

SAFETY REQUIREMENTS OF BUS
SEATS AND SEAT ANCHORAGES

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Abstract

Literature on bus safety was surveyed with emphasis on seat design, seat standards and injury mechanisms together with a study of accident statistics. Existing standards were investigated and the local manufacturing industry surveyed. Accidents were attended and studied with particular emphasis on seat and seat anchorage damage. A testing program was carried out on a representative sample of seats currently in use in Australia to determine seat back force deflection characteristics, energy absorbing properties and anchorage strengths. Inter-alia it was concluded unlikely that any of the seats tested would have satisfied all of the requirements of the current overseas bus seat standards.

Note:

This report is disseminated in the interest of information exchange. The views expressed are those of the authors and do not necessarily represent those of the Commonwealth Government.

The Office of Road Safety publishes two series of reports resulting from internal research and external research, that is, research conducted on behalf of the office. Internal research reports are identified by OR while external reports are identified by CR.

Glossary of Terms

| | |
|-------------------------|---|
| Displacement transducer | - an electrical device for measuring linear motion. |
| Femur | - thigh bone of the human body. |
| Kinetic energy | - energy due to a mass m moving at velocity v . ($K.E. = 1/2 mv^2$). |
| Load cell | - an electrical, strain gauged, device for measuring force. |
| Modesty panel | - a screen placed in front of the legs of frontal seated passengers. |
| Newton (N) | - unit of force in the S.I. system of units ($1 \text{ lbf} = 4.448 \text{ N}$). |
| Ramping | - forward sliding of the passenger over the collapsed seat-back of the seat in front. |
| S.W.G. | - a measure of thickness - Standard Wire Gauge. |
| Stiffness | - the ratio of the force applied to a structure to its resultant deflection. |
| Thorax | • - part of the body between the neck and abdomen enclosed by the backbone, ribs and sternum. |
| UNF, UNC | - Screw thread types : Unified National Fine, Unified National Coarse. |
| Work hardening | - a process where force increases with deformation. |
| Work softening | - a process where force decreases with deformation. |
| Web | - a thin, often triangular plate, welded between two intersecting structural members for stiffening purposes. |
| ϕ | - symbol for diameter. |

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CHAPTER 1

LITERATURE REVIEW ON BUS SAFETY

1.1 INTRODUCTION

The first approach made in acquiring literature on the topic of bus safety, with special regard to the internal fittings of buses and their injury causation, was to run a computerised data base search. The two data bases searched were; International Road Research Documentation (IRRD) and Literature Analysis System - Office of Road Safety (LASORS).

From several searches, a total of 294 citations were listed, although some articles were listed more than once. The relative importance of the literature was determined mainly from a consideration of the contents and the date of the article. Further, unless the abstract of the article was particularly relevant to this project, literature not available in English was discarded due to the associated problems of translation. The search of the articles, papers, standards and books commenced and continued throughout the duration of the project. Unfortunately, some of the literature was not obtained.

An additional source of references was extracted from the bibliographies of the literature examined. These are listed at the back of this report.

Both industry and governmental departments assisted in accessing articles that were difficult to obtain.

The particular literature which was sought, fell under the following eight headings:

- 1) Innovations in bus design.
- 2) Tests of bus seats.
- 3) Development of bus safety seats.
- 4) Crash barrier bus research.
- 5) Human impact tolerances as related to bus collisions.
- 6) In-depth bus accident reports.
- 7) Bus accident statistics.
- 8) Bus seat and anchorage standards.

Many of these topics are discussed in later chapters of this report. Consequently, for the major part of this chapter, injury-producing mechanisms involved in bus accidents and bus and bus-seat design innovations will be discussed.

It was soon established that the number of useful articles was limited and was predominantly either American or English in origin. The amount of useful information concerning bus safety in Australia was negligible and the value of accident statistics relating to buses was very limited. Furthermore, the type of accident injury information necessary to successfully analyse bus accident injury causation was not readily available in Australia.

1.2 INJURY PRODUCING MECHANISMS INVOLVED IN BUS ACCIDENTS

Clearly, due to the large mass and consequent inertia of buses relative to the majority of road vehicles, buses involved in collisions with other vehicles are unlikely to experience high levels of deceleration. Thus it was found that in the event of an accident between a bus and a car, the car and its occupants, were subjected to higher decelerations than the bus and its occupants.

Furthermore, Siegel et al.¹ found that in the event of such an accident the likelihood of a fatality is more likely to involve one of the car occupants. This trend however, was found not to

be true for casualties. Indeed the reverse seems to be the case, whereby the chance of injury is more likely within the bus than within the car. This observation has been said to be due to the lack of proper energy absorbing design of the interior of buses¹.

It has already been stated that if a bus collides with a lighter object, such as a car, the bus will not undergo as rapid a deceleration as the car. However, this is not the case if the bus impacts an object of similar mass. Fortunately, the proportion of heavy vehicles in the total road-user population is much less than the proportion of lighter vehicles, such as cars. Thus, the chance of a collision between a bus and another heavy vehicle is much smaller than a collision between a car and a bus.

It is important to recognize the five major categories of bus collisions and their relative severity. Generally, the most common type of impact is a "frontal" collision which may not involve another vehicle. This encompasses any collision involving impact at the front of the vehicle where the direction of deceleration is essentially towards the rear of the bus. "Rear-end" collisions usually involve another vehicle running into the rear of the bus, causing the bus to be accelerated. A collision which is characterized by lateral acceleration is a "side impact", typical of the type of accidents which occur at intersections.

When the contact of the bus is described as a "glancing blow to the side", the collision is commonly known as a "side-swipe". The fifth collision type, the "roll-over", is quite different from the others and requires a considerable amount of thought when contemplating the means of minimizing injury severity. This is due to the difficulty associated with passenger retention. In the following sections, the five collision types will be considered in relation to the type and severity of injury which can occur in each particular

type of accident. Apart from injuries resulting from collisions, there are a large number of accidents where the bus is not involved in contacting another object although passenger injuries do occur. These cases and their pattern of injuries will also be discussed.

1.2.1 The Head-on Collision

Bus accident data was collected for the State of Victoria during the course of this project. It was presented in a way that made classification of accidents into specific categories such as "head-on" very difficult to achieve. However, on inspection of police accident report forms, it was observed that a major proportion of all bus accidents were of a head-on variety. Furthermore, this observation has been documented in past studies. Indeed, Stansifer et al² found that 53% of a sample of bus accidents could be categorized as frontal impacts. Similar findings were presented by Johnson³ who found that out of a sample of 391 bus accidents 73% were simple enough to be classified under a single type. Of this group, 73% involved a head-on collision with a vehicle or stationary object. A further 16.5% were classified as a frontal impact into the rear of another vehicle. Thus again, over half of the classifiable accidents were head-on collisions. As a consequence of this high percentage of head-on accidents, a lot of work, mostly in the United States and some in England has gone into studying the mechanisms of injury of such collisions. Wiegel et al¹ noted that a large percentage of all severe injuries in bus collisions were to the head. Furthermore, the following comments were made: "Seats are the principal cause of both facial and head injuries due to the possibility

of frontal collision involvement, as well as the obvious potential for contact due to height similarities between seat backs and certain passengers. It appears that even the limited 'padded' seats of a charter bus offer an injury-reduction potential".

Because of the high percentage of head-on collisions and the role that the seats play in injury causation, a considerable amount of work to develop safe bus seats has been undertaken by such research groups as AMF Advanced Systems Laboratories, Virginia Polytechnic Institute Industry Centre and Leyland Vehicles Human Factors Group. The basic concept used is to employ the seats as a passive passenger retainer and thus prevent the passengers being catapulted through the bus with the possibility of being ejected, which results in a much greater injury risk¹. Furthermore, the seat not only serves to contain the passenger within a specified region designated as the survival space, but seeks to do so in such a manner as to minimize injury. Thus the seat is designed to absorb the kinetic energy of the passenger in a controlled manner so that peak deceleration of the head and thorax and peak loads in the femur are kept within acceptable human tolerances. It is important, as shown by Adams et al⁴, that movement of the passenger as a whole, should be controlled, but also the relative movements of various parts of the body should be limited. This finding has been found to be beneficial, in both retaining the passenger and minimising the severity of injuries both by Adams et al and Wojcik et al⁵.

There are many factors which influence the retention properties of a bus seat, all of which are mentioned at a later stage in this report. However, for the moment, it is sufficient merely to list these factors:

- 1) Strong seat anchorages to ensure seat retention.
- 2) Provision for knee penetration to minimize femur forces and to prevent the pivoting of the upper body and consequent high head impact loads.
- 3) Adequate seat back height to prevent ramping and unacceptable head impact.
- 4) Suitable seat-back stiffness to allow passenger retention without either
 - a) premature seat collapse or
 - b) excessive body forces.
- 5) Adequate energy absorbing padding in the knee and head protection zones to prevent unduly high localized forces.
- 6) Suitable seat back angle to enhance the retention capabilities of the seat.

In order to study head-on collisions, simulated dynamic sled tests have been carried out using instrumented manikins and high speed cinematography ^{6,7,4}. In some cases, real buses have been used in the tests instead of a test sled. These barrier tests allow precise study of injury causation and body movements resulting from a collision. Most of these tests are carried out using an impact velocity of 30 km/h and an average deceleration of about 10 G. In the tests, head decelerations of up to 106 G have been measured. The severity of such an impact is of a potentially fatal magnitude. Bus seat standards are worded so as not to be "design restrictive" and are aimed at achieving adequate seat strength, rigid anchorages and passenger restraint, and minimum injury causing potential. This means that hardware and design of the seat and anchorages are not stipulated, but factors relating to the impact of a test manikin are precisely detailed. Parameters such as the limits of body movement, maximum body forces and

accelerations are defined and specified. The standards that use dynamic test simulation also allow for the option of seat evaluation by static force/deflection tests. The more comprehensive of these tests involve dual loading, in order to allow for both knee and head impact on the back of the seat. Force/deflection limits are defined for both forward and rearward facing seats. A further test is sometimes incorporated into the standard and concerns the testing of energy absorbing padding in the knee and head protection zones. All these tests rely upon the assumption that the passenger survival space is maintained.

Another topic of concern is the strength of the bus body with respect to passenger protection and this has generated a considerable degree of interest. A number of detailed, in-depth studies have been carried out by delegates of the Economic Commission for Europe (ECE) and American and English research bodies.

The problem of maintaining passenger survival space is most critical in the roll-over accident case and appears to be difficult to achieve in serious accidents. Head-on barrier impact tests, similar to the one shown in a film* of a Leyland National bus showed very little passenger compartment intrusion. Furthermore, the driver's cab was so mounted that it displaced backwards, retaining both its integrity and the driver's survival space. This compares with a partial head-on collision between two buses on a curved section of road in the Latrobe Valley region in 1977. The entire side of one bus from the waist rail to the cant rail peeled off and was pushed through the second bus. Fortunately, the bus that had the wall section pushed through the front of the vehicle and finally finished protruding out of the rear window, was empty. The bus that had its side section peeled off, however, contained 49 passengers, four of whom died and 20 were injured. The fatalities resulted from the breakdown of their

* "Performance and Handling - National Bus",

Loaned to the authors by the Leyland Motor, Corporation of Australia, Ltd.

survival space and had nothing to do with the safety performance of the seats.

1.2.2 Rear-end Collisions

This type of accident, usually involves a car and hence the deceleration of the bus is small relative to that of the car. Furthermore, the bus is usually stationary or else moving towards or away from a bus stop at a low speed. Indeed, the nature of transit buses is such that due to the high number of stop/starts at bus stops, they are prone to this form of collision. Obviously, the loading on seat frames and passengers in this type of collision is completely different to those generated by a head-on collision. Thus such an impact needs to be studied and considered in its own right. Rear-end collisions usually involve slower impact velocities and milder acceleration levels. In the standards for seats and their anchorages, a dynamic reconstruction of such an accident typically involves an impact velocity of 15 km/h and an average acceleration of 10 G for 40 ms as opposed to 12 G for 85 ms for a front-on collision. The load applied to the passenger is distributed over his back and does not involve any point loads. There is a high possibility of whiplash with low back seats, especially padded ones, which provide a distinct neck bending location. In a study by Severy et al⁶, it was found that when a car, travelling at 60 mph rear ended a stationary bus, the resultant peak acceleration of the bus at 45 ms after impact was 10 G as opposed to the car's peak deceleration of 18 G at the same time. In the conclusion of this study, the following comments were made:

"Low back seat units with a seat back height less than 28 in., greatly increased the chances of injuries during school bus accidents. Seats most commonly encountered

in school buses have seat back heights ranging from 18 to 20 inches. These low back units provide no head support except for very young school children and leave the passenger in an extremely vulnerable condition when the vehicle is rear ended".

Furthermore, it was observed that there was a considerable amount of passenger rebound which often resulted in head impact on the back of the seat in front of unrestrained passengers.

In the case of a rearward facing seat in a rear-end collision, the type of body movement and points of body contact are essentially the same as a head-on collision. Injury severity of passengers in rearward facing seats is however, less serious than forward facing passengers involved in a head-on collision, due to the lower impact velocity and deceleration levels sustained. Rearward facing seats are sometimes located in the wheelarch area of the bus, such that two seats are positioned back to back so that the wheelarch does not restrict leg room. In such a case, the problem associated with this configuration is that the passengers in the rearward facing seats have no seat back in front of them to act as a restraint in the event of an accident. Furthermore, in the event of a head-on collision, these passengers are exposed to higher chances of injury from impact from the forward facing passengers who may be sitting opposite. The reverse is true for the forward facing passengers in the case of a rear-end collision, that is they are exposed to impact with the rearward facing passengers.

Side facing seats, which are sometimes used to minimize the restriction of floor space caused by the wheel arches, cause the same problems in rear end accidents as they do in head-on collisions. Again, the situation exists that the injuries sustained tend to be less severe in rear-end accidents due to the milder nature of the collision.

As with head-on collisions, intrusion into the passenger compartment tends not to be a problem with rear-end collisions. However, there have been cases where the rear seats have been displaced forward, although it is usually found that the impacting vehicle under-rides the bus. In such an event, there is normally very little bus damage and subsequent intrusion that infringes upon the passengers survival space. The impacting vehicle however, which is commonly a car, is usually subject to severe damage to the passenger cab area.

1.2.3 Side Swipe Collision

This form of collision is generally the least severe in terms of deceleration levels of all the collision types to which buses are subject. The major concern of such collisions involves the breakdown of the passenger survival space due to intrusion of the bus side wall structure. Fortunately, in the event of a collision with a car, the height of the passenger compartment is sufficiently high to maintain the passengers above the impact zone. With transit buses however, there is a trend for lower floor heights in order to facilitate ease of egress and boarding. The effect of this design change is to lower the passenger compartment to the extent where the intrusion of survival space is possible when the collision involves a car. In an article by Hartley⁹ a new style transit bus is reviewed. It features a floor height of only 432 mm.

In another article a prototype transit bus by Neoplan is reviewed. This vehicle has a boarding floor height of only 300 mm and is achieved by incorporating low profile tyres and kneeling air bag suspension. Buses with low floor heights are much sought after by transit bus proprietors due to the reduction in bus stop times which reduce transit trip times. The disadvantage of the trend is an increase in the weight of the vehicle due to the necessity of strengthening the side wall structure to prevent passenger compartment penetration. In the article by Hartley

concerning the new General Motors bus, the weight of the vehicle is 454 kg heavier than the conventional model. This added weight affects such parameters as fuel economy, tyre wear, braking distance and brake material life. In a report by Shanley¹⁰; side-swipe accidents were the largest single type of accident and accounted for 46% of all accidents. Unfortunately, it was again found that the Victorian accident statistical data was not suitable for categorizing into head-on, rear-end, side impact, side swipe and roll over type classifications. Even though there are 93 classifications allowable within the accident type coding system for Victorian accidents, the categories are difficult if not impossible, to split up into the five areas of frontal, rear-end, side impact, side-swipe and roll-over accidents.

1.2.4 Side Impact Collisions

Unlike a side-swipe collision, a side impact accident involves relatively high levels of deceleration as it involves a perpendicular impact rather than a glancing one. Because of the relatively high energy dissipated on impact, the chances of deformation of the passenger compartment is much higher than it is for side-swipe accidents. Furthermore, since most of the seats in buses are located transversely across the bus, the passenger's are subject to lateral loadings. The human body is more prone to sustain injury when loaded laterally in a seated position.² The problems associated with side impact collisions are numerous, however they stem back to three areas:

- 1) The possibility of relatively high lateral accelerations.
- 2) The increased exposure to injury that a seated passenger has when subject to lateral forces.
- 3) The difficulty in restraining passengers from sliding

out of their seats.

- 4) The possibility of vehicle intrusion into the passenger compartment, especially with low floored transit buses.

Window passengers are likely either to forcibly contact the window/wall structure or slide across the seat and ram the aisle side passengers into the arm rest, if one exists. If there is no arm rest, then there is a high probability of passengers being thrown out of their seats either into the aisle or across the aisle onto the adjacent seat and its occupants. In a paper by Mateyba¹¹ it was suggested that seats subject to lateral decelerations should be individually contoured and be covered with a non-slip material. In addition, adequately padded armrests should be designed to maximize the chances of restraining the passengers.

In one section of a report by Adams et al⁴ the side impact of a bus into a rigid pole is investigated. The criteria of the bus body design is such that sufficient penetration of the passenger compartment is allowed to facilitate a controlled absorption of the impact energy. This deformation of the bus structure however, has to be consistent with maintaining structural integrity of the vehicle. Excessive distortion results in the fracture of the frame and panels leaving sharp jagged pieces of metal which markedly increases the risk of more severe injuries. Adams et al⁴ call this the "cookie-cutter" effect. In their tests, they used energy absorbing pads in an attempt to minimize injury severity. However, it was found that the amount of padding required to protect all the bus passengers was unreasonable when an impact velocity of 48 km/h was considered. Indeed only marginal occupant protection could satisfactorily

be provided by 142 mm of padding under an impact of 16 km/h.

Unlike head-on and rear end collisions, which exposes all the passengers to an equal risk of injury, side impact does not. The closer a passenger is to the point of impact, the greater the chances of injury. Wojcik's⁵ paper concludes from the results of a side impact bus test that the close spacing, 680mm, of the seats in conjunction with adequately designed aisle restraining arm rests, appears to be sufficient to contain passengers within their seats.

Obviously, passengers sitting in rearward facing seats are subjected to similar movement and body decelerations and loadings as are forward facing passengers in a side impact collision. Adams et al⁴ does mention that apart from the windows, window frames and arm rests, body impact is made with the tops of the seat backs. Thus there is a case for the adequate padding of seat backs, particularly along the top rail, in order to absorb the energy of impact and to distribute the contact load.

Seats that face the aisle offer no means of passenger restraint and allow the passenger to be catapulted across the vehicle in the event of a side impact. This unrestrained movement is not only conducive to injury of the passengers originally located in these longitudinally orientated seats, but is potentially dangerous as the uncontrolled impacting body can have a considerable amount of energy and deliver a severe blow. Furthermore, not so much in side impacts, but in head on collisions there is a distinct tendency for unrestrained passengers to come to rest at the front of the vehicle and in the step well. This has the effect of making evacuation difficult especially if the unrestrained

passengers are unconscious and those to be evacuated are injured. In the event of any form of collision, unrestrained passengers tend to make the task of post impact evacuation much more difficult. This observation has been made by several authors and the problem of passenger evacuation has been a matter of concern to many legislative bodies. A project titled "A study of post-crash bus evacuation problems" by Purswell¹² involved a series of trial evacuations and noted that the time required to empty an upright vehicle is critically dependent on maintaining the effectiveness of the clearway. Furthermore, the evacuation time was affected by the number of available exits, the time required to establish the effective exit, the illumination level and the orientation of the vehicle. Considerably longer evacuation times were recorded for the bus on its side and in darkness. In addition, this test configuration was more prone to causing injuries as a result of the evacuation. It has been noted⁵ that the use of seat belts in buses could hinder the evacuation of the vehicle, although they would be beneficial in restraining passengers in their seats during an impact.

1.2.5 Roll-over Accident

It is widely recognized that the roll over condition of bus accidents is the most difficult in which to prevent injury. Passenger containment becomes extremely difficult if not impossible. Furthermore, the possibility of cab collapse is distinct and ranges in severity from slight to catastrophic, depending on the strength of the bus body and the circumstances of the roll-over. Accidents of this nature tend to involve a single vehicle and occur in non-urban areas and often involve mountainous terrain.

In the report by Adams et al⁴ the following is said about roll-over accidents:

"The roll-over collision mode is regarded as the most complex of all impact modes, essentially from the standpoint of understanding the interactions of the occupants with the vehicle interior and the mechanics of injury production."

"In this program, the technical effort addressing this accident mode was limited to the identification of key areas of bus interior most likely to be contacted during roll-over and the design of these interior surfaces to provide some level of protection for these impacts."

In a later section of the report headed interior surfaces, the types of collision are split into categories from minor to major. Roll-over accidents are classified as major and often involve either full or partial ejection through collision openings and through windows or window openings. The following were found to be of concern in such accidents with regard to bodily contact:

- seats
- modesty panels
- stanchions
- interior crash padding
- driver's compartment components
- side window

It is desirable to reach the objective of preventing injurious secondary impacts of the occupants within the bus during a collision without seriously compromising other interior design considerations such as passenger comfort, aesthetic appeal, resistance to vandalism,

production costs etc.

An in-depth description of the necessary padding required around the seat back to protect against knee, head and torso impacts is given including such things as padding size, thickness and density.

Modesty panels and stanchions are typically rigid non-yielding objects conducive to harsh concentrated impact loading. The Adams structure concentrates on being both practical as a normal passenger assist and efficient in controlling the occupants trajectory during a collision. The modesty panel functions as a load distributor, distributing the impact loads of the occupant to the floor (via the modesty panel frame) and to the roof structure (via a flexible stanchion). The stanchion consists of an aircraft quality high-tensile wire rope surrounded by a flexible plastic protective layer (Neoprene with suitable stiffness) and contained within a Kydex (a PVC acrylic blend) surface cover. The modesty panel is fitted with torso and knee pads, similar to those fitted to the seat backs. The energy absorption characteristics of these pads are designed to cope with a wide range of occupant sizes.

The interior crash padding consists of protective ceiling and wall surfaces where contact by an occupant during a severe collision is likely to occur. The padding modules comprise of a thin Kydex cover backed up by a plastic foam. The ceiling pad is specifically designed to attenuate the forces of impact that would be imposed on an occupant when they strike the roof during a roll-over. The inner skin, a Kydex ~~sheet~~, forming the ceiling cover functions as a tension membrane during impact, thus providing a "trampoline" effect. Underneath this skin is a layer of flexible plastic foam to reduce the "hard" spots created by the roof bow structure. Such a system is capable of withstanding an impact velocity of 35 km/h at a survivable deceleration level with a maximum design deformation of

100 mm. The side wall padding consists of three component subsystems: padding of vertical structure members of the body, padding of horizontal structural members and padding of the window frames. The window frame padding is primarily designed to function as a lateral restraint for seated occupants in side impacts. The components of the driver's compartment which are likely to cause injury upon impact of unrestrained occupants during a serious roll-over can be predominantly classified as harsh protruding hardware. The door actuating lever and control knobs fall into this category.

These are some of the lengths that are being taken to protect bus occupants from injury in the event of a serious collision such as a roll-over. It is of paramount importance to ensure passenger restraint. Yet even though considerable research has gone into the benefits of seat belts in buses and concluded that seat belts should not be fitted to buses with low back seats, it would appear that the roll-over case is the condition in which an active restraint system in the form of a seat belt would be of benefit. However, it has been established by several testing programs^{1, 7} that the use of lap type seat belts in buses can lead to an increase in injury severity due to the whipping effect of the upper body. Of course, this results from the lack of an upper anchorage point for a sash belt to restrain the upper body. In Wojcik's report⁵, it was found that substantially less severe head impact (44 G versus 67 G) could be achieved without the use of lap style seat belts if a suitable designed high-back seat was used. Furthermore, it has been found by Ursell¹² that less than 7% of the adult bus passenger population would use seat belts voluntarily in buses. If transit buses are considered, the use of seat belts (if they were provided) is considered to be almost zero due to the short nature of transit trips and the high percentage of passengers carrying objects, which makes seat

belt operation difficult. The cost effectiveness of seat belts in buses has been considered by many authors, all of whom come to a similar finding as Stansifer² and his comments on the matter were:

- 1) None of the seat belt options considered (7 in all, ranging from lap and sash belts for all occupants to be fitted to all buses, new and old, through to lap belts in the front 8 seating positions of new buses) demonstrated a favourable benefit/cost ratio at anticipated voluntary passenger use rates.
- 2) The passenger use rates which would be necessary to achieve a break-even benefit/cost ratio varies from 47% to 80% depending on the type of system and the degree to which it is implemented.
- 3) Voluntary passenger use of seat belts will not exceed approximately 17.6% and can be expected to average approximately 10.9%. (U.S. data)

Furthermore, the recommendations of the Romberg report are:

- 1) Requirements for passenger seat belts in intercity buses, as considered in the Stansifer project, are not recommended.
- 2) Optimization of the energy absorbing qualities of present seat configurations is recommended. Present seat design has many desirable features which need only slight modification to maximize restraint value and minimize injury producing potential.
- 3) An energy absorbing barrier in front of the first seat units on both sides of the bus is recommended. This type of barrier could contribute significantly to

reducing ejections of passengers through the front window. This device would also protect the driver from injury from passengers or flying luggage.

Similar findings are tabled in Ursell's report¹³, however, the aspect of the high incidence of acts of vandalism, particularly in transit buses was commented upon. It was noted that if the retractor was jammed by "chewing gum or paper wrappers" and experience has shown that this does occur, the belt would lie on the floor and become soiled and unsuitable for use. Consequently no-one would use it. The possibility of tripping over a seat belt whose retractor had been vandalised is high and could lead to civil law suits. Experience has shown that knives have been used to cut off the belts and the heavy buckle end used as a weapon. After discussions with numerous bus manufacturers and proprietors in Australia, it is clear to the authors that indeed there is a vandalism problem onboard buses and it is not necessarily caused by the school children age group.

The all important aspect of passenger survival space is seriously threatened in roll-over accidents, and has been the area of considerable debate and research in America, England and Europe generally.

In a study by the Structural Design Group of the Cranfield Institute of Technology, several severe roll-over accidents were examined¹⁴. It was found that collapse of the roof and wall structure sometimes resulted in a reduction of passenger survival space to the extent that the deformed roof line corresponded with the waist rail (bottom of the window frames) of the vehicle. Accidents of this nature are likely to cause severe injuries no matter how well designed the seat is. In conclusion of the report by Miles et al

the following comment was made:

"There is considerable evidence to show that if passengers can be retained inside the vehicle, fatalities are unlikely even if the roof (or luggage rack) touches the high seat backs provided in most touring coaches. Tests on structural sections of typical British manufacture have confirmed that considerable re-design will be necessary to meet "any reasonable" diagonal loading requirements".

The Cranfield Structural Group have been studying the crashworthiness of buses and particularly roll-over cases in an intensive manner. Papers have been published by members of the group concerning the bending collapse of rectangular section tube in relation to the bus roll-over problem, bus roll-over simulation and investigations into the behaviour of hinges produced by bending and collapse of vehicle structural components. In their studies, the use of extensive finite element programs have been employed to investigate the complicated structural problem of vehicle crashworthiness.

In a paper entitled "Autopsy of a Disaster: The Martinez Bus Accident" ¹⁵, the investigation of a bus accident which resulted in the vehicle landing on its roof is outlined. Twenty-nine of the fifty-one passengers died. In the opening paragraph of the report, the authors noted that the passengers who remained in their seats during the roll and impact, or those who were thrown into the space between the seat backs and the roof, suffered severe crushing injuries from the collapse of the roof (Fig.1.1 and 1.2). Those, however, who were thrown out of their seats into the spaces between the seats were somewhat protected as most of the seats remained attached to the floor and did not collapse. The combination of forward and downward impact forces applied to the roof resulted in the folding of the window pillars at the waist rail (bottom of the windows). Those passengers who were still sitting in their seats or who had been thrown between the seats and the roof were subjected to severe crushing blows.

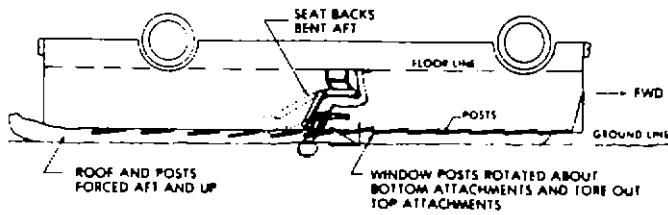


Fig.1.1 Bus position after impact, showing collapse of roof to bottom of windows.
(Ref.15)

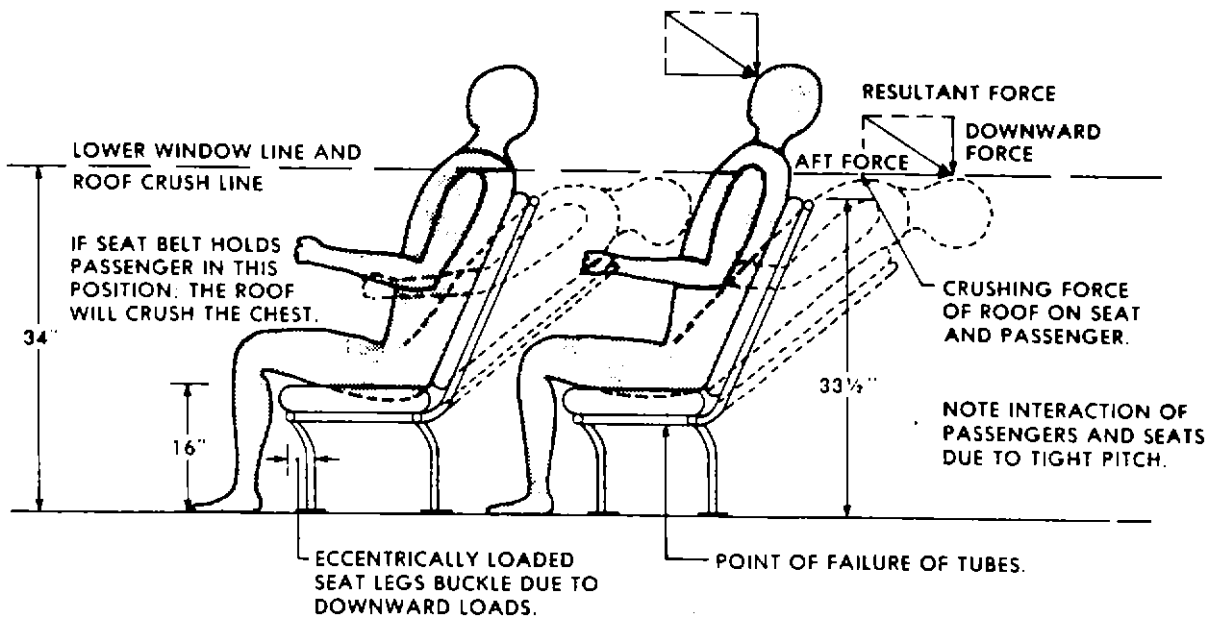


Fig.1.2 Diagram showing relation of collapsed roof to seat backs, and crushing forces likely to be produced on passengers.
(Ref.15)

In the report the following comment was made:

"When the bus rolls over, the structural support in the roof is typically unable to support the weight of the chassis and undercarriage and the roof collapses."

The complete collapse of the roof structure in this case created a major problem with respect to the extrication of the victims. There was no exit in the sides or bottom of the bus and the roof had collapsed to the base of the windows preventing any access to the bus interior. Thus there was no route to remove the injured passengers. Cutting torches could not be used due to the fire hazard: the fuel tanks of the bus had ruptured and fuel flooded the area. A period of 1½ hours elapsed before the first victim was removed from the wreckage. Access to the interior of the bus was achieved by lifting the vehicle by two mobile cranes. The bus was lifted, leaving the roof which had been completely detached upon impact, on the ground. It was later discovered that 10 of the fatalities were possibly preventable if medical treatment had been administered earlier. Essentially four of this ten died from excessive loss of blood, while the remaining six suffered chest trauma. The recommendations of the report regarding bus design were three fold:

- 1) Protection against roof collapse.
- 2) Passenger restraint.
- 3) Emergency access to the passenger compartment.

Perhaps the most potentially dangerous aspect of a roll-over accident is the threat of occupant ejection. In a study by Stansifer² it was reported that 53% of all ejected passengers were thrown out during a vehicle roll-over accident. Sixty-two percent of the ejectees went through side windows or openings caused by the impact.

Many accident cases could be cited from overseas accident investigations showing the severity of roll-over accidents and the incidence of occupant ejection or partial ejection. However, the authors feel that it will be sufficient to comment on two local accident cases, both of which involved coach style vehicles.

The first accident occurred on an alpine road in the Victorian Alps and involved the vehicle rolling several times down a steep mountain side. Fortunately, no-one was killed; however the passenger compartment of the vehicle was damaged to such an extent that the bus was winched back onto the road in two parts. The bus had come to rest against a large tree which had broken the chassis of the vehicle. Most of the 22 injured were reported as being ejected through openings in the passenger compartment as the vehicle rolled.

The second accident case happened in Hay in New South Wales and involved the vehicle running off the road into soft earth; the bus fell on its side and slid to a halt. The two school girls who were killed in this accident were partially ejected out the side windows in contact with the ground.

The factor leading to injuries in these two cases of bus roll-over is the breakdown of the passenger survival space in conjunction with occupant ejection.

Certain case studies performed by the Traffic Accident Research Unit (TARU) in New South Wales also gives valuable information concerning bus accidents. One case involved a head-on collision between a bus and a semi-trailer. The bus rolled onto its roof which collapsed; the rear half of the roof became detached at the right hand side and the rear half of the right side was torn out. Almost all of the bus seats collapsed. Two of the bus occupants sitting towards the rear of the vehicle but situated on opposite sides were killed.

The occupant sitting on the side of the bus where the side wall had been ripped away, died as a result of the following injuries: traumatic amputation of right leg, compound fracture of right leg, multiple rib fractures, lacerations of right lung, multiple transverse fractures of skull, laceration of brain, neck fracture at fifth cervical vertebrae. It is reasonable to deduce that it was the breakdown of survival space in conjunction with partial ejection which caused the severity of this passenger's injuries. The other occupant who received fatal injuries was located on the left side of the bus and sustained the following injuries; multiple injuries to head, thorax and limbs fracture of six right-side ribs, laceration of right lung and the detachment of the right pulmonary blood supply. The cause of these injuries was unknown. Twelve other occupants were admitted to hospital, predominantly with injuries to the head. A further twelve passengers were treated for lacerations and bruises but were not admitted. The driver of the bus sustained relatively slight injuries even though the original impact of the semi-trailer was on the front right hand side. It can be seen by investigation of such accidents, that the major cause of serious injury was due to deformation of the passenger compartment which interfered with the occupant survival space and the lack of passenger restraint which allowed partial or full ejection. The significance of these factors could be drastically reduced by the redesign of the bus body structure and the internal fittings, especially the seats.

1.2.6 Special Conditions Applying to Transit Buses

Transit buses are readily identifiable by having:-

- 1) low backed seats for ease of egress and boarding,
- 2) substantially higher number of passenger assist devices than most buses used for other functions,

- 3) a fare box accessible to the driver,
- 4) low floor height, which means substantially greater wheel arch intrusion into the passenger compartment. To combat this, a reorientation of the seating pattern is often required. The purpose of the low floor height is to assist in rapid and safe passenger egress. Sometimes however, especially in rear engined vehicles, a drawback of a low floor height is the necessity for steps in the floor in order to allow sufficient room for the engine and mechanical running gear. An alternative to a stepped floor is the introduction of ramped floors and often a combination of both steps and ramps are employed.
- 5) the common use of secondary rear doors which can lead to unusual seat layouts,
- 6) a seating orientation planned to allow for a high percentage of standees. These buses are usually subject to peak hour loads, where there are high percentages of standees.

The characteristic transit ride is unlike other forms of bus travel in that:-

- 1) the speeds are generally low,
- 2) the rides of passengers are often short,
- 3) there are a great number of stop/starts due to both passengers embarking and disembarking and traffic congestion,
- 4) passengers on transit buses are often carrying packages or bags of some description which slows down passenger movement.

These distinctive qualities of urban bus usage result in a particular injury pattern characteristic of transit buses. Studies in America conducted by the Booz Allen Applied Research Institute¹⁶ agree with the findings established by similar studies in England and performed by the Leyland Vehicles Human Factors Group.¹⁷ Furthermore, the accident statistics gathered during this

project on the injuries sustained by passengers travelling on Melbourne Metropolitan Tramways Board Vehicles show the same trend as the earlier studies. The major finding is that there is an extremely high proportion of injuries which are caused by non-collision incidents. The severity of these injuries is generally slight, the injuries themselves being largely due to falls within the vehicle.

If we consider the report by Mateyka¹¹ which investigates the nationwide trends in transit injuries in the United States, the following comments are made about the accident scenario (Fig. 1.3).

| | |
|--|---------------------------------------|
| <u>Bus Motion at Time of Acc't.</u> | <u>Passenger Location</u> |
| - 56% decelerating | - 39% forward of first cross seat |
| - 21% normal operation | - 32% first cross seat to rear door |
| - 16% accelerating | - 25% behind rear door |
| - 7% turning | |
| <u>Passenger at time of Acc't.</u> | <u>Was Passenger Carrying Object?</u> |
| - 46% standing | - 54% yes |
| - 30% sitting | - 46% no |
| - 17% walking | |
| - 7% unknown | |
| <u>Passenger Use of Assist Devices</u> | <u>What Was Object Being Carried?</u> |
| - 28% yes | - 47% package |
| - 72% no | - 33% purse |
| | - 14% umbrella |
| | - 6% child |
| <u>Which Device Used?</u> | <u>Sex of Injured Passenger</u> |
| - 34% stanchion | - 82% female |
| - 51% seat handle | - 18% male |
| - 5% overhead bar | |
| <u>How Injured?</u> | <u>Age Group of Injured Passenger</u> |
| - 61% fell to floor | -18% over 65 |
| - 17% hit seat | -53% over 50 |
| - 12% hit stanchion | -47% under 50 |
| - 9% hit farebox | |
| - 3% hit driver partition | |

Fig.1.3 Onboard Accidents

"The injuries that were sustained were not as a result of a severe crash, as might be typical of intercity buses, but rather one involving falls within the bus. A majority of the accidents (61%) occurred while the bus was decelerating and involved passengers who were standing or walking (65%). In most cases, passenger assists were not being used (72%). This perhaps can be explained by the fact that a majority of passengers were carrying objects (54%) or were located in areas of the transit bus that did not provide adequate passenger assists. For example, 39% of the injured passengers were standing in the large open area just to the rear of the bus driver and forward of the first cross (forward facing) seat."

There are two particularly interesting results that can be observed in these accident statistics that are worthy of note. First, the accident victim was typically over 50 years of age (53%) and secondly, the victim was likely to be female (82%).

In another report, Booz, Allen Applied Research¹⁶, the authors note after a subsequent human factor observation of 664 bus passengers, (Fig. 1.4), that transit bus ridership was skewed towards older people. Females made up only 51% of the bus riders observed and thus appear to be over-represented as onboard accident victims. The authors further note that there is no obvious explanation for this observation, however, they did make the following suggestions as possible explanations:

- 1) The propensity of females who carry packages, purses or need to be attending children.
- 2) The unstable quality of female footwear.
- 3) The declining physical strength and fragility of elderly females.
- 4) Social factors related to the greater propensity of women to admit to physical injury than men.

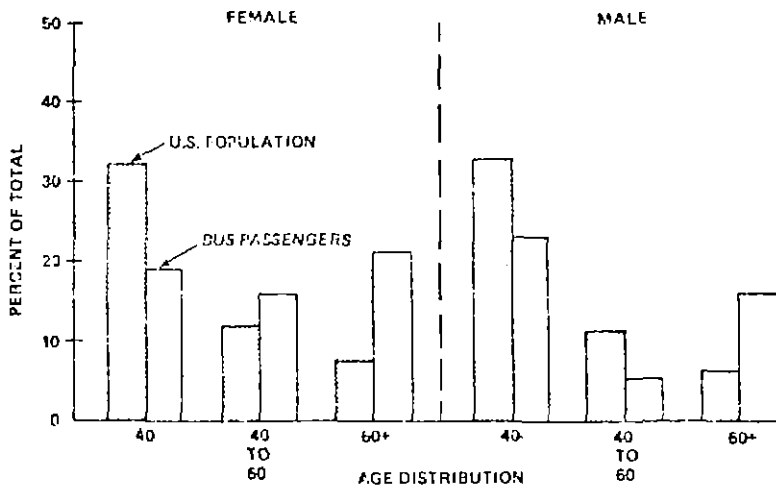


Fig.1.4 Demographic characteristics of 664 transit bus passengers observed in arterial route service in five cities.

The role of bus seats in transit bus passenger accidents is such that although 30% of the accident victims were seated, only 17% hit the seat during the accident. Thus, while the grab-rail at the top of the seat back is dangerous, the removal of this hazard alone would not greatly affect the overall statistics. Furthermore, a majority (51%) of the accident victims who were using passenger assists at the time of the accident were attempting to use the seat back grab-rail. Additional onboard observations of transit bus passengers performed by Booz Allen Research indicated that the seat back grab rails were generally too low and poorly designed for use of standee passengers. Surveys have shown that given the option, transit bus passengers will use vertical stanchions at a height of 40-50 inches above the floor in preference to all other passenger assists, such as seatback grab rails or overhead rails or straps. The Booz Allen Researchers comment that it is very clear from onboard accident statistics that rapid deceleration of the vehicle is the event which triggers most onboard accidents. Subsequently, a survey of ten typical bus routes was performed such that unknown to the driver an accelerometer was attached to the bus wall approximately in the middle of the vehicle.

626 typical stops were recorded, with the mean deceleration being 0.18 g. Furthermore, peak deceleration of 0.3 g were measured on 8% of all stops. Typical acceleration rates were less than 0.1 g, and no lateral accelerations or roll rates were measured.

As a result of the onboard accident statistics and the subsequent surveys of typical transit passenger behaviour, a series of tests were formulated to measure the safety inherent in the interior design of three prototype transit buses. Listed below are the findings of the test program which is split into two categories; general conclusions and findings specifically relating to seats, vertical stanchions and the front entrance area.

A. General findings:

- 1) The ability of the passengers to avoid an accident is primarily related to reflex ability rather than strength.
- 2) It is only when the vehicle has inadequate assists or improperly designed assists that the passenger's grip strength becomes an important human factor parameter.
- 3) Measures of response time, balance and the ability to grab a moving object are better and more relevant characteristics in relation to avoidance of onboard accidents.
- 4) The act of carrying a package substantially increases the injury risk.
- 5) In the situation where the passenger is using a passenger assist at the onset of deceleration, a vertical or near vertical stanchion is effective in avoiding an accident.
- 6) The overhead assists are extremely effective in avoiding accidents as long as they are being used before deceleration begins, but it is difficult to locate such an assist once rapid deceleration has commenced.

- 7) Getting into or out of seats or turning to the rear are not very hazardous.
 - 8) Turning towards the front or walking towards the front is in general, more dangerous than moving rearward. However, moving rearward and grabbing for, but missing a passenger assist is a potential accident situation.
- B. Findings Related to Seats, Vertical Stanchions and the Front Entrance Area.
- 1) All seats should be fitted with passenger assists which provide the walking occupant with a nearly vertical bar to grab. The height of this bar should be above the shoulder of a typical seated passenger, so that it is always available even in a crowded vehicle, photograph 1.1.



Photograph 1.1

A new transit bus interior. Note the large number of stanchions and the integration of stop buttons into the stanchions. These stop buttons help to keep seated passengers in their seat until the vehicle has stopped. The two stanchions shown on the far left near the entrance to the vehicle also have elevated stop buttons for standee passengers. Note also the prominent grab rails near the entrance area and the roll top seat backs.

- 2) It was found that seat back assists which were designed such that the centre section was enclosed, were extremely poor in preventing accidents involving falls onboard the bus.
- 3) The recommended staggered vertical stanchion spacing is not greater than 50", in this way a passenger can walk down the aisle and always have a grip on at least one stanchion.
- 4) If a portion of the bus is clear for more than 4 feet along the length of the aisle without any passenger assists, then it was found that the stanchions at either end of this void could be dangerous. Thus it is not the presence of stanchions which presents the risk of injury, but rather the presence of too few stanchions, particularly at the front of the bus which creates a dangerous situation.
- 5) The practise of padding any protrusion, including stanchions with thick padding with suitable energy absorbing characteristics is recommended.
- 6) The presence of an unprotected fare box, which is often constructed from heavy steel is potentially very dangerous. It was also observed that the area of the entrance steps and front landing is a high-hazard level area. The driver's barrier and front stanchions were also regarded as potential impact areas.

As mentioned earlier, a similar study was conducted by the Leyland Vehicle Human Factors Group¹⁷. This investigation is the second phase in an overall study into the associated problems found in transit bus operation and concentrates on the following areas:

- 1) Hand rail requirements for entering and exiting from transit buses.
- 2) Current acceleration levels in transit buses.
- 3) Bus passenger accident study.

- 4) Dynamic aspects of passenger travel in buses.
- 5) Retractable first step to aid entry and exit for transit buses.

Of major interest to this study is the "bus passenger accident study", however, the remaining areas are all related to injury causation. The accident survey included the analysis of 2045 bus accidents gathered from 30 British bus proprietors who collectively own some 30,000 public service vehicles.

If we focus upon overall composition of the accidents, with respect to who was injured, Table 1.1 shows that the majority (65% of those injured) were passengers of the bus. Table 1.1 however, also shows that only 8% of all injuries involved the passenger being injured in a collision. Thus 88% of the bus occupant population who sustained an injury received it as a result of a non-collision incident. Table 1.2 gives a more detailed breakdown of details of the buses movement at the time of impact and the number of resultant casualties.

TABLE 1.1 Accidents Reported - Overall Composition

| | | |
|---|-------------------|-------|
| Passenger injury accidents | - no collision 57 | } 65% |
| | - collision 8 | |
| Driver or conductor injury accidents | | 6% |
| Pedestrian injury accidents | | 19% |
| Motor or pedal-cyclist injury accidents | | 3% |
| Other personal injury accidents (mainly unclassified) | | 8% |
| Collisions with extensive PSV damage only | | 7% |

TABLE 1.2 Passenger Casualties and Bus Action at the Time of the Accident

| Bus Action | Passenger Casualties | | | | | | | |
|-----------------------------------|----------------------|-------|---------------------|-------|--------------|-------|-------|------|
| | In collisions | | In emergency action | | In falls etc | | Total | |
| | n | % | n | % | n | % | n | % |
| Stationary-At a bus stop | 3 | - | - | - | 303 | (20%) | 306 | 20% |
| -In traffic | 10 | - | - | - | 12 | - | 22 | 1% |
| Moving off-From a bus stop | 21 | (1%) | 51 | (3%) | 216 | (14%) | 288 | 19% |
| -In traffic | 18 | (1%) | 46 | (3%) | 37 | (2%) | 101 | 7% |
| Cruising | 101 | (7%) | 220 | (14%) | 100 | (7%) | 421 | 28% |
| Slowing down-Approaching bus stop | 32 | (2%) | 63 | (4%) | 98 | (6%) | 193 | 13% |
| -For traffic reasons | 18 | (1%) | 27 | (2%) | 28 | (2%) | 73 | 5% |
| Stopping (the final movement) | | | | | | | | |
| -At a bus stop | - | - | 2 | - | 29 | (2%) | 31 | 2% |
| -For traffic reasons | 5 | - | 6 | - | 12 | - | 23 | 2% |
| Reversing or other manoeuvres | - | - | 4 | - | 13 | - | 17 | 1% |
| Unknown bus action | 6 | - | 21 | (1%) | 23 | (2%) | 50 | 3% |
| Total | 214 | (14%) | 440 | (29%) | 871 | (57%) | 1525 | 100% |

PASSENGER CASUALTIES

by bus action & accident type

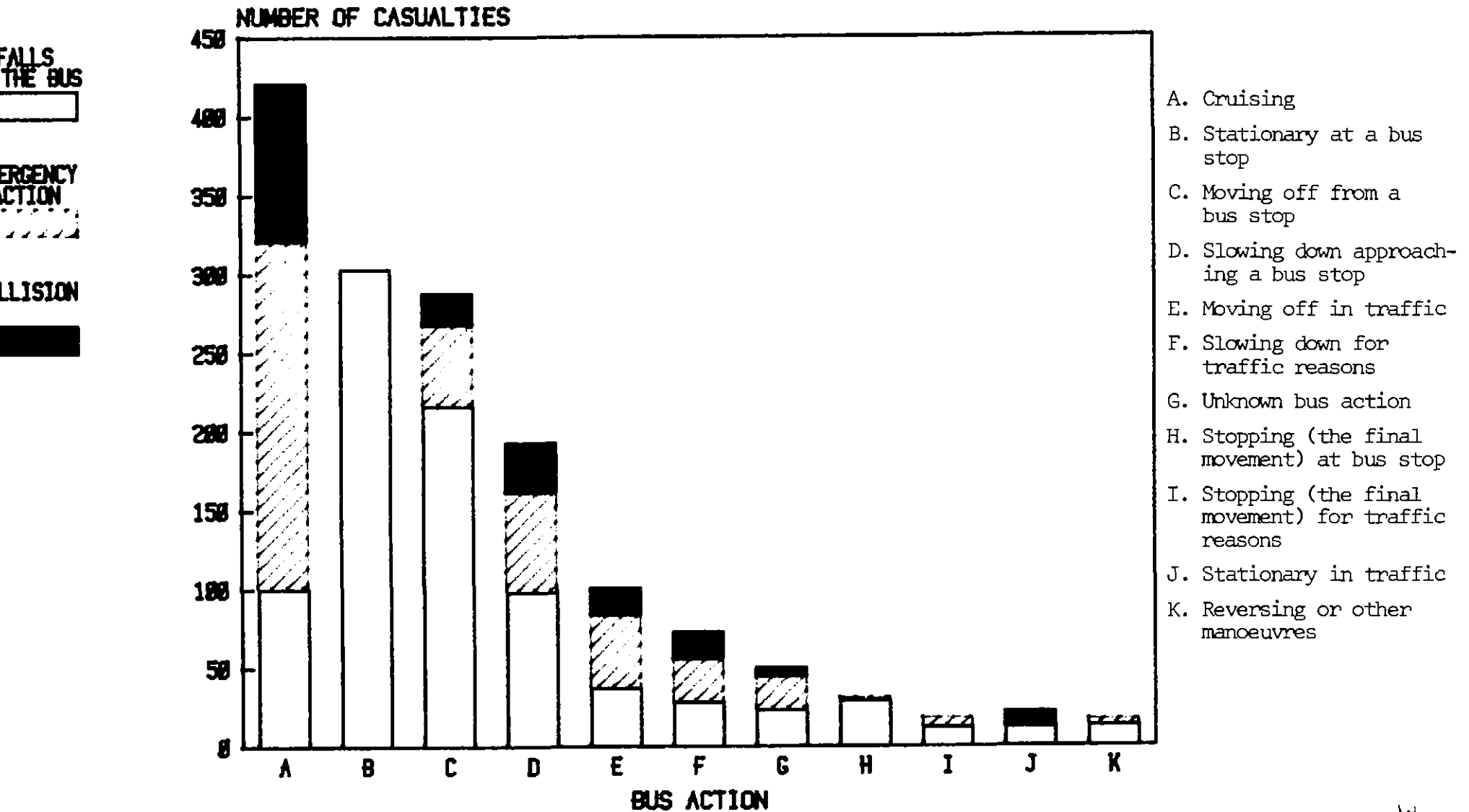


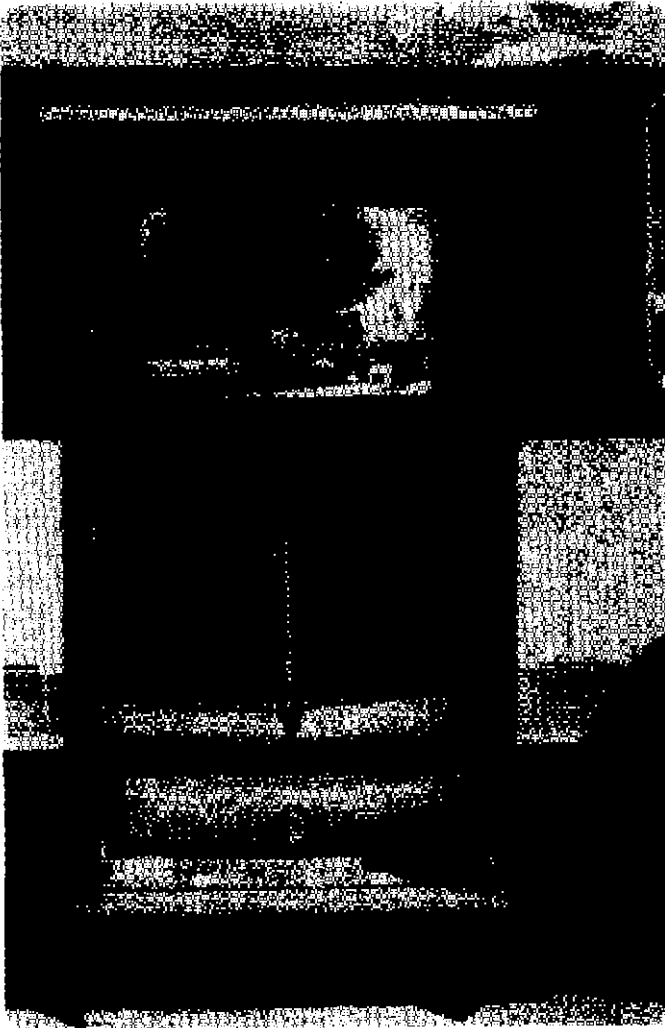
Fig. 1.5

It is interesting to note the high proportion of injuries which occurred as a result of the passenger falling (57%). Indeed, this accounted for 20% of all passenger injuries, which is the largest proportion of injury causation and is significantly greater than the percentage of passenger injuries caused by a collision (14%). To look at it in another way, of all the passengers injured, 86% occurred as a result of non-collision incidents and of these, 66% were not due to any form of emergency action. Furthermore of all the injuries caused due to falling, 35% occurred while the bus was stationary at a bus stop. This observation can be seen in Fig. 1.5. The relatively high proportion of collisions and emergency action situations which caused casualties while the vehicle was cruising can also be seen in this figure. It is interesting that more than twice the number of casualties caused by falls occurred while the vehicle was moving away from a bus stop rather than slowing down for a bus stop. Bus stops themselves are a location of high injury potential and 36% of all bus stop injuries occurred when the vehicle was stationary. Furthermore, of the bus stop accidents, 75% resulted in contact with the ground or in the entrance platform area. It was found that of boarding accidents, 70% resulted in the passenger falling onto the ground. The Leyland group suggest that this could be due to:

- 1) the step height is too high (compare photos 1.2 and 1.3),
- 2) the passengers tried to board at the last moment,
- 3) the grab handle was inadequate.

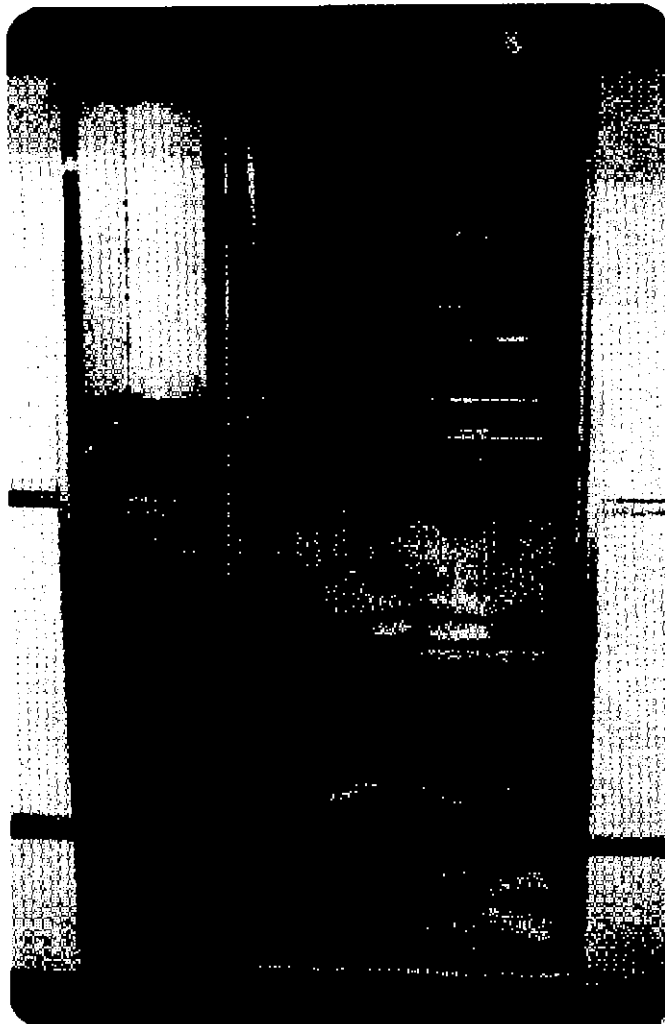
Of the accidents involving the alighting of passengers, it was found that 71% fell onto the entrance platform. Again, the suggestions for such an occurrence were put forward as;

- 1) incorrect grab handle layouts,
- 2) the floor design was incorrect. i.e. high steps or steep ramps (photograph 1.4),
- 3) poor illumination of the step well,
- 4) passenger overloaded with baggage.



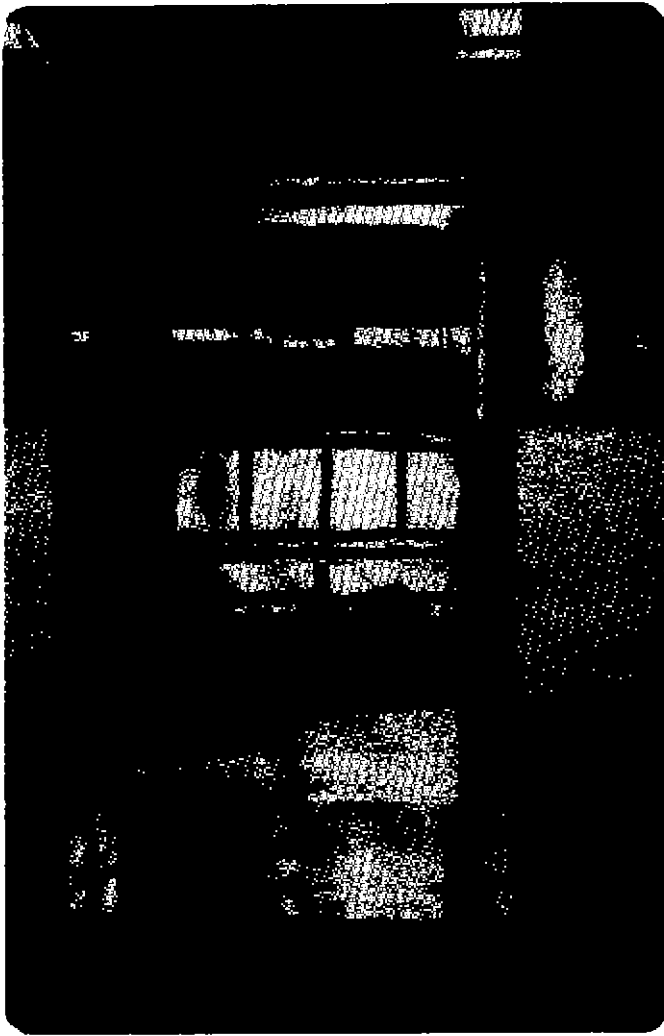
Photograph 1.2

A common feature of modern transit buses is the large secondary rear doorway. Note the low floor height and step rises and the central grab rail.



Photograph 1.3

This is another entrance to a transit bus, but note in comparison to photograph 1.2, the larger step rises and the congestion of the area.



Photograph 1.4

Although this vehicle under construction incorporates a wide rear doorway and a low floor and first step, note the angled third step. Such a design could be conducive to a passenger losing his footing in an accelerating vehicle

If we now consider the accidents which occurred while the vehicle was in motion (79% of all injuries) 82% of them resulted from non-collision incidents. Of these non-collision accidents, the majority (56%) of the casualties were due to falls, while the remainder were as a result of avoiding collision situations. Of this type of fall, 38% occurred while the bus was accelerating away from a bus stop, while 16% were as a result of the vehicle decelerating for a bus stop. Nearly half (48%) of all casualties due to collision avoidance occurred while the vehicle was cruising. Furthermore, these injuries account for half of the total casualties which occurred while the bus was cruising as again can be seen by inspection of Table 1.2 and Fig. 1.5. If we again consider the injuries which occurred while the bus was moving and were caused by falls or as a result of an emergency action, we find that they make up 66% of all the injuries to bus occupants. The possible causes for this high percentage, as seen by the Leyland group are:

- 1) the floor design,
- 2) the acceleration level,
- 3) the stanchion layout.

The argument for these reasons is strengthened if casualties which occurred during either vehicle deceleration or acceleration are investigated. It is found that of the injuries involving vehicle acceleration, 23% occurred in the gangway and 83% of these were caused to passengers moving to their seat. While with injuries which involved vehicle deceleration for a bus stop, 37% of the injuries happened in the platform area, while 24% occurred in the gangway. In both cases, the injuries were predominantly inflicted upon people either moving towards the door of the bus to alight or were waiting near the door ready to alight.

An important finding which resulted from the accident statistical study is the seemingly disproportionately high population of elderly females who injure themselves in non-collision situations as shown in Table 1.3. Indeed 72% of those injured are females, which is greater than would be expected considering the female ridership figures. The population of bus passengers who sustained an injury in a non-collision incident can be seen in Fig.1.6 and the skewing of the elderly female group is obvious. The elderly seem to find boarding hazardous, as 57% of those injured executing this function were over 60 years of age. The design and development of a lowering retractable first step was carried out as part of the Leyland group's research. Accidents involving the acceleration of the bus were considered as an area of concern by the Leyland group who suggested that the cause could be due to one or a combination of the following factors:

AGE OF PASSENGERS INJURED

NON-COLLISION, NON-EMERGENCY ACC.

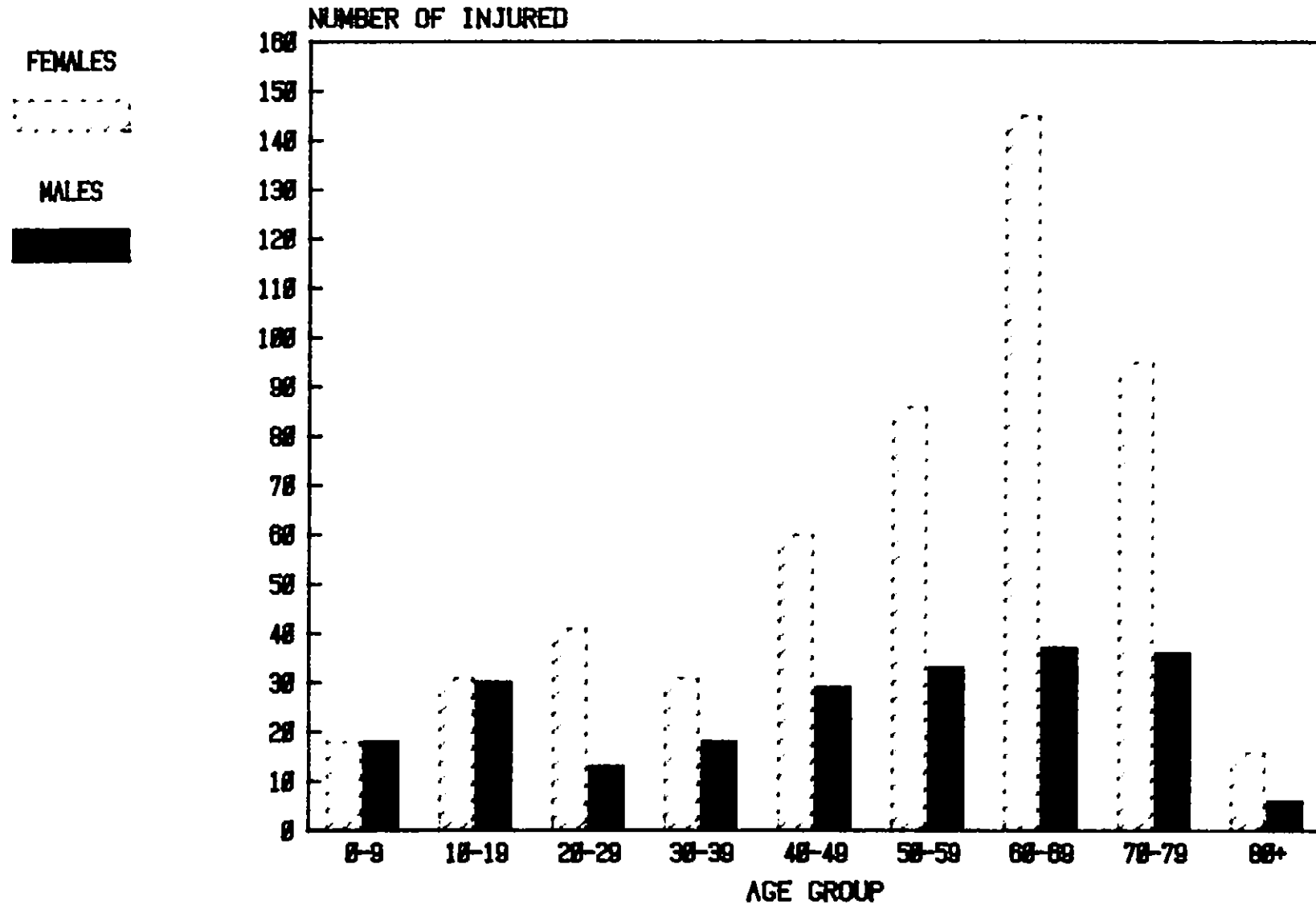


Fig. 1.6

- Acceleration capabilities of the vehicle is too high.
- Poor gear-change qualities.
- Inadequate floor design.
- Poor stanchion layout.
- Poor control of the vehicle by the driver.
- Reduced capability of some passengers.

TABLE 1.3 Estimates Age and Accident Type

| | Estimated Age | |
|--------------------------|---------------|-----------------|
| | Under 60 yrs | 60 yrs and over |
| Collision casualties | 276 | 83 |
| Non-collision casualties | 842 | 634 |

CHI SQUARE = 46.9 sig. at $p < 0.001$ (with $df = 1$)

The report by the Leyland Vehicle Human Factor Group goes far beyond looking at accident statistics and investigates many facets of transit bus operation as mentioned earlier. Decisions were made on the handrail design, clearance and surface finish as a result of a testing program incorporating 60 elderly subjects and a mock-up bus door and entrance. The configuration, shape and size of the handrail were investigated with the view of achieving maximum bodily support to maintain stability.

The study into current acceleration levels onboard transit buses involved a total of 40 hours of recording data with 980 events (categorized into gear-changes, deceleration into bus stop, stops, power starts etc.). It comprised 4 drivers driving over 28 routes. The finding of this study was that the acceleration levels ranged from -0.36 G to $+0.44\text{ G}$ and the limits of jerk (rate of change of acceleration) varied from -1.75 G/s to $+1.81\text{ G/s}$. While lateral accelerations were found to range from -0.41 G to $+0.35\text{ G}$, lateral jerk was limited to -0.88 G/s to $+0.88\text{ G/s}$. The threshold

figures of fore and aft and lateral acceleration for forward facing passengers can be considered to be .11 G to .14 G and .23 G to .25 G respectively. It was found that gear changes produced a large number of disturbing events with 0.15 G acceleration levels and jerk levels of -0.7 G/s to +0.5 G/s which caused passenger reaction. In addition, deceleration into bus stop and a jerky final stop produced a large number of events. Power starts were found to produce some of the highest jerk values.

The section investigating dynamic aspects of passenger travel in buses involved various gangway step heights, angles of ramped floor and different seat locations being tested by subjects while the vehicle underwent various manoeuvres such as gear changes, braking and swerving. Measurements of the load applied to stanchions were recorded as were acceleration levels. The findings of these trials were as follows:

- 1) Passengers can 'prepare' themselves for acceleration events and adopt postural changes that minimise disturbance.
- 2) The high force recordings and discomfort ratings resulted from the passengers not being prepared for the vehicle manoeuvre.
- 3) Almost 70% of body weight was reacted through the stanchions with fore and aft accelerations exceeding 0.15 G when going down 2° or 4° ramps. This condition was rated by the subject as uncomfortable. For steeper ramps and similar vehicle deceleration, forces of greater than 80% of body weight were recorded.
- 4) The trial subjects used were young and fit. There are serious implications for the elderly when these effort levels are required to maintain an upright posture.

- 5) Subjective ratings show a better correlation with the force applied to the stanchion than the overall acceleration level of the vehicle.

In the final area of investigation of this report, the introduction of a retractable first step was studied. Amongst the findings for this design change were that when the elderly subjects evaluate the new lower retractable step, they found that it significantly increased the ease of entry. The benefit to fit subjects was not as clear, although some considered it to be an improvement. The need for uniformity in step rises was observed as problems developed with the relatively higher second step. The report noted that even with the designed safety devices, the retractable step protruding from the bus represented a more serious hazard than the conventional entry.

1.3 INNOVATIONS IN BUS AND BUS SEAT DESIGN

Over the past ten years, there has been a considerable amount of work carried out to determine the crashworthiness of various types of buses and coaches. The major emphasis of this research has been fed essentially into two areas: the seat and body frame and the panelling. The objective of this work is to increase the crashworthiness of the vehicle and the minimization of passenger injury.

The protection of the passengers travelling in a bus is obviously related to the strength of the body in which they are travelling and the ability of that shell to resist penetration of impact objects into the passenger survival space. Furthermore, it is important that the panelling of the vehicle does not separate because such an occurrence can lead to extremely dangerous panel edges. To combat this, the number of internal and external panels have been reduced and the methods of joining refined¹⁸.

Due to the severity of such an occurrence, the collapse of the roof structure during a roll-over accident has become an area of major concern. Areas of the bus body frame which were found to influence the strength of the upper body were; the joints at the lower ends of the window pillars, and the side of the roof where it joins the cant rail¹⁹. Legislative bodies both in America²⁰ and Europe²¹ have drawn up draft regulations concerning the strength of the upper bus body which stipulate a maximum deformation when the structure is loaded to a specific loading regime. Often the test requires a standard roll-over of a bus in an effort to reconstruct an accident situation.

It would appear that the area of bus travel which has undergone the greatest degree of change lately is in the transit application in America, where there has been an extremely intensive development program of their yellow school buses. The school bus project has been based on a single objective: that of passenger safety. This has been commented on earlier in this chapter. The development work on transit buses however, has been more involved and is essentially concerned with improving the practicality of the design. The school bus study concentrates on the interior of the vehicle, while the transit bus development incorporates not only the interior but also the body and chassis structure, together with factors that influence running costs. . Considering recent trends, seemingly little research and development has been done on the top-end classification of omnibuses; i.e. the long distance, intercity, luxury coach. Yet, these vehicles are more prone to accidents involving high impact velocities and roll-overs, which result in roof collapse. One design aspect which is almost characteristic of a luxury coach is the forward angled window pillars. Longitudinal strengthening of the window frames and in particular the structural joints at the base of window pillars can be increased by the introduction of this concept. This basis of the increased strength comes from the triangulation of the window area, usually near the front of the vehicle.

There has been a marked tendency in all forms of omnibuses for the manufacturers to maintain and increase the glazing area, usually at the expense of a reduction in size and strength of the upper bus body.

Although the school bus research has focussed upon the development of an energy-absorbing safety seat, a considerable amount of effort has gone into identifying and redesigning injury-inflicting components of the vehicle's interior. Window latches have been recessed, side impact energy-absorbing pads on the walls have been incorporated for each seating position and further force-distributing padding has been used to cover structural members in the wall and roof. Particularly dangerous areas of the vehicle interior have been redesigned, such as the entrance stairwell and driver protection barrier. The problem of post accident passenger evacuation was investigated and the use of roof hatches, emergency side doors and removable or openable windows was recommended.

Transit bus design innovations include matters which result in the vehicle being more efficient in its function of transporting people over relatively short distances and consistent with this more appealing to the public and thus enticing an increased clientele. The reduction in floor height together with the introduction of wide doorways with low step heights is a suitable example which demonstrates the benefit to both proprietor and passenger. The low floor heights and fewer steps or smaller rises reduces the stop times required to load passengers which is desirable to both passengers and proprietors alike. Low profile tyres and "kneeling" air bed suspension are two methods used to reduce floor heights. As mentioned earlier, the introduction of low floors has resulted in the possibility of intrusion into the passenger's compartment by impacting vehicles. Thus the side wall sections have been strengthened to minimize the chances

of such an occurrence. As a result of this increased strength, it was found by the manufacturers that cantilevered seats could be hung from the side walls. This aspect of the new generation of transit buses is mentioned by Mateyka¹¹ and his comments are as follows:

"Cantilevering eliminates the seat leg on the aisle side and thus reduces tripping hazards. Elimination of bus seat legs is also a major step towards improving the cleanability of the bus. The use of cantilevered seats requires major structural changes to the entire vehicle and adds weight, since seat attachment rails must be added to the sidewall of the bus. This additional structure in the bus wall is yet another safety feature since it provides resistance to sidewall penetration by impacting automobiles at passenger hip height. This extra protection was considered to be essential for Transbus (a \$26 million transit bus development project funded by the U.S. Dept. of Transportation's Urban Mass Transportation Administration) since the new low floor designs result in a passenger hip height of about 3 feet above the road surface as compared to 4½ feet on current transit buses". Mateyka dynamically tested the three cantilevered seats fitted to the three transbus prototypes developed by A M General, Rohn Industries and General Motors (whose seats were designed by American seating). The reason for carrying out this test program was due to suspicions that cantilevered seats would perform poorly in a severe collision situation, resulting in the seat collapsing into the sidewall. Such a situation might trap and crush the passengers seated at the window and alternately launch aisle passengers dangerously into the aisle. It was found however, that all three seats exhibited excellent passenger containment, compared to a standard transit bus seat which was also tested. The standard seat's rear anchorages failed which resulted

in the seat actually moving away from the impacting dummies, and thus failed to satisfactorily restrain them. The conclusions, drawn by Mateyka on completion of the 10 G dynamic test program were:-

- 1) Passenger containment in severe bus crashes can be obtained with cantilevered seats.
- 2) Structural cross-members near the top of the seat back used to mount cantilevered seats to the wall must be heavily padded or smaller persons will be exposed to severe head impact hazards.
- 3) Energy absorbing grabrail/crashpads on transit bus seats can be designed so as to substantially reduce head impact severity but sharp corners must be avoided.
- 4) Retention of the passengers within the seat compartment and control of the trajectory of seat back impact and rebound is greatly enhanced if the seat back is designed to allow substantial knee penetration.
- 5) Overly rigid seat backs in the knee area can result in high femur loads and potentially unacceptable dummy rebound characteristics.

Furthermore, although it is commonly recognized that high backed bus seats have a greater potential for restraining passengers in such a way as to minimize injury causation, Mateyka comments that such a seat would "significantly reduce transit bus capacity and could present safety hazards in terms of safe passenger mobility within the bus".

While mentioning design concepts of bus seats, it is worthwhile outlining the two separate basic philosophies involved in the design of omnibus safety seats. On one hand it is considered that the entire seat frame should incorporate components which will plastically deform, so as to "catch" the occupant. Deflections of the top of the seat in the vicinity of 14 inches are allowable as a maximum in such a design, and are considered satisfactory for preventing passenger ramp-over. Examples of such seats have been designed and developed and tested by such bodies as the Virginia Polytechnic Institute and State University²² and the AMF Advanced Systems Laboratory¹. On the other hand, it is considered that the seat frame itself should undergo a minimum amount of plastic deformation such as is demonstrated by the UCLA safety seat. The energy-absorbing properties of such high-density padding in conjunction with seats are achieved by using open-weave steel mesh to cover the seat back, thus allowing knee-penetration, pocketing and deceleration.

The energy of the head and upper body is largely taken by the thick padding extending down the seat back from the top of the squab to just above the point of knee impact. The UCLA seat has as the basis of its stiffness, an "A-shape" frame structure in side elevation in conjunction with a wall mounting high on the seat back. Two other interesting design features of this seat are that it has no structural frame member in the seat back below 6½ inches (165mm) from the top of the unpadded seat back. Hence the penetration of the knees into the seat back will not result in the impact with a rigid member. The top of the "A" is effectively located at the top of the seat back with components of the "A" forming the two aisle side legs and the bar of the "A" is the member that locates and provides the anchorage for the cushion. The other design feature of interest is the large and extensively padded section fitted to the aisle side of the seat which together with the forward member of the "A" configuration restrains the occupants in the event of a side impact.

The Virginia Polytechnic Institute seat employs a rigid seat back/cushion configuration with crushable tube segments in the four floor mounted legs. The stiffness curves achieved during the development of this seat indicates that such a design could be satisfactory in restraining bus passengers and absorbing their forward energy in the event of a head-on collision. However, such devices are subject to vandalism and in the view of the authors, prone to damage upon tampering.

The AMF seat is complicated both in design and manufacture, yet it achieves the admirable results of retaining passengers with the application of acceptable loads and deceleration levels. The seat's components consist of 1 inch square hot rolled steel tubing of .065 inches thickness into which is inserted (in most places) a 0.75 inch diameter round cold drawn steel tubing with a wall thickness of 0.12 inches. Such a configuration achieves the bending characteristics required. Furthermore, there are no less than twelve sections of the seat frame which are designed to plastically deform and in such a way as to protect the passenger. In addition, the padding system consists of a chest and head impact pads. The chest pad is composed of Rapco Foam (urea-formaldehyde) which has a density of approximately 1.7 pounds per cubic foot, a crush strength of approximately 6 pounds per square inch and is five inches thick. The head impact pad, which lies across the top of the chest pad surrounding the top cross bar is a 3 inch thick layer of Ethafoam 225 (a fire-retardant formulation of polyethylene foam) which protects the head from excessive load concentration. A knee liner of 0.018 inch thick H1010 steel, in the form of a rectangular sheet attached to the seat structure so that the top and bottom edges are fixed and the sides are free. This seat for purposes of uniform and symmetrical deformation is, of course,

structurally symmetrical and has four floor anchorage points and no wall anchorages. The arm rest is an integral part of the overall seat deflection concept and assists in retaining occupants from being displaced out of the seat into the aisle.

Other recent design innovations to omnibuses include modular body construction which makes for relatively easy construction of different length bus bodies. These modules usually include one piece bow framing which increases the lateral strength of the passenger compartment and therefore increases the crashworthiness of the vehicle in the event of a roll-over. Another feature which influences the crashworthiness of omnibuses and in particular transit buses predominantly because of their low operating speeds, is the introduction of energy absorbing bumper bars^{7,23} which are designed to satisfactorily withstand a 10 km/h impact.

Various means of reducing vehicle weight are becoming more common as the running cost of fuel increases. To this end a larger composition of aluminium alloys is being used. Indeed there is a bus body builder in Melbourne who is already constructing aluminium bus bodies. In America aluminium honeycomb sandwich construction flooring has been introduced into vehicles²⁴ together with non-glass (either acrylic or polycarbonate) windows^{9,23}. This glazing has the advantage of being approximately 50% lighter than conventional materials, although at the expense of being 50% dearer. An added advantage of this form of glazing is its resistance to vandalism and it is reported to be bullet proof.

There is a growing awareness both in Government bodies and transit bus proprietors and manufacturers that in our present social/economic environment there is a greater need for public usage of public service vehicles. Yet

in an age where the private car is designed for comfort and ease of operation, the incentive for mass public use of public transit systems is not favourable. Thus there has been a change in attitude and in order to increase bus usage, the manufacturers have taken steps to raise the level of comfort in omnibuses⁹. Design changes in individual seat width, knee room, luggage space, floor height and step height are some of the internal aspects together with an improvement in aesthetics of the interior of the vehicle to entice passenger usage. The comfort rating for a trip has been markedly improved with the introduction of efficient yet silent heaters/airconditioners, stereos, effective audio insulation and air bag suspension which eliminates the harsh bumpy ride which used to be characteristic of transit buses. An article written by Torey²⁵ describes an innovation for transit vehicles which allows the conversion of a low back bus seat into a leaning post for standee passengers. The advantage of such a device is that it increases the carrying capacity of the vehicle and is claimed to improve the standard of comfort of the standees. The authors, however, consider that such a design would promote overloading and introduce additional problems associated with passenger disembarking. The aspect of passenger containment and injury causation is extremely dubious as the support offered to the standee is at upper thigh level. If the deceleration of the vehicle upon impact was opposing the direction in which the standee was facing, the possibility of severe back injury is high, especially considering the additional loading of other standee passenger and the lack of suitable passenger assists.

CHAPTER 2

BUS ACCIDENT STATISTICS

2.1 INTRODUCTION

A search for bus accident statistics was initiated early in the project and it was soon established that ideal data for this study did not exist. The possibility of gathering data from several sources and then collating the information to achieve the objective of this section was considered and work commenced along these lines. The aim was to bring together data concerning the number of accidents occurring each year with information giving: the type of accident, road and light conditions, speed, time, day and month and the number of vehicles involved etc. along with injury data; the types and severity of the injuries. Furthermore, it was hoped to investigate the correlation between the type of accident and the classification of seating arrangements with the types, severity and cause of the injuries.

The investigation of specific types of bus operation, such as transit networks seemed important, as it soon became apparent that different types of buses generated considerably different injury patterns. To this end, data was sought from the Melbourne Metropolitan Tramways Board (MMTB). In particular, we wished to investigate the incident of passengers falling in the bus, either as a result of a driver manoeuvre or due to a collision.

Both the MMTB and the Road Safety and Traffic Authority (RoSTA) provided details for every accident on their files. Other bodies and authorities were contacted and information was requested. In some cases, the data was forthcoming and was presented in a collated format. The following bodies also assisted the project: The Australian Bureau of Statistics (ABS) State Insurance and the Transport Regulation Board (TRB). The TRB undertakes inspections of buses, both on a regular accident prevention basis and after an accident, in order to establish the cause of the accident. Permission was recieved to study the TRB's accident files.

The major bus proprietors in Melbourne were contacted with the view of discussing their accident records. Most were cooperative, however these were generally the companies with excellent accident records and could provide us with very little useful accident figures. Discussions with these companies proved helpful. It became apparent that a substantial number of minor injuries were not recorded. These injuries were usually caused by a driver manoeuvre or a passenger tripping on a step or chair, or losing his balance, rather than from a collision.

Permission was also granted by the Victorian Police Department to study Traffic Accident Report (forms 513A), in order to gather more information regarding those injured in the accident and the hospitals where those concerned were treated.

The Motor Accidents Board of Victoria was contacted, however data was only available for 1980 and unsuitable for this project. Information on bus accidents was sought from South Australia, but no useful data was received. The Traffic Accident Research Unit (TARU) in New South Wales cooperated in allowing access to their accident files.

2.2 RoSTA DATA

As a result of investigating the list of accidents recorded by the Victorian police and processed by RoSTA, it has been possible to draw the following conclusions:

- 1) It is evident that the number of accidents involving buses was small (1%) relative to the total number of road accidents which occurred in Victoria during 1975 to 1980.
- 2) Until the final year of data (1980) the accident growth rate of bus accidents was greater than the overall growth rate of road accidents.
- 3) Based on the 1975 and 1976 data, approximately 60% of the people involved in a bus accident sustained no injury.

- 4) The likelihood of injury in an accident involving a bus is as follows:
 - a) 0.04 fatalities/bus accident (injury severity 1)
 - b) 0.35 serious injuries/bus accident (injury severity 2)
 - c) 0.65 minor injuries/bus accident (injury severity 3).
- 5) There are certain types of bus accidents which are more likely to cause serious injury:
 - a) Pedestrians
 - b) Cyclists
 - c) Motorcyclists.
- 6) Where the bus impacts a vehicle there is a higher chance of serious injury if the collision occurs at an intersection and the impacting vehicles are travelling along different streets. Furthermore, this type of accident has the highest occurrence of injuries of all the major accident categories.
- 7) Nearly 90% of all mid-block bus accidents are rear-end collisions.
- 8) Accidents involving cornering are likely to result in a relatively high percentage of more serious injuries. 67% of cornering accidents are described as a frontal collision.
- 9) Of the "off-path" accidents, 44.4% involve a mid-block frontal collision. Although this category of accident is likely to cause a relatively high percentage of injuries, their severity of apparently skewed towards minor injuries.
- 10) Accidents involving a bus passenger falling in or from the vehicle make up 16% of all recorded bus accidents. Injuries caused by this type of incident tend not to have a high percentage of serious injuries.

NUMBER OF ACCIDENTS BY YEARS AND SEVERITY

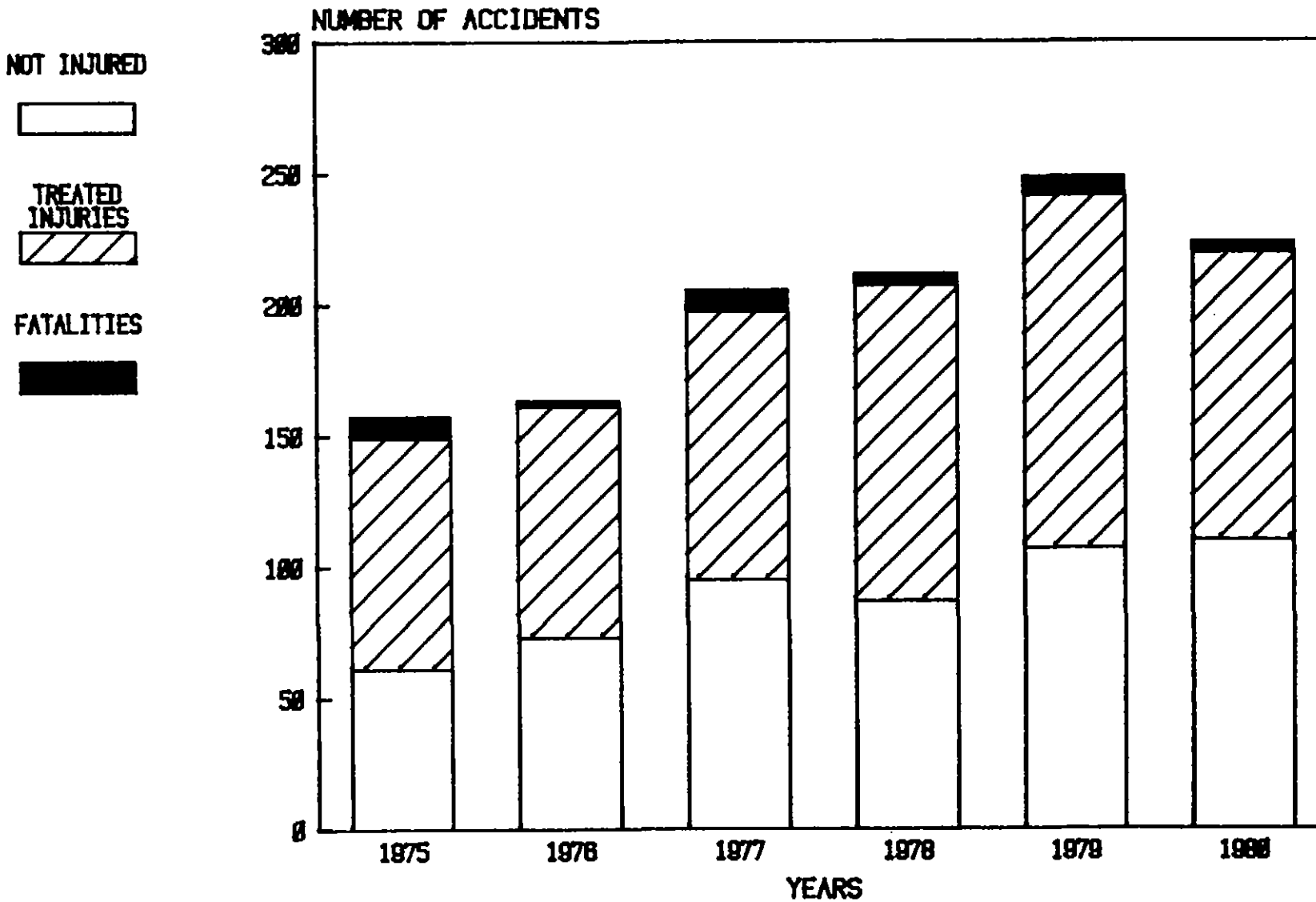


Fig. 2.1

NUMBER OF PEOPLE INJURED 1975-1980

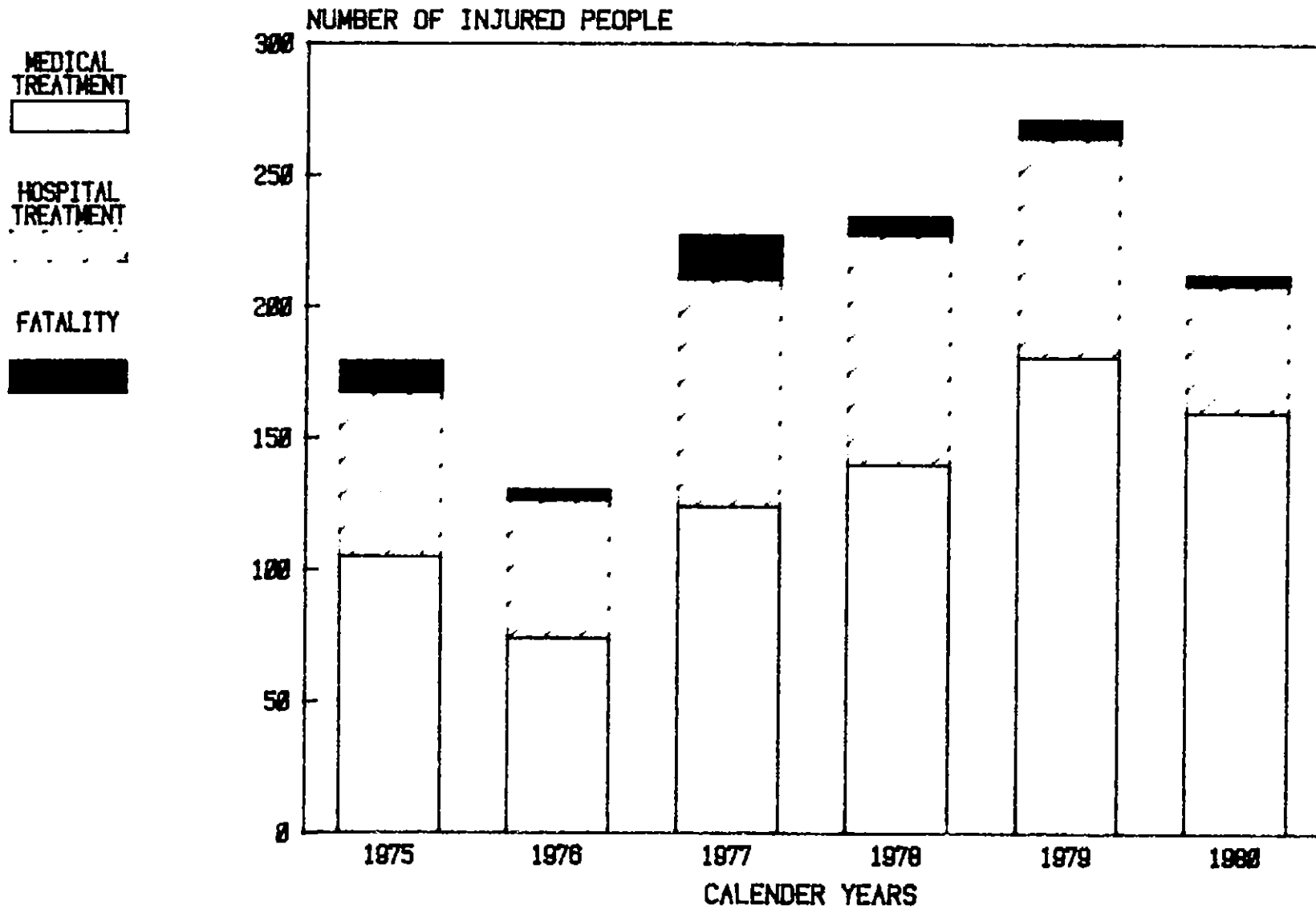


Fig. 2.2

NUMBER OF PEOPLE INJURED 1975-1976

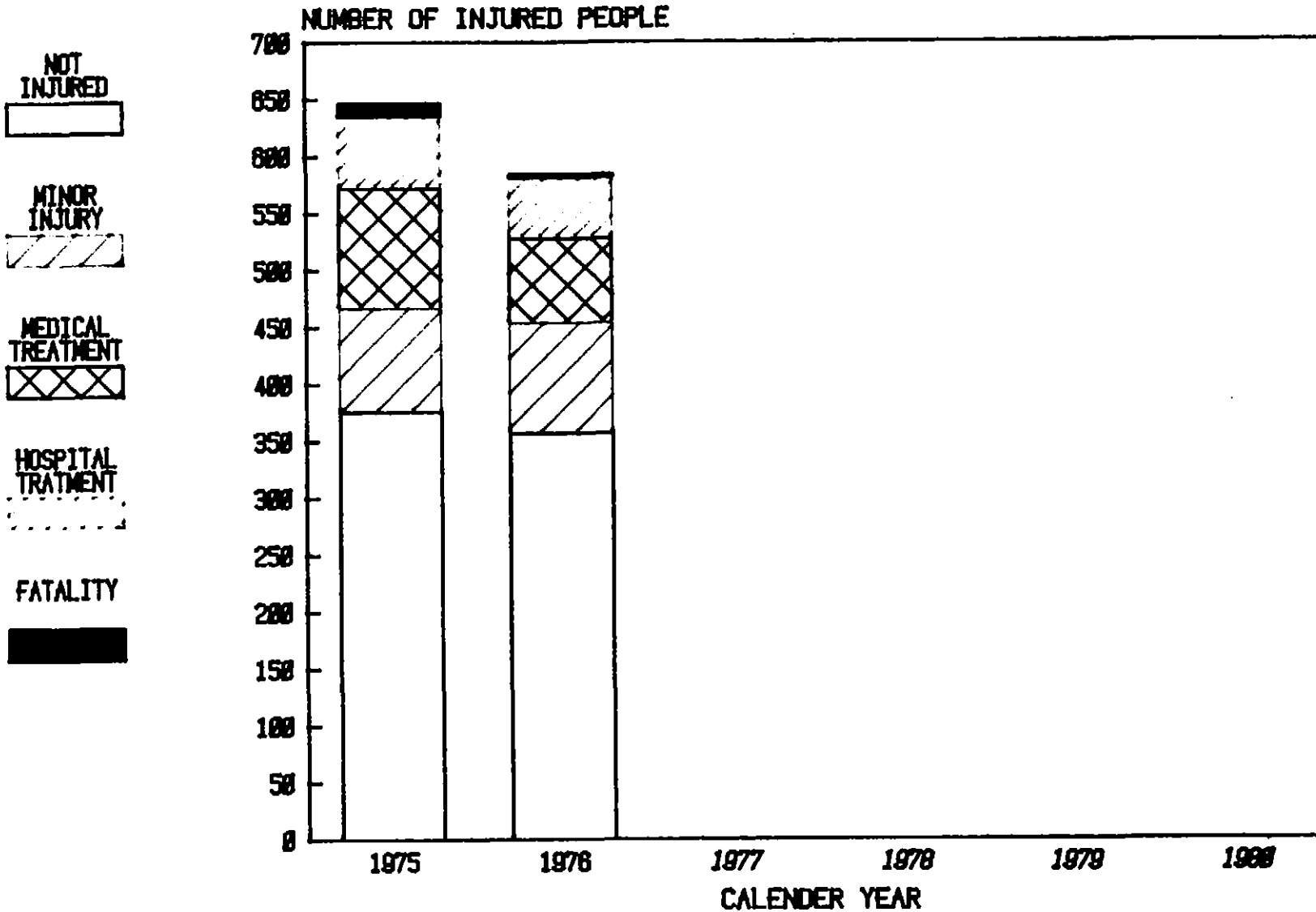


Fig. 2.3

NUMBER OF PEOPLE INJURED BY ROAD USER MOVEMENT (RUM)

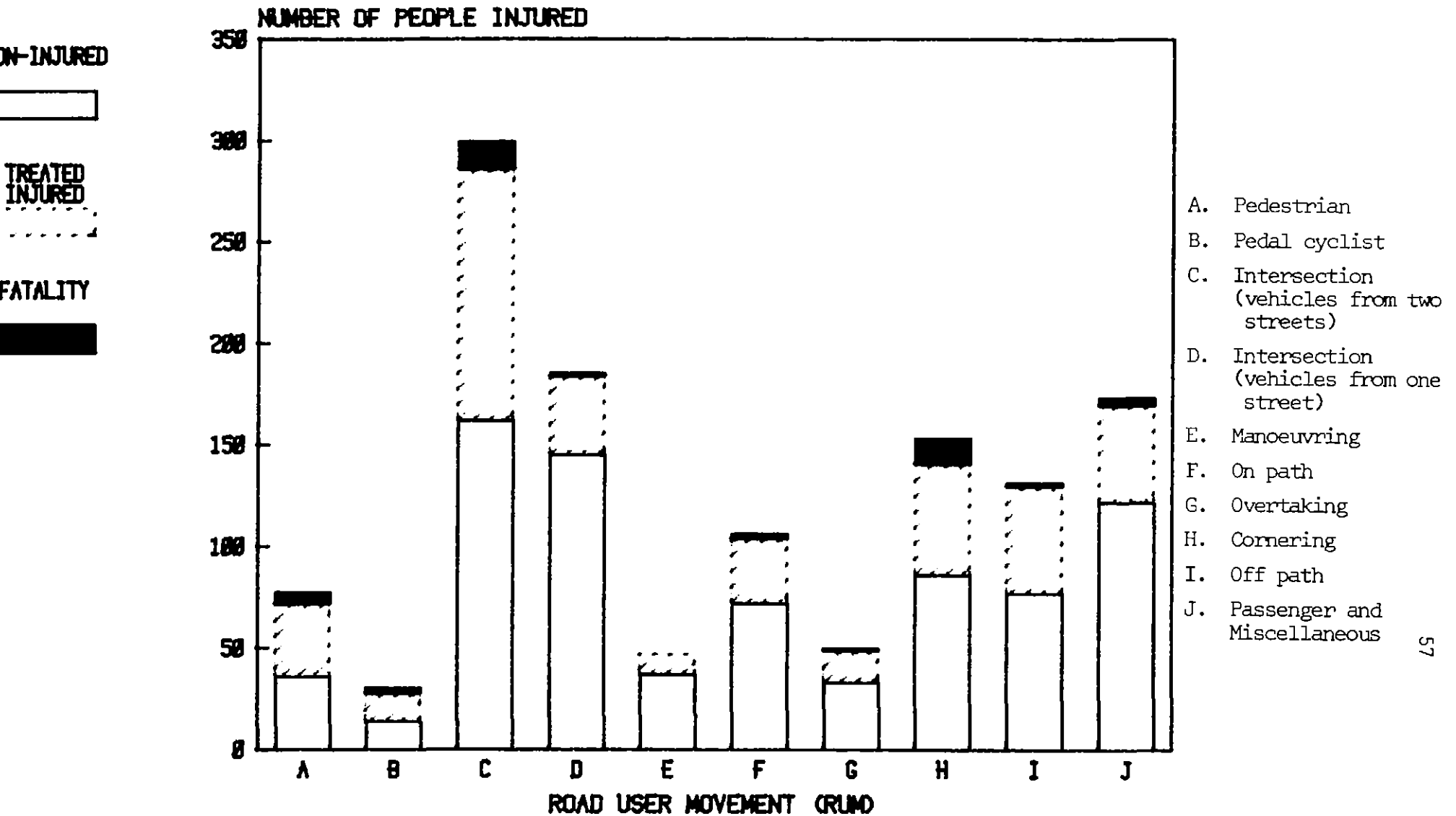


Fig. 2.4

- 11) There has been a steady growth in the incidence of passengers falling in or from a bus over the past six years.
- 12) 52% of all accidents involving a bus also involved a car or station wagon.
- 13) 26.5% of all bus accidents did not involve another vehicle. The injury severity of such an accident was significantly higher than accidents involving cars or station wagons.
- 14) It would appear that the collision of a bus with another bus results in severe injuries.
- 15) The greatest number of bus accidents occur between 8 am and 9 am and 3 pm and 5 pm.

Selected histograms of the RoSTA data are shown in Figures 2.1 to 2.4.

2.3 M.M.T.B. DATA - AN INVESTIGATION INTO TRANSIT BUS ACCIDENTS.

2.3.1 Introduction.

With respect to the Melbourne Metropolitan Tramways Board (MMTB) it was interesting to observe the incidence of passenger falls within the vehicle, which resulted in an injury, but were due to a non-collision situation. Fortunately, the MMTB keep an accurate record of all their accidents and employ a classification system which is quite suitable for investigating non-collision passenger falls. Case studies of every incident recorded resulting in an injury was gathered for the years from 1975 through until 1980. The data was studied, analysed and is summarised in Figure 2.5.

M. M. T. B. BUS ACCIDENT DATA

CLASSIFIED BY ACCIDENT TYPE

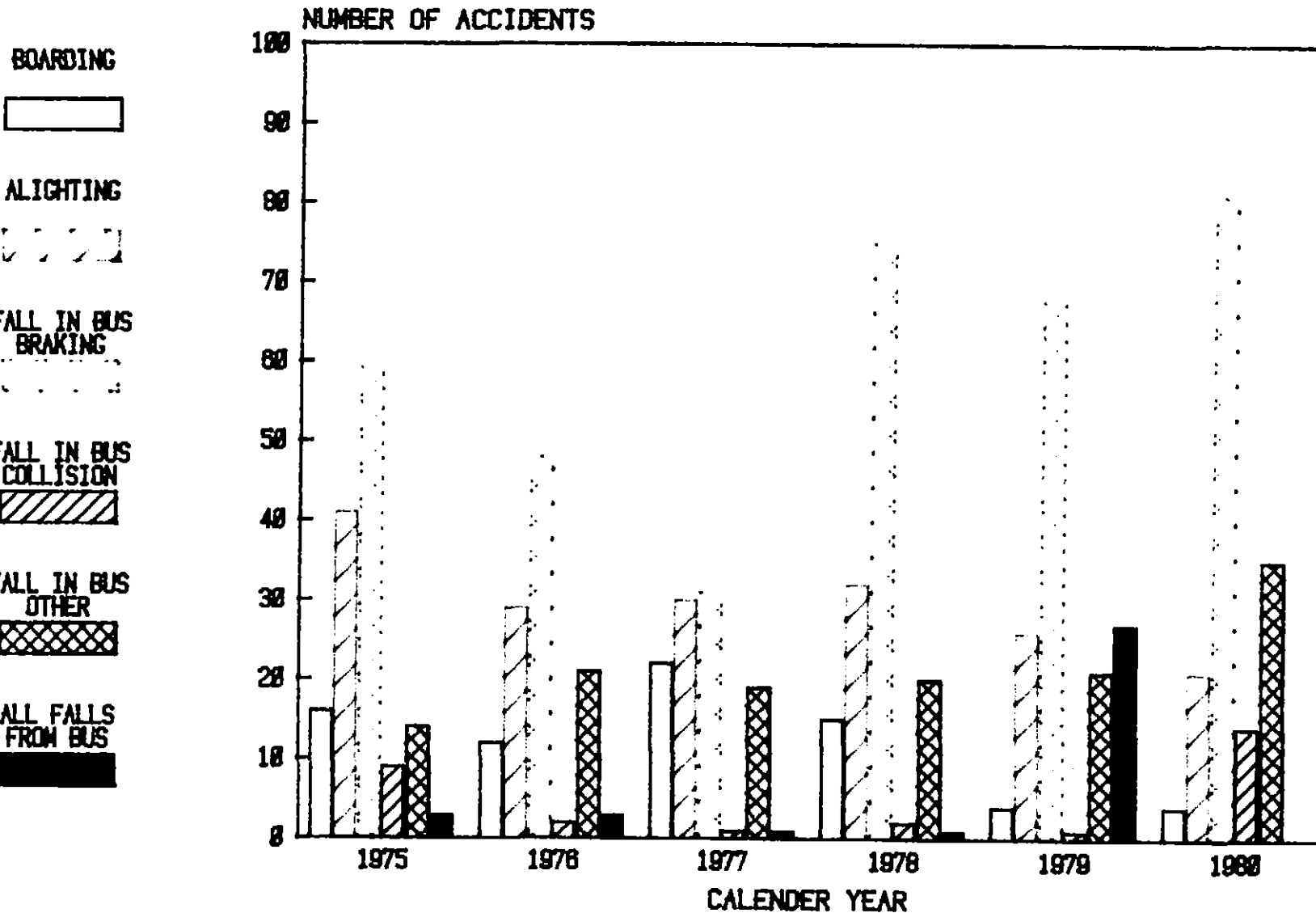


Fig. 2.5 Summary of MMTB Bus Accident Data

TABLE 2.1 M.M.T.B. Accident and Injury Figures.

| Year | No.of Acc. | No.of Injuries | No.of Injuries per Accident |
|-------|------------|----------------|--------------------------------|
| 1975 | 143 | 149 | 1.04 |
| 1976 | 115 | 116 | 1.01 |
| 1977 | 104 | 104 | 1 |
| 1978 | 145 | 147 | 1.01 |
| 1979 | 148 | 151 | 1.02 |
| 1980 | 155 | 159 | 1.03 |
| Total | 810 | 826 | Av. 1.02 |

It can be seen by inspection of Table 2.1 that since 1977 there has been a steady increase in the number of transit bus accidents in Melbourne. Correspondingly, there has been an increase in the number of injuries sustained in these accidents. Indeed, it is note-worthy that these accidents seldom involve the injury of more than one person per accident. It is an interesting point to note that while there were between 157 and 248 accidents on the RoSTA files per year (and not all of these resulted in an injury), the MMTB accident data files recorded between 104 and 155 accidents per year which caused injuries. While it is true that the MMTB have a large bus fleet, it would seem questionable as to whether in any one year the MMTB contributes up to 90% of the State's total of bus accidents which includes school buses, charter buses, intercity coaches and other transit buses throughout the state. Indeed, Table 2.2 shows the number of passenger vehicles licences issued at 30th June 1979 and 1980 by the TRB and the figures indicate that the MMTB operate less than 7% of the State's commercial bus fleet. However a comparison of total distance travelled would perhaps help to clarify this apparent anomaly.

TABLE 2.2 The Number of Passenger Vehicle Licences Issued at 30 June 1979 and 1980.

| Passenger Licences - Bus | | 1980 | 1979 |
|--------------------------------------|--|------|------|
| MO | Metropolitan Route | 986 | 993 |
| | Melbourne and Metropolitan Tramways Board | 282 | 278 |
| | Victorian Railways | 12 | 12 |
| MC | Metropolitan Charter | 275 | 264 |
| UO | Urban Route | | |
| | Ballarat | 41 | 40 |
| | Bendigo | 36 | 36 |
| | Geelong | 79 | 81 |
| CO | Country Route | 472 | 454 |
| CC | Country Charter | 4 | Nil |
| | Victorian Railways - Country | 4 | 4 |
| TS | School | 1657 | 1614 |
| TO | Touring | 118 | 121 |
| TP | Temporary Licences | 5 | 6 |
| SV | Special Vehicle | 196 | 184 |
| Passenger Licences - Taxi & Hire Car | | 4167 | 4087 |

On examination of Figure 2.5, the accident pattern appears quite consistent from year to year with the possible exception of the data recorded for 1977. During 1977, the proportion of accidents categorized as falls in the bus caused by braking decreased, while the incidence of accidents categorized as boarding, alighting and falls in the bus resulting from neither braking or a collision increased. On average, there were more than twice the number of 'alighting' accidents as compared to accidents

classified as 'boarding'. An average taken over the six years shows that 44% of all accidents were classified as a fall in the bus caused by braking. Indeed, the year by year variation in the proportion of these accidents is between 30% and 52% of the total accident count per year. In general, there were very few falls from the bus due to any reason. Furthermore, there were surprisingly few accidents caused by a collision, while only 6% required medical treatment. From the 810 accidents recorded over 6 years, only one fatality was registered.

If data relating to the number of injuries caused by transit buses are examined, it can be seen that most (approx. 98%) of the injuries occurred on board the bus. The injury severity sustained by victims of transit bus accidents was generally not severe, indeed only 17% of those injured required an ambulance.

2.4 CONCLUSIONS

In concluding this chapter which has investigated the available bus accident statistics in Victoria, a number of general comments can be made pertaining to omnibus accidents even though the sample of accidents per year was relatively small and the method of which the data is available was not ideal for this study.

First, comparing bus accidents and the number of consequent injuries with the total number of road accidents in Victoria indicates that the bus is a safe mode of road transportation.

Secondly, there are certain types of accidents which seem likely to result in more severe and numerous injuries. The more serious accident can loosely be divided into two groups: those where the injured party is not a bus passenger such as in bus collisions with bicyclists, motorcyclists and pedestrians and

those accidents where the injured party is a bus passenger such as in the case of bus roll overs. The most common type of bus accident, and one of the most dangerous with respect to injury severity, occurs at an intersection where the impacting vehicles are travelling (at right angles to each other) along the intersecting carriageways. Accidents at intersections where the vehicles involved are travelling along the same carriageway is the second most common category of accident, although the resultant injury severity is not as high as the above mentioned accident type. Another category of bus accident which results in a high incidence of casualties occurs when the bus is cornering. The high injury severity sustained in this type of collision is probably due to the majority (67%) of these accidents being frontal impacts.

Thirdly, an interesting feature evolves with respect to non-collision accidents which result in bus passenger injuries. There is a very high proportion of transit bus injuries resulting from bus passenger falling. 45% of all accidents recorded were as a result of the bus braking in a non-emergency situation, which resulted in the injured passenger falling in the vehicle. On the other hand, on average over a six year period from 1977 to 1980, only 6% of all MMTB bus accidents resulted in an injury due to a collision. Other areas of interest involve the high incidence of injury resulting from passenger boarding and alighting. The injury severity sustained in this type of bus accident is generally not high.

CHAPTER 3

SUITABILITY OF EXISTING BUS SEAT

AND ANCHORAGE STANDARDS FOR AUSTRALIAN CONDITIONS

3.1 INTRODUCTION

It became evident in the early stages of this project that work on secondary bus safety and more specifically bus seats and seat anchorages was being done by governmental and private research bodies in America, various parts of Europe, the United Kingdom and South Africa. The purpose of the foregoing research was essentially to establish the demands put upon seats and their anchorages both in day to day routine operations and in the event of an accident. It would seem that the work being performed in the U.K. is not as heavily biased towards seats as it is in either Europe or the U.S. The U.K. is however, a member of the Economic Commission for Europe and is actively involved in an ongoing investigation into safety provisions on motor coaches and buses. This committee called the "Group of Rapporteurs on Safety Provisions on Motor Coaches and Buses" (GRSA) concerns itself with all aspects of bus safety; however, they are presently concentrating on two aspects. First the strength of the superstructure of public service vehicles and secondly the strength of seats and seat mountings. The aim of the group is to establish a Standard and a testing procedure which is satisfactory for Europe generally. There have been lengthy and numerous meetings in an attempt to establish the requirements necessary for bus seats and a cost effective method of testing and regulating seats and their anchorages. The Group of Rapporteurs on this working party call upon the work that has been done in their respective countries and present an argument on behalf of the country's government, for seat requirements and test methods. Furthermore, this group of experts generate further investigatory work which is delegated to a particular country to perform and report back at the next meeting of the group. The meetings, research and presentation of draft regulations concerning the "UNIFORM PROVISIONS CONCERNING THE APPROVAL OF VEHICLES WITH REGARD TO THE STRENGTH OF COACH SEATS AND THEIR ANCHORAGES", have been an ongoing project covering a number of years.

The Americans have likewise been similarly concerned about the secondary safety aspects of buses. The American government has contracted work out to a number of research institutions in order to improve the understanding of crash dynamics and injury severity and its causation in bus accidents. American Federal Motor Vehicle Safety Standards (FMVSS) Nos. 220, 221 and 222 cover School bus rollover protection, School bus body joint strength and School bus seating and crash protection respectively. The Centre for the Environment and Man Inc., were contracted by the U.S. DoT to present Evaluation Methodologies of nine Federal Motor Vehicle Safety Standards²⁰ and one of their reports was titled "Final Design and Implementation Plan for Evaluating the Effectiveness of FMVSS 220, 221 and 222".

There is also FMVSS 207, Seating Systems which applies to passenger cars, multipurpose passenger vehicles, trucks and buses.

The research and Standards mentioned so far largely concern the strength requirements and performance of the seats and their surrounding structure. There are however, two other groups of regulations governing seats in buses and they are:

- 1) The physical dimensions of the seats, which encompass such areas as seat back height, padding depth, cushion width and longitudinal spacing of seats.
- 2) The method of seat attachment and the minimum specifications of the hardware necessary to facilitate this function.

The Californian Highway patrol have a set of regulations pertaining to the anchorage of bus seats as does the Victorian Transport Regulation Board (TRB). Indeed the TRB have recently introduced an "Ominibus Star Rating Charter Classification", which categorizes coaches and buses into five groups, ranging from a utility bus to a heavy duty luxury coach. The classifications depend on such features as, seats, windows, doors,

interior appointments (radio/tape recorder, airconditioning, heating, luggage racks and bins) and the general type and construction of the omnibus.

Most of the standards are written so as to encompass all categories of seats used in various types of omnibuses from reclining high backed coach seats to route bus seats.

3.2 MAJOR FACTORS INFLUENCING THE SUITABILITY OF EXISTING BUS SEAT AND ANCHORAGE STANDARDS FOR AUSTRALIAN CONDITIONS.

There are five main considerations that could influence the suitability of overseas standards to the Australian bus requirements and they are:

| CONSIDERATION | COMMENTS |
|---|---|
| 1) Road usage - the relative proportion of buses in the total vehicle fleet and the number of kilometres travelled. | Cost Benefit - The importance of travel in Australia. |
| 2) Accident Statistice - the type and severity of bus accidents and the speeds at which they occur. | Cost Benefit - Max Speed - Energy Absorption - Injury Severity |
| 3) The design concepts in Aust., necessary to cope with prevailing weather and road conditions. | Axle Loads - Deceleration levels - Injury Severity |
| 4) The size of the Australian coach building industry. | The ability of the industry to absorb the cost of a testing and testing facility. |
| 5) The type of seats used in Australia. | The movement of passengers in the event of an accident. The cost to the industry to be able to modify existing designs to comply with overseas standards. |

3.2.1 Road Usage

The relative proportion of the various types of vehicles on Australian roads will no doubt influence the types and severity of bus accidents that occur. This in turn will affect the injury pattern and severity of bus accident victims and therefore influence the design load criteria that would be required for any form of bus seat and anchorage standard. It may be that the pattern of general road usage, the types of vehicles used, the speed limits imposed and the variety and condition of road characteristics encountered is comparable enough between the US, Europe and Australia so as not to drastically affect the suitability of their standards, concerning seat and anchorage strength applying to Australia, however the differences may be irrelevant.

When considering the cost benefit of any modifications to bus design in order to improve their crashworthiness it is clearly necessary to bear in mind the significance of bus travel in Australia and its importance in the overall transportation system.

3.2.2. Accident Statistics

Even though the documentation of accident statistics specifically relating to buses in Australia is poor and the studies overseas tend to relate to a particular type of bus rather than the overall situation of bus accidents, it would appear that the trends in America and Europe are consistent with those indicated in the analysis of bus accidents in Australia*. Even though there are considerable differences between the Australian bus accident data compared to studies carried out in the U.S. and the U.K. it is unlikely that these differences would result in the use of either U.S. or European bus seat and anchorage standards being considered unsuitable for Australian conditions. Verification of this assumption is not possible at this point of time.

* Refer Ch.2. An investigation into aspects of bus design and passenger requirements Bus collision causation and injury patterns.

3.2.3 The Design Concepts in Australia Necessary to Cope with the Weather and Road Conditions.

The rough road conditions in parts of outback Australia through which long distance luxury coaches are driven take a heavy toll on suspension and running gear. As a consequence, these coaches have to be built stronger, which entails more weight. The Australian axle loads are lower than those for Canada and Europe and as a consequence, the buses are generally lighter. Yet they need to be stronger in order to cope with the poorer quality roads. The weight of the vehicle affects the deceleration of the bus in a collision and therefore the forces likely to be applied to the seats. To combat this problem, coach builders use a lazy axle so that the weight of the bus is distributed over three axles rather than two. Nevertheless, for all other types of buses in Australia which use the more conventional two axle configuration, peak crash decelerations could be higher than those measured in either the U.S. or Europe due to the Australian buses being lighter. This aspect will influence the suitability of both the U.S. and European Standards applying to Australia. It would be necessary to ascertain typical values of peak deceleration experienced by Australian made buses involved in specified collisions.

3.2.4 The Size of the Australian Coach Building Industry

Due to the relatively small number of coachbuilders in Australia and the fact that most of these are organised for very low production, the cost of elaborate tests necessary to verify seat strength specification Standards would undermine the smaller businesses. Therefore, dynamic tests although being the only method of satisfactorily determining seat and body forces and head decelerations have the limitation of requiring large production of the one style of seat so as to cover the initial cost of the testing facility or alternatively, the cost of hiring such a facility. Static

tests are very much cheaper to perform, largely due to reduction in measuring equipment and the lack of need for a deceleration device. Manikins, associated accelerometers and force transducers necessary to measure head and chest decelerations and femur loads, together with the machinery required to record, this data is formidably expensive. Indeed, even if an existing dynamic sled facility was utilised, the cost of setting up and performing the test is still substantial. The recording of acceleration and load levels is only one aspect of a dynamic test. It is also necessary to accurately ascertain the velocity of impact and to be able to control and know relatively accurately the deceleration profile of the sled, this is sometimes quite difficult to achieve, especially at higher decelerations. High speed cinemaphotography is also generally used to record the body movement of the manikins in order to establish points of body contact and to establish whether both head and knee remain within designated protection regions.

Some of the overseas dynamic tests developed for bus seats and anchorages could well be unsuitable for Australia due to the considerable cost of performing such tests. It is worth noting that there does exist a particular type of dynamic test facility which is specifically designed for low cost testing. This rig works on a pendulum principle and uses gravity as its energy source.

The cost of establishing and performing static force - deflection tests should not prove to be a major financial concern to even relatively small manufacturers.

3.2.5 The Style of Seat Design Employed in Australian Coach Building.

Static force/deflection tests rely upon numerous assumptions in order to relate the true dynamic accident situation to the simplified controlled static test. Among these assumptions are two in particular that could change with

changes in seat spacing and seating geometry. They are:-

- 1) the velocity at which the passenger would make contact with the seat in the real situation. The greater the distance between the seats, the greater the time lapse before the passenger undergoes deceleration. However, this time span allows a greater speed differential to be established between the passenger and the seat back due to the deceleration of the vehicle of impact. Thus, the greater the distance between seats, the greater the relative contact velocity and hence the greater body deceleration and jerk.
- 2) the points of body contact on the seat back in a collision that are assumed for static tests will change depending on the spacing and design of the seats. The advantage of dynamic testing is that during the impact phase, the body forces and points of body contact on the seat back are clearly evident and the influence of both seat spacing and seat design can be easily seen.

The seat spacing commonly used in Australia is similar to that employed in the U.K., U.S. and Europe, so it is unlikely that this factor will influence the suitability of how bus seat and anchorage Standards common to these countries would be implemented for Australian conditions. Due to the effect of seat characteristics on body motion during a collision, it would appear that overseas static test standards may be unsuitable for Australian use, insofar as static tests do not wholly represent an actual dynamic collision. The reason for this being that the use of different load magnitudes and points of load application can result in quite different seat force - deflection characteristics, inappropriate to the testing methods employed in this investigation.

3.3 THE AMERICAN FEDERAL MOTOR VEHICLE SAFETY STANDARD No.222 - SCHOOL BUS PASSENGER SEATING AND CRASH PROTECTION

This standard relies upon a static force - deflection test of bus seats in order to establish their stiffness both when the seat is loaded in a forward and rearward direction.

The criteria for forward seat performance is that the stiffness curve must fit within a specified window as shown in Fig. 3.1.

To avoid misrepresentation of the US standard, details are given in the units as written in the Standard. Approximate conversions are 1 inch = 25.4 mm, 1 pound = 454g and 1 lbf = 4.45 N.

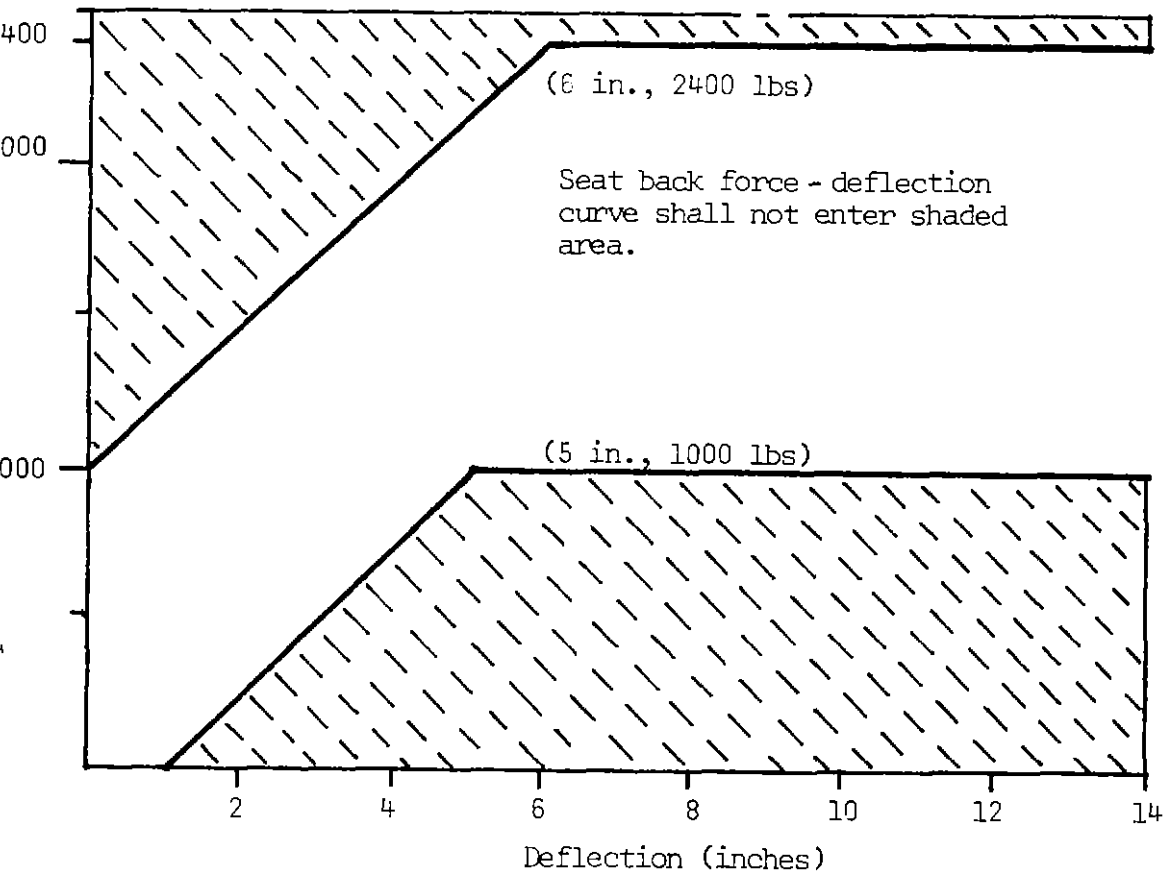


Fig. 3.1

There are two loading bars employed in the test; viz: an upper and a lower bar. The test requiring the characteristics to fit within the above force/deflection window concerns only those characteristics determined by the upper loading bar. Maximum deflection is not to exceed 14". A dual upper and lower loading bar is specified.

All specified loads are calculated in accordance with the width of the seat.

The anchorage requirements are such that the seat shall not separate from the vehicle at any attachment point and seat components shall not separate at any attachment point.

The location of the two loading bars are:-

- 1) Upper - 16" above the seat reference point,
- 2) Lower - between 4" above and 4" below the seat reference point.

An earlier characteristic used is shown in Fig.3.2.

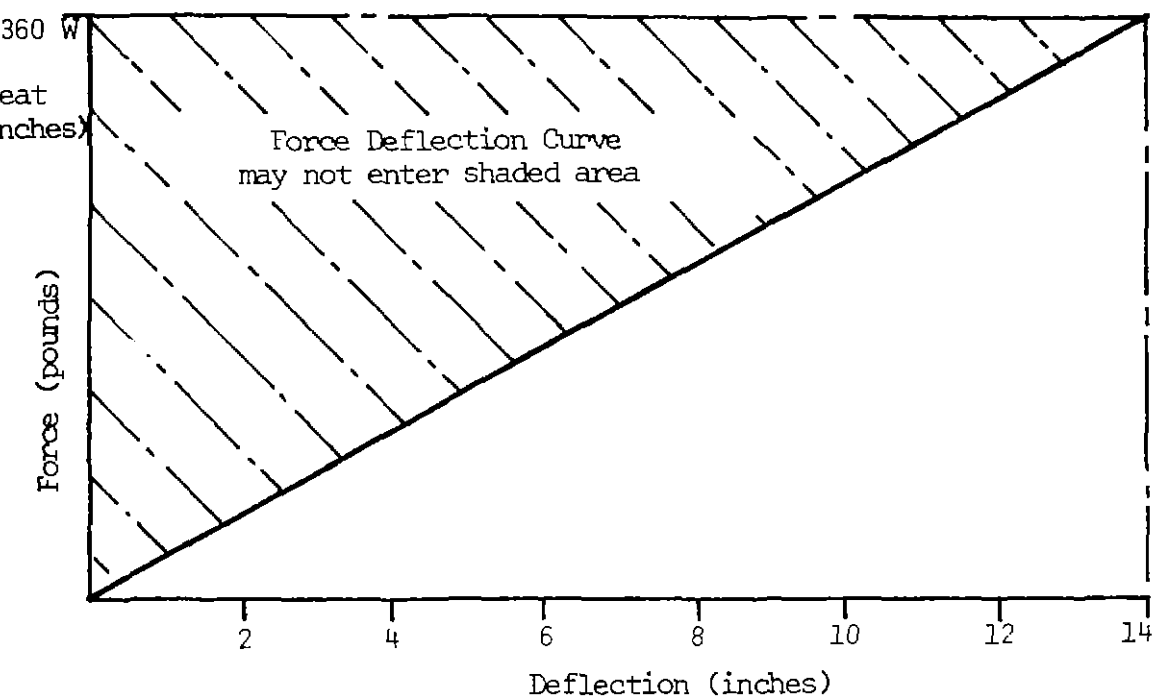


Fig. 3.2

An energy absorbtion figure of 4000 W in-lbf within 14" deflection is specified for the forward direction and 2800 W within 8" deflection for the rearward direction. (W is the width of the seat in inches). The dual loading is such that

- 1) a load of 700 W lbf is applied to the lower loading bar.
- 2) This load is reduced to 350 W lbf.
- 3) An additional load is applied to the seat through the upper loading bar until 4000 W lbf of work has been done.

A time of no less than 5 seconds or greater than 30 seconds is specified for obtaining the maximum loads.

The standard specifies the dimensions of the loading bars.

The minimum distance between any part of the seat being tested is stipulated to be 4".

The force/deflection window of Fig 3.1 does not apply to the rearward performance of the seat. Instead, a maximum load of 2200 lbf is specified together with a maximum deflection of 8". Furthermore, the load bar position for this test is to be 13.5" above the seat reference point.

This standard also involves a dynamic head form test, which involves the impacting of a head form on to the head protection zone at a velocity of 22 ft/s. Both the head form and head protection zone are specified. The criteria for this test is based upon the Head Injury Criteria HIC which is calculated according to the following equation.

$$HIC = \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a dt \right]^{2.5} (t_2 - t_1) < 1000$$

The resultant acceleration at the centre of gravity of the head form (a. measured in g) has to be such that the above inequality is true, i.e. $HIC < 1000$.

t_1 and t_2 are any two points of time during the test. Furthermore, the standard goes on to stipulate the head form force distribution, such that at an impact velocity of 22 ft/s the energy necessary to deflect the impact material shall not be less than 40 in lbf before the force level on the head form exceeds 150 lbf. Furthermore, when any contactable surface within such a zone is impacted by the head form from any direction at 5 ft/s, the contact area on the head form surface shall be not less than 3 sq.in.

There is an additional dynamic knee form test which is carried out on an area designated as the leg protection zone (that portion of the seat back bounded by the upper limit of 12" above and the lower limit of 4" below the seat reference point). When the knee form (which is specified in the standard) is impacted on the leg protection zone at 16 ft/s, the resultant forces shall not exceed 600 lb and the contact area shall not be less than 3 sq.in.

There is also a section relating to seat cushion retention and it is specified that there shall be no separation of the cushion from the seat at any of the attachment points when subjected to an upward force of five times the seat cushion weight.

In the American publications, there appear to be three different force/deflection envelopes that have been connected with this standard at various times. One of the plots has a non fixed force scale, which is determined by the width of the seat, while the remaining plots use a fixed scale.

A later characteristic is shown in Fig. 3.3

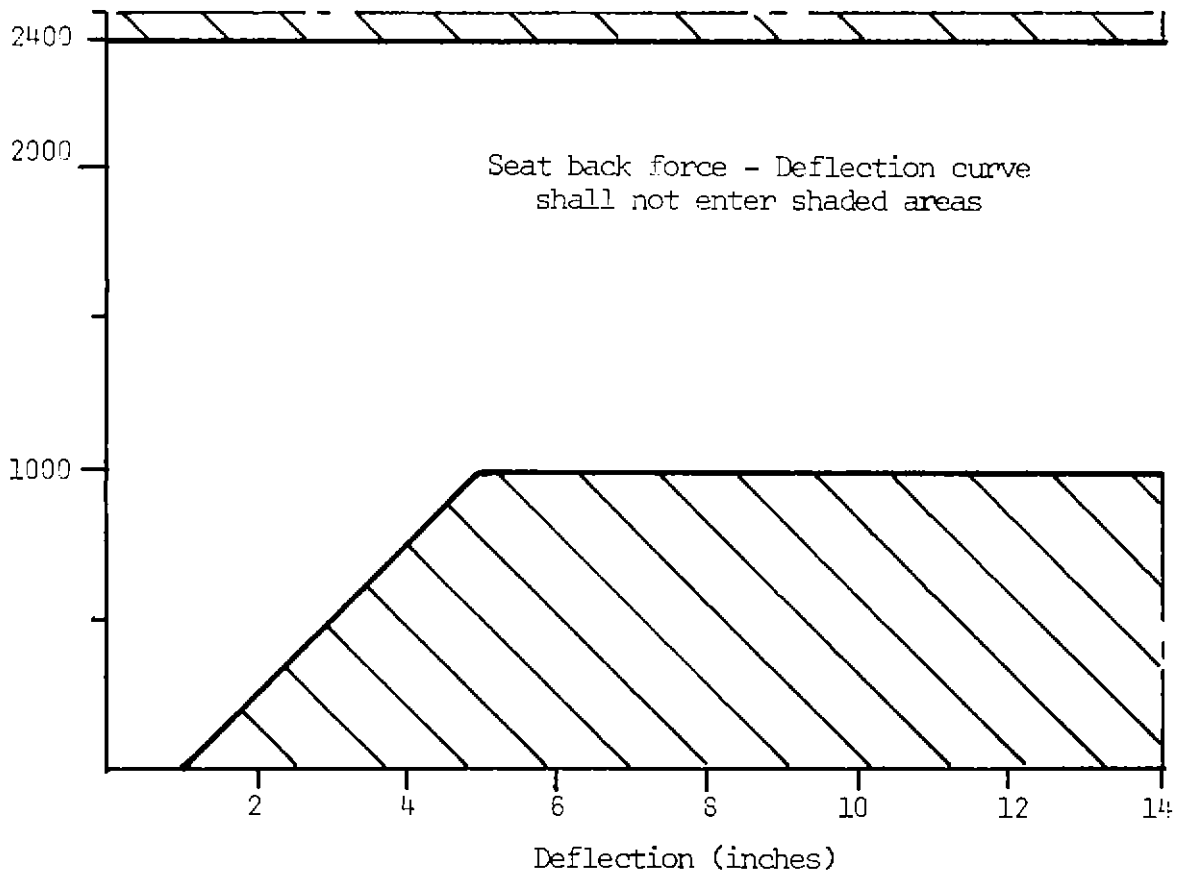


Fig. 3.3

The most recent and current characteristic in use is that shown in Fig. 3.1.

3.4 EXTRACTS FROM THE PROPOSED REQUIREMENTS FOR THE STRENGTH OF COACH SEATS AND THEIR ANCHORAGES IN PUBLIC SERVICE VEHICLES AS QUOTED FROM McHUGH ET AL¹.

These requirements cater for both static and dynamic testing. The provision is given that either test will be sufficient.

Failure of the seat structure mounting brackets or pedestals shall be permissible provided the dummies are contained and the areas of failure are not liable to inflict serious injury.

It appears that the dynamic test uses a non-instrumented manikin. The requirements for this test are such that under a 10 g deceleration from 20 mph., the seats shall contain the dummies positioned immediately to the rear.

The anchorage of the seats to the platform shall be as fitted during normal production. Failure of the seat structure mounting brackets or pedestals shall be permissible provided the dummies are contained and the areas of failure are not liable to inflict serious injury.

The spacing of the seats is required to be 24" (610 mm) between the back of the test seat and the front of the squab of the slave seat and the knees of the dummy are to be in contact with the back of the test seat.

The static test uses a single loading bar which loads the seat in the forward direction. The seat has to withstand a load exerted through the loading bar equivalent to 20 times the weight of the seat.

3.5 EXCERPTS FROM TITLE 13. CALIFORNIA ADMINISTRATIVE CODE

These regulations entitled Motor Carrier Safety are for trucks and buses with the exception of school and school pupil activity buses.

There is virtually no information relative to seating with the exception of S1270. Section a) refers specifically to the bus driver's seat, while section b) concerns bus passenger seats. It would appear that the only regulation concerning passenger seating is that "jump seats and seats in aisles shall not be permitted in any bus". On inspection of a copy of Title 13 of the Californian Highway Patrol Regulations, it was found that unlike the Motor Carrier Safety Booklet, it caters for all types of buses. Again, the Code is non-specific about the strength of the seat. However, with regard to Farm Labour Vehicle passenger seats, the Code states that "the seat frames and backs shall be rigidly constructed and maintained to ensure structural safety and resistance to displacement of any component in the event of an accident. Furthermore, the bus seat shall be secured to the vehicle by bolts at least $\frac{1}{4}$ " in diameter, uniformly spaced and of Grade 5 or better. Bolts have to meet the requirements of SAE Standard J 429. Bolts shall be equipped with flat metal washers at least $\frac{1}{16}$ " thick and $\frac{1}{4}$ " in diameter or better. Lock washers and nuts or self-locking nuts are to be used to secure the bolts. No less than four fasteners shall be used to secure each one to three passenger seat and at least six fasteners shall secure each four to six passenger seat. The Code states that if the vehicle design precludes the use of bolts, nuts and washers, an alternative securement method may be used only if its strength equals or exceeds the fasteners specified in this Code. In a later section of the Code which refers to floors, it would appear that the floor can either be 14 gauge steel or 5-ply $\frac{5}{8}$ " laminated wood. Since there is no mention of tapping or backing plates and $\frac{1}{4}$ " diameter washers are used then it would seem that these washers are used to distribute the attachment loads to the floor and not to the bus body directly. In section 1278 of the code entitled Pupil's Seats it is stipulated that the seats have to be mounted across the bus and not lengthwise.

There is to be a 13 in wide seat spacing for each pupil and the spacing of the seats, between the front of the squab of each seat and the rear of the squab of the seat immediately ahead is to be not less than 24 in., measured in a level plane parallel with the centreline of the bus. A provision for using $\frac{5}{16}$ " diameter self-tapping screws with a 12 gauge backing plate, to secure the seat frames is provided as an alternative to the $\frac{1}{4}$ " diameter bolts and nuts.

The Code states that all School buses constructed after Jan 1 1973, shall be equipped with interior protective padding capable of minimizing injuries from impacts as follows:-

- 1) All exposed passenger seat rails, except the rearmost seats , shall be padded down to seat cushion level and the top rail of the driver's seat shall be padded unless separated from passenger seating by a padded restraining barrier.
- 2) Stanchions shall be padded to within 3" of both the floor and ceiling.
- 3) Guard rails shall be padded from the bus wall to the farthest support.

3.6 ECONOMIC COMMISSION FOR EUROPE

Inland Transport Committee.

Working Party on Road Transport.

Group of Experts on the Construction of Vehicles.

Group of Rapporteurs on Safety Provisions on Motor Coaches and Buses (GRSA).

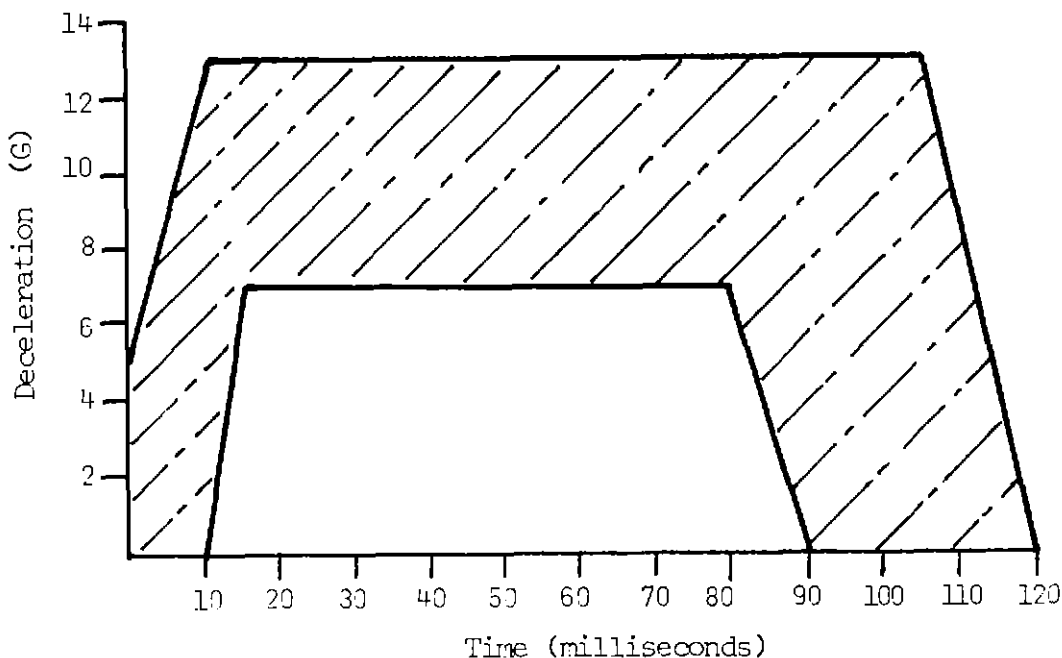
Draft Regulation: Uniform provisions concerning the approval of public transport vehicles with regard to the strength of seats and anchorages.

The history of the development of this draft regulation is lengthy and has involved a considerable amount of modification since its original conception. The various alterations to the draft came about as a result of feedback from work carried out in the countries of origin of the rapporteurs.

Throughout the development of the draft the option of either static or dynamic tests has repeatedly been written into the regulation. The first step considered by the GRSA involved the strength of seats and their anchorages. Then as a secondary objective the retention of passengers in their position during impact was considered.

The dynamic test in one proposal did not require the use of a manikin, instead, the seat was to be loaded by weights located in specified regions of the seat back. The seat was then anchored by normal production methods on to a platform which was decelerated from 32 ± 2 kph such that the deceleration equalled $6 \text{ G} \pm 2 \text{ G}$ for a minimum period of 105 ms. This form of dynamic test was thought not to be as meaningful as one using an instrumented manikin which measured deceleration levels at the head and torso and force levels at the knees.

Subsequently, a dynamic test was developed to test the capability of the seat and its anchorages to retain an impacting occupant from the seat immediately behind, when subjected to a deceleration of 10 G from 32 kph. It involved a specified deceleration envelope for the test platform as shown in Fig.3.4.



Note: The deceleration of the test platform should remain within the hatched area and peaks must not be outside this area for more than a total of 5 m.sec.

Fig. 3.4

If the seat was a reclining seat it was stipulated that for the test the seat squab had to be in its most vertical position.

The position of the manikin was specified and the spacing of the seats was required to be such that the knees of the dummy touched the back of the test seat. The performance requirements of the dynamic test were as follows:

- 1) No part of the seat or the seat mountings shall become completely detached; (does not apply to loose cushions).
- 2) The manikin must be retained by the seat under test so that no part of the dummy, except for the head, limbs and neck may be forward of the most forward part of the seat under test, when the test is completed.
- 3) There shall be no sharp edges or other protrusions likely to cause injury.
- 4) The seat squab adjustment system shall not be required to be in full working order after the test.

The static tests cater for both the strength of the seat and its anchorages. One test routine which was suggested involved four possible vehicle movements - seating orientation configurations:-

- 1) Forward facing seats with the vehicle moving forwards. i.e. a force applied to the back of the seat squab in the forward direction.
- 2) Rearward facing seats with the vehicle moving forwards. i.e. a force applied to the front of the seat squab (the side normally in contact with the passenger's back) in the forward direction.
- 3) Forward facing seat with the vehicle moving backwards. i.e. a force applied to the front of the seat squab (the side normally in contact with the passenger's back) in the rearward direction.

- 4) Rearward facing seat with the vehicle moving backwards. i.e. a force applied to the back of the seat squab in the direction of the back of the bus.

The magnitude and point of application of the static loads are different in each of four tests outlined above.

TEST 1: Forward test of forward facing seats.

A force of six times half the full seat weight plus 35 kg is applied to a loading bar positioned 500 mm above the R point of the seat and if this position cannot be met, then the loading bar shall be placed so that its upper edge is at the height of the seat back structure.

TEST 2: Forward test of rearward facing seats.

A force of six times half the full seat weight plus 50 kg shall be applied to the centre of the shape representing the back of the manikin (this shape is defined in the draft). The force is transmitted through the centre of the shape. i.e. 305 mm from point R with the distance measured along the reference line of the trunk.

TEST 3: Rearward test of forward facing seats.

A force applied to the shape representing the shape of the back of the manikin, as in test 2, such that a bending moment of 530 Nm is achieved at the H point of the seat.

TEST 4: Rearward test of rearward facing seats.

A force applied through the loading bar, as in test 1, such that a bending moment of 530 Nm is achieved at the H point of the seat.

The requirements of these static tests are as follows:

- 1) The seat shall remain firmly held at each anchorage point and the locking system shall remain locked throughout the test.
- 2) The adjustment and displacement systems and their locking devices shall not however, be required to be in full working order after the tests.
- 3) No structural part of the seat shall break or show sharp or pointed edges or other protrusions likely to cause injury.
- 4) During the tests, the deflection of the seat back in a horizontal plane 400 mm above point R shall not exceed 350 mm, relative to its original position before the test.

Furthermore, the deflection of the front of the seat cushion in a horizontal plane must not exceed 150 mm relative to its original position before the test.

Another static test routine proposed, involved two tests. The first was designed to test the seat anchorages and involved loading the seat through an individual loading bar positioned 450 mm above the floor with a force of ten times the seat weight divided by the number of seating places plus 4.3 kN applied simultaneously to the centre of the back of each seating position and maintained for at least 5 seconds.

The second test was designed to test the strength of the seat structure and involved the application of a horizontal load of 98 N per passenger place simultaneously applied centrally to the back of each seating position. The position up the seat back for the point of load application is not specified, although the draft stipulates that the load is to be increased until the

work done on the seat back is equal to or greater than 460 Joules. Furthermore, the horizontal deflection of the seat back at the point of load application in the direction of the exerted load is not to exceed 350 mm and the time to reach the maximum work is not to exceed two minutes. In addition, the standard requirements of such a test are also stipulated, namely:

- 1) No part of the seat or seat mountings shall become completely detached.
- 2) Failure of the seat structure shall be permitted providing that the test requirements are met. There shall be no sharp edges or other protrusions likely to cause injury.
- 3) The adjustment and displacement systems and their locking devices shall not, however be required to be in full working order after the tests.

A further set of specifications were drawn up by the Hungarian Government for the purpose of ECE evaluation and discussion. This draft regulation was similar to the specifications mentioned earlier in this section and obviously the earlier comments and discussions between the members of the group of rapporteurs had influenced the Hungarian proposal. There were, however, several unique points to the Hungarian proposal. Firstly, it made provision for three types of tests; a dynamic test, a static test and a calculation method for three standard road accidents; Head on, rear end and roll over. The aim of the dynamic tests was for the "Reproduction of a standard road accident". Throughout the draft seats are to be tested in conjunction with seat belts and if hand holds are provided on the seat backs, loadings are to be added to compensate for standee passengers. Seat orientation is taken into account in the dynamic tests and seats are tested in both the forward and rearward facing directions. Secondly it defines a stiffness envelope that the force/deflection characteristics

for the static test had to fall within. This envelope is very similar in part to the American specification, although the Hungarian envelope involves a ceiling load 11% higher than the American specification and does not stipulate any minimum load requirement. The stiffness envelope is shown in Fig.3.5.

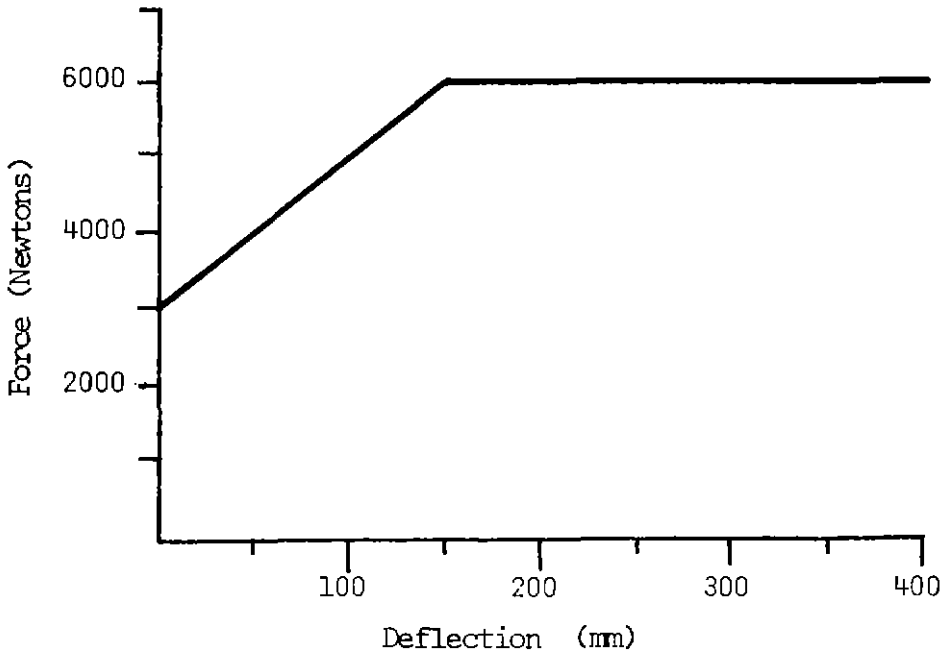


Fig. 3.5

This draft also defines the deceleration envelope of the dynamic test sled for both head-on and rear-end collision reproduction Fig.3.6.

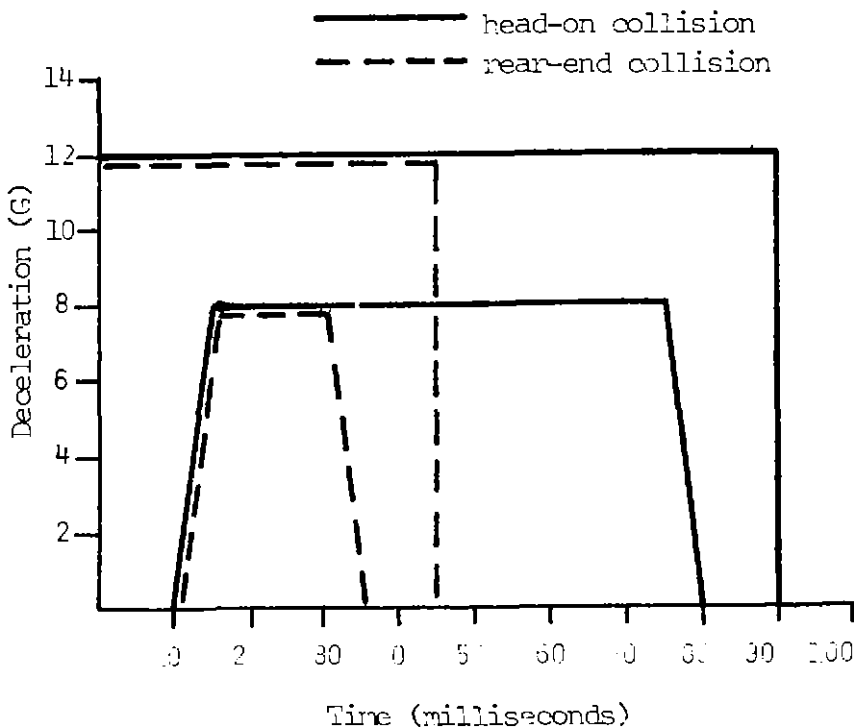


Fig. 3.6

The requirements for the dynamic test of the forward facing seat in a head-on collision of 30 ± 1 kph are:

- 1) No structural part of the seat shall have any fracture or sharp or pointed edge or corners liable to cause body injury.
- 2) Seat anchorage bolts shall not fracture.
- 3) For reclining seats, the blocking device in the end position shall be observed, although conservation of operation is not required.
- 4) The deformation in a horizontal plane turning longitudinally parallel with the axis of the bus and 400 mm above the "R" point must fall within the limit values of 150 mm and 350 mm.
- 5) The forward deformation of the front of the seat cushion must be less than 150 mm, when measured in the horizontal plane.
- 6) The deceleration measured in the manikin's head must not exceed 80 g for more than 3 ms.
- 7) The deceleration measured in the manikin's thorax must not exceed 60 g for more than 3 ms.
- 8) The maximum force measured in the manikin's femur must not exceed 7500 N.

For rearward facing seats conditions 1, 2 and 3 listed above apply and the horizontal deformation of the seat back 400 mm above the 'R' point must be less than 200 mm.

For the dynamic reconstruction of a rear end collision, the same requirements apply except the impact velocity is set at 15 ± 1 kph.

In both the head on and rear end collision reconstructions, in the test which involve the impact force being taken on the manikins back (i.e. the seat is facing in the opposite direction to the movement of the test sled), the manikins used are not instrumented.

Knee and head impact tests are specified with both knee and head forms being instrumented with accelerometers. The velocity of impact in both tests is 7 ± 0.25 m/s. The mass, dimensions, surface roughness and hardness of the impact forms are specified. The draft stipulates both the knee and head impact zones. The requirements of these tests are:

- 1) Head impact test: the measured deceleration must not exceed 30 G for a period longer than 3 ms.
- 2) Knee impact test: the measured deceleration must not exceed 30 G for a period longer than 3 ms.

In this draft, there are two additional tests: the static rupture test and a head protection zone padding test, either of which to date have not been cited in any other standard. Both of these tests are difficult to understand due to the manner in which they are worded. However, it is understood that the head protection padding test requires a plate of given dimensions to be placed at the back of the top of the seat squab. A force is applied to this plate in a specified manner, where upon the padding has to absorb a given amount of energy. The static rupture test requires the loading of the seat frame to be done in several ways, so that the most adverse loading of the anchorages is achieved.

The section dealing with the verification of seat strength requirements by calculation is not well defined. The specifications state that the calculations have to show that the requirements for the static and dynamic tests are met. It further states that the calculation techniques may only be used, when they take into consideration the following criteria:

- 1) Plastic strain properties of the seat structure, anchorages and energy absorbing elements (if any).
- 2) Kinetics of passenger movements.

Furthermore, the calculation techniques have to be capable of describing the process "correctly" and they have to be previously proven by experiment.

3.7 STANDARDS CONCERNING SEAT DIMENSIONS AND SPACING

3.7.1 Introduction

Apart from strength requirements and the ability of a bus seat to be able to retain passengers in a collision situation in a safe manner, there is the need to ensure that the seats are of adequate size and properly spaced. Leaving aside the aspects of comfort, the dimensions and spacing of the seats can affect the way in which the seat performs in an accident situation. The points of body contact will in part depend on the dimensions of the seat. Similarly, the relative magnitudes of body forces and decelerations will be altered by the physical size of the seat due to the seats influence on body phase movement control. The spacing of the seats directly influences the velocity of impact of the passenger on the back of the seat. The greater the spacing between the seats, the longer the interval of time between the collision of the vehicle and the impact of the passenger on the seat. Consequently, the greater the relative velocity between the bus and the passenger due to the fact that during the

time interval the bus has been decelerating while the passenger has not.

3.7.2 Omnibus Seating Standards - Dimensions

Fig.3.7 and Table 3.1 were presented in a report by Lewis²⁹ and compare the dimensional regulations set down in regulation 36 of the Economic Commission for Europe to the preferred seating dimensions of a sample of bus passengers. Two hundred elderly subjects were used as the sample of bus passengers.

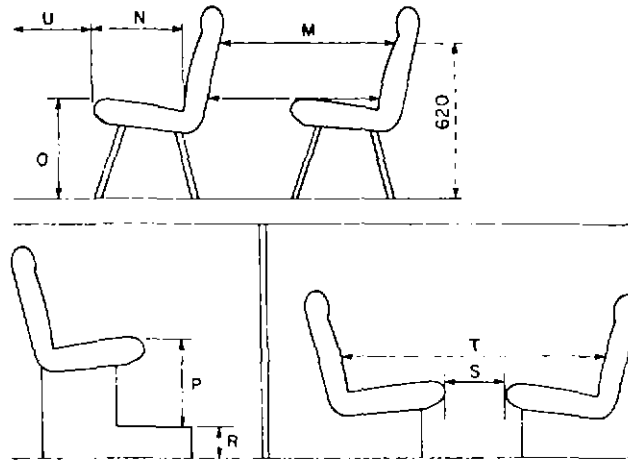


Fig. 3.7

TABLE 3.1

| Dimension | Body Dimension | Preferable (mm) | Acc'ble (mm) | ECE 36(mm) |
|---|---------------------------------|-----------------|--------------|-------------|
| M Seat clearance | Buttock to knee plus | 720 | 680 | 680 |
| N Seat depth | Buttock to popliteal depth | 400 420 | 380 430 | 350 400 |
| O Seat height | Popliteal height | 432 | 400- 460 | 400- 500 |
| P Seat to footstool | 5th percentile popliteal height | MAX 200 | 100-250 | - |
| S Back to back kneeroom clear | 95th percentile Buttock to knee | 700 | 600 | 600 |
| T Back to back clearance | 2x buttock to knee plus | 1460 | 1360 | 1300 |
| U Clearance of front seat to front of bus | 680 - seat depth | 310 | 280 | 280 |

The reason for using elderly subjects, some of whom were disabled, was as a result of an investigation by Brooks et al¹ which showed that there was an extremely high proportion of bus passenger injuries sustained by the elderly female population. Furthermore, most of these injuries were as a result of non-collision situations, i.e. either as a result of an emergency action, collision avoidance or a fall. See Figs. 3.8 and 3.9

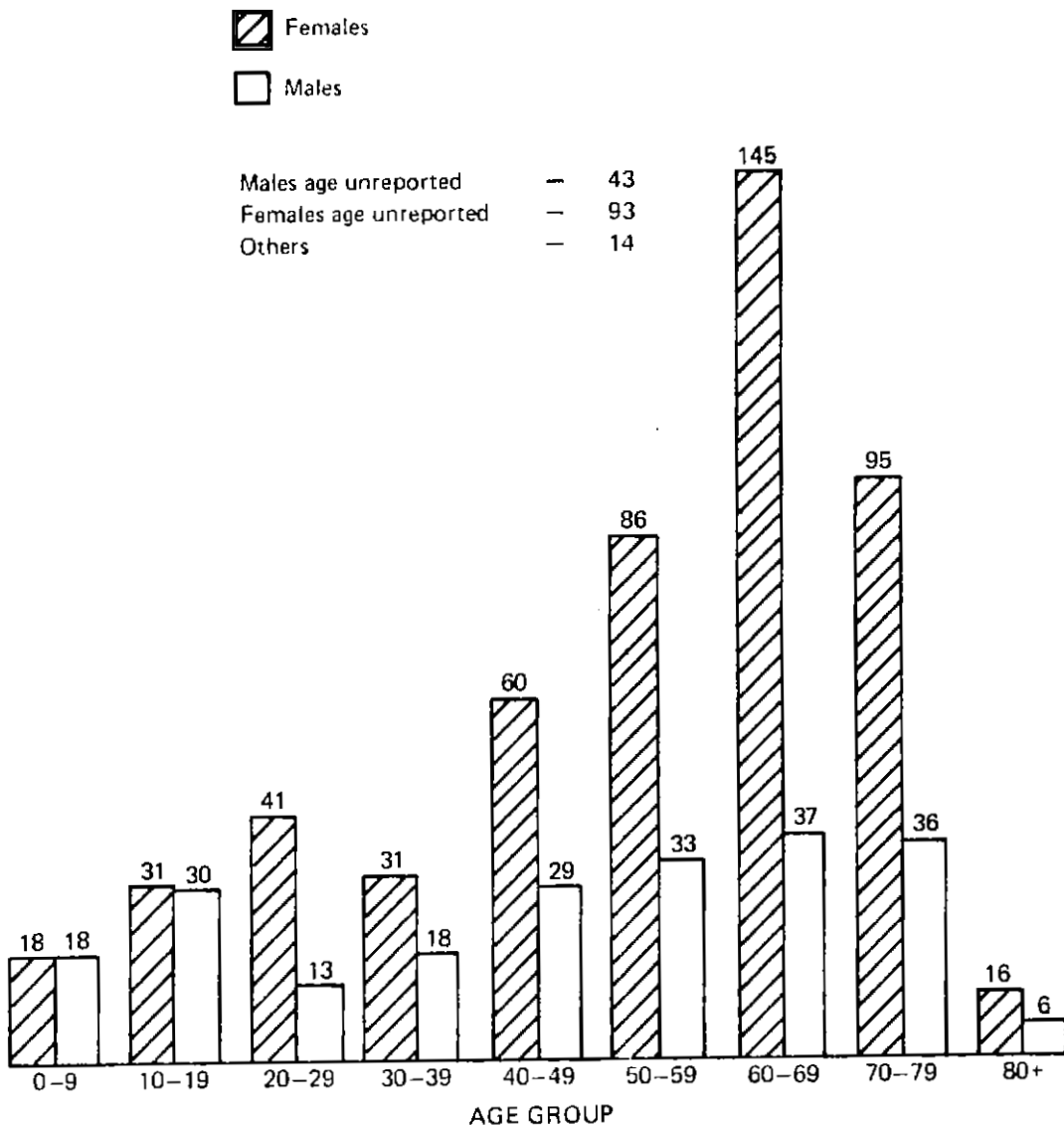


Fig.3.8 Reported Age of Passengers Injured in Non-Collision or Non-emergency Stop Accidents. (Brooks et al¹)

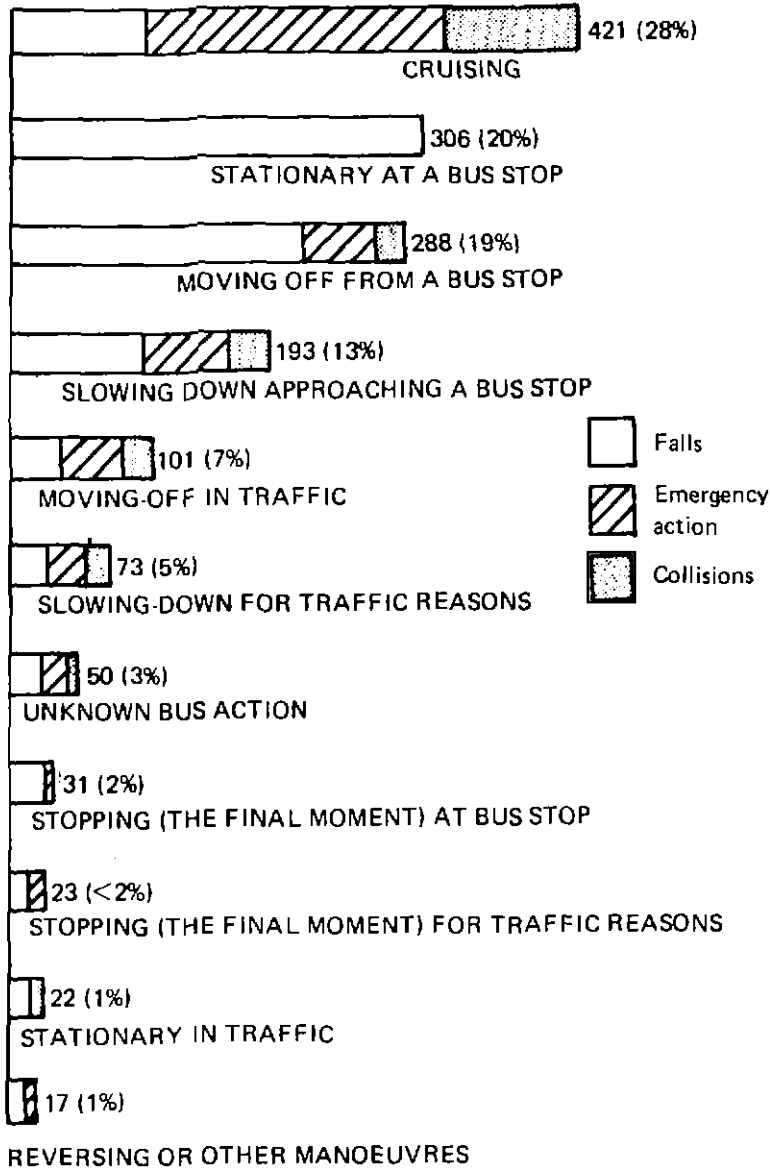


Fig. 3.9 Passenger Casualties by Bus Action and Accident Type.
(Brooks et al¹)

If Figs.3.7 and Table 3.1 are compared with Fig.3.10 and Table 3.2 which are the equivalent seat dimension standards set down by the TRB of Victoria, it can be seen that the dimensions are very similar. Furthermore, the TRB regulations make particular note about seat spacing which is to be 660 mm and "measured horizontally on the centreline of the seating position at the level of the highest point of the seat cushion on the seat centreline".

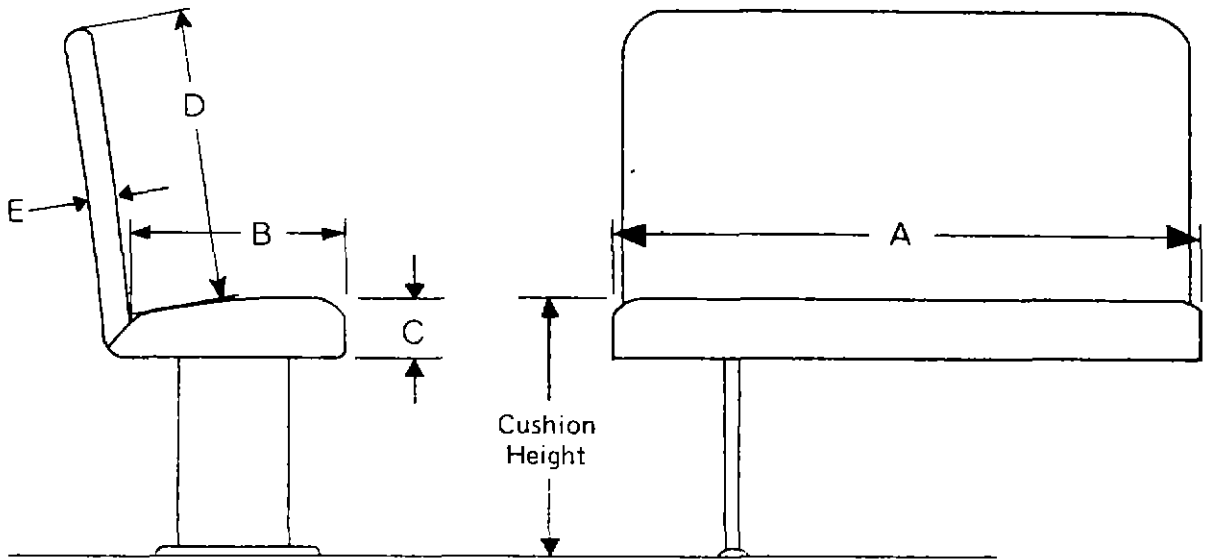


Fig.3.10 Omnibus Seating Standards Dimensions

This figure of 660 mm can be directly compared to dimension M in Fig.3.7. It can be seen that the TRB dimension is marginally smaller than the ECE's. The TRB makes a particular note concerning cushion height, especially in respect to the effect of wheel arches. Essentially, however, the height of the top of the seat cushion from the floor is not to exceed 500 mm nor be less than 380 mm for small omnibuses or 400 mm for large omnibuses. These dimensions are directly comparable to dimension O in Fig.3.7. According to the bus passenger sample in Brooks et al, the seat cushion height of 380 mm is on the border

of being unacceptable. The seat cushion depths are all similar, with the exception of the preferred minimum distance being 400 mm as opposed to the 350 mm minimum quoted in both the TRB and ECE specification. The bus passenger sample preferred a seat back height of between 432 mm and 457 mm for a transit type seat.

TABLE 3.2

| | Cushion Width A mm min. | Cushion Depth B mm min. | Cushion Thickness C mm min. | Back Height D mm min. | Back Thickness E mm min. |
|-----------------------------|-------------------------------|-------------------------------|-----------------------------------|-----------------------------|--------------------------------|
| Utility | 800 (400) | 350 | - | 420 | - |
| Standard | 810 (400) | 380 | 100 | 530 | 40 |
| Commuter | 830 (410) | 400 | 100 75* | 600 | 50 |
| Coach | 840 (415) | 400 | 100 90* | 640 | 50 |
| Luxury Type | 860 (425) | 420 | 110 90* | 640 | 50 |
| Luxury Head Rest Type | 860 (425) | 420 | 110 90* | 680 | 50 |

() For single seats

* For seats without hard backed cushions, incorporating some form of spring suspension.

A comparable seat in the range of seats stipulated in the Victorian regulations would be either the utility or standard seat which exhibit specified seat back heights of 420 mm and 530 mm respectively. The minimum seat back height quoted in the ECE draft regulation paper of 1974 was 650 mm. This is considerably more than the minimum seat back height allowable under the TRB's specifications of 420 mm. In a study by Severy et al⁶ where a series of head-on rear end and side impact bus collisions were performed using 39 fully instrumented manikins and photographic units, the conclusion was reached that a seatback height of less than 28 inches (711.2 mm) greatly increased the chances of injury during school bus accidents. Severy et al noted that the most commonly encountered seat back height in school buses ranged from 18 inches (457 mm) to 20 inches (508 mm).

The seat dimensions stipulated in the proposed requirements for the strength of coach seats and their anchorages in public service vehicles as quoted by McHugh et al²⁶ is as follows:

- 1) The top of the seat when measured on the centreline is to be at least 23" (584 mm) vertically above a point on the undepressed seat cushion and 2" (51mm) forward of the squab trim line.
- 2) The spacing of the seats is to be such that the distance between the front of the seat squab of one seat and the back of the seat squab of the seat immediately in front of the first seat is 24" (610mm).

3.7.3 Comments on Seat Dimensions and Spacing.

It would appear that there are two dimensions which are of prime importance with regard to the crashworthiness of bus seats and they are:

- 1) The height of the seat back.
- 2) The distance between seats.

Once allowances have been made for the different methods of measuring certain seat parameters from one standard to another, it is surprising how similar most of the dimensions are.

From the observations of the authors, there appears to be a less definite uniform idea of what the desired seat back height should be. Indeed, it would appear that this dimension in some cases, has been omitted or given a seemingly low priority, yet it has been established as a major factor concerning passenger injury¹.

As far as passenger protection is concerned, the TRB has extended its specifications and in so doing, has banned exposed bars above or behind the seat back except where the bar forms corner handgrips on commuter seats.

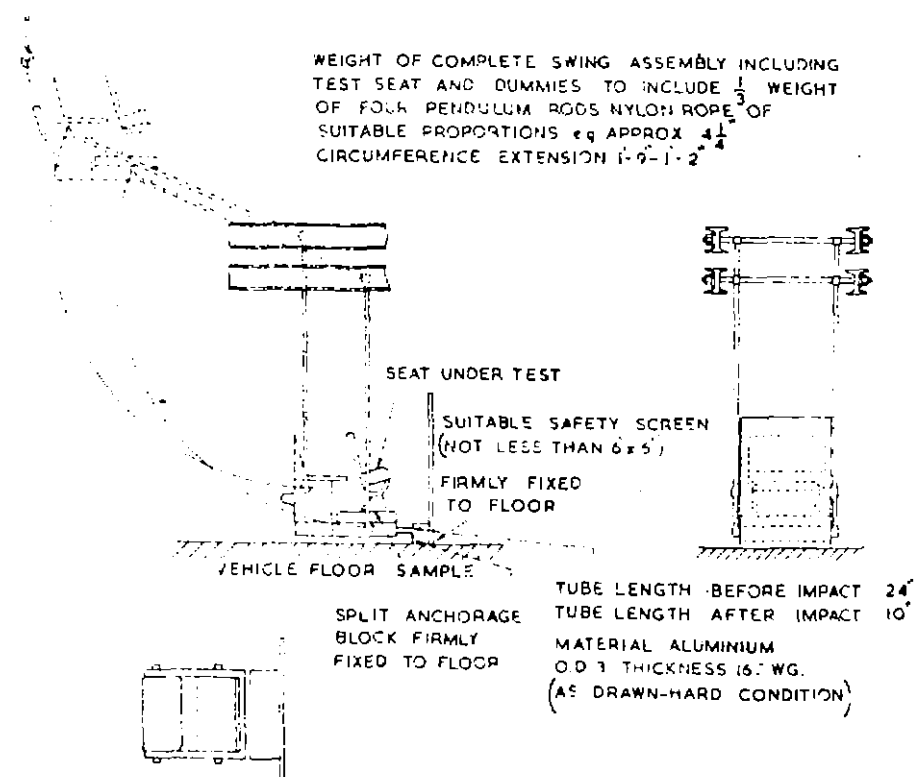
3.8 OBSERVATIONS ON STANDARDS SURVEYED

3.8.1 Strength of Seats and their Anchorages

Most of the standards that have been studied have the option of either static or dynamic testing. A major influencing factor concerning the adoption of any form of bus seat testing program for Australia is the cost of such a program, especially where a dynamic test is concerned, not only is there the need for equipment to simulate a collision, but in addition, there is the required measuring and recording apparatus which includes several specialized photographic units, force transducers, accelerometers and several instrumented manikins. Such

a testing facility would be expensive but nevertheless capable of reconstructing a life-like accident situation, with the capability of the crashworthiness of the seat and its anchorages. Furthermore, the injury severity would be realistically obtained without the need to make any assumptions other than the deceleration profile of the test sled.

It would be possible to establish a much simpler dynamic test which would merely load the seat in a dynamic mode by means of an uninstrumented dummy. The result of the test would be subject to the interpretation by a qualified person of the damage to the dummy and the seat on completion of the test. The machinery necessary for such a test-bed would also be simpler and could be based on a pendulum design as in Fig.3.11. Such a device requires a simple means of winching the load to the required height.



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RIG FOR TESTING P.S.V. SEAT FRAMES

Fig. 3.11

The energy is converted from potential into kinetic energy upon release of the pendulum. The deceleration form of the test bed depends upon the characteristics of the object struck by the pendulum. There is no reason why an instrumented manikin and photographic or cinematographic equipment could not be used to study the injury type and severity inflicted during a collision situation.

If a seat is fitted with a passenger assist device, either in the form of a handle on the back of the seat or a stanchion attached to the top of the seat back, then it is quite likely that in the event of an accident, this will create an additional loading on the seat. In the case of a standee using a passenger assist, it is conceivable that up to 160% of a passengers body weight could be transferred through the passenger assist to the seat frame¹⁷. This is an additional dynamic loading of a significant magnitude which has not been considered in any of the existing standards, although a Hungarian draft prepared for the ECE did take it into account.

The concept of dynamic head form impact on a specified region of the seat back appears to be a simple method of testing, that particular area of the seat, especially as it is of prime importance with regard to injury type and severity. It needs to be remembered that there is a high percentage (approximately one third of all injuries are to the head region⁴) in bus collisions. Consequently, instead of a fully instrumented manikin, an instrumented head form could be used to impact the seat back. However, it would require careful consideration as to the velocity direction and point of impact. Furthermore, any future regulation of this nature would need to define the "head protection" zone carefully.

It needs to be restated that the further removed from a fully instrumented dynamic sled test, the more remote the test is from a real collision situation. As such, interpretation of the results is necessary in order to correlate the laboratory data to a real life accident situation. Thus as the tests become simpler and less expensive and easier to set-up and perform, they also become more difficult to comprehensively plan. For example, with the fully instrumented manikin dynamic sled test, the only decision necessary is the initial speed of impact and the consequential deceleration profile. The results of such a test need relatively little interpretation and are complete as they give points of bodily contact, bodily movement in a real time domain, body forces and decelerations which will lead to an injury severity score. If however, we consider the instrumented head form dynamic impact test, assumptions concerning where head contact will occur, and at what velocity and direction (both could well be difficult as a result of body "whipping"). Not only do these assumptions need to be made, but their validity is difficult to ascertain. For example, the seat may undergo plastic deformation due to knee penetration and thus the head impact zone could possibly be in a completely different position. In some cases, the seat may be rebounding after the torso has elastically deformed it, and as this occurs, the head is flicked forward, producing an abnormally high impact velocity involving an unusual force direction. The possibilities of complicating factors resulting in invalid assumptions become higher as the complexity of the impact and movement of a human form on to the back of a seat back is truly understood. Thus, the step in test procedure from dynamic to static testing is again becoming more remote from the accident situation.

The more comprehensive static tests involve both a knee and head form loading and require that the force/deflection plot falls within a specified envelope. The position of application of the loads and the form of envelope require exhausting evaluation. The values of force and deflection of the stiffness envelope determine in effect, the injury inflicting potential of the seat. Furthermore, a decision as to whether the knee form load is going to be sustained during the head form loading or allowed to relax, and if so, in what manner is required in order to standardize the test procedure.

Such a static test is superior to a single force application test in evaluating the crashworthiness of a bus seat, particularly if it includes specifications for seat back padding for the knee and head regions. The most simple of tests, involving a single loading bar positioned on the seat back at a specified height and either loaded to a limit load or displacement or until a quoted energy level had been reached, is satisfactory for comparison of seats and for determining a seat's weakness and mode of failure. However, such a test is too far removed from the accident situation to be of use in evaluating accurately the crashworthiness and injury potential of a seat. In any form of seat test, whether static or dynamic, there need to be several general conditions met, and they are:

- 1) That all anchorage points are to be intact on completion of the test.
- 2) That there will be no failure of the seat that results in any sharp edges or protrusion likely to inflict injury.

- 3) That all components of the seat remain intact and attached to the seat (with the possible exception of loose soft cushions).

It would appear that, for the major part, the existing standards specify the strength requirements for both the seat and its anchorages. This is to be contrasted with the TRB's specifications which concern anchorages alone and specify:-

- 1) At least $4 \times \frac{5}{16}$ " high tensile bolts, or metric equivalent.
- 2) Body builders are encouraged to fit adequate seat mounting rails in production. If bolts are tapped into these rails, the thickness should be consistent with the bolts for strength. $\frac{3}{8}$ " thick for coarse thread and $\frac{5}{16}$ " thick for fine thread, or metric equivalent.
- 3) Some manufacturers use $\frac{1}{4}$ " thick rails in which case a lock nut is required if the bolt is tapped through the rail or a nut and lock washer if a clearance hole is drilled in the rail.
- 4) Where a suitable mounting rail is not fitted or does not line up with the seat mountings, a minimum requirement is for at least 50 mm x 50 mm x 3 mm plates or equivalent for each bolt.

These regulations dictate to the manufacturers, what is required. However, due to changing seat design, these specification may become unsuitable. For example, if the pedestal leg concept is extended then the size of the bolts and the backing and tapping plates would need to become larger as the distance between the bolt holes decreased, due to the increased anchorages force as a result of the decreasing moment arm. With the type of legislation involved in the ECE or American regulation such design changes are of little consequence as the test is being carried out on an entire seat and seat anchorage system. Nevertheless, if the TRB's specification did not exist the present methods of seat anchorage would not be

standardized and the possibility of unsafe seat anchorages may exist. Indeed, due to the normal service life of a bus and the fact that the TRB's guidelines of bus seat anchorages have not been in existence for longer than this length of time, there are buses in operation with seat anchorage systems which may possibly fall a long way short of the present regulations. Some of the anchorage methods used in N.S.W. show that specifications similar to the TRB's may be necessary. One of the most adamant points of all the standards studied, is that the test bed and the method of anchorage is to be identical to that used in production. Thus the TRB's specifications aim to achieve this goal.

3.8.2 Seat dimensions and spacing

The dimensions of a seat not only affect the quality and comfort of the ride but can influence the crashworthiness of the seat, as can the spacing between the seats. More important, however is the influence that seat orientation has on the safety aspects of the seat. It is generally accepted both in the aeronautical and automotive industries²⁷ that greater passenger protection is potentially available in a rear facing seat than a forward facing seat in the event of forward impact. The nature of bus accidents is such that the major proportion of them involve frontal collisions as is evident on inspection of the road user movement coding of the bus accidents on the police records. This observation has also been shown by Johnson³, where a study of 391 bus accidents resulted in the following breakdown of collision accidents. The concept of passengers facing the rear of the bus and unable to see where they are going is not well accepted, as indicated in a survey by Brooks²⁸ who tested the reaction of 200 elderly bus patrons and also in later work performed by the Transport and Road Research Laboratory (TRRL).

TABLE 3.3 Collision Accident Breakdown*

| | No | % |
|---|-----|------|
| Head on collision with vehicle or stationary object | 108 | 27 |
| Offside sideswipe with vehicle or stationary object | 18 | 5 |
| Nearside sideswipe with vehicle or stationary object | 7 | 14 |
| Front of bus into rear of other vehicle | 56 | 12 |
| Front of other vehicle into rear of bus | 48 | 5 |
| Bus into side of other vehicle | 18 | 2 |
| Front of other vehicle into side of bus | 30 | 8 |
| Multiple collisions with vehicles or stationary objects | 19 | 5 |
| Unclassified | 87 | 22 |
| | 391 | 100% |

* excluding collisions with pedestrians or pedal cyclists

Table 3.4 shows that the elderly population least preferred the rearward facing seat, while the overall sample of bus patrons ranked the rearward facing seat third.

TABLE 3.4

| | | | |
|---|----------|---------------------------|----------------------|
| 1. Problems encountered with buses (all subjects) | | | |
| Getting into bus seats | 50% | mentioned it as a problem | |
| Comfort of bus seats | 33% | mentioned it as a problem | |
| Getting out of bus seats | 51% | mentioned it as a problem | |
| 2. Preferred seat height 432 mm - 457 mm | | | |
| 3. Preferred footstool height 88% preferred 203 mm footstool to a 254 mm one. | | | |
| 4. Seat type comparison | | | |
| | | Rank preference | |
| Front facing 26.5 in (760 mm) spacing | | 1st | |
| Rear facing | | 2nd | |
| Front facing 24 in (610 mm) spacing | | 3rd | |
| Side facing 8 in (200 mm) footstool | | 4th | |
| Side facing 10 in (255 mm) footstool | | 5th | |
| 5. Seat position | | | |
| | % rating | All subjects rank prefer. | Elderly rank prefer. |
| Forward facing | 91 | 1 | 1 |
| Rearward facing | 5 | 3 | 4 |
| Side facing at front of bus | 3 | 2 | 2 |
| Side facing at rear of bus | 0 | 4 | 3 |

It is also worthwhile commenting, at this stage, on side facing seats, especially as they were ranked second on the priority list for both the elderly and overall bus population sample. In a paper by Unsell¹³, it is noted that in Californian School Buses, side facing seats are not permitted because "the human body has a minimal impact tolerance to a sideways impact. Furthermore, the capabilities of a side facing seat to retain passengers is distinctly less than in either a forward or a rearward facing seat.

There is a tendency to fit as many seats as possible into commercial buses with the rationale possibly being the more paying passengers the better. This, however, has the marked hazard of making entering and leaving the seat difficult as it can lead to stumbling and tripping, particularly in the case of elderly passengers. In a paper by Brooks²⁸, it was found that 50% of the test population had difficulty getting into and out of their seats, because of the cramped spacing between seats. In a paper written by Lewis²⁹, it was observed that large seat spacing presented a problem to some elderly passengers because they felt insecure, primarily due to the greater distance necessary to reach for the grab rail on the seat in front. However, in a prepared paper by the Booz Allen Applied Research Institute¹⁶, it was established that getting into or out of bus seats is not very hazardous compared with moving towards the front of the bus or moving to the rear of the bus and missing a passenger assist device.

Nevertheless, there is a case on a passenger retention/ impact basis for the minimization of seat spacing. In the event of a collision, the impact velocity of the passenger on the back of the seat in front of him is reduced as the distance between him and the seat decreases. This may not be the case in the event of the passengers upper body being shipped downwards over a low backed-seat. However, provided that the seat back is a suitably

padded high back seat, then the compacting of seats should result in the minimization of injury and an increase in passenger retention in the event of an accident.

Some dimensions such as cushion height, depth and thickness and seat width are mainly concerned with passenger comfort, however, there are other seat dimensions which are not only comfort related, but have a significant role in the crashworthiness of the seat. These dimensions predominantly deal with the seat back and specifically relate to the height and angle of the seat squab. The point of contact on the head is quite drastically altered by the height of the seat back. Indeed the contact point can range from the upper forehead region down to the thoracic area. In the event of an accident, it is common for low back seats to produce a whipping effect of the upper body such that the head is brought down upon the top of the seat back with considerable force. Such a condition is unlikely to occur with high back seats because it is found that the back of the seat squab is much closer to the passengers head and is at such a height that the head makes contact with the back of the upper section of the seat back. Thus with high back seats, the impact load is distributed over a much greater surface area and therefore minimizes the chance of bone fracture. The parameter of seat squab angle influences the crashworthiness of the seat in two ways. Firstly, in a similar manner as described above, the more reclined the seat is, the more exposed the top of the seat back is to head/thoracic impact upon collision.

The consequence of this increased exposure is a reduction in contact surface area, which leads to localized force application and on increase in the possibility of bone fracture and high injury severity. If on the other hand, the seat squab is inclined too far forward, the distance

between head and seat back is increased to such an extent that the time delay between the collision of the bus and the impact of the head on the seat back is so great, that the velocity of head impact is greatly increased, again increasing the risk of injury. The second way in which the seat squab angle can influence the injury potential of a high backed seat, is by maximizing the retaining capacity of the passenger in a "survival space". The means of achieving this containment is by striving to minimize the time delay between contact of the knees and head with the seat back. The simultaneous or near simultaneous impact of the knees, chest and head effectively controls the relative motion of parts of the body and makes subsequent bodily displacement continuous with relatively low degrees of isolated body deceleration.

CONCLUSION

There is one very important point that needs to be stressed. In a properly thought out dynamic/manikin test, there is absolutely no need for specifying any seat dimensions, seat spacing or any anchorage specifications because if:

- a) The manikin has been adequately retained and
- b) the head deceleration and knee/femur forces are within specified limits and
- c) the seat has remained securely anchored to the floor and
- d) none of the seat members have failed leaving sharp edges or protrusions likely to cause injury,

then the seat/anchorage system has worked satisfactorily. The only factor of concern is whether it will work with the same degree of satisfaction once it has been in operation for ten to fifteen years. The qualities necessary to cope with this question are, skill, experience and the ability to understand the demands that are put upon servicing bus seats.

SURVEY OF BUS SEAT INDUSTRY

4.1 INTRODUCTION

The following lists the aims of visiting bus bodybuilders and seat manufacturers.

- (a) To introduce the investigators and the project to the bus and coach building industry.
- (b) To survey the variety and quality of seats, presently being manufactured and installed, taking into special account the strength, rigidity and any potential injury inflicting aspects of design and hazardous aspects of its use in operation and in the event of various types of accidents.
- (c) To view and record the various methods of seat anchorage to both floor, wall and passenger assist stanchions.
- (d) To question leading designers as to the trends in bus seat manufacture and design.
- (e) To collect drawings of seats and their methods of anchorage together with samples of fasteners.
- (f) To listen to case studies related by senior engineers involving failure of seats and seat anchorages which have occurred due to accidents, vandalism and normal working operation.
- (g) To listen to senior management's views of State by State regulations of seat and seat anchorages.
- (h) To study the various methods of construction of buses and coaches, with particular reference to the overall strength and stiffness of the structure, in particular, the walls/roof and floor.
- (i) To get an overview of the work that is being done in the testing and development of bus and coaches.
- (j) To obtain an idea of the requirements that a bus proprietor demands from a bus and the reasons for these.

- (k) To impress upon the industry, that the work being undertaken is in the best interests of the industry. To ensure that they felt free to contact us on any aspect of bus and coach safety, we requested them to contact us as soon as possible in the event of a serious accident.

4.2 CLASSIFICATION OF SEATS

4.2.1 Construction Methods.

In Australia, where the total volume of bus seats manufactured is small and the variety of seats quite substantial, the introduction of capital intensive processes in the construction of bus seats is financially unrealistic. Some bus seat manufacturers tend to customize the seats of particular buses to the proprietors specifications, so that there is no true standard seat manufactured by that company. This adds to the problem and keeps the manufacture of bus seats highly labour intensive. There are no injection mouldings or high degrees of automation and there has only recently developed a trend towards fibreglass seat back components. Thus the method of manufacture is largely; cutting lengths of steel tube to size, either bending or light pressing them into the required shape and then welding the components while held in a jig. If the seats are of a coach style, they will have sprung cushions and backs, using either rubber straps clipped to the frame or coil springs in conjunction with paper covered wire, otherwise the frames are likely to have marine ply board secured to them. These boards are then used as the basis for trimming up the seat, with a foam pad and a vinyl covering. In the trimming of coach seats, the shaping and construction of trimming is more elaborate, as sections of different density foams are glued together in order to give support where it is required, yet remaining soft for long distance travel.

The method of attachment of the plywood backing boards, used in school and route bus seats is often by welding securing tabs to the seat frame and then fastening the board to the tabs by self tappers.

4.2.2 Variety of Materials Used.

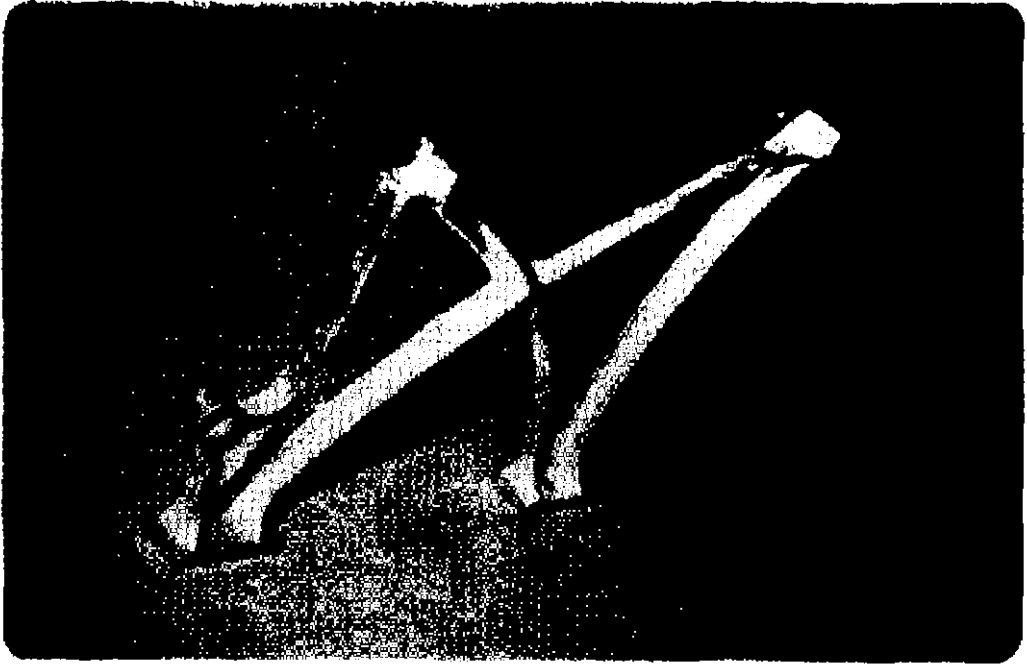
Most of the school and route bus seats use 1" ϕ tubing. If it is mild steel, the tube wall thickness is usually 16 SWG, and if it is stainless steel, the tube wall thickness is reduced to 81 SWG. Unfortunately a combination of both metric and imperial units is used in the industry.

With coach seats, the seat cushion frame is often made from mild steel 1" square tubing with a wall thickness of 16 SWG. The rectangular tube is orientated so that the larger dimension runs parallel with the longitudinal axis of the bus. The floor mounting plate, which is welded to the legs of the seat and is the means of securing the seat to the floor and the wall mounting bracket, which is welded to the side of the seat and is the means of securing the seat to the wall of the bus, is normally 3mm thick mild steel and 2mm thick if it is stainless steel.

4.2.3. Design Concepts in Australia

- (a) Variety of Leg Used. In the past, the legs that have been used to support the aisle side of the coach seats have been cast, (Photo 4.1) with the feet being separated by a distance of about 300 mm with one bolt securing each foot to the floor. The current trend is to replace this cast leg with a single pedestal fabricated from stainless steel sheet (Photo 4.2). The distance between the securing bolts has been significantly reduced from the figure of 300 mm to about 180 mm. The beneficial effects of this modification are: reduction of cost; easier cleaning and less chance of passengers tripping over the legs; however, it also has the detrimental effect of increasing the load on the anchorage bolts thereby increasing the risk of anchorage failure.

In contrast, transit and route bus seats and seat legs have remained essentially unchanged. The legs consist of two vertical stainless steel tubes which are tethered together at their base by a stainless steel plate, which is welded to the legs and provides the anchorage holes for



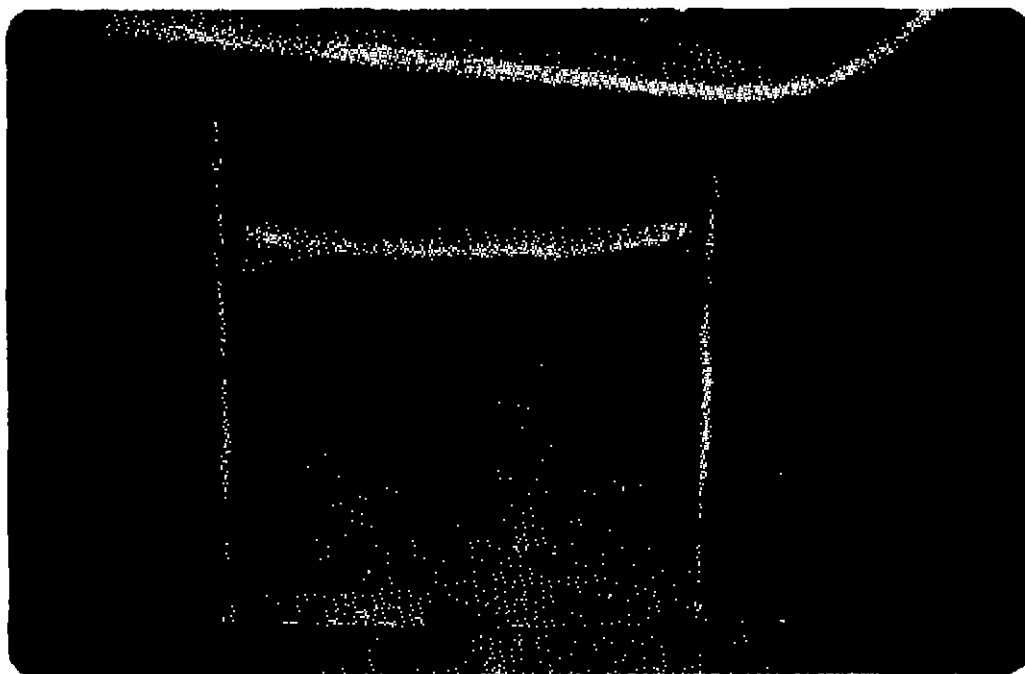
Photograph 4.1. An early bolt-on seat leg, which exhibits four bolt holes; two to attach the legs to the floor and two to fasten to the seat frame.



Photograph 4.2. A pedestal seat leg which is now common in most coach seats. Note four widely spaced bolt holes to allow attachment to the seat frame and hopefully provide lateral stiffness over the early two bolt system.

the bolts to secure the seat to the floor (Photo.4.3). Occasionally, tabs are welded to the bottom of the steel tube legs, thus providing the means of fastening the seat to the floor, instead of using a section of flat bar between the two tube legs. There are cheaper standard seats which use mild steel tubing in place of the stainless steel but apart from the material used, the overall geometry and design is unchanged although it is common for a thicker walled tube to be used when mild steel is employed.

- (b) Variety of Seat Frames. Again it is necessary to discriminate between coach seats and route transit type bus seats. Coach seats, whether they are reclining or not, have support cushion and squab frames which are often constructed from square or rectangular section tubing. Both cushion and squab frames have some form of springing either by means of Pirelli rubber straps or Pulmaflex with springs and paper covered wire (Photo 4.4). The cushion frame is bolted to the legs by four bolts, usually two at the front and two at the back. The purpose of having two at either end is supposedly to build in lateral rigidity which, when coupled to a suitable floor and wall mounting system stiffens the side wall of the bus. In effect, the seat is being used as a stressing or bracing member in the lateral direction. In the past, seat legs only accommodated two bolts to effect the attachment of the seat frame (Photo.4.1). However, the development of seat legs has been such that the number of fasteners attaching the legs to the frame has increased to three and is now commonly four (Photo's 4.5, 4.6 & 4.2). In this way the lateral stiffness of the seat is believed to have been increased. Another important aspect to note is that the squab frames, two to each seat cushion frame are independently attached. A common means of positioning the fixed angle of the seat back on non-reclining coach seats is to have both seat squabs pivoted at their bases, (Photo.4.7) in the same manner as is accepted for reclining seats. However, instead of installing a reclining mechanism a simple pin bolted to the arm rest (Photo.4.8) and slotted into a hole of the squab frame locks the seat back in place.



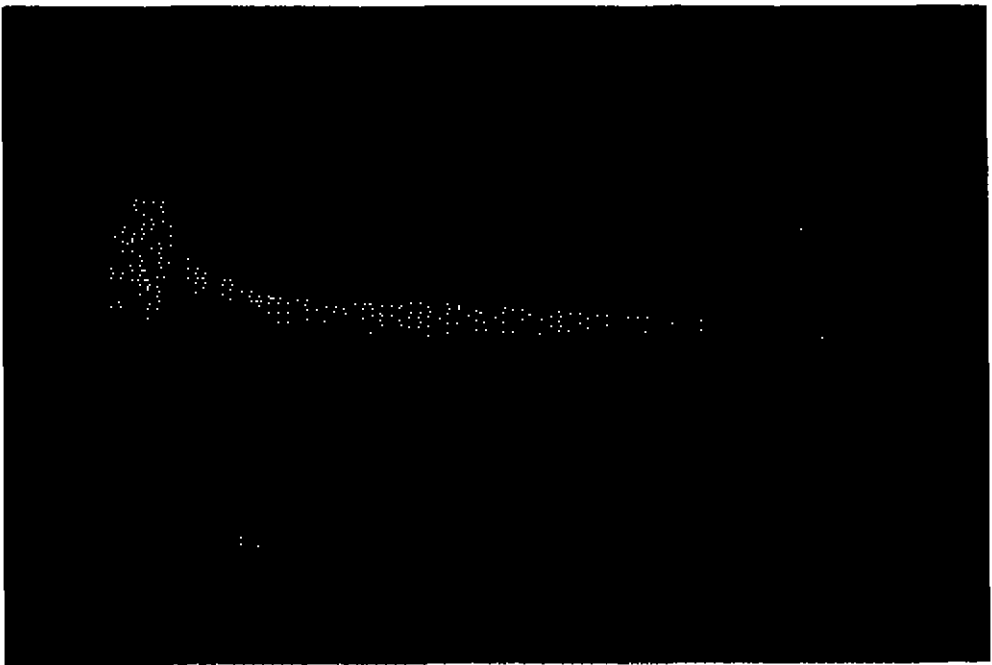
Photograph 4.3 A typical route bus seat leg/frame arrangement. Unlike this example some seats have separate attachment tabs welded to the base of the feet, rather than a continuous strip running between the legs.



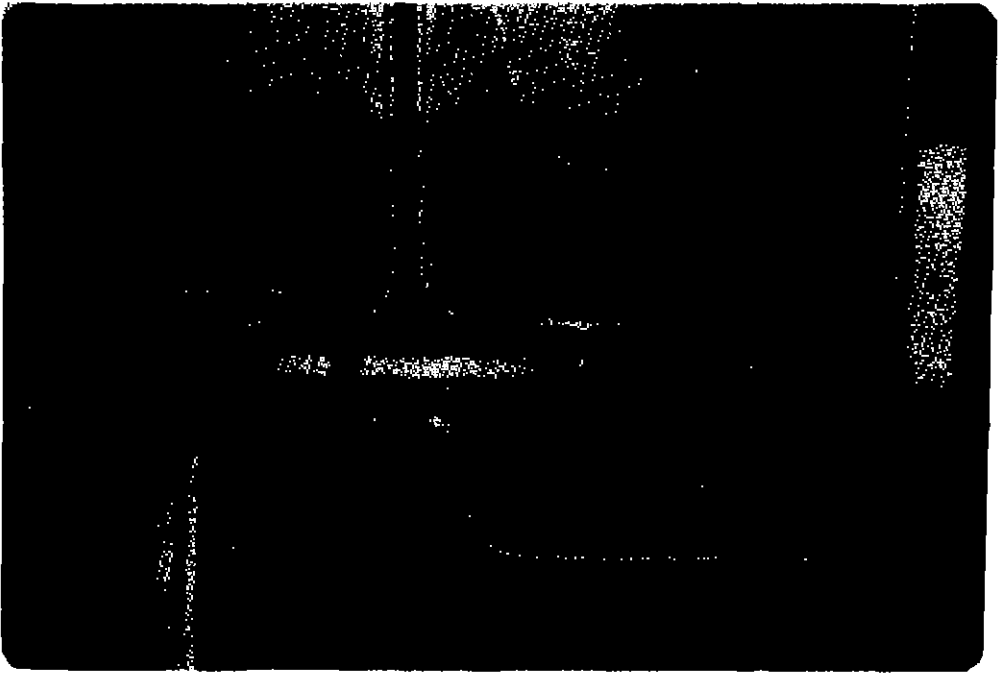
Photograph 4.4 A three way incremental seat back reclining coach seat. The pivoting point of the seat back, together with the reclining mechanism is shown.



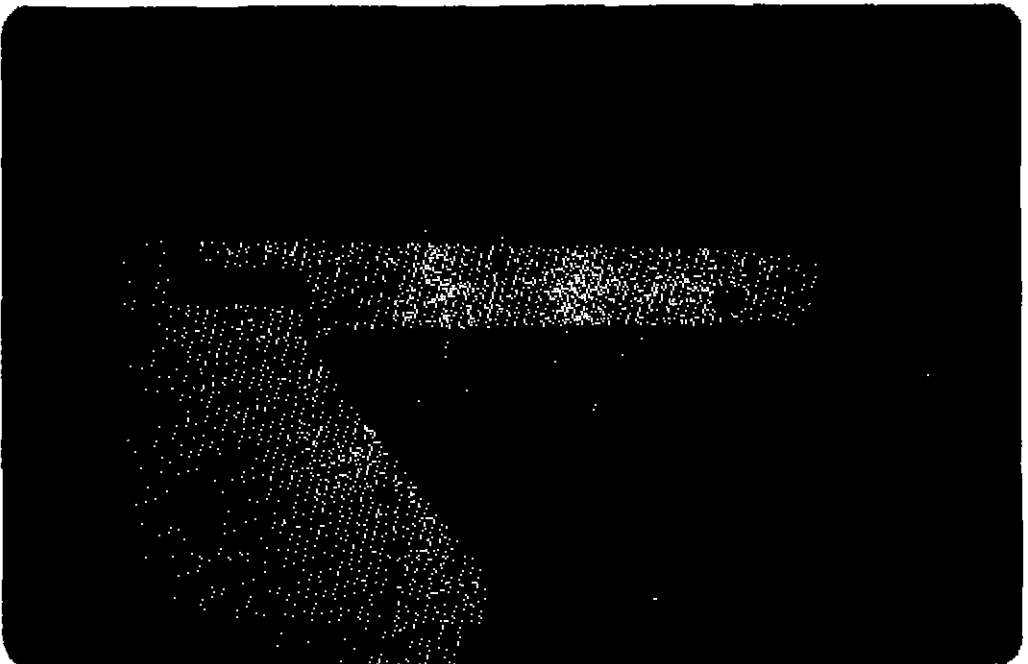
Photograph 4.5. A later seat leg from the one shown in photo.4.1 which exhibits a wider base of attachment to the seat frame for the purpose of providing lateral stiffness.



Photograph 4.6. A current cast coach seat leg which is a good example of the wide base bolting of the legs to the seat frame. The foot rest attachment point can be seen on the right leg.



Photograph 4.7. A fixed back coach seat which has pivoting seat backs that are locked into position by a pin bolted to the top of the arm rest. Note also the foot rests and widely spaced bolt positions of the pedestal leg attachment to the seat frame.



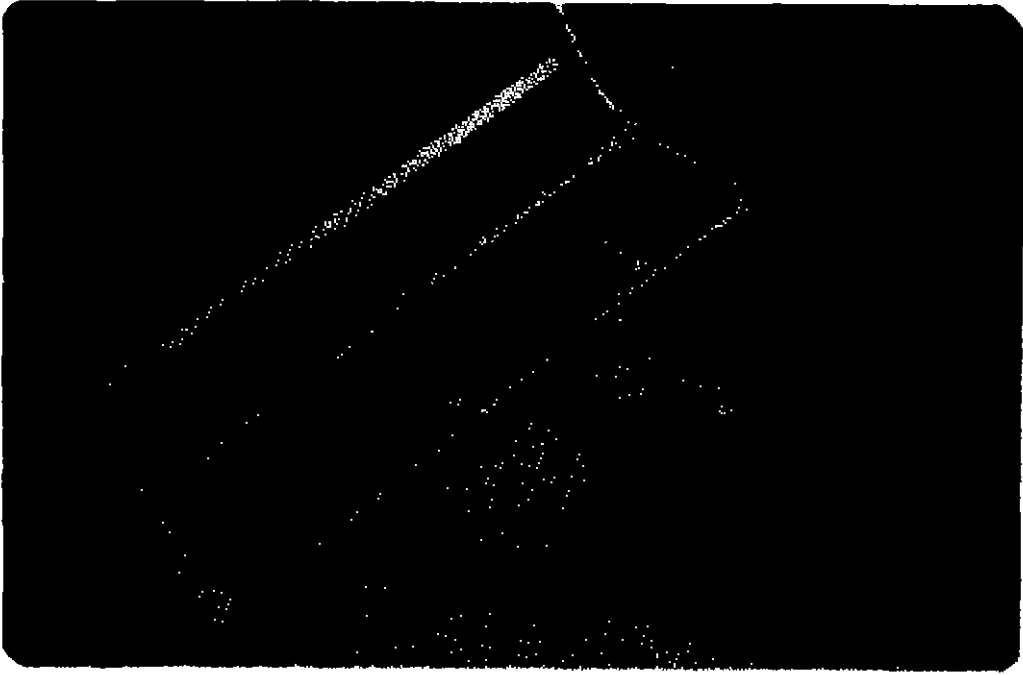
Photograph 4.8. This is the armrest fitted to the seat in photo.4.7. Both the position of the pivot point for the seat squab and the retaining pin can be seen. Note the single bolt holding the pin.

This method means that in the case of an accident, or if the seats are abused and the arm rests are damaged, the squab may be free to collapse. The pin itself does not appear to be particularly strong and is only secured to the arm rest by one bolt (Photo.4.8). Again if the bolt came loose or broke, the squab would most likely collapse.

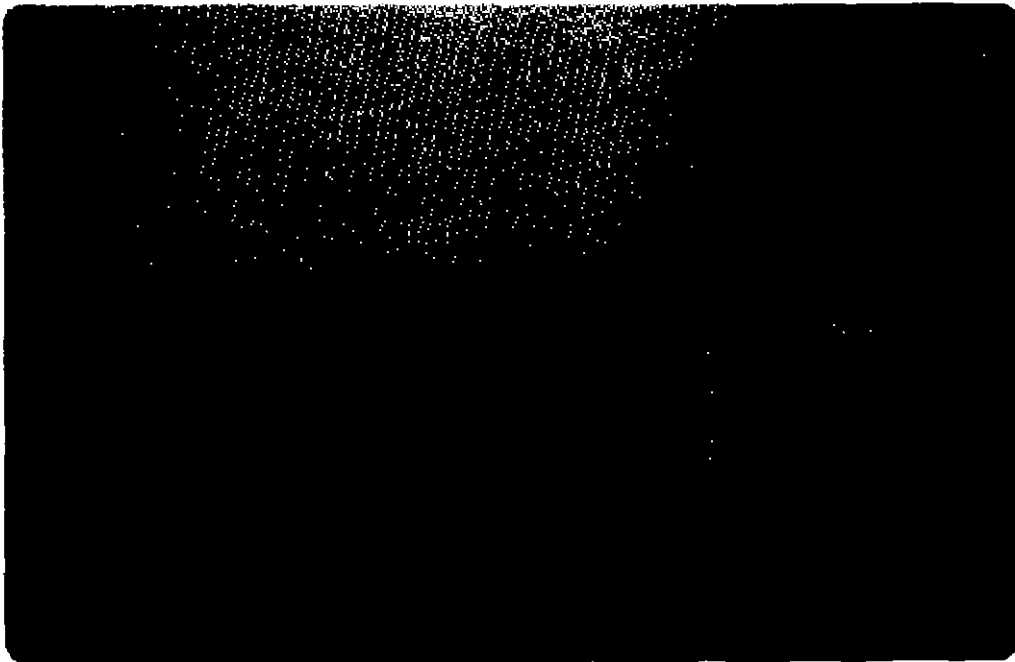
Most coach seats have an optional tubular stainless steel foot-rest at the back of each seat for the comfort of the passengers immediately behind (Photo.4.7). These foot-rests can be pivoted upwards so as to allow a more comfortable position for resting with the legs extended. In the event of an accident however, such features may create possible hazards for the feet of passengers.

Some of the coach seats being manufactured have a high density closed-cell foam covering the back of the head rest whose purpose is to absorb the kinetic energy of the impacting passenger from the seat behind and is aimed at minimizing the severity of injury in the event of an accident.

If we now consider route bus seats, we will see that they are built and designed to be simple, cheap and functional (which effectively means tough enough to take a considerable amount of vandalism). They are normally constructed from circular cross section stainless steel, (Photo.4.9) although there are a number of mild steel frames and in some instances, the combination of mild steel and stainless steel is used (Photo.4.10). In this latter method, the appearance of stainless steel is appealing as is the cost saving of mild steel. The question needs to be asked however, how successful and consistent is the joint welding of the two types of steel, especially considering the fact that some of the locations where the two tubes are joined may be highly stressed? In Victoria, the typical route bus frame with its seat back grab-rail bar is not allowed, although it is permitted in other states. A "roll-top" seat is currently fitted to route buses in Victoria.



Photograph 4.9. A typical stainless steel route bus seat.

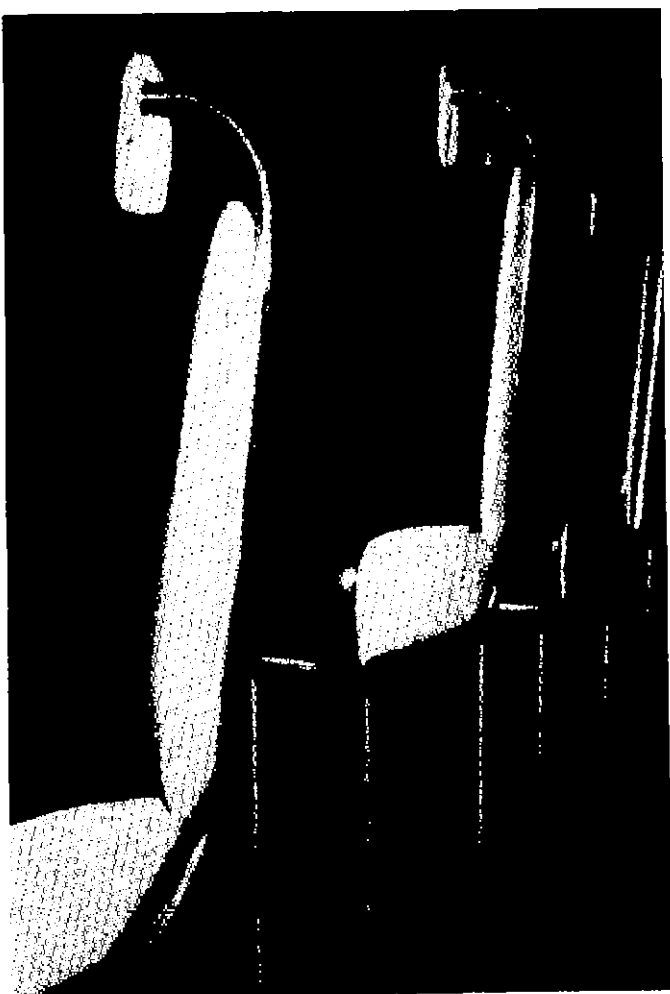


Photograph 4.10. The joining of the sections of stainless steel and mild steel can be seen, as can the wall mounting bracket which in this case uses three fasteners to secure it to the wall

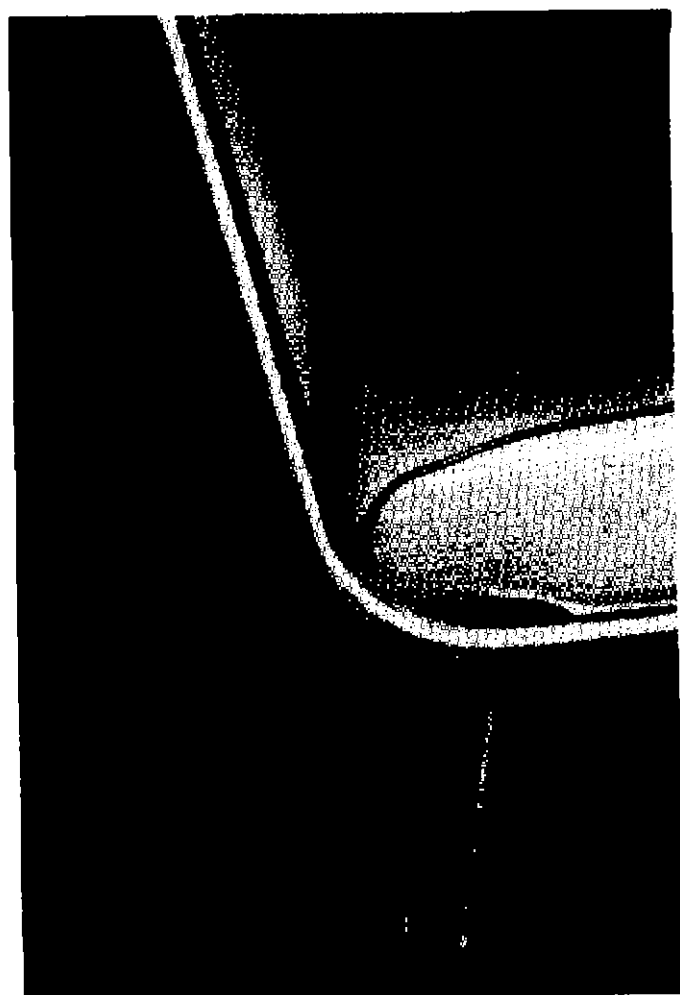
Effectively, this means that the grab bar has been covered and padded in as an attempt to prevent injuries, (Photo.4.11).

- (c) Seat Trimming. The trimming of coach seats is fairly standardized with an individual contoured cushion and squab for each passenger. Often a variety of foams of differing densities are used in order to develop firm and soft sections in both cushion and squab, thus giving both comfort and support. A wide variety of coverings are used, with large use of material covers. Wool blend cloth is being used and has the added advantage of being flame retardant. There has been an interest shown within the coach industry to use both flame retardant foams and fabrics in the trimming of seats.

Unlike coach seats, transit and route bus seats have no form of spring or suspension system directly attached to the frame, instead the trimming is built on plywood which is then fastened to the frame. In some instances, the padding provided on the plywood is not very thick, particularly in the squab, (Photo.4.12). Due to their application, it is important that such seats are of robust construction, nevertheless, the barrier that a passenger faces in the event of an accident, is not conducive to the minimization of injury (Photo.4.13). For example, starting at the top, there is the grab-rail across the top of most route and transit bus seats (outside Victoria), then usually about 50 mm or so below there is a stainless steel channel securing a padded board which acts as the squab. Both of these horizontal members are likely to be contacted by the head/neck area of a primary school child and more likely to be contacted by the neck/chest area in the case of an adult. In the case of the channel section, impact is potentially dangerous due to the tight-radius edges and the rigidity of the structure, increasing the chance of bone fracture.



Photograph 4.11. An example of the roll-top seat. Note the increased height of the middle seat and the extra stiffening tube running between the legs. Two tabs, instead of one flat plate are welded to the seat legs to allow anchorage to the floor.



Photograph 4.12. A route bus seat exhibiting a thinly padded seat back.

The backing board for the squab itself is a relatively hard, rigid member which could cause injury to the knee and femur in a collision. Most coverings for route bus seats are vinyl, although there are some which have been trimmed in a heavy duty ribbed material similar to industrial carpet.

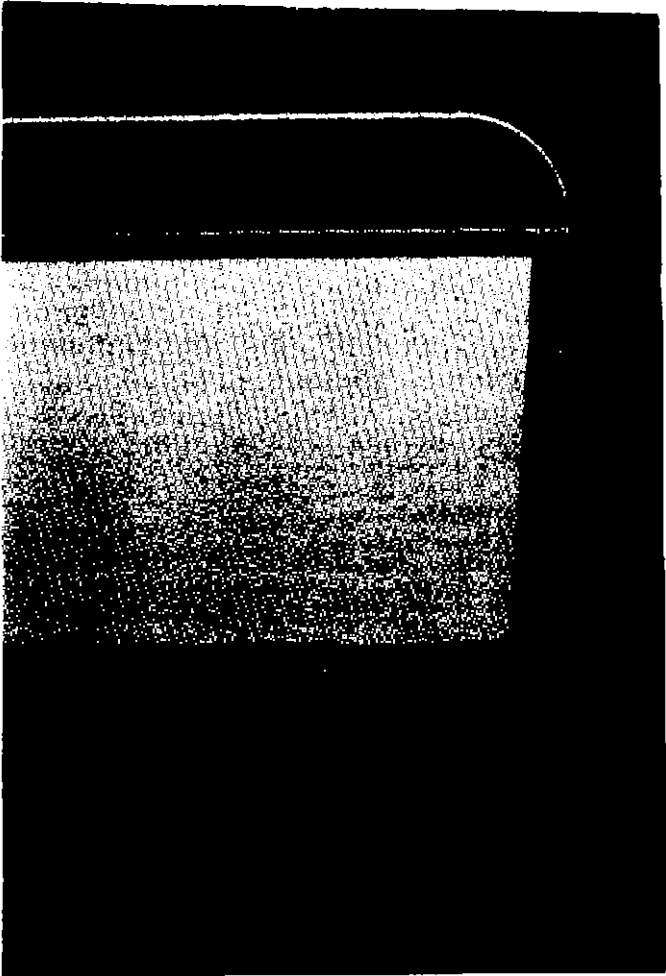
Both the new buses for Brisbane and the recently built buses for the Sydney transit authority employ interesting features (photo.4.14). Points of interest are a newly designed pedestal leg, roll top seats; stanchions attached to every seat rail, ensuring adequate and effective passenger assists, stop buttons on each stanchion; some rearward facing seats; low step heights and wide doorways with adequate grab-rails.

4.2.4 Trend in Bus Seat Design.

A considerable amount of work has been done in America, the U.K. and Europe, on safety seats which are energy absorbing and control the movement of the passenger with particular emphasis on protecting the head, neck, chest and knee regions. Some fibreglass moulded seats have been produced overseas, however they have not been accepted into the industry in Australia. This is due, perhaps, to the large tooling cost which is inherent in such a process. Moulded seats have the advantage of being robust and particularly resistant to acts of vandalism, however, the capabilities for absorbing energy in a collision is questionable.

Proprietors appear to be very conscious of the maximum number of passengers which can be fitted into a bus, and the thickness of the back of the seat is being investigated by some manufacturers as a possible means of reducing the space occupied by passenger and seat, and therefore maximizing the number of seats on a bus.

The use of flame retardant foams and fabrics in coach seats is becoming more popular, particularly in the more expensive long distance coaches. In the cheaper route type buses, the proprietor would have difficulty establishing justification for the use of flame retardant materials on a cost-benefit consideration.



Photograph 4.13. A typical example of the back of a route bus seat.



Photograph 4.14. The new generation transit bus. Note the large intrusion of the wheel arch into the passenger compartment due to the low floor height. The step seen in the photo may cause passenger falls while getting into or out of their seats. Note also the roll-top seat, small but laterally braced pedestal leg and the stop button integrated into the seat back attached stanchion.

There appears to be an increase in the use of fibreglass seat backs for charter style bus seats. The moulded fibreglass seat backs are secured to the steel seat frame in much the same manner as the more traditional plywood seat backs.

The advantages of fibreglass over plywood are:

- 1) The ability to easily mould into contours in two dimensions.
- 2) Strong, rigid yet consistent with light weight.
- 3) Resists acts of vandalism.
- 4) Enables the seat back to be thinner.

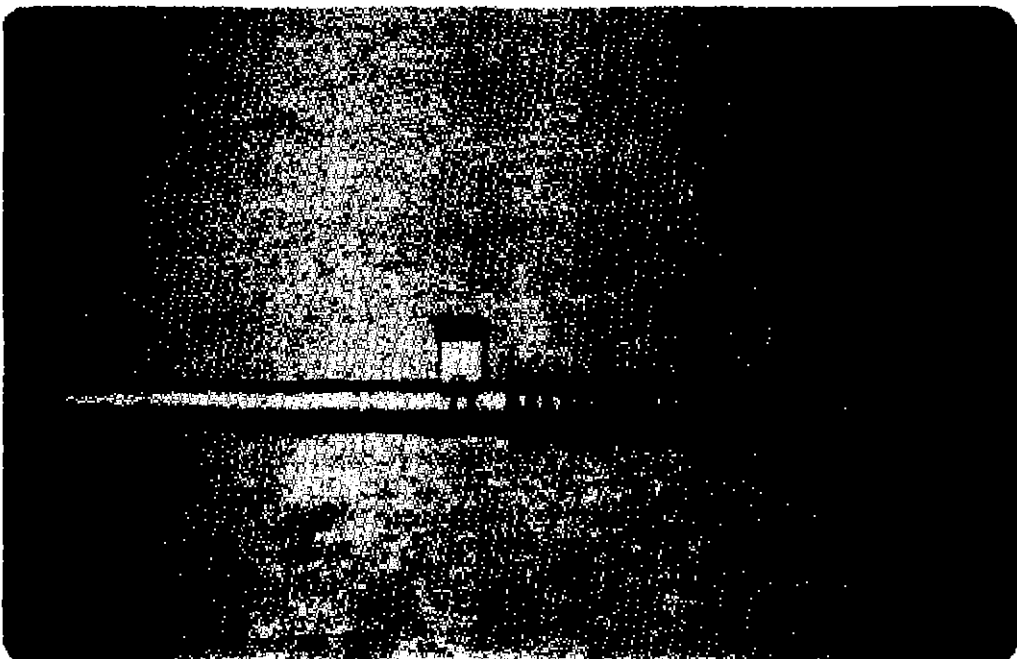
As mentioned earlier, there is a trend away from cast seat legs for coach seats. Instead, a single pedestal leg is being used, constructed usually from 2 mm thick stainless steel. The major consequence of using this new leg is the reduction in the distance between the securing bolts from approximately 300 mm to 180 mm. This has the effect of increasing the loads on the bolts. TRB accident case study reports show that the cast legs occasionally suffer from a brittle type fracture in the event of an accident. The new style of leg, however is more susceptible to plastic deformation of the lower floor plate, thus it would be expected to absorb more energy.

The reclining mechanism employed in coach seats has also changed. At one time the system used an incremental adjuster which relied upon a positive locking device usually located in the arm rest (Photo.4.15). The new mechanisms (Photo.4.16), however fit under the seat cushion and are normally cable operated, infinitely adjustable and do not involve a positive lock. Instead, they use either a clamping device around a sliding rod or an equalized pressure piston/cylinder arrangement.

In America there has been a great deal of interest shown in the development and improvement of transit buses. It was realized that a great number of elderly people (who make up a substantial proportion of the transit bus population) found negotiating the entrance/exit of a bus difficult.



Photograph 4.15. A typical positive locking incremental reclining mechanism. Note pivoting point for the seat back on the armrest and the bush welded into the seat squab tubing which allows the securing of the reclining mechanism.



Photograph 4.16. An example of the new generation of infinitely adjustable piston type devices for control of seat squab angle. This particular item is cable operated and relies upon the clamping action of a spring wound around the central shaft for holding it in position.

As a result, a new bus design concept evolved. It was considered important to lower the floor height, thus making the number and height of the steps that needed to be negotiated, less of a problem. This however, introduced another problem which had not been encountered before. In this new generation bus, the passengers were now sitting much closer to the ground and thus susceptible to injury due to side impact intrusion in the event of a collision. It was therefore decided to strengthen the side wall structure and a consequence of this increased strength was that it was now possible to hang the seats cantilever style from the side walls. The advantages of having fully cantilevered seats are:

- 1) Ease of cleaning the floor.
- 2) More room for passengers' bags.
- 3) Removes the possibility of a passenger tripping over the seat leg.

The disadvantages however, are that in a crash situation, the force deflection characteristics of the seat are inherently non-symmetrical and as such less capable of safely retaining passengers during an accident. Obviously, the aisle side seats could undergo larger deflections than those possible for the wall side seat. Thus the rate of change of force of the wall side seat will be greater than that for the aisle side seat. As a result, there will be a tendency for the seat to pivot forward around its anchorages on the wall as well as around the base of the seat back. It would, however, seem possible that the seats in a substantial frontal collision could swing forward, emptying the aisle side passengers into the aisle itself.

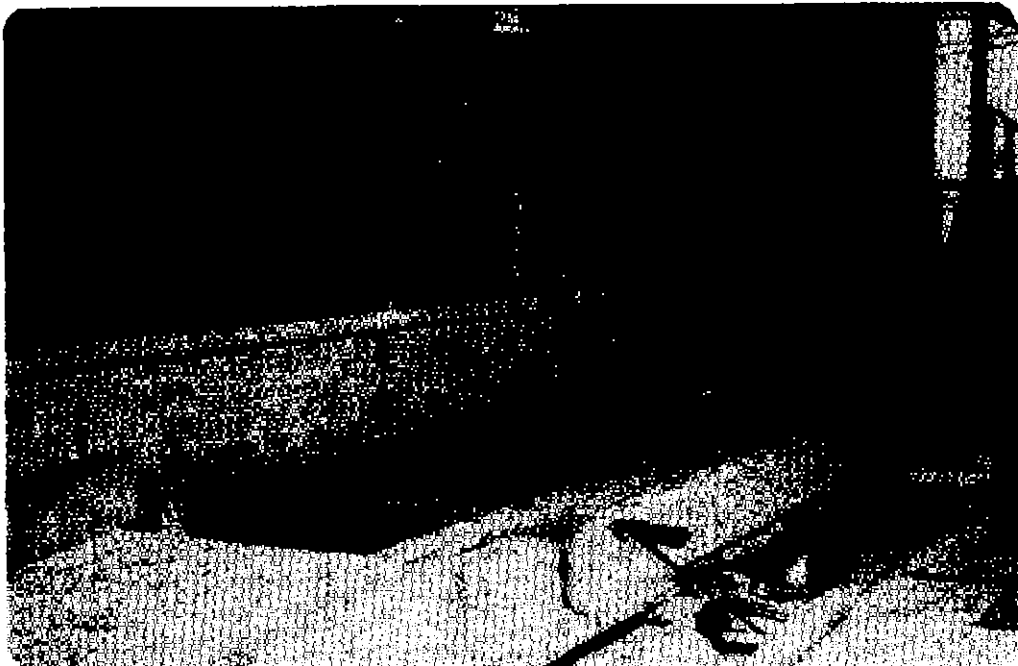
4.3 CLASSIFICATION OF ANCHORAGES

4.3.1 Floor Mountings

a) Floor Construction. Whether the chassis of the bus is of a space frame construction or a more conventional chassis rail type configuration, the floor is always wider than the structure below. Thus, floor bearers are mounted on the chassis to support the floor. These, like so many facets of bus and coach construction, vary from builder to builder (Photo.4.17 and 4.18).



Photograph 4.17. A floor structure which is raised from the straight rail chassis by the use of pedestals (bottom right). Note the size and number of floor bearers compared with photo.4.18.



Photograph 4.18. The internal view of the structural wall and floor members. Note the size and number of floor bearers. The chair rail can be seen running along the wall near the top of the inner skin.

The wall structure is built up from the floor bearers and the floor which is usually plywood between 12 and 16 mm thick is often resin impregnated on the underside, and is fastened by means of self tapping screws.

The entire bus body is often clamped to the chassis. The reason for this method of securing is unknown. It seems less positive than other available methods such as welding. It was noted that in a number of bus accidents, the body had moved relative to the chassis and it seems difficult to see how this behaviour would be beneficial in the event of a serious accident. The height of the floor for a particular design of bus body is essentially constant due to standardized wheel sizes and it is necessary to have adequate clearance between the tyres and the wheel arches to allow for suspension travel. Chassis rail heights, however, from one make of chassis to another are not always the same, therefore, coachbuilders step the entire bus body on platforms at each clamping post, so as to maintain a constant floor height. This would appear to be a practice which could be unnecessarily weakening the bond between the chassis and the body of the bus (Photo.4.17).

b) Tapping Plates. The effectiveness of any fastener depends on the way in which it is used and in this application the structure to which the bolt is screwed can drastically alter the mode of failure of the seat anchorage, especially the floor mountings. For example a $\frac{5}{16}$ " UNF bolt may be screwed into a $\frac{5}{16}$ " thick mild steel tapping plate. A $\frac{5}{16}$ " UNF bolt has a thread with a pitch of 1.06 mm and therefore there are 7.5 thread pitches in contact with the tapping plate. The type of failure of the system described would most probably be failure of the bolt in tension. If, however, a coarse threaded $\frac{5}{16}$ " self tapping screw was mated with a $\frac{3}{16}$ " thick tapping plate then the type of failure most likely to occur could be the pulling out of the bolt from the tapped hole, due to a shearing of the threads on either the bolt or the hole. With this system there would be only 2.25 thread

pitches in contact with the tapping plate.

Tapping plates are used extensively in the anchorage of bus seats, both for the floor and wall mountings (refer Photo's 4.21 & 4.22). At this stage, the distinction is made between a tapping plate, which is either drilled and tapped, ready to receive a bolt (or is merely drilled for a self tapping screw) and a backing plate which is drilled and is used in conjunction with a bolt and nut (i.e. is not threaded).

Now, it is insufficient just to ensure adequate plate thickness and bolt strength to facilitate a safe anchorage. For the case of the bus floor, the backing plate has to be of a size large enough to prevent it from being pulled through the wooden floor. This depends somewhat on the construction and thickness of the floor and the method used to fasten it to the bus body. A safer and more structurally integrated method is to weld the backing plate onto the chassis. Thus lengths of tapping or backing plate are welded between the floor bearers, so that the anchorage forces are transmitted through to the bus body. This considerably reduces the significance of floor strength on the anchorage system. In this way there is an effective fastening plate running the length of the bus. Apart from the advantage of increased strength and structural integrity, it is good engineering practice to transmit major loads directly from the seat to the chassis structure and so avoid using the rather more flexible and weaker floor structure as a means of load bearing, it also reduces the time and labour necessary to fasten the seats into the bus. In other methods where the backing plate is not secured to the bus body two people are required, one under the bus holding the plate and placing the nuts and washers on the bolts, which are being pushed through the anchorage point on the seat and through the floor by the other worker. The task of the person under the bus is often difficult, due to the presence of structural members, such as floor bearers, obstructing vision, access and sometimes preventing the plate from being positioned at all.

In contrast with a tapping plate welded to the bus frame, the securing of the seats is a one man operation. The tapping plate is drilled, tapped and the seats positioned and secured from inside the bus in a quick and efficient operation.

Individual backing plates positioned under the floor vary in size from $2\frac{1}{2}$ " x $1\frac{1}{2}$ " x $\frac{1}{8}$ " thick and cater for single bolts, to plates that are 18" long x 2" wide and $\frac{3}{8}$ " thick, catering for two bolts. These two bolts cater for the floor-anchorage requirements for a single seat.

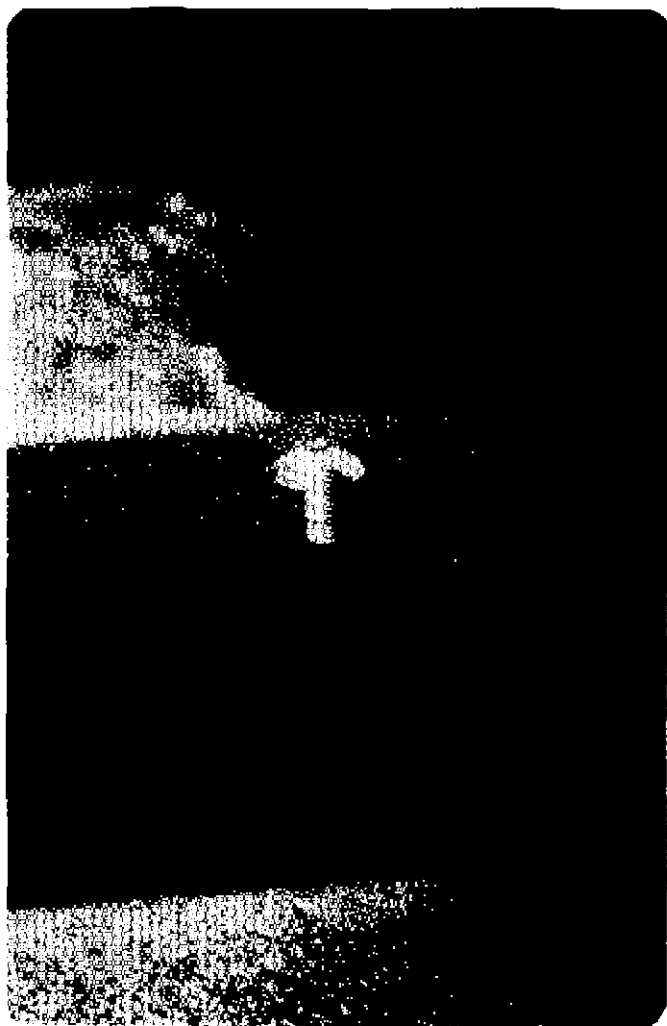
One particular bus manufacturer fastens seats without any form of backing tapping plate, instead a 'T' nut is screwed on to a $\frac{1}{4}$ " UNF bolt under the floor (Photo.4.19). This method, which relies entirely on the strength of the wooden floor distributes the floor anchorage forces over a very small area ($2.3 \times 10^{-4} \text{ m}^2$ for each T-nut). There are two T-nuts per seat. The area for each 'T'-nut is slightly smaller than the surface area of the side of a one cent piece, $2.4 \times 10^{-4} \text{ m}^2$. As the bolt is done up, the 'T' nut is drawn upwards and in doing so punctures the underside of the wooden floor with three prongs which point upwards from the 'T' nut. These prongs, prevent the nut from turning while the bolt is being done up.

c) Fasteners Employed. As a result of the TRB guidelines in Victoria, the variety of fasteners used to fasten the bus seats to the floor and wall anchorage points, is smaller than the range of fasteners used in other States.

Even though the fasteners used in buses and coaches registered in Victoria do not always meet the TRB guidelines, the method of fastening is controlled and inspection of the fasteners is carried out.

Victorian Fasteners

| <u>Floor</u> | | <u>Wall</u> |
|-------------------------------|--|-------------------------------|
| $\frac{5}{16}$ " UNF bolts | } with or without the tapping plate | $\frac{5}{16}$ " UNF bolts |
| $\frac{5}{16}$ " UNC bolts | | $\frac{5}{16}$ " UNC bolts |
| $\frac{5}{16}$ " self tappers | | $\frac{5}{16}$ " self tappers |



Photograph 4.19. The underside of a wooden bus floor. The $\frac{1}{4}$ " UNC bolt and 'T' nut fasten the seat to the floor of the vehicle.

Other States' Fasteners. $\frac{1}{4}$ " UNC bolts which are sometimes used in conjunction with 'T' nuts are used in states other than Victoria, and such fasteners do not comply with the existing TRB guidelines.

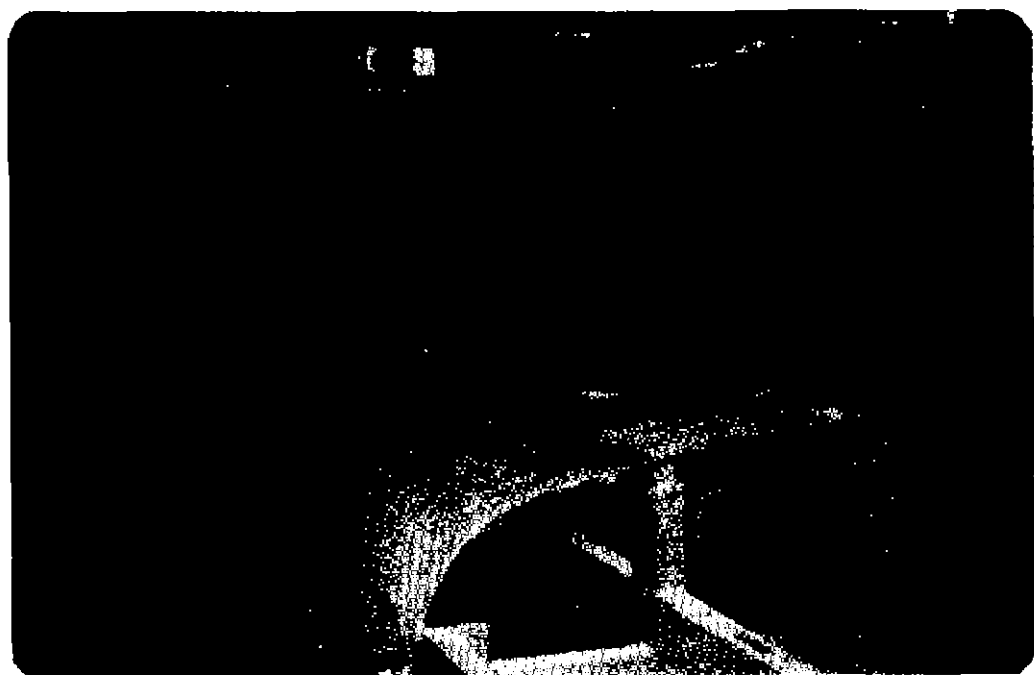
In some cases, high tensile bolts are used. The fine threaded bolts generally have a greater strength in a tapping plate of a given thickness than either a coarse threaded bolt or a self tapping screw of the same diameter due to the increase in the number of thread pitches in contact with the tapping plate.

4.3.2 Wall Mountings

a) Wall construction. There is a wide and interesting variety of coach designs, even though they often incorporate some fundamental structural components which are common throughout.

Essentially, there are a number of major horizontal and vertical structural members which make up the basic framework for the wall of the bus. These members are usually square or rectangular tubing, the size of which varies from one body-builder to the next. The floor bearers or outriggers spread

across the width of the bus with a spacing of about 1 m and meet the floor rail. The floor rail is one of the four major horizontal members, which run the length of the bus. The other horizontal members are the waist rail, cant rail and skirt rail. The skirt rail runs along the bottom of the bus wall and provides the footing for one of the two major types of vertical wall members, the side pillar, which extends up beyond the floor rail to the waist rail and forms the lower mounting position for the window frames. The other major vertical wall member, which is often not vertical but is angled slightly especially in coach design, is the window pillar. At the top of the window pillar, runs the remaining major horizontal wall member, the cant rail, on to which is mounted the roof frame. This is built up on a separate jig (Photo. 4.20).

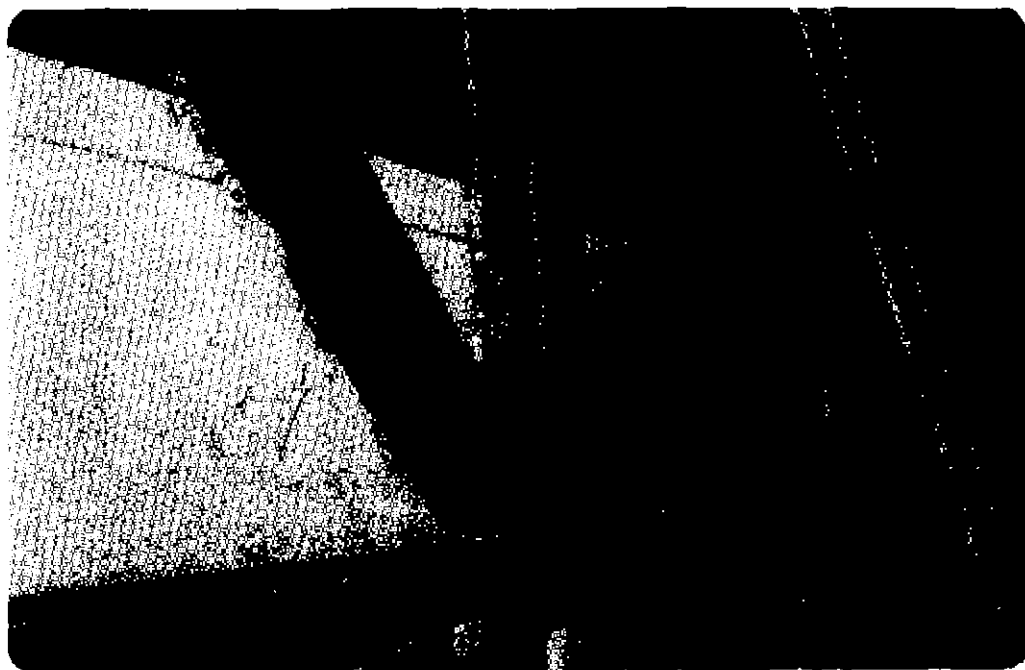


Photograph 4.20. The construction of the roof structure.

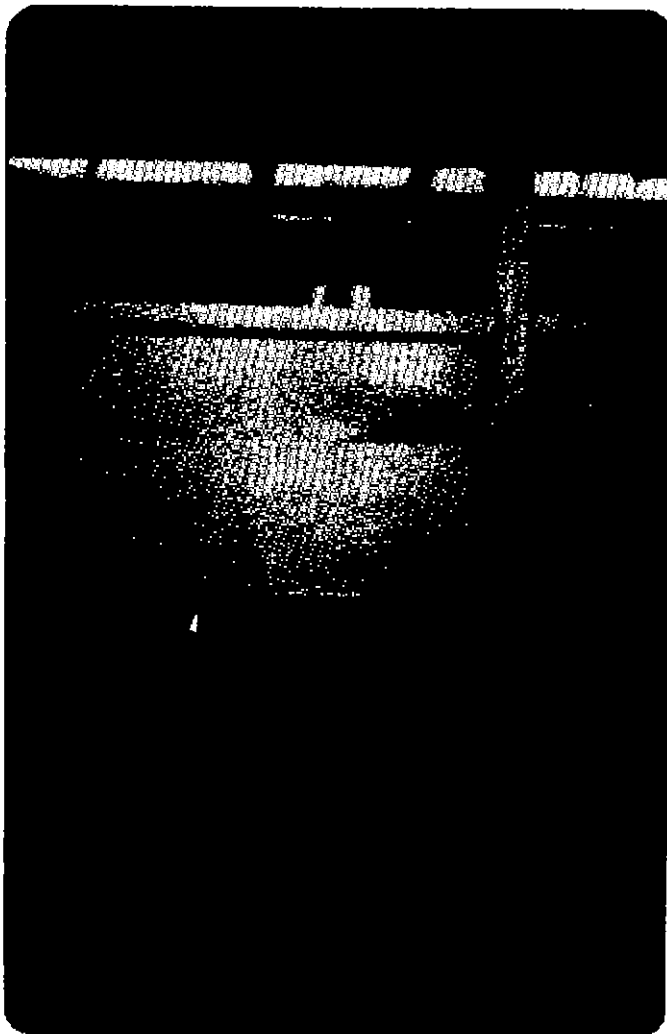
Some bus builders only install vertical and horizontal wall members, (sometimes in conjunction with stressed skins), (Photo.4.22) while others incorporate a large degree of cross bracing, triangulation and gussetting (Photo.4.21). Apart from one company manufacturing aluminium bus bodies, the material used for bus body construction is mild steel.

On the side wall frame an outer or external skin is either welded or rivetted. This skin is sometimes a stressed member designed to take shear stresses and is heated and stretched prior to fastening to the wall frame (Photo.4.23). Sometimes stiffeners and strengthening plates are attached to the frame or the skin.

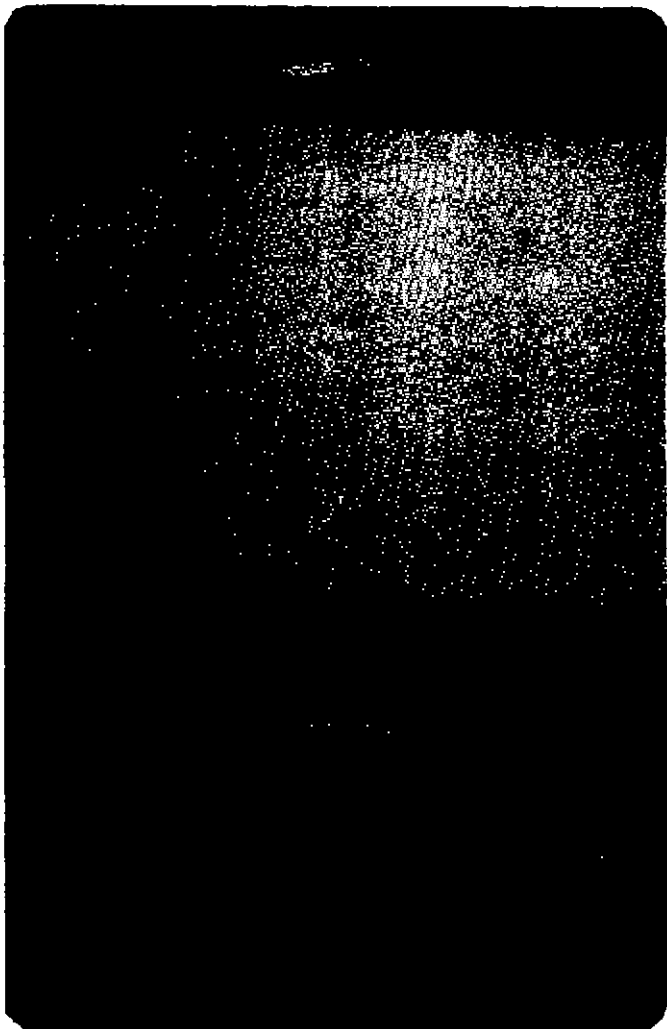
In most bus design there is usually some form of internal skin, welded to the frame so that it runs the length of the bus and extends from the floor level either all the way up to the waist rail of part there-of. This internal wall skin is the crux of the seat wall mounting.



Photograph 4.21. A section of bus wall showing the use of triangulation and bracing. Note the welds securing the inner skin which at the fold near the top form the chair rail that the seats are fastened to.



Photograph 4.22. Another section of bus wall. This example employs an outer stressed skin (not shown) and an inner skin with a wall tapping plate for fastening the seats. Note the simplicity of the design compared to that shown in photo 4.21.



Photograph 4.23. The outer stressed skin concept. Note the number of spot welds securing the panel which is one piece section that runs the length of the bus. Note also the simplicity of the window pillar when compared with photo 4.24.

b) Tapping Plates and Chair Rails. If the seats use a chair rail, the internal wall skin could possibly consist of one, two, three or four components, as described below.

A chair rail is a ledge which runs the length of the passenger compartment and protrudes into the bus (approximately 40 mm and is about 200 mm above floor level) from the inner wall skin. On this ledge the seats rest and are secured usually by two $\frac{5}{16}$ " UNC bolts. The means of constructing this ledge are:

- 1) A single sheet of steel is bent so that it creates a lower inner skin from the floor then the ledge, which is two thicknesses of the steel plate, is created by bending back the sheet upon itself and then it is continued on to form an upper inner skin above the chair rail.
- 2) Two inner skins are involved, both of which are used to form the chair rail ledge which is therefore two thicknesses of steel thick. The two skins are spot welded together along the seat rail.

Sometimes a backing plate is placed under the chair rail to add strength and guard against the pulling out of the securing bolts.

- 3) The same construction as used in 2) except ~~that~~ under the chair rail a length of angle iron or bar is welded, thus increasing the strength in the anchorage. In addition, the seat is not directly bolted to this rail. Instead, an aluminium extrusion is bolted to the ledge and the extrusion allows tapped plates to slide along the length of the chair rail. The seat is then bolted through to the tapping plate which is held in the 'C' section extrusion.

When a tapping plate system is utilized, a similar inner skin is used but it is backed by a piece of bar or angle iron, the thickness of which is typically $\frac{1}{8}$ " - $\frac{1}{4}$ " and ranges from a width of 6" down to 1". This tapping plate runs the length of the passenger compartment and is welded into place to the side pillars and diagonal triangulation members if there are any.

(c) Fastening Systems. Where chair rails are concerned, the use of $\frac{5}{16}$ " UNC bolts together with spring washers and nuts, is common almost to the extent of being universal throughout the industry. However, in the case of tapping plates, the range of fasteners is more varied. $\frac{5}{16}$ " UNC bolts are often used, and while $\frac{1}{4}$ " self tapping screws are sometimes used, they are not common.

Most body builders use two wall mounting fasteners per seat; however, three have been used on occasions.

4.4 CONCLUSION

4.4.1 Seats

The range of seats inspected was considered to be a fair representation of bus seats being used in Australia and encompassed route and transit bus seats, charter seats, fixed back coach seats and reclining coach seats. The prices of these seats range from approximately \$100. up to \$350 untrimmed.

On inspection, there were some design aspects of the seats considered to be structurally undesirable in the event of an accident. Specifically these are:-

- 1) The use of non-positive locking devices on reclining seats.
- 2) The practice of welding stainless steel tubes to mild steel tubes of different wall-thickness at points of the seat frame which could be highly stressed.

- 3) The use of light gauge materials which would cause the structure to be weak.
- 4) The lack of protective, high density padding on the backs of seats, particularly over structural frame members on the top of the seat squabs.
- 5) The use of a low energy absorbing material to fill in the central region of the seat squab, such as plywood or fibreglass.
- 6) The use of cast seat legs, which in the event of sudden loading may fail in a brittle manner and thus the subsequent possibility of the seat becoming dislodged.

4.4.2 Anchorages

As mentioned previously, it is considered important that the seats remain fastened to the bus body in the event of an accident. Therefore, the anchorages need to be structurally adequate, even after many years of service. To this end, we would question the practice of not using suitable floor backing structures of tapping plates that are continuous and welded to the bus chassis.

Tapping plates are apparently adequate only as long as the thickness of the plate is consistent with the tensile strength of the fastener and its thread pitch.

Thus, the use of self tapping screws is questionable unless the thickness of the tapping plate is three times the pitch of the self tapper (which typically have large pitches of the order of twice the pitch of a comparably sized UNF bolt). This configuration of tapping plate thickness should ensure an equality between the tensile strength of the bolt and the shear strength of the thread.

It is considered that both wall tapping plates and chair rails are adequate, however care needs to be taken to ensure the use of appropriate metal thicknesses for the internal wall

skin making up the chair rail. Thickness is required to provide both rigidity and strength to the ledge and its surroundings. The use of a length of angle or bar under the ledge is insufficient to compensate for a thin inner skin.

4.4.3 Bus Body and Chassis

On inspection of the bodies of various buses, especially the floor and wall areas, there was found to be a marked difference in the amount of material used. It is probable that there would be a substantial range in the strength of these structures. With regard to secondary safety of bus passengers, it is clearly beneficial to have an overdesigned body ad, due to its increased mass, it is both stronger and more difficult to decelerate quickly in the event of an accident, hence minimizing the forces of retardation of the passengers. However, there is a cost/benefit trade-off, as the heavier the bus, the more costly it could be both to manufacture and to run. Of course, there is also the problem of meeting axle load regulations.

Ideally, the structure of the bus should be optimized to achieve the lightest possible body/chassis combination consistent with adequate strength to ensure the integrity of the passenger survival space in the event of any type of accident and with sufficient strength and rigidity to cope with normal operation.

Finally, we feel inclined to question the long standing practice of clamping the body to the chassis as it does not appear to ensure a positive locking of the position of the body may be able to move on the chassis. This has been observed on inspection of buses involved in accidents in Australia³¹.