RETRACTOR SEAT BELTS

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The Traffic Accident Research Unit was established within the Department of Motor Transport, New South Wales, in May 1969 to provide a scientific approach to the traffic accident problem.

This paper is one of a number which report the results of research work undertaken by the Unit's team of medical, statistical, engineering and other scientists and is published for the information of all those interested in the prevention of traffic accidents and the amelioration of their effects.

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SEPTEMBER, 1976

ABSTRACT

The crash performance of emergency locking retractor (inertia reel) seat belts is examined by in-depth field investigations and by laboratory simulations. It is found that the inclusion of the retractor increases body excursions for the wearer of a lap/sash seat belt. The increase is not excessive and in general, crash performance is found to be satisfactory.

The Australian Design Rule requirements for emergency locking retractor seat belts are examined and a number of deficiencies are discussed. It is concluded that a revised dynamic test is required, based on the limitation of excursions of a specific validated anthropomorphic dummy.

ACKNOWLEDGEMENTS

The work reported here involved many officers of the Traffic Accident Research Unit. Special acknowledgement is due to the laboratory staff supervised by Mr. Neil Gillies and to the in-depth crash investigation teams supervised by Mr. Brian Vazey. Financial support was provided for this study by the Commonwealth Government of Australia.

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INTRODUCTION

Complaints about difficulties experienced in reach to driving controls by wearers of static lap/sash seat belts led to the proposal that drivers should have seat belts that permitted shoulder movement. A survey of attitudes to seat belt usage conducted by Freedman et al.[1*] in 1970 showed that difficulty of reach to controls was one of the main reasons given by drivers for loose adjustment of their belts. Seat belts incorporating emergency locking retractors (inertia reels) permit such shoulder movement and lock if the vehicle decelerates suddenly. Emergency locking retractors also remove unwanted slack from seat belts and provide automatic stowage when unfastened. From 1st January 1975, the front outer seating positions of new passenger cars were fitted with seat belts incorporating emergency locking retractors in order to satisfy mandatory requirements specified by the Australian Design Rules[2].

This report presents the results of an evaluation of retractor performance in traffic crashes and in laboratory tests which included specially devised crash simulations. Most of the specimen retractors were obtained prior to mandatory fitment and this necessarily restricted the field study to cars in which retractors had been fitted voluntarily by manufacturers. Because of this restriction, the car models may not be representative of the current population and the retractors are not necessarily those now being fitted.

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* Numbers refer to References on page 32

FIELD STUDIES

Mackay et al.[3] reported 7 cases in England where excessive unreeling of webbing from inertia reels had occurred and had resulted in wearers of lap/sash retractor belts being injured. In Australia there have been two known cases of excessive unreeling of an inertia reel (both in Silver Anniversary Holden Premier Sedans)[4].

In-depth studies of 349 casualty accidents which occurred in New South Wales in the period 1973 to 1975 revealed 36 cases in which retractors were involved. The criterion for selection of cases was that an adult occupant of a case vehicle was killed or kept in hospital for at least 24 hours in spite of wearing a lap/sash seat belt[5,6] but some cases (the 'S' series) were investigated because they involved circumstances of particular interest. Only 25 of the 36 retractors were of the inertia reel type. The others were all of the non-locking variety that is, they were designed merely to stow the webbing when the belt was not in use. It is well established that such retractors should not be installed, since they might be used with webbing stowed on the reel. Stored webbing will withdraw in a crash, introducing unwanted slack and thus any failure of this system is really a failure of the wearer to tighten his seat belt. Non-locking retractors do not meet Australian Standards[7] and are not permitted by Australian Design Rules[2].

NON-LOCKING RETRACTORS

A typical non-locking type of retractor is illustrated in Figure 1; it is an accessory, "clip on" type, fitted by the car owner to the sash part of a lap/sash belt. Several makes have been available in Australia for some years. The following case histories refer to the use of this type, but the brand names were not identified at belt examination.

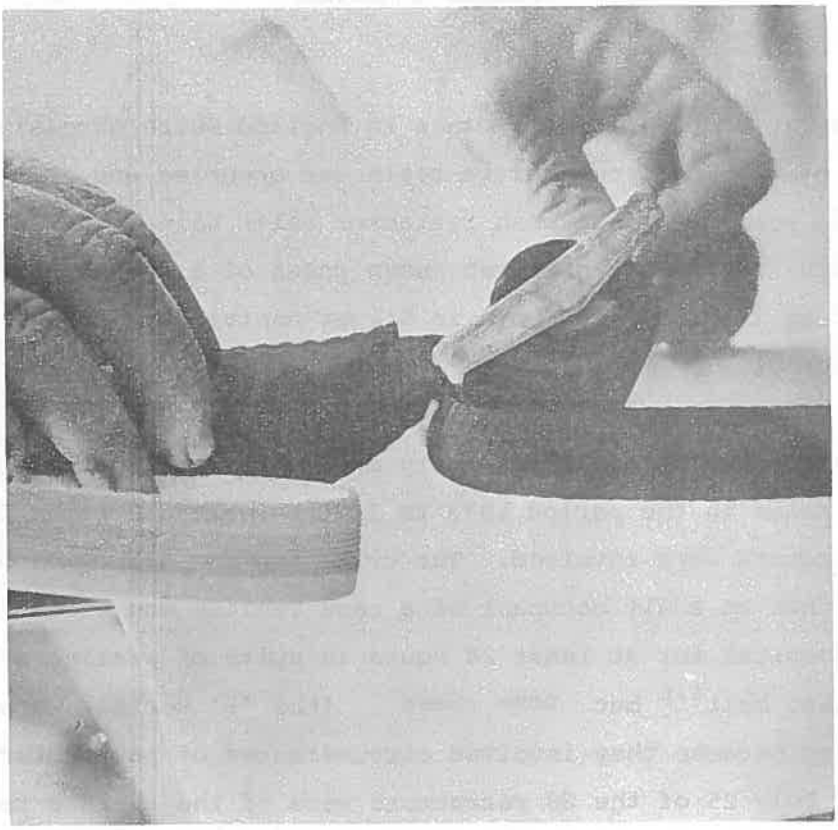


FIGURE 1: "Clip-on" non-locking retractor (TARU Neg. 268/7).

Case 1/5: Retractors fitted to driver's and front passenger's belts in a 1969 model Volkswagen 1600 that ran under the rear of a table top truck on the passenger's side of the car front. The truck tray penetrated the head space of the passenger, pushing the car's bonnet before it; the passenger died of extensive subdural haemorrhage of the brain two days later and it was clear that he would have died even in a tightly adjusted non-retracting belt. The driver received bruising of the left knee, left mandible and left side of the chest, probably produced by impact with the steering wheel and column, both of which were severely bent, because he had introduced slack into his belt. It appeared that the driver would have been uninjured in a correctly adjusted belt.

Case 1/47: Retractors fitted to driver's and front passenger's belts in a 1972 model Datsun 180B that left the roadway on a bridge and plunged into deep water. Little damage was sustained by the cabin of the car. The driver was found drowned with a slight cut on his scalp; it appeared probable that he was knocked unconscious because he was not adequately restrained, and drowned. The front passenger sustained no injury and was able to escape from the immersed vehicle.

Case 1/90: Retractor fitted to driver's belt in 1973 model Leyland Mini 850 that ran under the rear of a semi-trailer. The head space of the driver was invaded by the truck tray and the driver died with extensive facial fractures and a skull fracture. If the seat belt been worn tightly the driver's head might not have been impacted by the truck.

Case 2/14: Retractor fitted to front passenger's belt, but not driver's, in a 1961 model Holden station wagon which was involved in multiple impacts with a car and a truck. The driver, apparently wearing his non-retracting belt very loosely, received a cut to the right side of his head, from an unknown source; the steering wheel was bent, probably by chest impact. The passenger sustained a ruptured spleen, probably from wearing his belt loosely. In each case the occupant would probably have been free from injury in a tight belt.

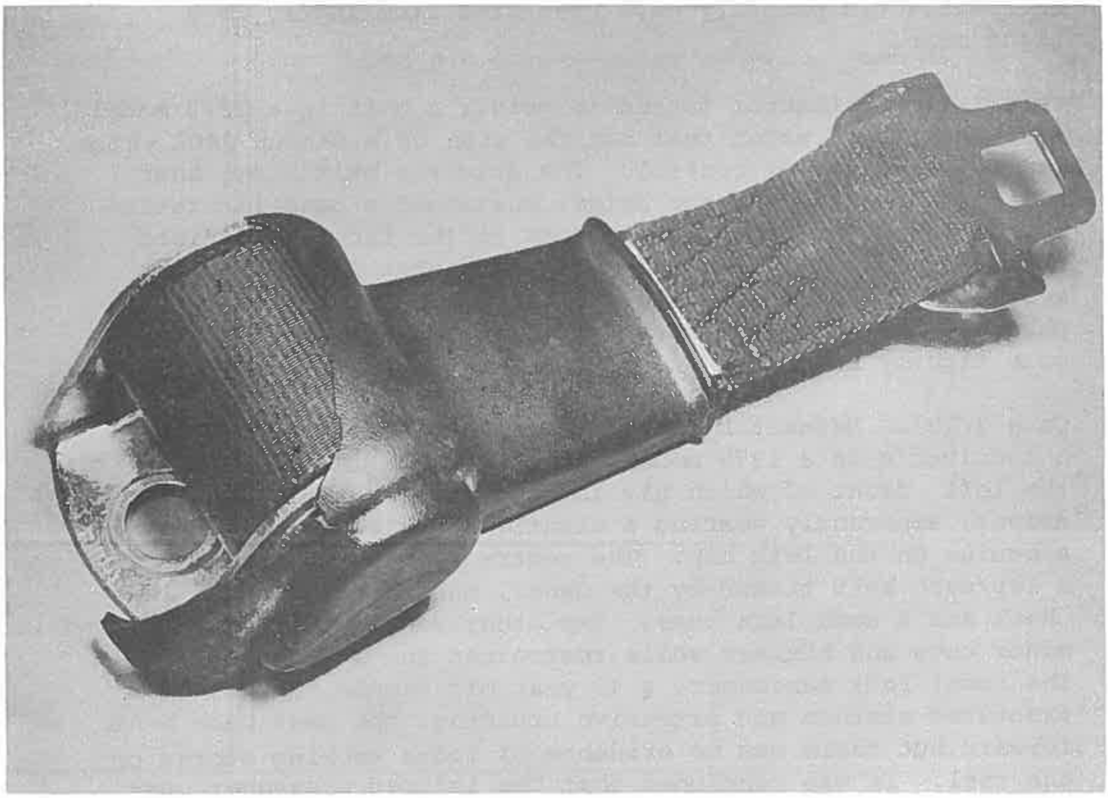
Case 2/71: Retractor fitted to driver's belt in a 1973 model Renault station wagon that hit the side of a Datsun 240Z which was spinning out of control. The driver's belt broke near a floor anchorage and the driver sustained a deep laceration on the forehead, other lacerations to the face and bruised chest and left hip. The seat back adjuster failed and the seat back collapsed,loading the driver and her belt. It is possible that the belt would not have broken had it been more tightly adjusted.

Case 2/107: Retractor fitted to front passenger's belt but not driver's in a 1975 model Chrysler Valiant VG Pacer the left front of which hit the rear of a parked car. The driver, apparently wearing a tightly adjusted belt, sustained a bruise on the left hip. The centre rear passenger, wearing a lap/sash belt fitted by the owner, had a graze on her left cheek and a sore left knee. Two other rear passengers suffered minor cuts and bruises while restrained in lap/sash belts. The front left passenger, a 45 year old female, sustained a fractured sternum and extensive bruising; the seat back bent forward but there was no evidence of loose webbing stored on the reel. It was concluded that the injured passenger sustained additional loading because the seat back failed and that the retractor was used correctly; it is possible that the seat back was contacted by the restrained rear seat passenger.

Case 2/115: Retractor fitted to driver's belt in 1969 model Toyota Crown sedan that was impacted on the rear by another car. The driver was leaning forward to pull on the handbrake and sustained whiplash injury when he was thrown rearwards, breaking the seat back. In this case, the absence of a lock appeared not to be a factor in the performance of the retractor.

All of the above-mentioned retractors were accessories. However in two Toyota sedans manufactured in 1969, non-locking retractors manufactured by Takata have been found mounted on the floor by the car manufacturer in line with the lap strap. One of these is illustrated in Figure 2 and was taken from the car in Case 1/51 described below.

FIGURE 2: Takata non-locking retractor (TARU Neg. 986).



Case 1/51: 1969 model Toyota Corona MKII hit by a truck on the car's left front while the truck was turning right. There was little car damage aft of the fascia panel but the steering wheel spokes were severely deformed deflecting the rim and exposing the hub. The driver died of multiple rib fractures and brain damage, presumably resulting from head and chest impact against the steering wheel. The passenger sustained severe facial injuries from impact with the glove box and fascia. Both occupants should have been free from injury in properly tightened belts.

INERTIA REEL RETRACTORS

In each of the following cases, emergency locking (inertia-reel) retractors were fitted to the sash part of driver's and front passenger's lap/sash belts. It is possible that these retractors did not comply with present day requirements, since fitting was voluntary at that time although in every case fitting had been carried out by the car manufacturer or dealer.

Case 1/35; Kangol Magnet retractors in 1973 model Chrysler Charger VH which hit a pole with impact at the rear of the driver's seat, intruding 0.75m(29.5in). The driver, involved in a right-angled impact, survived with a fractured pedicle of the 2nd cervical vertebra and bruising of the abdominal wall. The female passenger died from brain haemorrhage and a long linear fracture to the back of the skull, probably produced in impact with the invading pole. In each case the retractors appeared to have locked but it is doubtful whether seat belts could play significant roles in ameliorating these injuries.

Case 1/109: Kangol Magnet retractors in 1973 model Holden Statesman that hit a tree centre front. One unrestrained rear passenger was thrown between the front seats and sustained leg and arm fractures; whereas the other was thrown against the driver's seat and sustained fractured ribs. The driver's seat was severely damaged and the driver died of a ruptured aorta and multiple rib fractures; the steering wheel rim was slightly damaged but the hub was untouched. The knees of the front passenger hit the glove compartment and he sustained three fractured right ribs. It was concluded that both retractors operated satisfactorily but that the injuries of the front occupants were increased by the presence of unrestrained rear passengers.

Case 1/136: Essem retractors in 1973 model Ford Falcon XB hit on front passenger's door by another car. The passenger and her seat were pushed inwards by the impact and she died of multiple injuries produced by this intrusion. The driver sustained bruises and contusions on the left chest and a fractured left clavicle, probably from loading by seat belt and passenger. Retractors probably were not a factor but appeared to have locked.

Case 1/142: Kangol Magnet retractors in 1973 model Valiant VH that was crushed under a semi-trailer. Seat belts were irrelevant.

Case 1/144: Kangol Magnet retractors in 1974 model Holden Statesman that hit a tree centre front and was gutted by an ensuing fire. Not known for certain if belts worn.

Case 2/29: Essem retractors in 1974 model Ford Fairmont XB which was hit square on left side by another car. The intrusion pushed the passenger and seat on to the driver who survived with broken ribs and a punctured lung. The passenger survived with fractured clavicle, ribs and pelvis and a punctured lung. Retractors apparently locked satisfactorily.

Case 2/106: Volvo retractors in 1974 model Volvo 144 sedan impacted by a panel van on right hand rear door. Driver sustained a fractured jaw together with bruising on the right side of the head, across the abdomen and on the right shoulder, also pain in the back. Passenger sustained a facial fracture and a rib fracture on the right side. Both retractors appeared to have locked satisfactorily.

Case 2/123: Essem retractors in 1974 model Ford Fairlane XB hit on left side by another car, and pushed into a pole at driver's B pillar. Driver sustained fractured ribs, injury to sternum and bruises to left hip. Passenger sustained fractured clavicle, ribs and pelvis, and a punctured lung. Retractors apparently locked satisfactorily.

Case 2/138: Essem retractors in 1974 model Ford Fairmont XB sedan impacted on left front by a utility truck. The Fairmont was travelling at about 85km/h and the utility 90km/h. The driver sustained a fractured wrist and slight abrasion to left hip. The dash was pushed back against the front passenger who sustained fractured nose and cheek bone and bleeding from left ear. Retractors locked satisfactorily.

Case S/25: Essem retractors in 1974 model Ford Falcon XB station wagon which hit a pole centre front. Driver (in hospital 1 day only) sustained a bump and bruise on the forehead, severe bruising of the left side of the chest and across the abdomen and minor lacerations and bruising to both legs. The driver claimed that the retractor did not lock and he travelled straight forward and hit his head. The upper half of the rim of the steering wheel was bent and the steering column energy absorber was collapsed but there were loading marks on the seat belt's buckle and tongue. The rear seat back broke away from its mounting during the crash and struck the front seat, which moved fully forward on its runners. This applied substantial extra load on the driver and dragged the front buckles through the seating structure; the driver's buckle did not appear to have been damaged however. The driver's chest injuries were consistent with the retractor locking quickly and the seat loading the belt. There was loose luggage of about 10kg mass in the rear; the bolt retaining the spare wheel had pulled out leaving the wheel unrestrained. A simulation of the driver's seating position was undertaken in the same model vehicle with the same type of retractor. The retractor was locked with the front seat in its rearmost position and the seat was then moved forward on its runners. Under these conditions the driver's head was able to contact the rim and the centre of the steering wheel, such contact being possible even without the extra travel which would have been possible when the seat belt stretched under load. The retractor was removed from the case vehicle and subjected to a 0.5g locking test; it locked within 25mm of webbing payout. It was assumed that the retractor had operated as designed and that the driver's head impact was the result of seat adjuster failure. This incident was not retractor related, the seat movement would also have allowed head contact for the wearer of a non-retracting seat belt.

Case S/26: Essem retractors in a 1974 model Ford Falcon XB 2-door which swerved off the road then hit a parked panel van on the left front. Before leaving the road the case vehicle had been travelling at 65km/h. Driver was uninjured apart from a bruise on the left hip. He stated that the retractor locked up and the seat belt restrained him fully. There was extensive damage to the front of the vehicle. Retractor operated satisfactorily.

Case S/30: Essem retractors in 1974 model Holden Torana LH 4-door sedan which was proceeding across an intersection at approximately 25km/h when it was hit on the left hand side by another vehicle. Driver suffered a small cut over the left hip but was not treated for it. He stated that after the accident he was still on the seat with the seat belt tight around him. There was intrusion of the front passenger's door which had bent the passenger seat back rest. The driver's seat back rest was partly reclined. Retractor operated satisfactorily.

Case S/33: Essem retractors in 1974 model Ford Falcon XB station wagon which was in collision with a tourist bus and three other vehicles. Driver sustained bruising across chest along line of belt. Passenger sustained bruising across chest along line of belt, and bruised back. The driver was not treated; the passenger was treated at hospital but not admitted. It was stated that both belts held firmly in each of the four separate impacts. The vehicle sustained damage across the front, along the left hand side and on the left hand rear corner. The occupant space was not intruded nor distorted but the front bench seat back rest was bent backwards. Retractors operated satisfactorily in multiple impacts.

Case S/24: Essem retractors in 1975 model Mazda 929 station wagon. The vehicle had been extensively damaged on the front and had panel damage on left hand side. There was no intrusion or distortion of the occupant space. The driver was not injured. The passenger sustained minor injuries to the lower legs and was treated at hospital but not admitted. Retractors apparently locked satisfactorily.

AUTOMATIC LENGTH ADJUSTING AND LOCKING RETRACTORS

Retractors installed in passenger seating positions are not required to be of a type that permits shoulder movement. (This function would not be necessary in any seating position if driving controls were located always within reach of tightly belted drivers). For passenger seating positions, ADR 4C allows the installation of either emergency locking retractors or automatic length adjusting and locking retractors. The latter type of retractor provides automatic adjustment to the wearer but requires no external event to initiate locking;it does not permit any payout of webbing after the belt has been secured around its wearer. Automatic length adjusting and locking retractors thus do not permit their wearers the freedom of movement associated with emergency locking retractors and this may be a reason why car manufacturers choose not to install them. (Another important reason is the economic advantage of producing and stocking only one type of retractor).

No field crash was located involving automatic length adjusting and locking retractors and these devices are not known to be in use in any current model Australian car.

LABORATORY STUDIES

The work reported in this section deals with emergency locking retractor (ELR) seat belts exclusively; these were the only types which were known to be installed in Australian cars as original equipment.

The objective of the work was to examine the contribution of retractors to the crash performance of lap/sash seat belts and to assess the validity of the crash performance tests which were specified under relevant Australian Design Rules[2]. Crash simulation data originated from original research, from routine compliance work and from minor projects conducted in support of the activities of the Standards Association of Australia and of the Australian Transport Advisory Council's Advisory Committee on Safety in Vehicle Design. A number of short reports were published for the latter groups; these were not intended for general circulation although their content was not unduly critical. Most of the applicable data are reproduced in this paper.

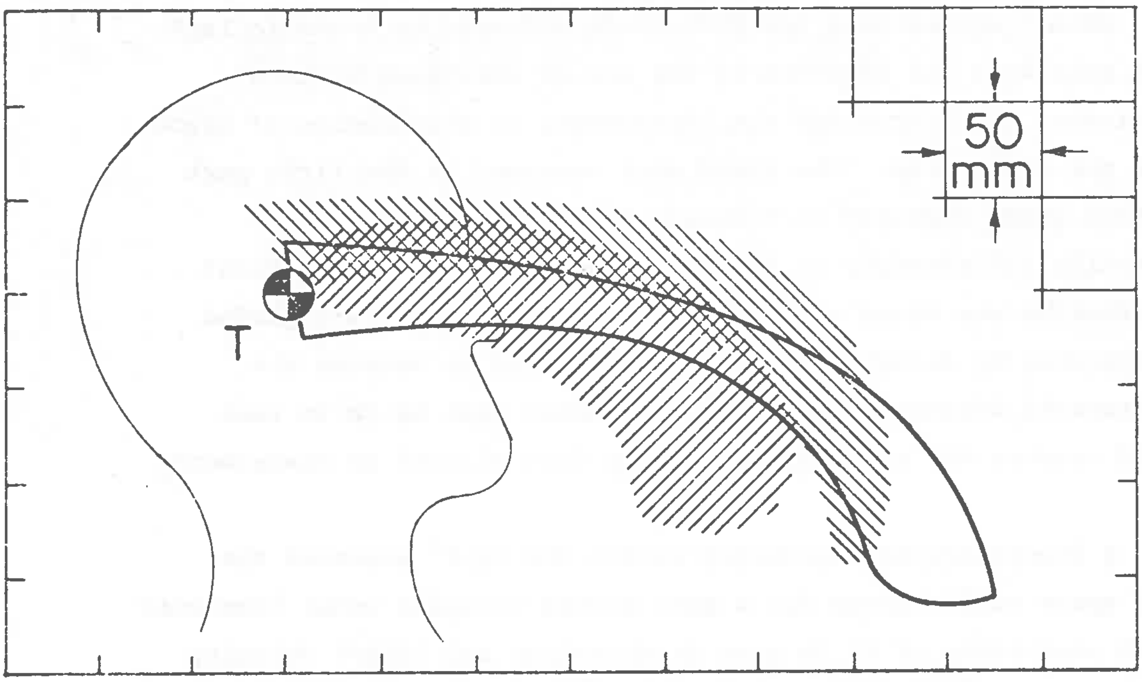
Grime[8] showed that the protection afforded by a static lap/sash seat belt was improved by the use of emergency locking retractors and attributed the improvement to elimination of slack from the sash strap. The field work reported in the first part of this paper appeared to indicate that ELR seat belts were generally satisfactory in their functions since no significant information was found which was adverse; this must be regarded as approval by default. It was not possible to measure the differences between ELR and non-retracting seat belts in real world crashes but existing laboratory data allowed an assessment.

A recent project conducted within the Unit[9] assessed the head space requirements for a seat belted occupant under simulated crash conditions of 15.5g peak deceleration and 24km/h velocity change. A validated 50th percentile male dummy was used and the study was conducted using a 1975 production automobile seat and a lap/sash seat belt which incorporated an emergency locking retractor.

The experimental technique required the establishment of datum conditions in which restraint was provided by non-retracting seat belts, tightly adjusted or slackened. In this case the non-retracting belts consisted of separate lap and sash belts and the slackened case was achieved by the placement of a 75mm diameter cylinder between the dummy's torso and the sash strap during tightening process.

The results of the head space project were plotted head motions and the ELR seat belt was seen to permit greater head excursions than did the tight non-retracting belt. (The ELR belt was not compared directly with the slackened non-retracting belt). The increase in head excursion did not appear to be hazardous for the 50th percentile subject in any of three vehicles considered, these being representative of small, medium and large passenger cars. It was notable that no head contacts were indicated, in frontal crashes, and subsequent analysis has shown that chest impacts against the steering wheel **would not occur** either.

FIGURE 3: Comparison, by head excursion, of ELR and non-retracting seat belts.



Emergency locking retracting lap/sash belts

Non-retracting separate lap and sash belts, slack in sash

Tightly adjusted non-retracting separate lap and sash belts

The question arises whether increased head excursions are indicative of similarity between the ELR seat belt and the slackened non-retracting seat belt. Figure 3 shows that the head excursions observed with the ELR belt were greater than the slack condition considered by the head space project but this was not associated with a corresponding increase in the sash force as would have been expected of a slackened non-retracting seat belt*. Peak sash force of the ELR belt was 10% less than that of the tightly adjusted non-retracting belt but peak sash force of the slackened non-retracting belt was 10% greater. A brief summary of the relevant crash simulation data is presented in Table 2 (p. 38).

Caution should be exercised in the extrapolation of these data to the real world of car crashes. The degree of tightness to which belts are adjusted in the real world may be slack by laboratory standards and the human body is more compliant than a dummy so there may be little difference between retracting and non-retracting belts in terms of forces experienced in real crashes. The ELR seat belt would still be beneficial however, if it reduced jerk in cases of extremely loose adjustment or if it resulted in more widespread seat belt usage because of its greater convenience.

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* There is some evidence that seat belt forces are greater when the belt is slack than when it is tightly adjusted[10,11,12]. The increase may be attributed to the delay occurring whilst slack is taken up; the wearer misses the initial rise of crash deceleration and when restraint becomes effective a jerk results. Hontschik and Schmid[12] reported an increase in total loop forces of 20% for slack produced by a 25mm board inserted behind the dummy's back while the straps were tightened. This was for a particular design of lap/sash belt; another design showed a 20% increase for 50mm slack.

The increase in occupant excursion which we observed with the ELR seat belt was associated with payout of webbing from the retractor reel during the locking process; there was also an increase in excursion attributable to the stretching of the additional webbing in the system. By inspection of some representative ELR mechanisms it was determined that payout occurred in three distinct stages:

1. Unreeling of webbing during the time elapsed between impact and engagement of the sensor mechanism.

2. Rotation of the reel to align the teeth of the locking assembly.

3. Tightening of the relatively loosely coiled webbing on the reel. Webbing stretch would also be anticipated during this process.

It was not possible to determine the payout occurring during sensor response. The instrumentation was designed for measurement of peak quantities and was not sufficiently sensitive to small magnitudes of webbing displacement and force. Webbing force at the reel only become measurable about 30ms after impact (Figure 4) and it was highly probable that both sensor and lock were engaged by this time because sash force was then measurable and its magnitude was approximately 0.5kN. Elapsed time between initial impact and maximum payout was generally of the order of 100ms.

An alternative approach was to determine the payout occurring in stage 2 of the locking sequence, i.e. payout during alignment of locking teeth. The measurement was made by tilting the retractor to a point at which it was known that the sensor was engaged, then extending the webbing until the locking teeth were felt to engage. Results for some common retractors will be found in Table 3 (p.38). When these payouts were checked on plots of webbing displacement and force, it was found that they would have occurred about 25ms after impact, ignoring payout during sensor engagement. If it were assumed that sensor reaction was very rapid, within 5ms after impact when payout is negligible, then the figures can be seen to agree well. It was thus assumed that the sash force could be present prior to

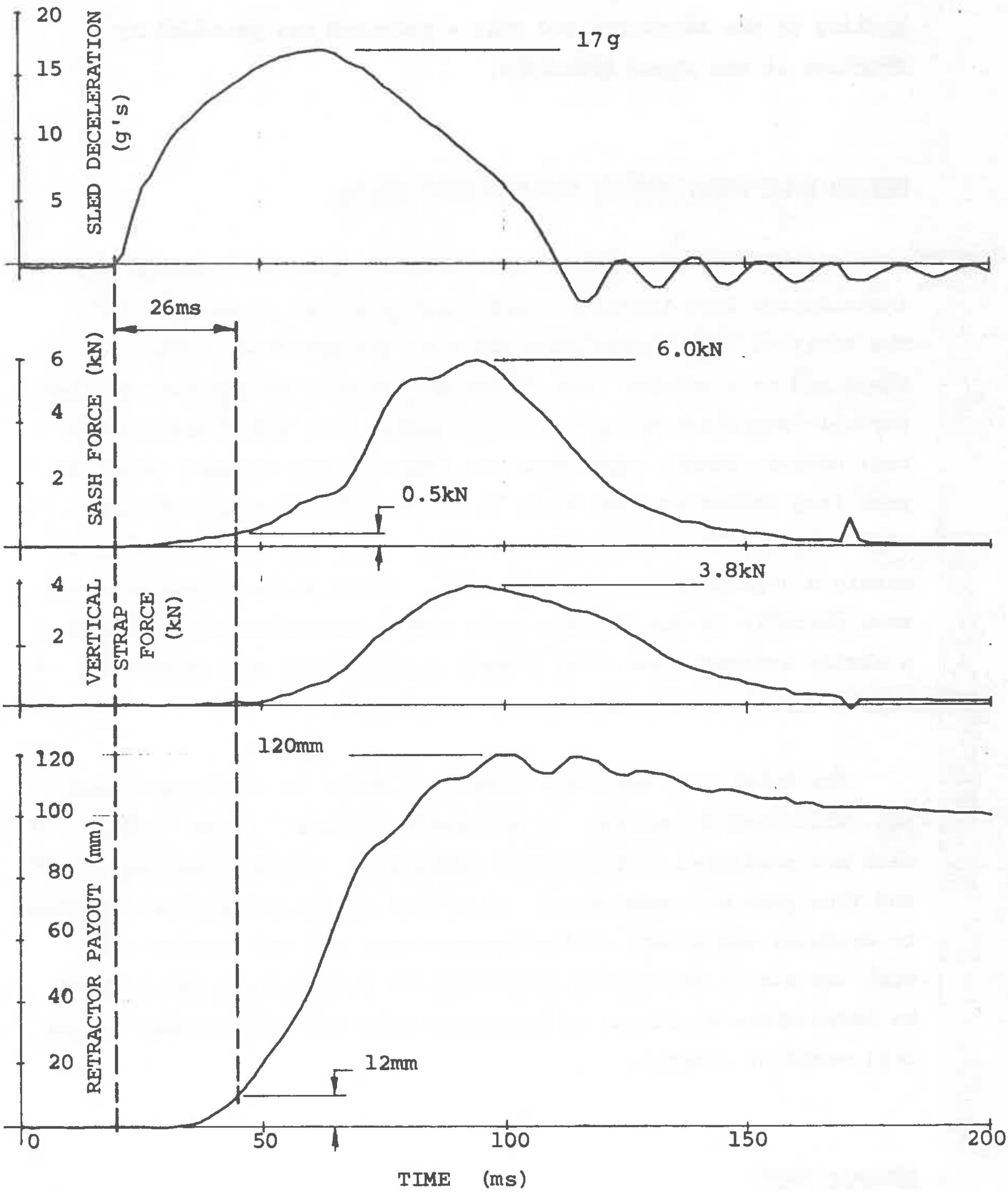


FIGURE 4: Results of crash simulation 74-518

locking of the retractor and that a reaction was provided by friction at the upper anchorage.

DESIGN RULE REQUIREMENTS FOR ELR SEAT BELTS

At the time this report was prepared, seat belt design and installation were specified respectively by ADR 4C and ADR 5B[2]. The first of these rules required that the seat belt system be subjected to a dynamic test (crash simulation) to demonstrate that the belt would not break; no requirements were specified for the test device (dummy) other than its mass and the minimum values of peak loop forces it must apply to a seat belt in a calibration test. It must be concluded therefore, that this dynamic test was merely a sophisticated strength test. Other tests of ADR 4C which were specific to the ELR seat belt were a threshold locking test, a static strength test when locked, a withdrawal and retraction durability test and a retracting force test.

The durability test was thought to refer to reliability and the retracting force test to ergonomic factors. These tests were not pertinent directly to a discussion of crash performance and thus were not considered. This part of the project was confined to critical assessment of the dynamic test and the locking test with the aim of developing proposals for alternatives which would be based on the avoidance of hazardous head and body contact in the real world of crashes.

DYNAMIC TEST

Tarriere et al.[13] stated that whenever seat belt wearers avoided head contact in real accidents, they generally escaped serious injury, even when the estimated Head Injury Criterion[14,15] exceeded the supposed survival limit of 1000. This view was supported by Mackay[16].

The primary objective of a dynamic test should be to ensure that wearers would be restrained **without** hazardous impact of the head or torso against any rigid surface in a vehicle interior; this objective can be assured by the application of excursion limits to a test device. The seat belt should also provide ride down for its wearer starting immediately after the onset of crash deceleration and this implies a requirement for rapid locking. Ideally, the belt should not separate but partial breakage could be acceptable, as in a force limiting device, since it may be indicative of substantial energy dissipation. Demonstration of ride down by body segment deceleration would be desirable, but the current generation of anthropomorphic dummies is not sufficiently realistic to permit this.

The Unit has conducted a considerable number of crash simulations involving retractor seat belts under a variety of crash pulses. These are summarised in Table 4 (pp 39-54) and are provided to demonstrate some general results which might be expected from dynamic tests; also to show variation among data for successive nominally similar runs and to show variation among data obtained at differing crash pulse severities or using different dummies. The retractors used were sampled from a variety of makes and many are not now current models.

The development of a dynamic test for retractors requires resolution of a variety of factors but, before discussing these in depth, it should be noted that no distinction need be made between static belts and those incorporating retractors. The functional requirement of the seat belt under dynamic test simply is to limit forces on, and excursions of, the human body. The dynamic test currently specified by ADR 4C does not examine such requirements. The factors influencing the test are:-

i. Space requirements.

It has been shown that, in frontal crashes, head and chest clearance was available when a typical production belt incorporating an emergency-locking retractor was in use in each of three cars[9]. The clearance measurements did not allow for any rearward displacement of the steering column and so it was not possible to state whether any reduction of cabin space would have been permissible. Any chest displacement requirement of a dynamic test should take account of cabin space available for occupant excursion and perhaps the probable deformation characteristics of the car structure.

ii. Dummy construction.

Appendix A describes in some detail how the dynamic test result can be affected by the dummy characteristics. The most satisfactory way to ensure uniformity of belt loadings is to specify the dummy design; preferably the dummy should be nominated by make and model. If this were done, then a realistic proof value could be specified for the seat belt forces during pre-test calibration. Ideally the footrest should be eliminated from the test rig, to avoid reduction of seat belt forces. A complex dummy is not required; in fact a very sophisticated device can produce wide ranging results if not carefully maintained. In the test work (see Table A1) the TNO 10 was compared with the more complex Sierra 1050 in a series of carefully controlled crash simulations. TNO 10 proved to be consistent in its loadings and excursions and these quantities were seen to be comparable with corresponding data obtained by use of Sierra 1050. Other attractions of TNO 10 are that it should be within the financial means of most testing organisations and is already in widespread use in Europe.

iii. Test Rig.

It has been shown that occupant excursion is greater when a wooden seat is used than when a cushioned seat is used[9]. This being so it is evident that seating design can affect the result of the dynamic test. Although the smooth surfaced wooden seat is the more severe case, the cushioned seat could arguably constitute part of the restraint system and it is thus desirable that seat belts be tested in the actual vehicle seating installation for which they are intended. Such a test condition may not be feasible when a simple dummy is used however and it might be more acceptable to retain the existing ADR 4C test rig if TNO 10 were to be adopted as a standard test device. This is an area in which further research is required.

LOCKING TEST

The ADR 4C locking test required emergency locking retractors to lock within specified payout limits prior to an acceleration level of 0.5g being reached at an onset rate of 10g/sec. Permissible payout was limited to 80mm in one webbing storage condition and 30mm in another.

The locking test could be regarded as a quality control tool but in the absence of a detailed dynamic test it was the only method available for limiting occupant excursions and its effectiveness as a measure of retractor behaviour at 20g or 30g was debatable. Reservations about the locking test also arose because of the nature of payout. Some apparent unreeling of a retractor could occur after the locking mechanism was engaged as the test rig's accelerating platform completed its travel. Such payout results from tightening of webbing on the reel and depends on the force characteristics of the compensating device which provides overrun displacement after the retractor locks. The Rule did not specify any value for this force and thus testing laboratories could obtain differing results ranging from "pass" to "fail", depending on detail design variations in their test rigs. A discussion of locking test rigs will be found in Appendix B.

The results of locking tests for some typical retractors are also presented in Appendix B. From these, it will be observed that considerable variability occurred in the results obtained with each retractor. The samples used were not all current models and later versions may have different characteristics.

The range of payouts observed might be attributed in part to webbing effects. In order to achieve consistency in results the webbing was removed and in its place was substituted a light steel cable which was flexible but did not stretch appreciably under the loads applied in the locking test. Results in this mode are also presented in Appendix B. These showed generally smaller payouts and better consistency.

One retractor (Britax, not fitted as original equipment by Australian manufacturers) was found to permit very large payouts in the locking test. In this case the cause was attributed to a frequency response characteristic whereby the locking pawl instead of engaging, repeatedly bounced off the teeth on the spool. Mackay[3] observed a locking failure in the field with an ELR seat belt and ascribed to it a similar cause.

DISCUSSION OF RESULTS

FIELD DATA

Results of field investigations are summarised in Table 1. (p.36). It is clear from the individual crash reports that the use of non-locking retractors should be positively discouraged.

The crashes discussed in this report generally were sampled on the basis that a seat belt wearer died or was injured; retractor failure was not an influence in any of these cases. Excessive payout of webbing from a retractor might be expected to result in head impact but no such cases were observed. The only case of head impact occurred because a car seat failed.

The available field data relating to Australian emergency locking retractors suggested that their crash performance was generally satisfactory. This observation must be treated with caution however, in view of the relatively small number of cases which were available; it must also be remembered that the field data were two years old. Two failures to lock in Silver Anniversary Holden Premier sedans plus reported failures in England indicate the necessity for careful monitoring of retractor performance now that their installation and use are compulsory in new cars.

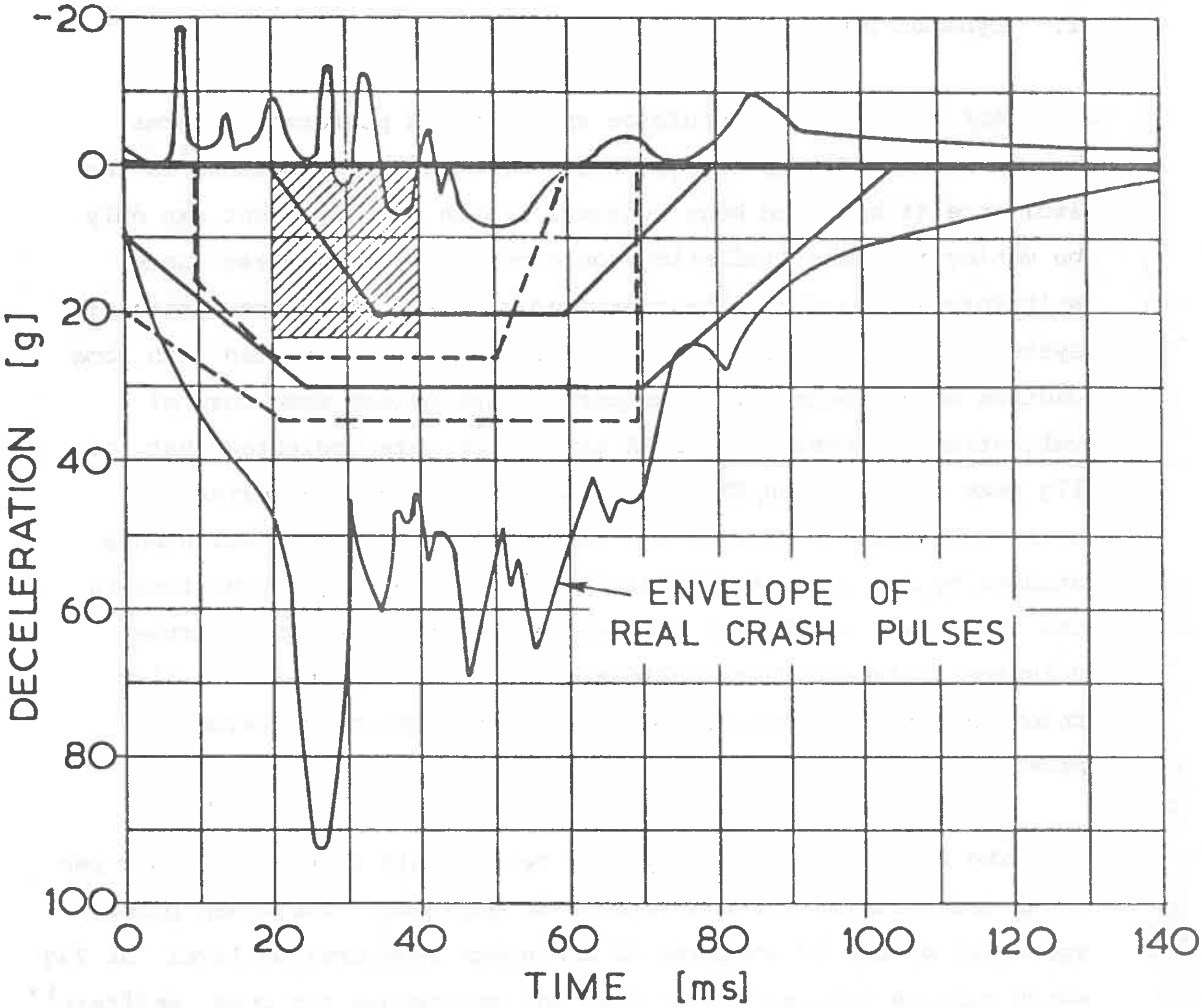
LABORATORY DATA

Laboratory data supported the field observation that crash performance of emergency locking retractors was not inadequate. It appeared however, that this state of affairs was not promoted by the applicable Australian Design Rule (ADR 4C). The Rule, at the time of writing,did not recognise key aspects of the crash performance of retractors and it is relevant therefore to consider possible improvements which might be applied.

i. Dynamic test

ADR requirements should be specified in performance terms rather than by design limitations. Of greatest importance is the avoidance of head and body contacts. Such a requirement can only be met by imposing limitations on excursions of the test dummy. Belt forces should also be specified to ensure that the restraint system is exercised but all quantities should be treated with some caution as a measure of human performance unless some form of validation is possible. Crash simulation data indicated that, at 17g peak deceleration, TNO 10 could be expected to experience a chest excursion of between 150 and 200mm whilst human volunteers studied by Armstrong and Waters[17] experienced chest excursions in the range 25mm to 75mm at similar deceleration levels. Further volunteer data and dummy validations are required before a firm recommendation of permissible dynamic test chest excursion is made.

The crash pulse for a dynamic test should simulate a floor pan crash deceleration for the vehicle in question. The crash pulse specified by ADR 4C consists of a minimum deceleration level of 24g which must be reached within 20ms and maintained for 20ms. Seiffert[18] has described a dynamic test pulse based on floor pan decelerations of a number of European cars. This pulse was proposed by the Committee of Common Market Automobile Constructors (CCMC) and is shown in Figure 5 where it is compared with the requirements of the European regulation ECE R16[19] and of the Australian Design Rule. The ADR 4C pulse does not appear to represent a real deceleration-time pattern like the CCMC and ECE R16 pulses but it is consistent with the Rule's apparent intention of setting a minimum strength requirement. If a dynamic test were to be specified in performance terms a pulse closer to the real world of crashes would be desirable.



Envelope proposed by CCMC

Envelope required by ECE Reg.16.

Minimum requirement of ADR 4C.

FIGURE 5: Spectrum of floor pan decelerations of common European cars compared with dynamic test requirements (basic information from Seiffert[18]).

ii. Locking test

The status and utility of a locking test are dependent upon the nature of the associated dynamic test. If the latter is regarded as a measure of crash protection based on performance requirements then the locking test would be best applied as a test of the sensing and locking systems to ensure minimum locking performance at threshold conditions of vehicle deceleration and webbing acceleration. This function should be performed with webbing removed from the reel in order to minimise avoidable variations in results. Differences of results occurring between laboratories could be eliminated by specification of a standard test rig.

Lack of consistency was observed in some locking tests and could be attributed to the webbing stored on the retractor reel. Webbing is reeled in by retraction force only and is thus stored in a loose condition; it must tighten before significant restraint force can be applied. Wearers of ELR seat belts must be expected to undergo greater body excursions than would wearers of tightly adjusted non-retracting belts. A reduction in payout was observed in the results of locking tests when webbing was replaced by an inextensible wire cable and it is probable that retractors could be made more effective by such simple design changes. Substitution of wire for webbing, on the reel only, would result in earlier application of restraint forces and reduced occupant excursions and should permit a reduction in retractor size. Alternatively a reel hub of larger diameter might improve performance in respect of webbing slippage by reducing the number of coils on the reel.

SUMMARY

The results of this project demonstrate that seat belts which incorporate emergency locking retractors (inertia reels) generally operate satisfactorily under crash conditions. A sample of 25 car crashes involving such devices did not reveal any case in which the retractor failed to lock. Crash simulations involving retractors numbered 257; only one failure to lock was observed and this was a specimen, undergoing retest, that had sustained previous damage directly contributing to the failure. This failure emphasises the necessity for routine replacement of any seat belt component which has been subjected to crash loading. Two alleged cases of locking failure in Silver Anniversary Holden Premier cars, coupled with reported failures in England, suggest that the monitoring of performance should continue.

The crash performance of emergency locking retractors could be adequately controlled by dynamic testing, the basic criterion for compliance being the limitation of body excursions of the wearer in order to avoid impacts against the car structure. Currently, the dynamic test specified by Australian Design Rule 4C is little more than a strength test and does not limit body excursions. A retractor which completely unreels its webbing could not be said to fail the test. A locking test is specified by the Rule and this applies limits to the unreeling of webbing under deceleration conditions such as braking but this cannot be extrapolated to predict performance in crashes.

The locking performance of retractors could be improved by simple modifications to retractor reels.

CONCLUSIONS

1. Data obtained from field work and laboratory simulations indicated that the crash performance of emergency locking retractors was satisfactory. There was no evidence to suggest that failure of locking mechanisms was a significant factor in car crashes.

2. In frontal crashes, an average male occupant of a medium sized Australian car will not sustain hazardous head or body contacts which are attributable solely to the addition of an emergency locking retractor to the seat belt system.

3. The requirements of Australian Design Rule 4C do not provide an adequate evaluation of seat belt systems, particularly those incorporating retractors. The minimum dynamic test requirement should include specific limits to body segment excursions of the dummy seat belt wearer; a representative crash deceleration pulse should be specified and the dummy itself should be defined in detail. It will be necessary to validate the dummy by use of available human volunteer crash data.

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TABLES

TABLE 1: Summary of crashes from field study.

Case No.*	Retractor	Possible influence of retractor in degrading belt performance
1/5A	Non-locking accessory	Unnecessarily injured
1/5C	Non-locking accessory	No influence
1/47A	Non-locking accessory	Knocked unconscious and drowned
1/47C	Non-locking accessory	No influence
1/90A	Non-locking accessory	Excessive head motion and impact
2/14C	Non-locking accessory	Ruptured spleen from loose belt
2/71A	Non-locking accessory	Slack belt broke
2/107C	Non-locking accessory	Fractured sternum from slack belt
2/115A	Non-locking accessory	No influence
1/51A	Takata non-locking	Fatal head and rib injuries from excessive motion
1/51C	Takata non-locking	Severe head injury from excessive motion
1/35A	Kangol emergency lock	No influence
1/35C	Kangol emergency lock	No influence
1/109A	Kangol emergency lock	No influence
1/109C	Kangol emergency lock	No influence
1/136A	Essem emergency lock	No influence
1/136C	Essem emergency lock	No influence
1/142A	Kangol emergency lock	Irrelevant

TABLE 1 (Continued)

Case No.*	Retractor	Possible influence of retractor in degrading belt performance
1/142C	Kangol emergency lock	Irrelevant
1/144A	Kangol emergency lock	Unknown
1/144C	Kangol emergency lock	Unknown
2/29A	Essem emergency lock	No influence
2/29C	Essem emergency lock	No influence
2/106A	Volvo emergency lock	No influence
2/106C	Volvo emergency lock	No influence
2/123A	Essem emergency lock	No influence
2/123C	Essem emergency lock	No influence
2/138A	Essem emergency lock	No influence
2/138C	Essem emergency lock	No influence
S/25A	Essem emergency lock	No influence
S/30A	Essem emergency lock	No influence
S/33A	Essem emergency lock	No influence
S/33C	Essem emergency lock	No influence
S/34A	Essem emergency lock	No influence
S/34C	Essem emergency lock	No influence

* Suffix A signifies driver, C the front outer (left)passenger.

TABLE 2: Crash simulation data relating to comparison of non-retracting and emergency locking retractor seat belts.

Seat Belt	Simulation No.	Peak Decel. (g)	Velocity Change (km/h)	Peak Force in Sash (kN)
Tight non-retracting separate lap and sash belts	75/020 75/038 75/041	15.4 15.3 15.6	21.2 21.0 21.0	4.4 5.7 3.4
	Mean	15.4	21.1	4.4
Slack non-retracting separate lap and sash belts	75/023 75/036 75/037	15.4 15.6 15.0	21.2 21.0 20.4	4.4 5.4 5.2
	Mean	15.2	20.9	5.0
Emergency locking retractor lap / sash belt	75/043 75/044 75/045	16.3 16.0 16.0	23.2 22.2 22.0	3.3 4.2 4.6
	Mean	16.1	22.5	4.0

TABLE 3: Payout from retractors when tilted. (average values).

Retractor	Type I Britax	Type II Rainsfords	Type III Repa	Type IV Cooldrive
Mean angle to lock	30°	24°	21°	22°
Mean payout when locked	10mm	15mm	6mm	11mm

TABLE 4: Summary of all crash simulations involving ELR seat belts (see key to terms p.55)

Run number	Test rig	Crash pulse	E L R specimen	Sash force (kN)	Retractor payout (mm)	Dummy	Chest excursion	Defects in performance of retractor
73.022	ECE	28g-78ms	MT495	5.35	N.R.	TNO10	N.R.	Nil (buckle tongue failed)
73.069	ECE	28g-78ms	MT522	8.37	N.R.	TNO10	N.R.	Nil (buckle released)
73.070	ECE	28g-78ms	MT525	8.93	N.R.	TNO10	N.R.	Nil (webbing failed)
73.071	ECE	28g-78ms	MT526	9.07	N.R.	TNO10	N.R.	Nil (webbing failed)
73.072	ECE	28g-78ms	MT527	N.R.	N.R.	TNO10	N.R.	Nil
73.073	ECE	28g-78ms	MT528	N.R.	N.R.	TNO10	N.R.	Nil
73.074	ECE	28g-78ms	MT538	N.R.	N.R.	TNO10	N.R.	Nil
73.075	ECE	28g-78ms	MT529	N.R.	N.R.	TNO10	N.R.	Nil
73.076	ECE	28g-78ms	MT531	N.R.	N.R.	TNO10	N.R.	Nil
73.077	ECE	28g-78ms	MT521	7.60	N.R.	TNO10	N.R.	Nil (webbing failed)
73.078	ECE	28g-78ms	MT523	6.82	N.R.	TNO10	N.R.	Nil (webbing failed)
73.079	ECE	28g-78ms	MT524	9.16	N.R.	TNO10	N.R.	Nil
73.202	ADR4A	28g-78ms	MT671	N.R.	N.R.	TNO10	N.R.	Nil
73.203	ADR4A	28g-78ms	MT670	N.R.	N.R.	TNO10	N.R.	Nil
73.211	ADR4A	28g-78ms	MT639	N.R.	N.R.	TNO10	N.R.	Nil
74.006	ADR4A (mod.)	17g-100ms	MT558	N.R.	61	TNO10	N.R.	Nil
74.007	ADR4A (mod.)	17g-100ms	MT561	0.39	37	TNO10	N.R.	Nil (buckle released)
74.008	ADR4A (mod.)	17g-100ms	MT561	5.16	100	TNO10	N.R.	Nil
74.009	ADR4A (mod.)	17g-100ms	MT731	4.10	68	TNO10	N.R.	Nil (webbing failed)
74.010	ADR4A (mod.)	17g-100ms	MT732	5.38	79	TNO10	N.R.	Nil

TABLE 4: (Continued)

Run number	Test rig	Crash pulse	E L R specimen	Sash force (kN)	Retractor payout (mm)	Dummy	Chest excursion	Defects in performance of retractor
74.011	ADR4A (mod.)	17g-100ms	MT740	4.56	105	TNO10	N.R.	Nil (dummy slipped from sash)
74.012	ADR4A (mod.)	17-100ms	MT736	4.59	127	TNO10	N.R.	Nil (dummy slipped from sash)
74.013	ADR4A (mod.)	17g-100ms	MT739	6.73	100	TNO10	N.R.	Nil (dummy rotated in belt)
74.018	ADR4A (mod.)	17g-100ms	MT737	5.84	N.R.	Sierra 1050	92	Nil
74.019	ADR4A (mod.)	17g-100ms	MT738	5.98	123	Sierra 1050	118	Nil
74.020	ADR4A (mod.)	17g-100ms	MT740	5.55	106	Sierra 1050	101	Nil
74,021	ADR4A (mod.)	17g-100ms	MT767	6.67	91	Sierra 1050	203	Nil
74,022	ADR4A (mod.)	17g-100ms	MT767	6.54	93	Sierra 1050	210	Nil
74,023	ADR4A (mod.)	17g-100ms	MT766	4.95	113	TNO10	N.R.	Nil
74.024	ADR4A (mod.)	17g-100ms	MT764	5.23	78	TNO10	N.R.	Nil
74.079	ADR4A	17g-100ms	MT736	N.R.	108	Sierra 1050	125	Nil
74.080	ADR4A	17g-100ms	MT736	N.R.	68	Sierra 1050	316	Nil
74.081	ADR4A	17g-100ms	MT736	N.R.	63	Sierra 1050	349	Nil
74.082	ADR4A	17g-100ms	MT765	N.R.	92	Sierra 1050	185	Nil
74.083	ADR4A	17g-100ms	MT765	N.R.	69	Sierra 1050	182	Nil
74.084	ADR4A	17g-100ms	MT765	N.R.	62	Sierra 1050	160	Nil

TABLE 4: (continued)

Run number	Test rig	Crash pulse	E L R specimen	Sash force (kN)	Retractor payout (mm)	Dummy	Chest excursion	Defects in performance of retractor
74.085	ADR4A	17g-100ms	MT736	N.R.	93	Sierra 1050	300	Nil
74.086	ADR4A	17g-100ms	MT736	N.R.	73	Sierra 1050	275	Nil
74.087	ADR4A	17g-100ms	MT764	N.R.	80	Sierra 1050	200	Nil
74.088	ADR4A	17g-100ms	MT764	N.R.	70	Sierra 1050	180	Nil
74.089	ADR4A	17g-100ms	MT738	N.R.	140	Sierra 1050	272	Nil
74.090	ADR4A	17g-100ms	MT738	N.R.	82	Sierra 1050	263	Nil
74.187	ADR4A	28g-78ms	MT908	N.R.	N.R.	TNO10 (mod.)	N.R.	Nil
74.188	ADR4A	28g-78ms	MT888	N.R.	N.R.	TNO (mod.)	N.R.	Nil
74,191	ADR4A	28g-78ms	MT943	N.R.	N.R.	TNO10 (mod.)	N.R.	Nil
74.214	ADR4A (mod.)	18g-119ms	MT874	6.61	107	Sierra 1050	N.R.	Nil
74.215	ADR4A (mod.)	18g-119ms	MT874	N.R.	117	Sierra 1050	N.R.	Nil
74.216	ADR4A (mod.)	18g-119ms	MT874	N.R.	123	TNO10	N.R.	Nil
74.217	ADR4A (mod.)	19g-117ms	MT874	5.00	88	TNO10	N.R.	Nil
74.218	ADR4A (mod.)	19g-117ms	MT875	6.06	91	TNO10	N.R.	Nil
74.219	ADR4A (mod.)	19g-117ms	MT875	5.82	50	TNO10	N.R.	Nil
74.220	ADR4A (mod.)	19g-117ms	MT875	7.00	48	Sierra 1050	N.R.	Nil

TABLE 4 (Continued)

Run number	Test rig	Crash pulse	E L R specimen	Sash force (kN)	Retractor payout (mm)	Dummy	Chest excursion	Defects in performance of retractor
74.221	ADR4A (mod.)	19g-117ms	MT875	7.39	60	Sierra 1050	N.R.	Nil
74.254	ADR4A	28g-78ms	MT958	N.R.	N.R.	TNO10 (mod.)	N.R.	Nil
74.255	ADR4A	28g-78ms	MT955	N.R.	N.R.	TNO10 (mod.)	N.R.	Nil
74.256	ADR4A	28g-78ms	MT956	N.R.	N.R.	TNO10 (mod.)	N.R.	Nil
74,257	ADR4A	28g-78ms	MT954	N.R.	N.R.	TNO10 (mod.)	N.R.	Nil
74.269	ADR4A (mod.)	20g-117ms	MT988	4.56	95	TNO10	N.R.	Nil
74.271	ADR4A (mod.)	17g-112ms	MT988	5.24	95	TNO10	N.R.	Nil
74.272	ADR4A (mod.)	17g-112ms	MT988	6.70	87	Sierra 1050	N.R.	Nil
74.273	ADR4A (mod.)	17g-112ms	MT988	4.82	65	Sierra 1050	N.R.	Nil (buckle released)
74.274	ADR4A (mod.)	17g-112ms	MT978	6.90	78	Sierra 1050	N.R.	Nil
74.275	ADR4A (mod.)	17g-112ms	MT978	5.50	61	TNO10	N.R.	Nil
74.276	ADR4A (mod.)	17g-112ms	MT982	5.69	38	TNO10	N.R.	Nil
74.277	ADR4A (mod.)	17g-112ms	MT982	6.85	39	Sierra 1050	N.R.	Nil
74.355	ADR4A (mod.)	19g-117ms	MT988	N.R.	N.R.	Sierra 1050	N.R.	Nil
74.361	E L R	20g-115ms	MT874	5.56	81	TNO Torso	265	Nil
74.362	E L R	20g-115ms	MT874	5.02	53	TNO Torso	265	Nil

TABLE 4 (Continued)

Run number	Test rig	Crash pulse	E L R specimen	Sash force (kN)	Retractor payout (mm)	Dummy	Chest excursion	Defects in performance of retractor
74.363	E L R	20g-115ms	MT874	5.65	45	TNO Torso	431	Nil (buckle failed)
74.364	E L R	20g-115ms	MT736	5.90	89	TNO Torso	253	Nil
74.365	E L R	20g-115ms	MT736 drive	5.03	50	TNO Torso	428	Nil (buckle released)
74.366	E L R	20g-115ms	MT961	5.93	57	TNO Torso	210	Nil
74.367	E L R	20g-115ms	MT961	6.04	66	TNO Torso	210	Nil
74.368	E L R	20g-115ms	MT961	5.52	53	TNO Torso	435	Nil (buckle released)
74.369	E L R	20g-115ms	MT960	5.98	74	TNO Torso	210	Nil
74.370	E L R	20g-115ms	MT960	5.77	39	TNO Torso	185	Nil
74.371	E L R	20g-115ms	MT960	5.78	37	TNO Torso	430	Nil (buckle released)
74.386	E L R	17g-144ms	MT960	6.67	55	TNO Torso	N.R.	Nil
74.387	E L R	17g-144ms	MT877	5.99	62	TNO Torso	N.R.	Nil
74.388	E L R	17g-144ms	MT877	5.86	50	TNO Torso	275	Nil
74.389	E L R	17g-144ms	MT877	6.28	82	TNO Torso	348	Nil
74.390	E L R	17g-144ms	MT877	6.17	79	TNO Torso	326	Nil
74.391	E L R	17g-144ms	MT877	6.03	34	TNO Torso	290	Nil
74.392	E L R	17g-144ms	MT877	6.47	30	TNO Torso	211	Nil

TABLE 4 (Continued)

Run number	Test rig	Crash pulse	E L R specimen	Sash force (kN)	Retractor payout (mm)	Dummy	Chest excursion	Defects in performance of retractor
74.393	E L R	17g-144ms	MT871	6.13	46	TNO Torso	244	Nil
74.394	E L R	17g-144ms	MT738	6.06	48	TNO Torso	240	Nil
74.395	E L R	17g-144ms	MT738	6.48	53	TNO Torso	271	Nil
74.396	E L R	17g-144ms	MT738	6.77	44	TNO Torso	220	Nil
74.397	E L R	17g-144ms	MT738	7.08	50	TNO Torso	252	Nil
74.398	E L R	17g-144ms	MT738	6.96	51	TNO Torso	461	Nil
74.399	E L R	17g-144ms	MT738	6.46	43	TNO Torso	216	Nil
74.400	E L R	17g-144ms	MT738	9.83	30	TNO Torso	243	Nil
74.401	E L R	17g-144ms	MT738	5.83	41	TNO Torso	282	Nil
74.402	E L R	17g-144ms	MT738	6.72	46	TNO Torso	241	Nil
74.403	E L R	17g-144ms	MT738	6.72	58	TNO Torso	289	Nil
74.404	E L R	17g-144ms	MT877	6.55	43	TNO Torso	220	Nil
74.405	E L R	17g-144ms	MT877	6.68	45	TNO Torso	218	Nil
74.406	E L R	17g-144ms	MT877	6.57	45	TNO Torso	221	Nil
74.407	E L R	17g-144ms	MT877	6.15	49	TNO Torso	257	Nil
74.408	E L R	17g-144ms	MT885	6.44	40	TNO Torso	228	Nil

TABLE 4 (Continued)

Run number	Test rig	Crash pulse	E L R specimen	Sash force (kN)	Retractor payout (mm)	Dummy	Chest excursion	Defects in performance of retractor
74.409	E L R	17g-144ms	MT885	6.32	39	TNO Torso	218	Nil
74.410	E L R	17g-144ms	MT885	5.82	41	TNO Torso	454	Nil (webbing failed)
74.411	E L R	17g-144ms	MT884	6.57	41	TNO Torso	247	Nil
74.412	E L R	17g-144ms	MT884	6.72	37	TNO Torso	230	Nil
74.413	E L R.	17g-144ms	MT884	6.24	34	TNO Torso	247	Nil
74.414	E L R	17g-144ms	MT884	6.37	31	TNO Torso	219	Nil
74.415	F L R	17g-144ms	MT884	6.36	32	TNO Torso	211	Nil
74.416	E L R	17g-144ms	MT884	6.35	28	TNO Torso	206	Nil
74.417	E L R	17g-144ms	MT884	6.29	25	TNO Torso	195	Nil
74.487	E L R	17g-144ms	MT877	6.05	49	TARU Torso	189	Nil
74.488	E L R	17g-144ms	MT877	5.37	69	TARU Torso	426	Nil (Webbing failed)
74.489	E L R	17g-144ms	MT877	5.63	30	TARU Torso	221	Nil
74.490	E L R.	17g-144ms	MT877	6.60	N.R.	TARU Torso	N.R.	Nil (webbing failed)
74.491	E L R	17g-144ms	MT877	5.82	45	TARU Torso	410	Nil (webbing failed)
74.492	E L R	17g-144ms	MT022	4.82	0	TARU Torso	34	Nil

TABLE 4: (Continued)

Run number	Test rig	Crash pulse	E L R specimen	Sash force (kN)	Retractor payout (mm)	Dummy	Chest excursion	Defects in performance of retractor
74.493	E L R	17g-144ms	MTA022	5.52	0	TARU Torso	13	Nil
74.494	E L R	17g-144ms	MTA022	5.80	60	TARU Torso	139	Nil
74.495	E L R	17g-144ms	MTA022	5.60	45	TARU Torso	128	Nil
74.496	E L R	17g-144ms	MTA022	5.25	34	TARU Torso	114	Nil
74,497	E L R	17g-144ms	MTA022	5.79	69	TARU Torso	145	Nil
74.498	E L R	17g-144ms	MTA022	6.01	73	TARU Torso	145	Nil
74.499	E L R	17g-144ms	MTA022	6.01	73	TARU Torso	150	Nil
74.500	E L R	17g-144ms	MTA022	6.03	77	TARU Torso	144	Nil
74.501	E L R	17g-144ms	MT981	6.40	173	TARU Torso	244	Nil
74.502	E L R	17g-144ms	MT981	6.25	135	TARU Torso	197	Nil
74.503	E L R	17g-144ms	MT981	5.71	54	TARU Torso	133	Nil
74.504	E L R	17g-144ms	MT981	6.07	14	TARU Torso	163	Nil
74.505	E L R	17g-144ms	MT981	6.44	135	TARU Torso	184	Nil
74.506	E L R	17g-144ms	MT981	5.76	47	TARU Torso	124	Nil
74.507	E L R	17g-144ms	MTO25A	5.75	83	TARU Torso	168	Nil
74.508	E L R	17g-144ms	MTO25A	5.75	34	TARU Torso	134	Nil

TABLE 4 (Continued)

Run number	Test rig	Crash pulse	E L R specimen	Sash force (kN)	Retractor payout (mm)	Dummy	Chest excursion	Defects in performance of retractor
74.509	E L R	17g-144ms	MTO25A	5.79	136	TARU Torso	240	Nil
74.510	E L R	17g-144ms	MTO25A	6.06	64	TARU Torso	160	Nil
74.511	E L R	17g-144ms	MTO25A	5.34	56	TARU Torso	156	Nil
74.512	E L R	17g-144ms	MTO25A	N.R.	N.R.	TARU Torso	N.R.	Nil
74.513	E L R	17g-144ms	MTA036	6.07	42	TARU Torso	430	Nil
74.514	E L R	17g-144ms	MTA036	5.84	39	TARU Torso	431	Nil
74.515	E L R	17g-144ms	MTA036	5.73	23	TARU Torso	431	Nil
74.516	E L R	17g-144ms	MTA036	5.72	34	TARU Torso	431	Nil
74.517	E L R	17g-144ms	MTA036	5.69	32	TARU Torso	431	Nil
74.518	E L R	17g-144ms	MT906	5.97	N.R.	Sierra 1050	N.R.	Nil
74.519	E L R	17g-144ms	MT906	5.57	44	Sierra 1050	N.R.	Nil
75.001	E L R	17g-144ms	MTA038	4.49	54	TARU Torso	96	Nil
75.002	E L R	17g-144ms	MTA038	4.66	44	TARU Torso	N.R.	Nil
75.003	E L R	17g-144ms	MTA038	4.91	61	TARU Torso	117	Nil
75.004	E L R	17g-144ms	MTA038	5.33	35	TARU Torso	116	Nil
75.005	E L R	17g-144ms	MTA038	5.63	43	TARU Torso	357	Nil

TABLE 4 (Continued)

Run number	Test rig	Crash pulse	E L R specimen	Sash force (kN)	Retractor payout (mm)	Dummy	Chest excursion	Defects in performance of retractor
75.006	E L R	17g-144ms	MTA038	6.39	53	TARU Torso	171	Nil
75.007	E L R	17g-144ms	MTA038	3.93	50	TARU Torso	426	Nil
75.008	E L R	17g-144ms	MTA038	3.89	245	TARU Torso	424	Nil
75.043	Head Space	15.5g-60ms	MT050	3.33	120	Ogle MIRA	N.R.	Nil
75.044	Head Space	15.5g-60ms	MT050	4.20	35	Ogle MIRA	N.R.	Nil
75.045	Head Space	15.5g-60ms	MT050	4.02	43	Ogle MIRA	N.R.	Nil
75-063	Head Space	15.5g-60ms	MT059	2.57	78	Ogle MIRA	N.R.	Nil
75.064	Head Space	15.5g-60ms	MT059	3.44	49	Ogle MIRA	N.R.	Nil
75.065	Head Space	15.5g-60ms	MT059	4.29	43	Ogle MIRA	N.R.	Nil
75.066	Head Space	15.5g-60ms	MT059	4.21	58	Ogle MIRA	N.R.	Nil
75.067	Head Space	15.5g-60ms	MT059	4.18	42	Ogle MIRA	N.R.	Nil
75.068	Head Space	15.5g-60ms	MT059	3.88	47	Ogle MIRA	N.R.	Nil
75.069	Head Space	15.5g-60ms	MT059	3.84	59	Ogle MIRA	N.R.	Nil
75.070	Head Space	15.5g-60ms	MT059	3.90	51	Ogle MIRA	N.R.	Nil
75.071	Head Space	15.5g-60ms	MTA059	4.96	48	Ogle MIRA	N.R.	Nil

TABLE 4 (Continued)

Run number	Test rig	Crash pulse	E L R specimen	Sash force (kN)	Retractor payout (mm)	Dummy	Chest excursion	Defects in performance of retractor
75.072	Head Space	15.5g-60ms	MTA059	4.93	52	Ogle MIRA	N.R.	Nil
75-073	Head Space	15.5g-60ms	MTA059	5.06	45	Ogle MIRA	N.R.	Nil
75.074	Head Space	15.5g-60ms	MTA058	3.09	114	Ogle MIRA	N.R.	Nil
75.075	Head Space	15.5g-60ms	MTA058	4.05	50	Ogle MIRA	N.R.	Nil
75.076	Head Space	15.5g-60ms	MTA058	4.33	44	Ogle MIRA	N.R.	Nil
75.077	Head Space	15.5g-60ms	MTA058	3.27	40	Ogle MIRA	N.R.	Nil
75.078	Head Space	15.5g-60ms	MTA058	3.77	37	Ogle MIRA	N.R.	Nil
75.079	Head Space	15.5g-60ms	MTA058	3.84	23	Ogle MIRA	N.R.	Nil
75.080	Head Space	15.5g-60ms	MTA058	3.36	39	Ogle MIRA	N.R.	Nil
75.081	Head Space	15.5g-60ms	MTA058	3.14	35	Ogle MIRA	N.R.	Nil
75.091	Head Space	15.5g-60ms	MTA061	3.12	50	Ogle MIRA	N.R.	Nil
75.092	Head Space	15.5g-60ms	MTA061	3.38	46	Ogle MIRA	N.R.	Nil
75.093	Head Space	15.5g-60ms	MTA061	3.59	47	Ogle MIRA	N.R.	Nil
75.094	Head Space	15.5g-60ms	MTA061	2.14	32	Ogle MIRA	N.R.	Nil
75.095	Head Space	15.5g-60ms	MTA061	2.33	34	Ogle MIRA	N.R.	Nil

TABLE 4 (Continued)

Run number	Test rig	Crash pulse	E L R specimen	Sash force (kN)	Retractor payout (mm)	Dummy	Chest excursion	Defects in performance of retractor
75.096	Head Space	15.5g-60ms	MTA061	2.32	28	Ogle MIRA	N.R.	Nil
75.097	Head Space	15.5g-60ms	MTA061	1.61	29	Ogle MIRA	N.R.	Nil
75.098	Head Space	15.5g-60ms	MTA061	2.07	28	Ogle MIRA	N.R.	Nil
75.099	Head Space	15.5g-60ms	MTA061	2.03	34	Ogle MIRA	N.R.	Nil
75.119	Head Space	15.5g-60ms	MTA060	2.81	119	Ogle MIRA	N.R.	Nil
75.120	Head Space	15.5g-60ms	MTA060	3.65	64	Ogle MIRA	N.R.	Nil
75.121	Head Space	15.5g-60ms	MTA060	3.80	63	Ogle MIRA	N.R.	Nil
75.122	Head Space	15.5g-60ms	MTA060	3.80	64	Ogle MIRA	N.R.	Nil
75.123	Head Space	15.5g-60ms	MTA060	2.65	60	Ogle MIRA	N.R.	Nil
75.124	Head Space	15.5g-60ms	MTA060	2.36	56	Ogle MIRA	N.R.	Nil
75.125	Head Space	15.5g-60ms	MTA060	2.37	53	Ogle MIRA	N.R.	Nil
75.126	Head Space	15.5g-60ms	MTA060	2.48	54	Ogle MIRA	N.R.	Nil
75.160	ADR4B (mod.)	17g -100ms	MT982	5.31	48	TNO10	N.R.	Nil
75.161	ADR4B (mod).	17g-100ms	MT982	5.27	36	TNO10	N.R.	Nil
75.162	ADR4B (mod.)	17g-100ms	MT982	5.60	36	TNO10	N.R.	Nil
75.163	ADR4B (mod.)	17g-100ms	MT982	6.50	32	TNO10	N.R.	Nil

TABLE 4 (Continued)

Run number	Test rig	Crash pulse	E L R specimen	Sash force (kN)	Retractor payout (mm)	Dummy	Chest excursion	Defects in performance of retractor
75.164	ADR4B (mod.)	17g-100ms	MT982	N.R.	N.R.	TNO10	N.R.	Nil
75.165	ADR4B (mod.)	17g-100ms	MT982	6.16	37	TNO10	N.R.	Nil
75.166	ADR4B (mod.)	17g-100ms	MT982	6.16	36	TNO10	N.R.	Nil
75.167	ADR4B (mod.)	17g-100ms	MTA155	N.R.	N.R.	TNO10	N.R.	Nil
75.168	ADR4B (mod.)	17g-100ms	MTA147	5.06	97	TNO10	N.R.	Nil (buckle released)
75.169	ADR4B (mod.)	17g-100ms	MTA158	5.51	104	TNO10	N.R.	Nil
75.170	ADR4B (mod.)	17g-100ms	MTA158	5.71	32	TNO10	147	Nil
75.171	ADR4B (mod.)	17g-100ms	MTA158	5.71	29	TNO10	173	Nil
75.172	ADR4B (mod.)	17g-100ms	MTA158	5.96	35	TNO10	174	Nil
75.173	ADR4B (mod.)	17g-100ms	MTA171	5.79	143	TNO10	N.R.	Nil
75.174	ADR4B (mod.)	17g-100ms	MTA171	1.61	N.R.	TNO10	N.R.	Failed to lock owing to damage sustained on previous run(see key p56)
75.175	ADR4B (mod.)	17g-100ms	MTA172	5.17	135	TNO10	N.R.	Nil (dummy fellout of sash)
75.176	ADR4B (mod).	17g-100ms	MTA147	5.71	104	TNO10	N.R.	Nil (buckle released)
75.177	ADR4B (mod.)	17g-100ms	MTA147	5.84	34	TNO10	187	Nil
75.178	ADR4B (mod.)	17g-100ms	MTA147	6.37	100	TNO10	180	Nil

TABLE 4 (Continued)

Run number	Test rig	Crash pulse	E L R specimen	Sash force (kN)	Retractor payout (mm)	Dummy	Chest excursion	Defects in performance of retractor
75.179	ADR4B (mod.)	17g-100ms	MTA147	5.78	40	TNO10	173	Nil
75.180	ADR4B (mod.)	17g-100ms	MTA147	6.39	36	TNO10	N.R.	Nil
75.181	ADR4B (mod.)	17g-100ms	MTA034	5.71	71	TNO10	N.R.	Nil
75.182	ADR4B (mod.)	17g-100ms	MTA034	6.24	46	TNO10	190	NIL
75.183	ADR4B (mod.)	17g-100ms	MTA034	5.96	54	TNO10	184	Nil
75.184	ADR4B (mod.)	17g-100ms	MTA034	5.15	29	TNO10	N.R.	Nil (buckle released)
75.185	ADR4B (mod.)	17g-100ms	MTA034	5.70	60	TNO10	N.R.	Nil
75.186	ADR4B (mod.)	17g-100ms	MTA034	6.04	44	TNO10	189	Nil
75.187	ADR4B (mod.)	17g-100ms	MTA159	5.61	111	Sierra 1050	N.R.	Nil
75.188	ADR4B (mod.)	17g-100ms	MTA159	6.10	71	Sierra 1050	199	Nil
75.189	ADR4B (mod.)	17g-100ms	MTA159	6.35	57	Sierra 1050	197	Nil
75.190	ADR4B (mod.)	17g-100ms	MTA159	6.31	68	Sierra 1050	198	Nil
75.200	ADR4B (mod.)	17g-100ms	MTA029	5.72	100	Sierra 1050	234	Nil
75.201	ADR4B (mod.)	17g-100ms	MTA029	5.96	62	Sierra 1050	N.R.	Nil
75.202	ADR4B (mod.)	17g-100ms	MTA029	5.88	108	Sierra 1050	209	Nil
75.203	ADR4B (mod.)	17g-100ms	MTA028	5.88	102	Sierra 1050	216	Nil

TABLE 4 (Continued)

Run number	Test rig	Crash pulse	E L R specimen	Sash force (kN)	Retractor payout (mm)	Dummy	Chest excursion	Defects in performance of retractor
75.204	ADR4B (mod.)	17g-100ms	MTA028	6.28	83	Sierra 1050	192	Nil
75.205	ADR4B (mod.)	17g-100ms	MTA028	5.23	88	Sierra 1050	N.R.	Nil (webbing failed)
75.206	ADR4B (mod.)	17g-100ms	MT560	5.43	86	Sierra 1050	N.R.	Nil (webbing failed)
75.207	ADR4B (mod.)	17g-100ms	MT559	6.16	104	Sierra 1050	N.R.	Nil
75.208	ADR4B (mod.)	17g-100ms	MTA173	5.99	66	Sierra 1050	185	Nil
75.209	ADR4B (mod.)	17g-100ms	MTA173	6.16	74	Sierra 1050	189	Nil
75.210	ADR4B (mod.)	17g-100ms	MTA173	5.82	63	Sierra 1050	185	Nil
75.211	ADR4B (mod.)	17g-100ms	MTA173	5.80	55	TNO10	N.R.	Nil (webbing failed)
75.212	ADR4B (mod.)	17g-100ms	MTA173	6.30	69	TNO10	N.R.	Nil
75.213	Torana buck	15.5g-60ms	MT060	N.R.	N.R.	Ogle MIRA	N.R.	Nil
75.214	Torana buck	15.5g-60ms	MT060	N.R.	N.R.	Ogle MIRA	N.R.	Nil
75.215	Torana buck	15.5g-60ms	MT060	N.R.	N.R.	Ogle MIRA	N.R.	Nil
75.216	Torana buck	15.5g-60ms	MT060	N.R.	N.R.	Ogle MIRA	N.R.	Nil
75.217	Torana buck	15.5g-60ms	MT060	N.R.	N.R.	Ogle MIRA	N.R.	Nil
75.218	Torana buck	15.5g-60ms	MT060	N.R.	N.R.	Ogle MIRA	N.R.	Nil
76.001	Torana buck	15.5g-60ms	MT060	5.36	N.R.	Ogle MIRA	N.R.	Nil

TABLE 4 (Continued)

Run number	Test rig	Crash pulse	E L R specimen	Sash force (kN)	Retractor payout (mm)	Dummy	Chest excursion	Defects in performance of retractor
76.002	Torana buck	15.5g-60ms	MT060	3.87	N.R.	Ogle MIRA	N.R.	Nil
76.003	Torana buck	15.5g-60ms	MT060	4.48	N.R.	Ogle MIRA	N.R.	Nil
76.004	Torana buck	15.5g-60ms	MT060	4.52	N.R.	Ogle MIRA	N.R.	Nil
76.005	Torana buck	15.5g-60ms	MT060	4.36	N.R.	Ogle MIRA	N.R.	Nil
76.006	Torana buck	15.5g-60ms	MT060	4.73	N.R.	Ogle MIRA	N.R.	Nil
76.007	Torana buck	15.5g-60ms	MT060	4.87	N.R.	Ogle MIRA	N.R.	Nil
76.008	Torana buck	15.5g-60ms	MT060	4.35	N.R.	Ogle MIRA	N.R.	Nil
76.009	Torana buck	15.5g-60ms	MT060	4.01	N.R.	Ogle MIRA	N.R.	Nil
76.010	Torana buck	15.5g-60ms	MT060	3.36	N.R.	Ogle MIRA	N.R.	Nil
76.011	Torana buck	15.5g-60ms	MT060	4.55	N.R.	Ogle MIRA	N.R.	Nil
76.012	Torana buck	15.5g-60ms	MT060	3.22	N.R.	Ogle MIRA	N.R.	Nil
76.013	Torana buck	15.5g-60ms	MT060	3.99	N.R.	Ogle MIRA	N.R.	Nil
76.014	Torana buck	15.5g-60ms	MT060	3.96	N.R.	Ogle MIRA	N.R.	Nil
76.015	Torana buck	15.5g-60ms	MT060	3.90	N.R.	Ogle MIRA	N.R.	Nil
76.016	Torana buck	15.5g-60ms	MT060	3.37	N.R.	Ogle MIRA	N.R.	Nil
76.017	Torana buck	15.5g-60ms	MT060	4.15	N.R.	Ogle MIRA	N.R.	Nil
76.018	Toranal buck	15.5g-60ms	MT060	3.91	N.R.	Ogle MIRA	N.R.	Nil

KEY TO TERMS IN TABLE 4

TEST RIGS

ECE	Rigid seat test rig designed for testing to requirements of ECE regulation 16 .
ADR4A	Rigid seat test rig designed for testing to requirements of Australian Design Rule 4A.
ADR4A (mod.)	ADR4A test rig with minor modifications for research purposes.
ADR4B	Rigid seat test rig designed for testing to requirements of Australian Design Rule 4B.
ADR4B (mod.)	ADR4B test rig with minor modifications for research purposes.
E L R	Special test rig designed for evaluation of emergency locking retractors; consists of rails and bearings to accept a sliding body block; not a seating installation.
Headspace	Single seat test rig fitted with production automobile seat and representing typical compact car installation.
Torana buck	GM-H Torana body shell adapted for repeated crash simulations.

DUMMIES

TNO10	Standard dummy representing 50th percentile male; manufactured by Instituut Voor Wegstransportmiddelen T.N.O. Netherlands. Usually used with head removed.
TNO10 (mod.)	Standard TNO10 dummy with modifications incorporated to tighten or lock knee and hip.
TNO10 torso	TNO10 torso on wooden hip block designed to slide on rails of E L R test rig.

Sierra 1050	Standard dummy representing 50th percentile male; manufactured by Sierra Engineering, Santa Madre, California.
TARU torso	Wooden torso block pivoted on wooden hip block; designed to slide on rails of E L R . test rig.
Ogle MIRA	Ogle/MIRA M50/71 dummy representing 50th percentile male; manufactured by David Ogle Limited, Letchworth, England.

RETRACTOR FAILURE

Crash simulation number 75-174 was the only case in which a retractor failed to lock. Subsequent to the simulation the retractor was dismantled and inspected. The retractor had been subjected to crash simulation previously (simulation 75-173) and it was found that the locking mechanism had sustained damage; the primary locking pawl had been overloaded and its pivot pin had detached from the base plate. The locking system was thereby rendered inoperative.

APPENDIX A

THE DYNAMIC TEST FOR SEAT BELTS

Dummy design was thought to be a factor in the result of dynamic tests. For example, the dummy might be tuned within the provisions of the design rule, for unnaturally low seat belt forces. In order to demonstrate this hypothesis two series of crash simulations were conducted; the first compared the results obtained with two different production dummies; the second showed the variation in data resulting from modifications to one of these dummies.

The anthropomorphic dummies considered were the Dutch TNO10 and the American Sierra 1050. They differed in basic design but both were acceptable for dynamic testing in accordance with ADR4C.

The TNO10 was a rugged device originally designed to meet the requirements of ECE regulation 16 and primarily intended for repeatable use under low maintenance conditions. All body segments were fabricated from plastic, cast on steel frames. No arms were fitted and the dummy's legs were moulded as a single articulated unit. Articulation of the common leg and of the neck was available only in the mid-sagittal plane. The TNO10 dummy was operated with its head removed since its restraint forces were found to be more repeatable in this condition.

The Sierra 1050 was more human-like than was TNO10. Sierra's body proportions and dimensions were patterned on the 50th percentile American male; it had a fully articulated skeleton with shaped pelvis and thoracic cage, soft internal padding representing subcutaneous tissue and abdominal contents; a vinyl skin enclosed all components.

The dynamic test procedure of ADR 4C requires that the dummy is seated on a test rig and is restrained by the seat belt to be tested. The rig is subjected to a simulated frontal impact during which it undergoes a velocity change not less than 49km/h and a deceleration in the range 24g to 34g. Duration of deceleration must not be less than 20 ms. (The crash pulse was shown pictorially in Figure 5 of the main text.

The Rule states only two requirements controlling dummy design:

1. Mass shall be 74kg ± 2kg
2. During a calibration run, which is detailed, the sum of the peak restraining forces in the free lengths of each of the separate lap and sash belts shall be not less than 10kN.

When the TNO dummy was subjected to the calibration procedure of ADR4A, the sum of the peak loads in each belt was usually found to be of the order of 14kN. These loads were somewhat higher than the minima set by the Rule, but it was thought generally that loads of this magnitude were inevitable. If it is accepted that belt loads are not greatly affected by variations in dummy design then the minimum 10kN figures can be seen as safeguards against gross manipulation of the test to produce very low belt loads.

Crash simulation data comparing the two dummies under similar conditions will be found in Table A1. It will be seen that in spite of the differences in dummies seat belt forces were similar. Chest excursions were not expected to be comparable because of differences in body proportions and thus in seat belt fit, nevertheless their magnitudes were of the same order. It was concluded from this comparison that changes in dummy design would have to be extreme in order to influence the dynamic test result.

Table A2 summarises the results of crash simulations, conducted with TNO10, in which seat belt forces were made to reduce significantly. Before the project was commenced, the dummy's mass was reduced to the minimum permitted by the Rule (72kg) and the movable masses were distributed so as to achieve similar loads in lap and sash belts. This was the datum condition.

Firstly, the knee and hip joints were tightened to inhibit articulation and the dummy's foot was placed against the footrest of the test rig in an attempt to transmit some crash forces through this component. Belt forces were not significantly affected by this modification even when the friction reducing joint plates were eliminated.

Next, the dummy's knee joint was positively locked and in this condition there was a reduction in lap belt force which was interpreted as indicative of some restraint being provided by the footrest. A more spectacular reduction was obtained when the lap belt was slackened although this is not specifically permitted by the rule.

Finally the dummy, with knee locked, was placed on the rig with its foot wedged tightly against the footrest. Three simulations were then performed, to demonstrate repeatability, and the lap belt force was found to be consistently 30% below the original datum figure and just above the minimum 10kN required by the Rule.

Sash forces were not significantly affected by the modifications, although a slight reduction was observed overall. Both sash and lap belt loads could have been reduced to 10kN without difficulty by further rigidising the dummy, with struts running from shoulders to knees and simulating the dummy's arms; alternatively mass could have been transferred from the torso to the lower segment of the leg.

With the exception of slackening the lap belt, none of the modifications described was contradictory to the Rule. The implication of the above results is that the specified minimum belt loop loads of 10kN are not simply safeguard figures but are achievable targets. Thus a seat belt which failed a dynamic test, using a conventional dummy whose belt forces were of the order of 15kN, could not be said to have failed to meet the minimum requirements of the Rule. Any testing organisation which broke a belt at 15kN loop force would be obliged to modify its dummy and retest.

TABLE A1: Comparison of TNO 10 and **Sierra** 1050 dummies

Dummy	Retractor type	Run	Peak decel. (g)	Velocity change (km/h)	Peak belt forces (kN)				Retractor outlet strap force (kN)	Retractor maximum payout (mm)	Dummy chest excursion (mm)
					sash	lap	common	total			
Sierra 1050	I (Britax)	75.200	18.0	39	5.7	7.2	8.2	21.1	4.7	102	234
		75.202	17.6	38	5.9	7.3	9.1	22.3	4.4	105	209
		75.203	17.9	39	5.9	7.3	9.1	22.3	3.8	99	216
		75.204	18.1	39	6.3	7.4	9.8	23.5	3.9	84	192
		Mean	17.9	39	6.0	7.3	9.0	22.3	4.2	98	213
		Range	0.5	1.0	0.6	0.2	1.6	2.4	0.9	19	42
TNO10	I (Britax)	75.208	16.7	39	6.0	6.6	8.2	20.8	N.R.	69	185
		75.209	17.3	40	6.2	7.2	8.8	22.2	N.R.	76	189
		75.210	17.2	40	5.8	7.5	9.2	22.5	N.R.	63	185
		Mean	17.1	40	6.0	7.1	8.7	21.8		69	186
		Range	0.6	1.0	0.4	0.9	1.0	1.7		13	4
Sierra 1050	II (Rains-fords)	74.021	17.0	38	6.7	N.R.	9.3	N.R.	N.R.	78	203
		74.022	16.9	38	6.5	N.R.	N.R.	N.R.	N.R.		210
		74.088	16.7	38	N.R.	N.R.	N.R.	N.R.	N.R.	62	131
		Mean	16.8	38						72	181
		Range	0.3	0	0.2					26	79
TNO10	II (Rains-fords)	75.182	17.4	40	6.2	7.4	9.5	23.1	4.2	46	190
		75.183	16.4	38	6.0	7.1	9.0	22.1	4.1	54	184
		75.186	17.4	40	6.0	7.5	9.3	22.8	3.9	45	189
		Mean	17.1	39	6.1	7.3	9.3	22.7	4.1	48	188
		Range	1.0	2.0	0.2	0.4	0.5	1.0	0.3	9	6

TABLE A1 (Continued)

Dummy	Retractor type	Run	Peak decel. (g)	Velocity change (km/h)	Peak belt force (kN)				Retractor outlet strap force (kN)	Retractor maximum payout (mm)	Dummy chest excursion (mm)
					sash	lap	common	total			
Sierra 1050	III (Repa)	75.188	18.1	40	6.1	7.4	9.9	23.4	4.3	72	199
		75.189	17.4	38	6.4	6.4	9.0	21.8	3.9	57	197
		75.190	17.7	39	6.3	6.6	9.4	22.3	4.0	68	198
		Mean	17.7	39	6.3	6.8	9.4	22.5	4.1	66	198
		Range	0.7	2.0	0.3	1.0	0.9	1.6	0.4	15	2
TNO10	III (Repa)	75.170	16.6	38	5.7	7.3	9.9	22.9	4.0	33	147
		75.171	16.4	38	5.7	6.9	9.6	22.2	4.0	31	173
		75.172	17.1	40	6.0	7.0	10.3	23.3	4.0	36	174
		Mean	16.7	39	5.8	7.1	9.9	22.8	4.0	33	165
		Range	0.7	2.0	0.3	0.4	0.7	1.1	0	5	27
Sierra 1050	IV (Cool-drive)	74.018	17.8	39	5.8	6.3	7.7	19.8	N.R.	92	256
		74.019	17.3	38	6.0	6.3	7.7	19.8	N.R.	118	272
		74.020	16.9	38	5.6	5.9	8.5	20.0	N.R.	101	253
		Mean	17.3	38	5.8	6.2	8.0	19.9		104	260
		Range	0.9	1.0	0.4	0.4	0.8	0.2		26	19
TNO10	IV (Cool-drive)	75.177	16.9	38	5.8	7.6	10.4	23.8	4.1	33	187
		75.179	16.5	38	5.8	6.4	9.7	21.9	3.8	40	180
		75.180	16.3	38	6.4	6.7	9.3	22.4	4.1	38	173
		Mean	16.6	38	6.0	6.9	9.8	22.7	4.0	37	180
		Range	0.6	0	0.6	1.2	1.1	1.9	0.3	7	14

TABLE A2: Reduction of seat belt forces in the dynamic test

Run No.	Dummy Condition	Seat Belt Loop Forces (kN)		
		Sash	Lap	Total
A1	Datum (Head removed; joints set to 1g. 25mm spacer behind dummy when belt tightened)	13.6	15.0	28.6
A2	Datum with joints tightened to 27.5N.m. bolt torque	14.1	14.8	28.9
A3	Datum with joints tightened to 55.5N.m. bolt torque	14.2	15.2	29.4
A4	Datum, joint spacer plates removed giving high friction joint articulation	13.7	14.0	27.7
A5	Datum with kneejoint positively locked	12.7	11.3	24.0
A6		12.6	12.5	25.1
A7	Datum with knee joint locked; sash tight, lap slack; footrest adjusted to contact foot firmly	12.5	8.7	21.2
A8	Datum with kneejoint locked, lap and sash tight. Footrest adjusted to contact foot firmly	12.5	10.8	23.3
A9		12.2	10.4	22.6
A10		12.3	10.8	23.1

APPENDIX B

THE RETRACTOR LOCKING TEST

ADR 4C requires that emergency locking retractors should lock under acceleration not exceeding 0.5g which must be attained within 40ms. When the length of webbing stowed on the reel is 150mm, payout must not exceed 30mm; when the stowed length is 450mm or 750mm, payout must not exceed 80mm. The retractor is required to lock when accelerated longitudinally, laterally or vertically. No specific testing apparatus is nominated.

The effectiveness of this 0.5g locking test as a measure of crash performance appeared to be dubious since it was not related to any excursion requirement under crash conditions. The value of the locking test was also questionable as a control of threshold sensitivity since the payout result could vary according to test rig design and it was thus possible that different test rigs would yield different results, ranging from "pass" to "fail" with the same model of retractor.

The Unit's locking test rig was originally designed and constructed to carry out tests in accordance with the requirements of Australian Standard E35 Part II; these originated in a recommendation issued by the International Standards Organisation[1]. The test rig was specified by Appendix D of AS E35 Part II which stated in part: "...The apparatus consists of a motor-driven cam, the follower of which is attached by wires to a small trolley mounted on a track. The cam follower incorporates a lost-motion device which absorbs any movement should the reel lock before the full stroke of the follower is completed". The test rig illustration presented in ASE35 Part II is reproduced in Figure B1.

The lost-motion device on the test rig was a floating anchorage restrained by a spring and the resistance which it offered to the webbing was adjustable, depending upon the spring tension. Originally a friction device had been fitted but this had been discarded since its resistance was not repeatable being subject to sticking and unduly sensitive to adjustment. Variations in release force of the lost-motion device resulted in differing payouts depending upon the degree of webbing tightening which occurred after locking.

The force in the spring of the lost-motion device was required to exceed maximum withdrawal force in order to avoid spring extension occurring during acceleration of the retractor; this could result in a smaller payout than should have occurred. Withdrawal force was found to be as high as 25N with two types of retractors and a spring force of 30N was selected when testing these. The other two types of retractors had withdrawal force of the order of 13N and were tested with spring force of 15N. A summary of test results is presented in Table B1.

Locking tests were conducted in accordance with the Rule at a nominal condition of 450mm reeled webbing. In fact, tests were conducted at reeled lengths of 450mm and 455mm. The reason for variation of reeled length was to avoid any overloading or burring of locking teeth under repeated use, also to compensate in the results for initial phase relationships of locking teeth. Approximately twenty tests were conducted with each retractor. The results are summarised in Table B1 and are presented in detail in Table B2.

Retractor payout in the locking test was seen to range widely with individual retractors and this was attributed to tightening of the coiled webbing on the retractor reel after locking because of spring force applied by the lost-motion device. To achieve more consistency in the results, webbing was removed from the retractor and in its place was substituted a light cable on a spool, the diameter of which was selected in order to maintain the retractor's withdrawal force at 450mm reeled webbing length. Table B1 indicates that payout decreased and became generally more consistent in this modified condition.

As stated in the main text of this paper, a frequency response effect was observed with the type I (Britax) retractor and this may explain why this was the only device which was not affected when cable replaced webbing. In some locking tests the retractor failed to lock or it produced excessive payouts. Indeed in some tests, payout was found to exceed the stroke of the test rig's cam, suggesting that it could have been the application of the carrier trolley's brakes which initiated locking. On two occasions when the retractor locked at large payouts a rattle could be heard during retractor displacement. This sound was thought to be the result of the locking pawl striking and rebounding from the tips of the locking teeth on the rotating reel. The condition was reproducible in other Britax retractors during locking tests but did not occur in any crash simulations or in field work.

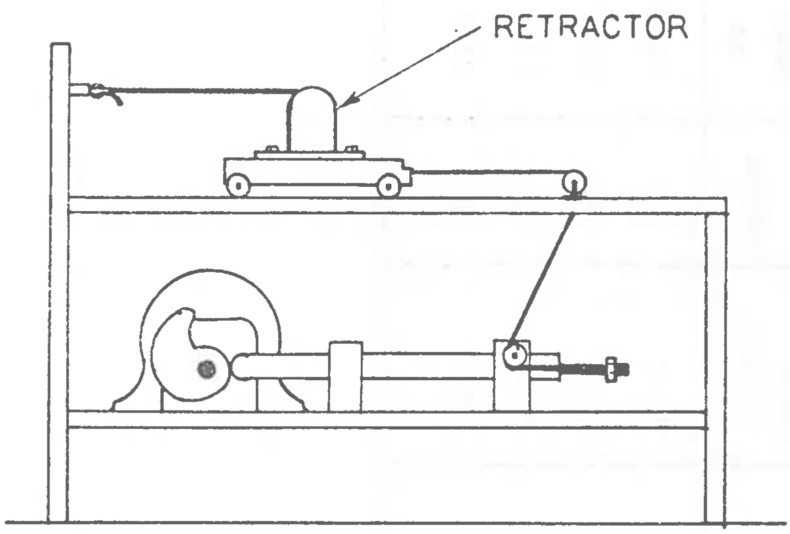

FIGURE B1: AS E35 Retractor locking test rig (reproduction of SAA drawing).

REFERENCE

1. *"Motorists' Seat Belts with Retractors"*, Draft ISO Recommendation No. 1534, International Standards Organisation, Undated.

TABLE B1: Summary of locking test results.

Type	Retracting force Newtons	Maximum withdrawal force Newtons	Spring force Newtons	Webbing payout			Cable payout		
				Mean mm	Standard deviation mm	No. of readings	Mean mm	Standard deviation mm	No. of readings
I (Britax)	5.6	17.7	30	34.2	(3.1)	16	34.6	(7.3)	17
II (Rainsfords)	7.6	24.3	30	25.9	(4.2)	20	16.7	(5.2)	20
III (Repa)	5.4	13.8	15	17.4	(3.2)	20	14.0	(0.3)	20
IV (Cooldrive)	5.8	12.5	15	23.7	(2.9)	20	18.7	(0.8)	20

TABLE B2: Results of locking tests

Retractor	Lost motion spring force.	Payouts recorded in order of tests (mm)																			
Britax with webbing	30N	101*	100*	100*	32	83*	25	38	35	35	38	35	35	32	35	32	35	36	32	36	36
		* Retractor locked but with large payout. These numbers are not in Table B1. (see text page 63).																			
Britax with cable	30N	33	52	*	31	32	*	42	32	33	32	34	30	30	30	30	26	30	41	50	*
		* Retractor failed to lock																			
Rainsfords with webbing	30N	28	22	22	22	23	22	22	28	22	22	28	27	27	26	28	21	33	27	34	33
Rainsfords with cable	30N	20	21	21	26	14	22	15	22	15	15	9	15	14	21	10	10	10	20	32	21
Repa with webbing	15N	17	17	19	19	18	19	18	18	19	18	23	23	14	15	23	14	14	14	14	12
Repa with cable	15N	14	14	13	14	14	14	14	15	14	14	14	14	14	14	14	14	14	14	14	14
Cooldrive with webbing	15N	20	22	21	29	21	25	25	25	26	25	29	21	22	22	30	22	22	22	22	23
Cooldrive with cable	15N	18	18	18	17	18	18	18	18	19	19	19	19	19	19	19	20	19	19	20	20