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Title and Subtitle

Investigation of the effect of bull-bars on vehicle-pedestrian
collision dynamics

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Abstract

In this introductory study into one specific aspect of the bull-bar problem, a statistical sampling was conducted to evaluate the number of passenger cars fitted with bull-bars in metropolitan Melbourne. Experiments were carried out using a pedestrian dummy and two car models fitted with different types of bull-bars. The motion of the dummy during collision was recorded and evaluated. The results of tests with bull-bars were compared with those without bull-bars to show that control of the attachment of bull-bars to passenger cars in metropolitan areas should be considered.

NOTE

This report is disseminated in the interest of information exchange. The views expressed are those of the author(s) 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

SUMMARY

The findings of a research program on the contribution of bull-bars fitted to passenger cars and their derivatives to pedestrian trauma are presented. The program is considered as an introductory study into one specific aspect of the bull-bar problem.

The statistical and experimental results obtained suggest that the mounting of bull-bars to sedan cars constitutes a problem sufficiently serious to warrant attention from regulatory authorities.

It was clearly demonstrated that the attachment of bull-bars to the front of the vehicle negates the positive results of vehicle frontal design for pedestrian safety already incorporated in most modern cars.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND TO PRESENT STUDY

In 1978 short studies in various aspects of vehicle safety were undertaken by fourth year degree students from the Department of Mechanical & Production Engineering of RMIT as part of the Vehicle Design course. One of the studies involved an investigation of the broad issues associated with the mounting of bull-bars on automobiles (Andrews, 1978).

The report emphasized that:

- (a) There is a lack of specific standards relating to fitment of bull-bars to automobiles.
- (b) A bull-bar can significantly alter the profile of a vehicle's front end structure.
- (c) A change in frontal profile can lead to increased vehicle aggressiveness in a vehicle-pedestrian collision.

On the basis of the recommendations in the report, a more detailed research program was initiated in 1979 as a final year student project on the effect of bull-bars on vehicle-pedestrian collision dynamics. The program comprised a detailed literature survey and analysis of problems associated with pedestrian safety in general; the accumulation of information about bull-bar design features and about the extent of usage in the Melbourne Metropolitan area; and the estimation of contribution of bull-bars to pedestrian trauma in car-pedestrian collisions (Chiam, 1979).

The findings of both studies were presented to the Office of Road Safety within the Commonwealth Department of Transport. In late 1979, a five months study was commissioned to investigate the effect of crash simulation with a pedestrian dummy. The research program started on December 1, 1979 and was concluded on April 30, 1980.

1.2 OBJECTIVES OF THE PRESENT STUDY

The objectives of this study are summarised as follows:

- (a) To identify the various types of bull-bars fitted to passenger cars and their derivatives in metropolitan Melbourne.
- (b) To estimate the proportion of passenger cars and their derivatives fitted with bull-bars in metropolitan Melbourne.
- (c) To develop an experimental methodology for consistent and repeatable simulation of car-pedestrian collisions using a pedestrian dummy.
- (d) To investigate the effects of commonly available bull-bars on pedestrian trauma as compared with collisions without a bull-bar.

1.3 SCOPE OF THE STUDY

The study focused on one specific aspect of the bull-bar problem namely to compare vehicle-pedestrian kinematics with and without bull-bars currently in use. This involved development of an experimental methodology for crash simulation and application of the technique to conduct comparative vehicle-pedestrian collisions involving cars with and without bull-bars for selected impact speeds, braking conditions and dummy positions.

The emphasis was placed on obtaining qualitative results by means of high speed photography and on developing expertise in quantitative data gathering techniques.

1.4 OUTLINE OF THE REPORT

The format of the report is as follows:-

- Chapter 2 reviews the existing pedestrian casualty rates. The conflict between pedestrian trauma mitigation through vehicle design and the installation of

| | |
|------------|---|
| Chapter 3 | describes and categorizes the myriad of bull-bars observed on Melbourne roads. An estimate of the number of Victorian cars fitted with these structures is made. |
| Chapter 4 | presents the results obtained from the impact tests. Selected frames from the high speed film*are reproduced. Peak acceleration values and severity indices are evaluated and tabulated. Consistency of results is also demonstrated. |
| Chapter 5 | discusses the effect of bull-bars on pedestrian kinematics based on high speed photographic sequences and the pedestrian trauma from the acceleration measurements. |
| Chapter 6 | summarizes the direct findings and conclusions of the study. |
| Chapter 7 | recommends remedial actions and suggests further research into bull-bar problems and pedestrian safety. |
| References | comprise only the papers relevant to this study, selected from a vast literature on pedestrian safety. |
| Appendices | contain detailed descriptions of experimental procedures, the analytical evaluation of pedestrian kinematics, and acceleration time diagrams which were used for the evaluation of maximum values and severity indices in Chapter 5. |

* An edited video-cassette of the film (with commentary) is available on loan from the Department of Mechanical and Production Engineering, R.M.I.T., 124 La Trobe St., Melbourne 3000.

CHAPTER 2

REVIEW OF THE PEDESTRIAN SAFETY SCENE

2.1 PEDESTRIAN CASUALTY ACCIDENTS IN VICTORIA

Victoria's road traffic accidents involving casualties from 1973 to 1978 are summarized in Figures 2.1 and 2.2 (ABS, 1979). Pedestrian casualties for the same period are superimposed for comparison purposes.

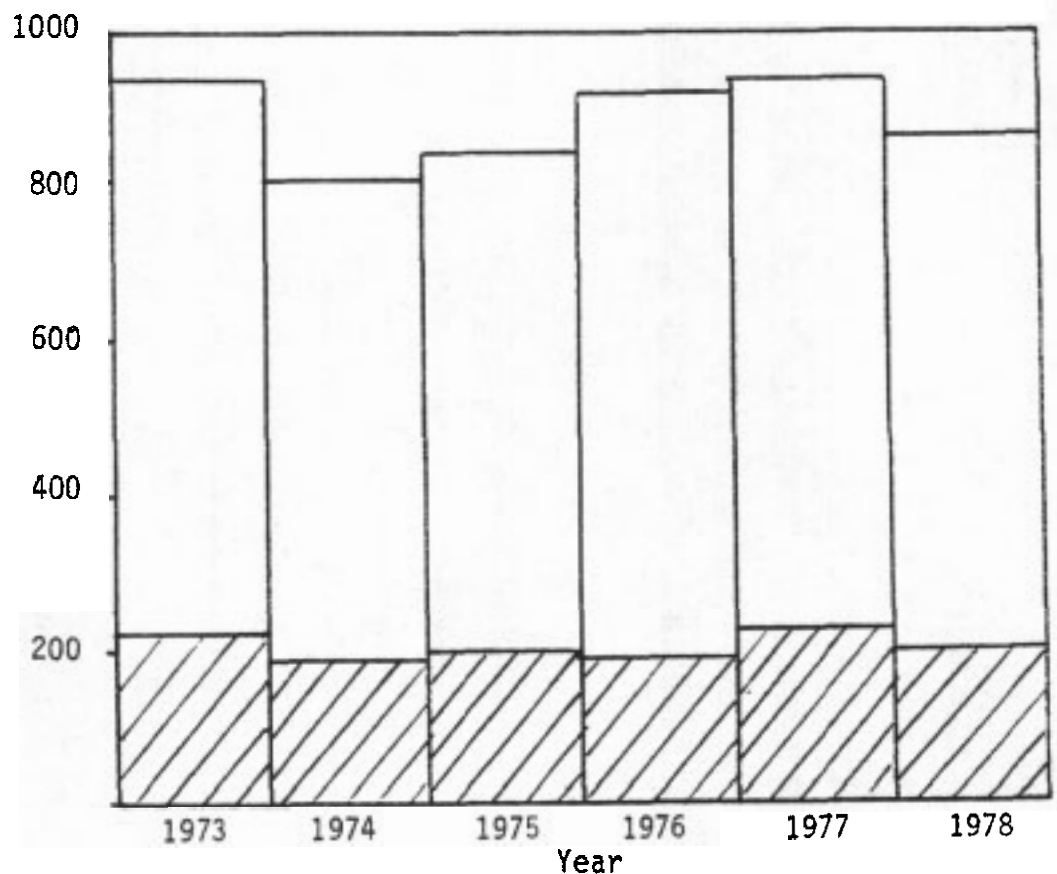


FIGURE 2.1 Road traffic fatalities for Victoria from 1973 to 1978

□ All fatalities, ▨ Pedestrian only

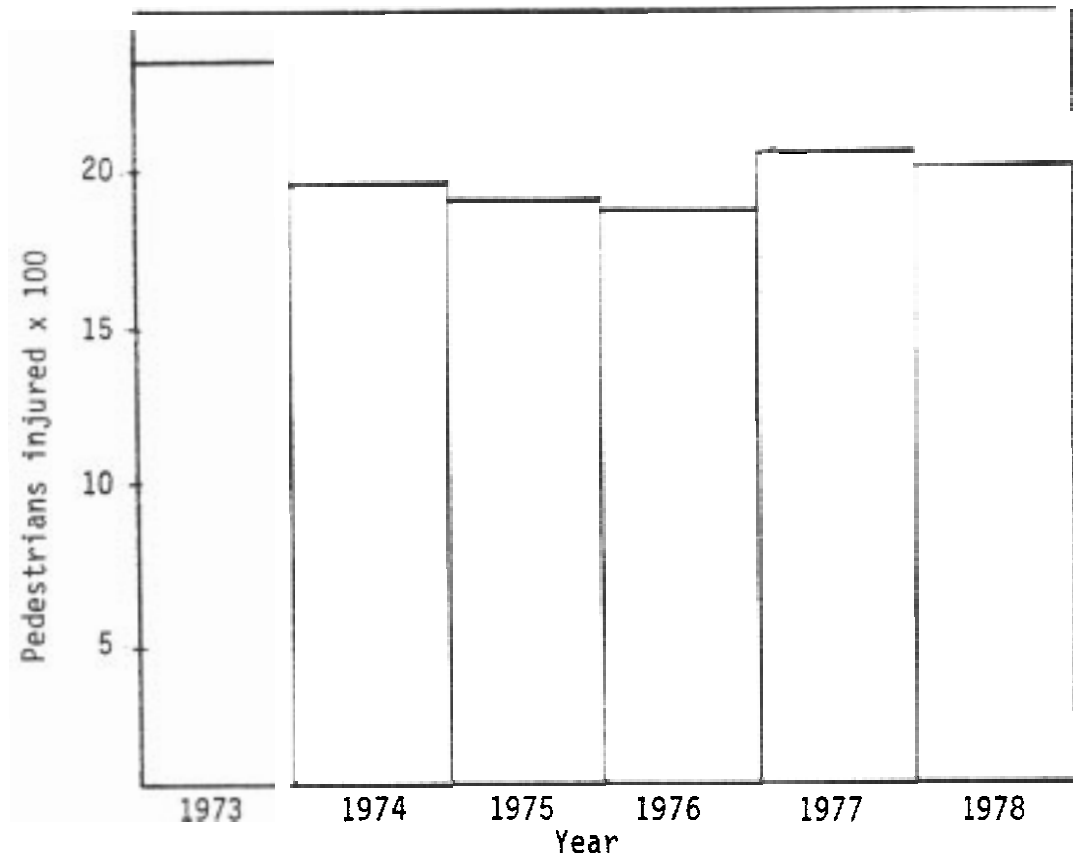


FIGURE 2.2 Pedestrians injured on Victorian roads between 1973 and 1978

It should be recognised that pedestrian casualties have not decreased significantly during the period. A detailed analysis of the road traffic casualties for 1978 is presented in Table 2.1 (ABS, 1979).

TABLE 2.1 COMPARATIVE ANALYSIS OF ROAD TRAFFIC CASUALTIES
IN VICTORIA FOR 1978

| Type of accident | Number of casualty accidents | Persons injured | Persons killed | Fatality per 100 casualty accidents | Fatality per 100 casualties |
|--------------------|------------------------------|-----------------|----------------|-------------------------------------|-----------------------------|
| Vehicle-Vehicle | 8592 | 12699 | 369 | 4.3 | 2.8 |
| Single Vehicle | 4285 | 5629 | 303 | 7.1 | 5.1 |
| Vehicle-Pedestrian | 2080 | 2049 | 197 | 9.5 | 8.8 |

Although vehicle-pedestrian accidents comprise 14% of all road casualty accidents, pedestrian fatalities account for 23% of all fatalities. Furthermore, pedestrian fatalities account for 8.8% of all pedestrian casualties compared with 5.1% and 2.8% for single- and multi-vehicle accidents, respectively.

The casualty statistics show that the incidence of fatalities in accidents involving pedestrians is greater than those sustained in vehicle-only accidents. They testify that the pedestrian invariably suffers most in an accident. This relationship was also reported by Fisher and Hall (1970) and Vaughan (1972) in New South Wales.

2.2 RECENT DEVELOPMENTS IN VEHICLE DESIGN FOR PEDESTRIAN TRAUMA MITIGATION

Vehicle design features relevant to pedestrian injury control include use of surface compliant materials to the main vehicle-pedestrian contact areas (including the windscreen and the wipers) on standard production cars (Kuehnel and Appel, 1978; Pritz, 1977).

Kramer (1975) reported that the most favourable front design for reducing the severity of head injuries as well as chest and pelvic accelerations is a low hood (approximately 850 mm) with a

Kuehnel et al (1978) used foam and rubber to shield locations with the greatest potential for inducing injuries in pedestrian impacts. Lessening of loadings in the critical vehicle-pedestrian contact zones were achieved.

Pritz (1977) concluded that reduction of pedestrian injuries, especially in the knee and the lower body area, can be achieved by straightforward modifications to existing production cars.

TABLE 2.2 REDUCTION OF PEDESTRIAN ACCELERATION LEVELS DUE TO CAR MODIFICATIONS (PRITZ, 1979)

| | Production car | Modified car |
|------------------------|----------------|--------------|
| Head: peak accel. (g) | 115 | 39 |
| S.I. - index * | 940 | 385 |
| HIC - index * | 617 | 313 |
| Chest: peak accel (g) | 34 | 43 |
| Pelvis: peak accel (g) | 94 | 76 |
| Knee: peak accel (g) | 350 | 120 |
| Foot: peak accel (g) | 153 | 72 |

Vehicle velocity 40 km/h Adult dummy results * See Appendix C

These modifications involve the incorporation of energy absorbing materials across the front of the vehicle, notably the bonnet's leading edge and the bumper and the optimisation of car frontal geometry.

Pedestrian safety is an integral aspect of many current experimental safety vehicle (ESV) programs. Measures tested and evaluated include energy absorbing bonnets, various means of retaining the pedestrian on the bonnet after the initial collision, and devices for controlling the trajectory of the impacted pedestrian.

There are strong indications that this research may ultimately

2.3 THE BULL-BAR PHENOMENON IN AUSTRALIA

Australia is one of the very few developed countries where vehicle modifications are not strictly regulated. The consequence is that many car owners physically modify their vehicles in a variety of ways.

To all intents and purposes, the bull-bar is peculiar only to Australia and similar fittings have been observed on the rear (Fig. 2.3) and the side of vehicles (Fig. 2.4). Nowhere in Europe or the USA are cars equipped with similar fittings.

A serious consequence of installing a bull-bar to the front of a passenger car is that the front end geometry is drastically altered. The design characteristics of the bull-bar are quite arbitrary, thus contradicting the research efforts for a compliant and tuned structure compatible in collisions with other road users.

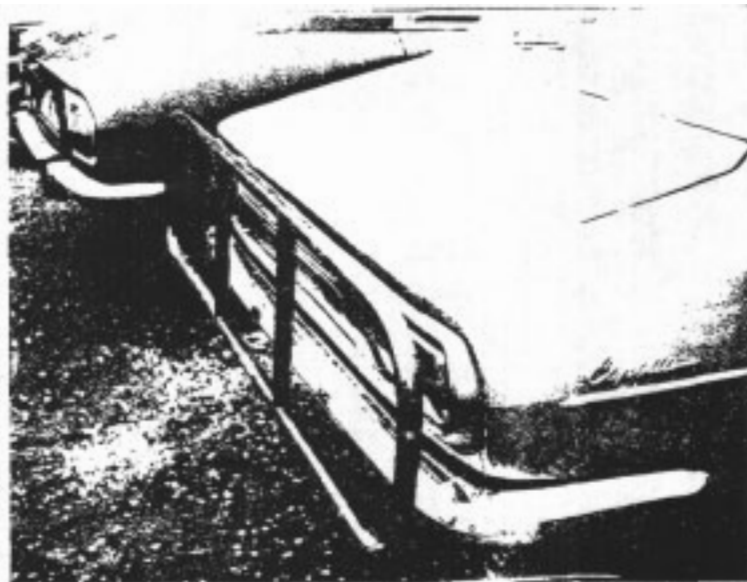


FIGURE 2.3 A bull-bar mounted to the rear of a car



FIGURE 2.4 The mounting of a bull-bar or a similar structure on the side of a car

CHAPTER 3

SURVEY OF VICTORIAN CARS FITTED WITH BULL-BARS

3.1 BULL-BAR CHARACTERISTICS

The bull-bar is essentially a metal or plastic frame of arbitrary design. The metal frames are usually fabricated from thick-walled tubes or rectangular sections of aluminium or steel and welded together. Thermoplastic bull-bars are more recent developments and are comparatively standardized frames comprising two or three clear polycarbonate tubes. The structures presently available vary considerably in design, construction, orientation and size.

3.1.1 Design and Size

Choice of design is largely decided by the owner of the car. The model of the vehicle, particularly the body width and the sub-frame, constrains the type and size of the structure that can be accommodated.

3.1.2 Height

Whilst the top edge of most bull-bars do not exceed the bonnet height, usually 760 mm - 860 mm for passenger cars, there are some that clearly protrude above the leading edge of the bonnet. This difference in height can be as much as 150 mm above the bonnet's leading edge (Fig. 3.1).

3.1.3 Slope

The majority of bull-bars are vertical frames. Some, however, slope forward by as much as 20° from the vertical so that the leading edge is some 18 inches ahead of the bonnet edge (Fig. 3.2). Other bull-bars display elements which protrude at an angle at leg and hip

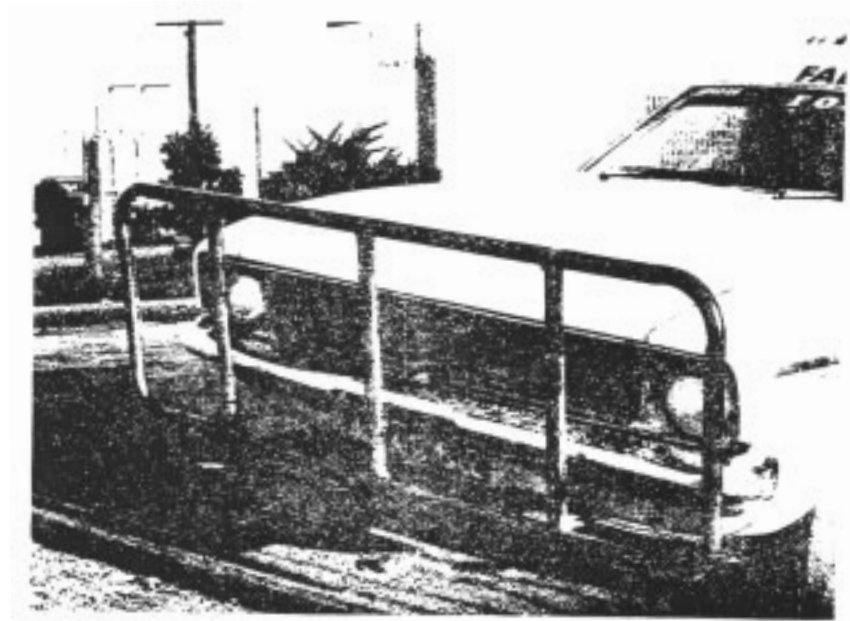


FIGURE 3.1 Example of the top edge of a bull-bar exceeding the leading bonnet edge by approximately 150 mm

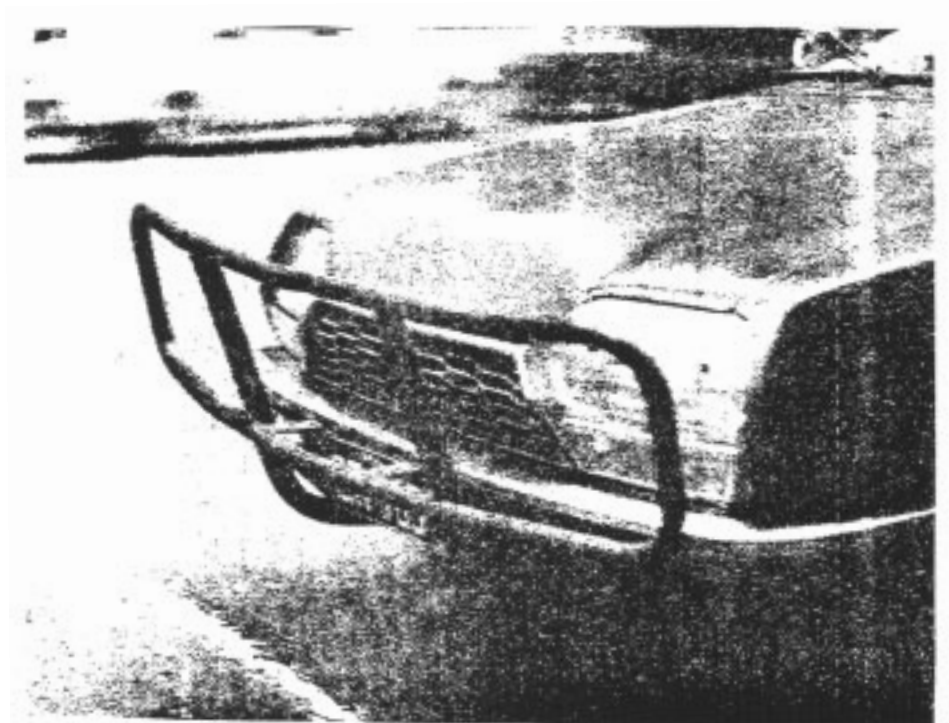


FIGURE 3.2 The bull-bar on the vehicle slopes forward at an angle of 20°



FIGURE 3.3 Elements of some bull-bars protrude at hip and lower leg heights

3.1.4 Material

Bull-bars, as mentioned earlier, are usually fabricated from aluminium, steel or thermoplastic. On a qualitative basis, the thermoplastic structures are lightest and the steel ones the heaviest. The actual weight differences are appreciable, e.g. a thermoplastic structure weighs 8 kg whereas a similar sized steel one is approximately 27 kg.

An associated characteristic is the rigidity of these structures. The thermoplastic bull-bar deforms easily but the metal ones are comparatively rigid.

3.2 CLASSIFICATION OF BULL-BARS

A survey of 65 bull-bars fitted on passenger cars and their derivatives was conducted in the Melbourne metropolitan area. The structures can be classified into three broad categories on the basis of the main materials used for the fabrication, namely:

- (a) thermoplastic (polycarbonate)
- (b) aluminium
- (c) steel.

The third category (steel) exhibits further characteristic variations in design. Hence, this group has been divided into three sub-groups:

- (i) arbitrary design;
- (ii) tubular steel;
- (iii) truck type. *

Samples of bull-bars belonging to each of the above categories and sub-group are presented in Figures 3.4 to 3.9.

* The heaviest type used. It has a form of bull-bars seen on heavy vehicles.

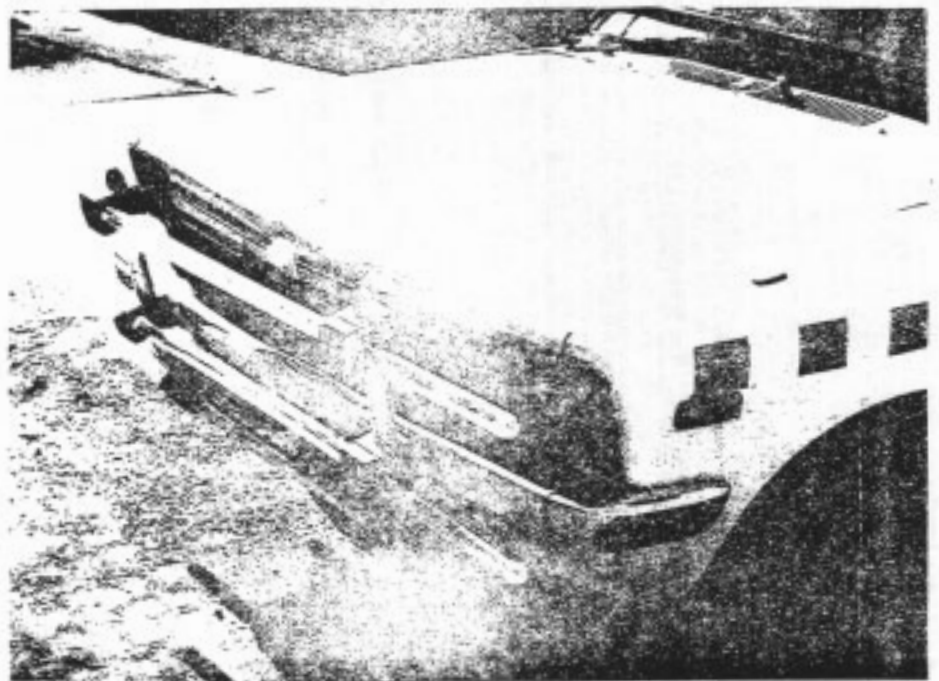
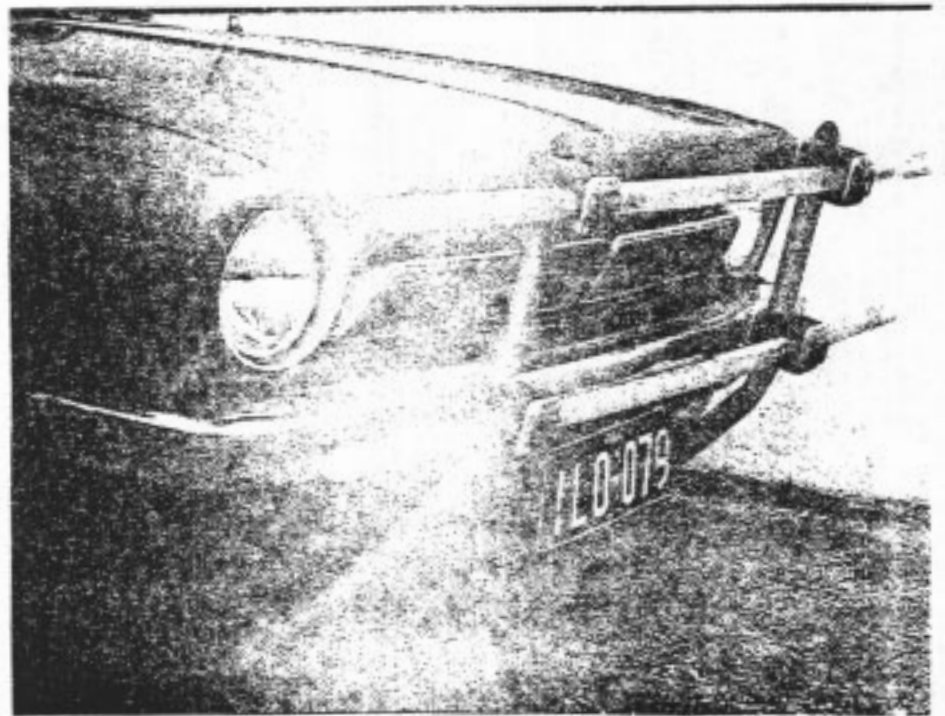


FIGURE 3.4 Thermoplastic bull-bars may have two or three polycarbonate members supported by metal tubes

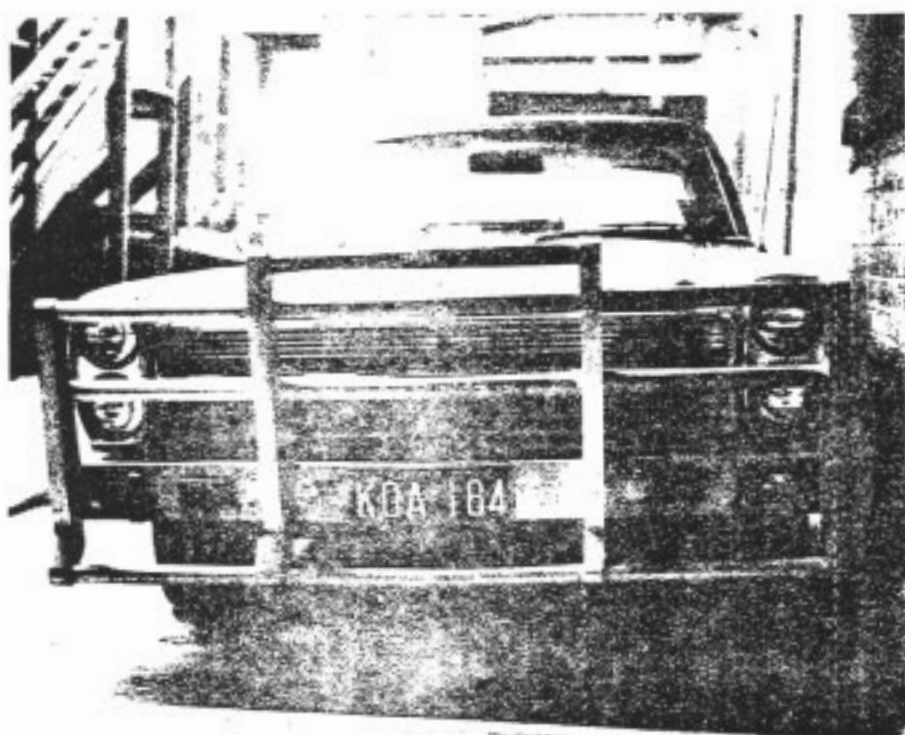
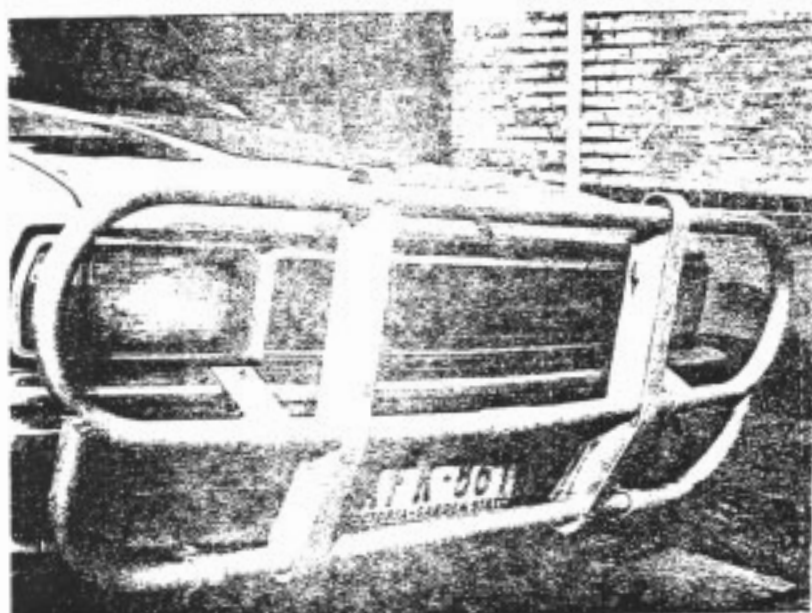


FIGURE 3.5 Aluminium structures. Note the secondary supports (top) and the removal of the bumper (bottom)

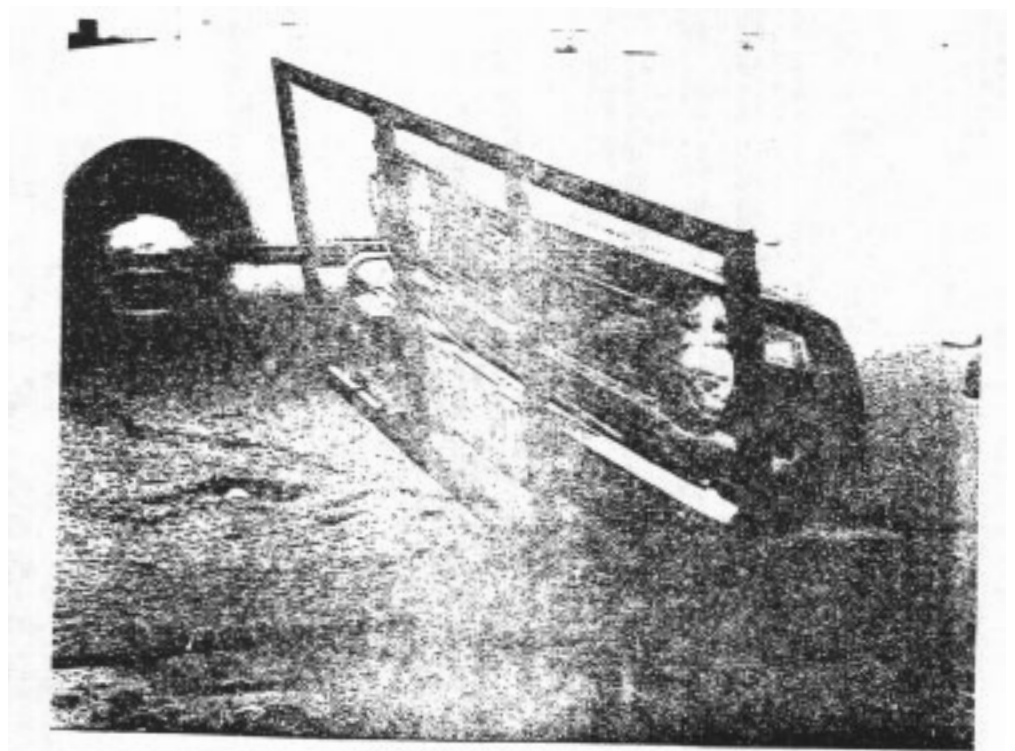
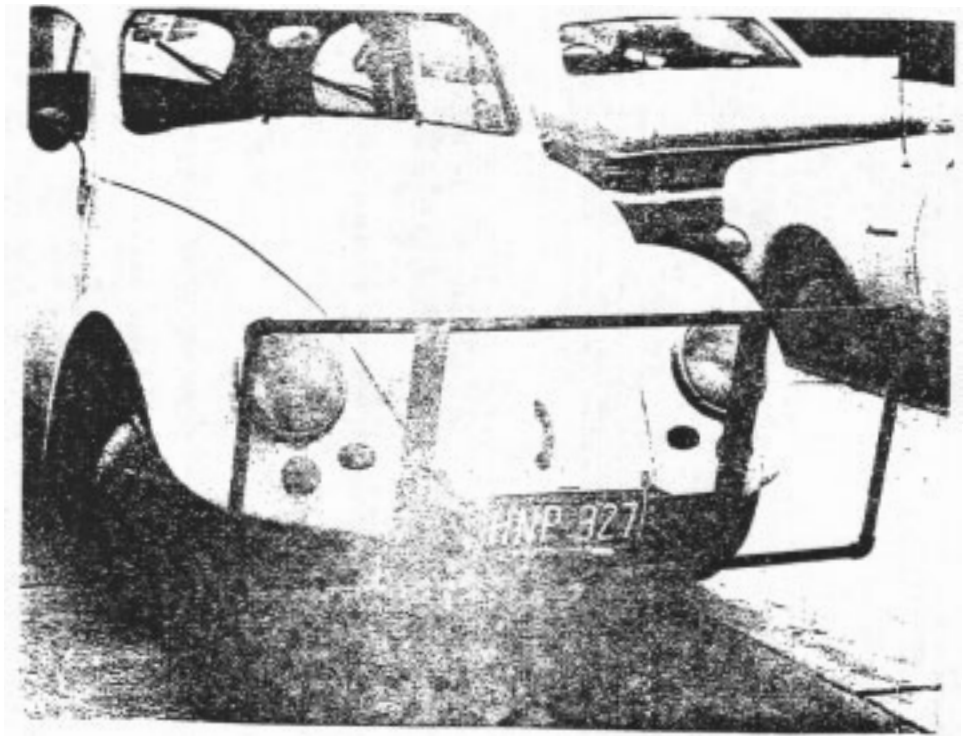


FIGURE 3.6 Steel bull-bars such as these are of arbitrary design.

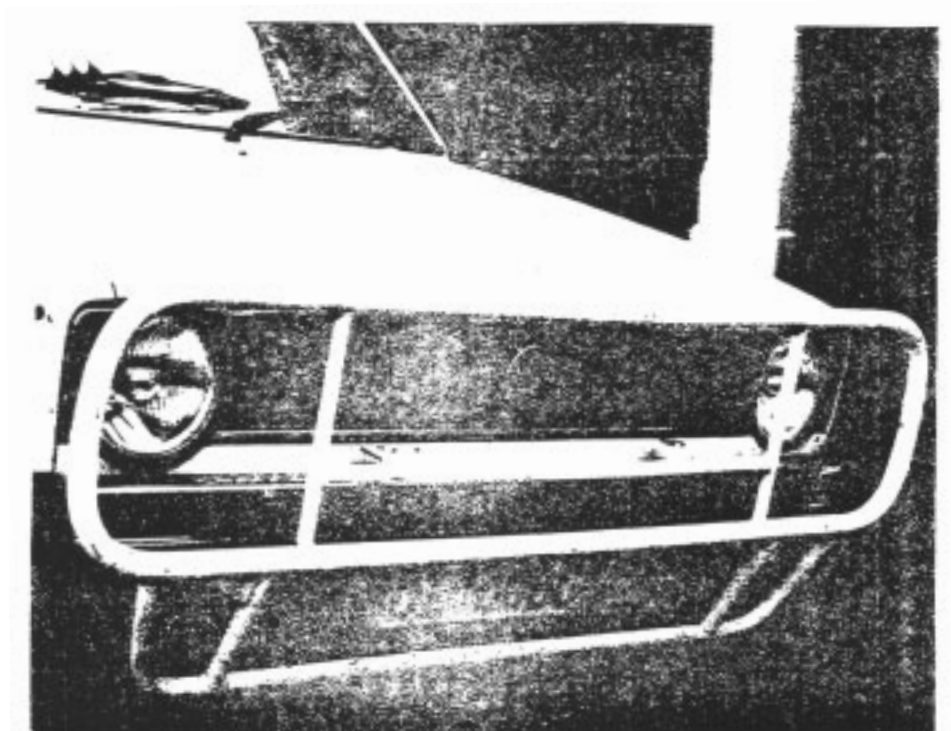
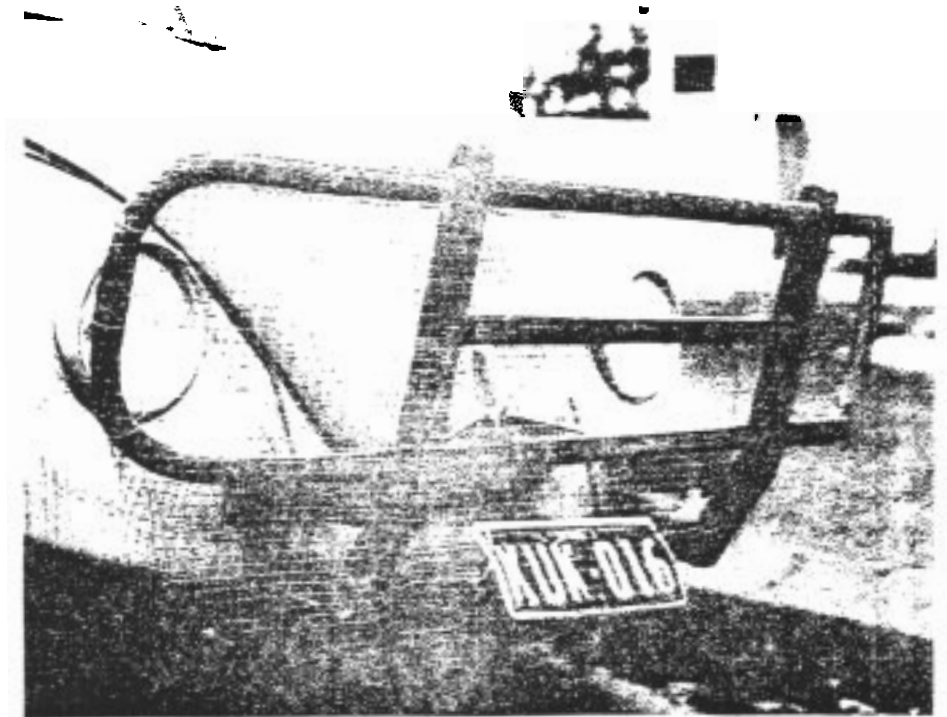


FIGURE 3.7 Tubular steel bull-bars were by far the most common structures found on motor cars in the Melbourne metropolitan area.

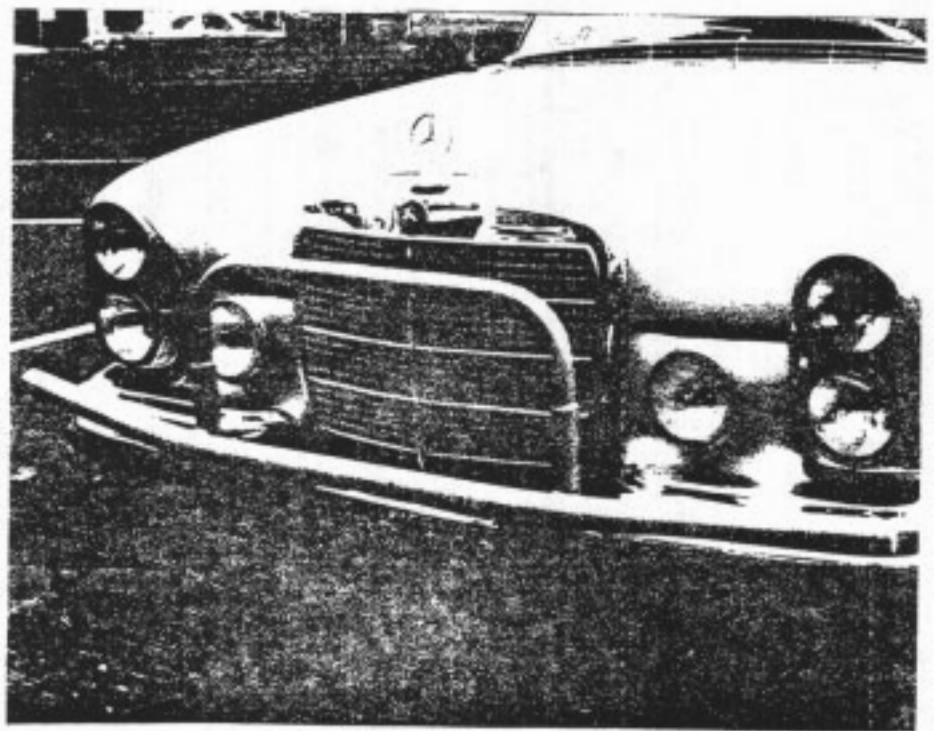


FIGURE 3.8 Small tubular steel bar

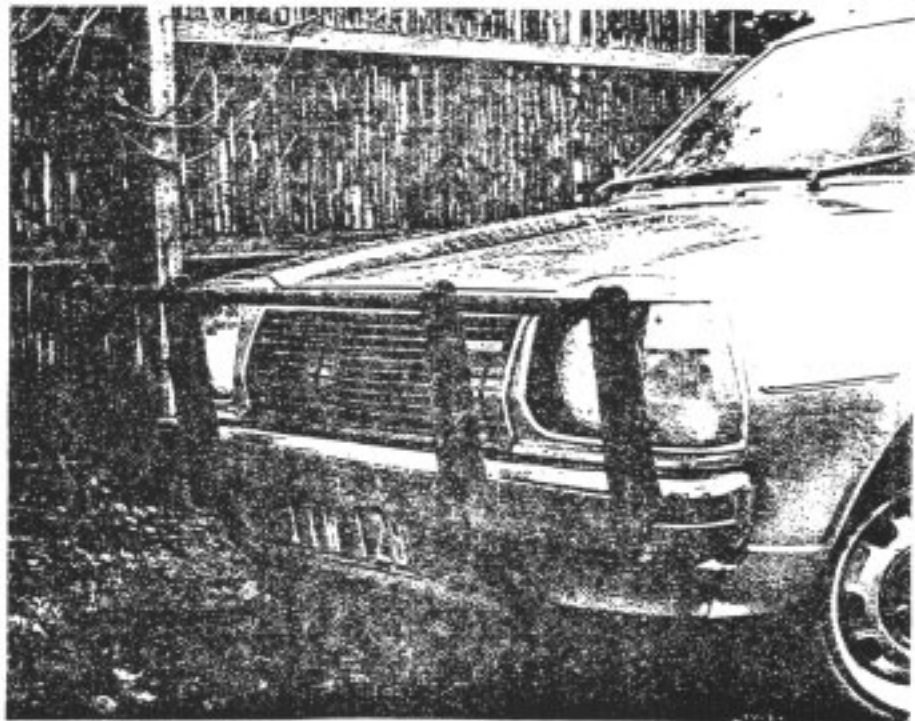
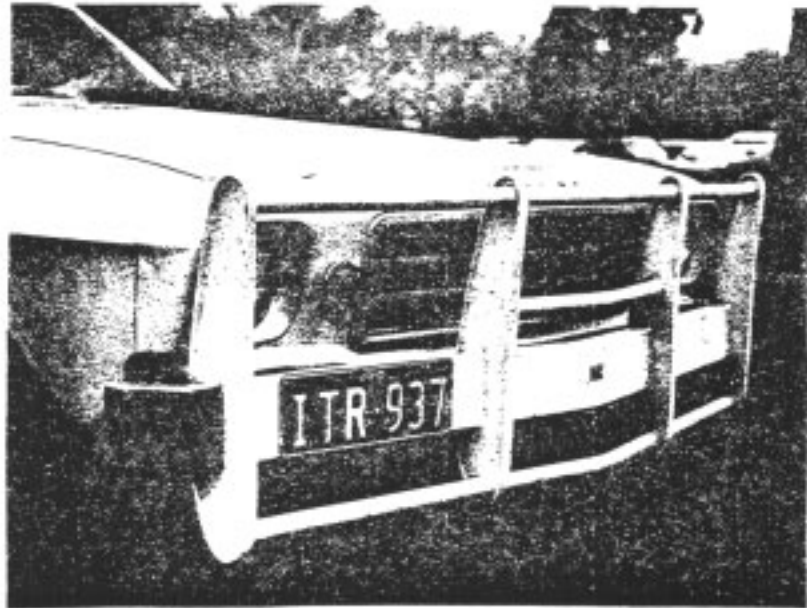


FIGURE 3.9 Truck-type structures are the heaviest group of bull-bars

3.3 ESTIMATION OF CARS FITTED WITH BULL-BARS IN VICTORIA

3.3.1 Victoria's Motor Car Registrations

There were 1,544,900 motor cars and station wagons on register in Victoria at the end of June 1978. Of these as estimated 74% i.e. 1,143,000, were registered in the Melbourne Statistical Division (ABS, 1979).

3.3.2 Motor Cars and Derivatives Fitted with Bull-Bars

A statistical sampling of passenger cars and their derivatives was conducted over a three month period in 1979. Prior to this study no published statistical data in this area was available.

The sample of 26,000 sedan cars and their derivatives (excluding the four-wheel drive vehicle except the Subaru 4WD) on non-strike affected weekdays was sufficiently large to yield a representative result at a 95% confidence interval. The results are presented in Table 3.1.

Based on this data, the percentage of passenger cars and their derivatives fitted with bull-bars in the Melbourne metropolitan area is estimated to be between 0.70% and 0.92%.

3.4 ESTIMATED CASUALTIES ASSOCIATED WITH BULL-BARS ON PASSENGER CARS

Assuming that vehicles fitted with bull-bars are uniformly distributed throughout the accident population, between five and six pedestrians are killed and between sixty-three and eighty-three are injured each year in Australia in collisions involving bull-bars. This does not take into account an expected increase in severity for collisions involving bull-bars.

TABLE 3.1 - SURVEY OF PASSENGER CARS AND THEIR DERIVATIVES FITTED WITH BULL-BARS
IN VICTORIA IN 1979 (NO FOUR WHEEL DRIVE VEHICLES)

| Location of Road Intersections | Date | Day & Time | With bull-bars | Without Bull-bars | Percentage % |
|---|---------|-----------------------------|-------------------|----------------------|-----------------|
| Flemington Rd & Elliot Dve | 4/5/79 | Friday 4.45 pm - 5.30 pm | 15 | 3452 | 0.612 |
| Dandenong Rd & Glenferrie Rd | 14/5/79 | Monday 4.30 pm - 5.43 pm | 21 | 2196 | 0.956 |
| Racecourse Rd & Smithfield Rd | 15/5/79 | Tuesday 7.33 pm - 8.33 pm | 19 | 1444 | 1.316 |
| Gatehouse Rd and Royal Pde | 15/5/79 | Tuesday 4.45 pm - 5.45 pm | 25 | 2721 | 0.919 |
| Princess St & Rathdowne St | 16/5/79 | Wednesday 7.45 am - 8.45 am | 23 | 3422 | 0.672 |
| High St, Carlisle St & Brighton Rd | 16/5/79 | Wednesday 4.40 pm - 5.40 pm | 23 | 3553 | 0.648 |
| Tullamarine F'way & Church St | 18/5/79 | Friday 7.30 pm - 8.30 pm | 18 | 2880 | 0.625 |
| Victoria Pde & Johnson St | 18/7/79 | Wednesday 7.40 am - 8.40 am | 13 | 2048 | 0.625 |
| Rose St & Burwood H'way (Upper Ferntree Gully) | 15/8/79 | Wednesday 7.05 am - 8.05 am | 17 | | |
| Main St, Belgrave | 15/8/79 | Wednesday 8.40 pm - 9.40 pm | 5 | | |
| Maroondah H'way, Lilydale | 16/8/79 | Thursday 7.25 am - 8.25 am | 6 | | |
| Main St, Ararat | 15/8/79 | Wednesday 5.00 pm - 6.00 pm | 14 | | |

CHAPTER 4

PEDESTRIAN IMPACT EXPERIMENTS

4.1 SMALL CAR - GEMINI COUPE

4.1.1 General Information

Experimental procedure is described in detail in Appendix A.

Three sets of pedestrian impact experiments were carried out using the Gemini coupe. The first set consisted of two sessions of four to five hours each and was conducted without the pedestrian dummy. A simple dummy was specially prepared using filled bags. Its weight and height were representative of the pedestrian. This simple dummy was impacted several times by the car without and with bull-bars to achieve the consistency of the impact speed of 20 km/h and to determine the most reliable type of signal for braking. After many tests, an audio-signal to the driver caused by the impact itself was found to be the only consistent one. Good repeatability of impact speed and braking distance was achieved.

The second set was conducted without any instrumentation in the pedestrian dummy and was essentially a photographic exercise.

The dummy was fully instrumented for the third set of impact tests. These tests were not recorded on film.

The segregation of impact experiments into photographic sessions and instrumentation sessions accelerated the development of an experimental methodology. Problems of one group did not slow down the progress of the other group.

Only the photographic data are presented and analysed in the case of the Gemini tests. The measurements of acceleration in these Gemini tests were only used for development of experimental technique.

Two types of bull-bars were selected for the Gemini tests:

1) Thermoplastic bull-bar

Material : Polycarbonate
 Type : FLEXEBAR - 3 bar
 Manufacturer : Betabuilt Products Pty. Ltd.,
 49 Kinkaid Ave., Nth Plympton,
 South Australia 5037.
 Retailer : James McEwans & Co. Pty. Ltd.,
 Bourke Street, Melbourne, Victoria.
 Mass : 9 kg
 Price : \$109

2) Tubular steel bull-bar

Material : Steel
 Type : Tubed, 2" diameter
 Manufacturer : Track Engineering,
 Factory 2, 100 Canterbury Road,
 Bayswater, Victoria.
 Mass : 20 kg
 Price : \$70

The spacial configuration of the bull-bars with respect to the test car can be seen from figures 4.1 and 4.2.

The same vehicle-pedestrian collision configuration, lateral impact into the right side of the dummy was maintained throughout the tests. The nominal vehicle speed was 20 km/h.

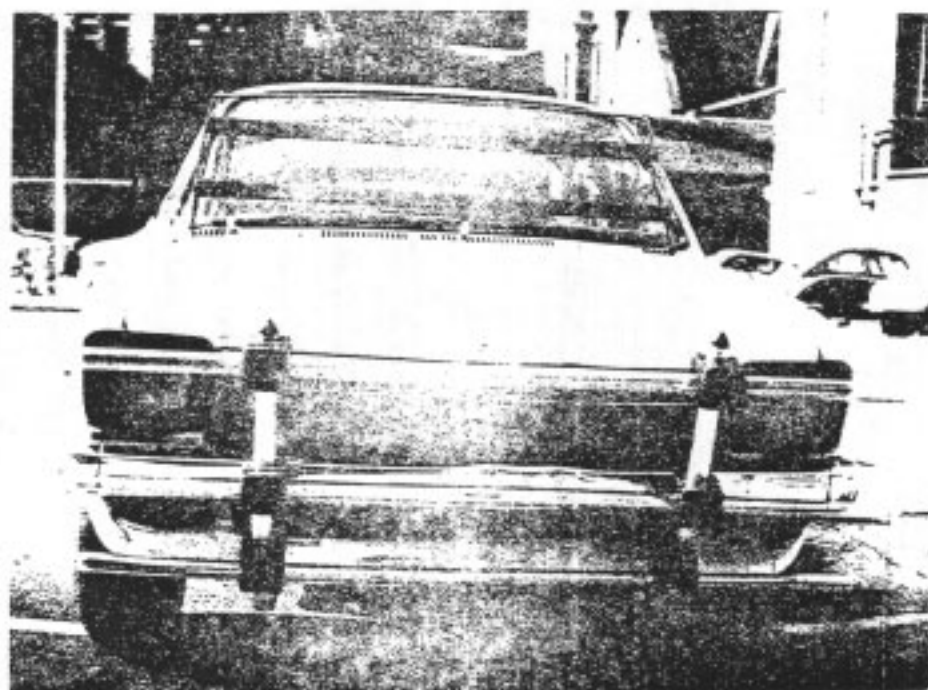


FIGURE 4.1 Thermoplastic bull-bar used in experiments with Genfini



FIGURE 4.2 Tubular steel bull-bar used in experiments with Gemini

4.1.2 Overall Results

Table 4.1 details all experiments with the Gemini coupe listing the bull-bar used, the throw distance of the dummy from initial position, the braking distance of the car and the damage to the dummy.

TABLE 4.1 COLLISION EXPERIMENTS USING THE GEMINI COUPE
(P - PHOTOGRAPHY, I - INSTRUMENTATION)

| Test No. | Bull-Bar Type | Throw distance (m) | Braking distance (m) | Post impact condition of dummy |
|----------|---------------|-----------------------|----------------------------|--------------------------------------|
| G1/P | Thermoplastic | 3.5 | 2.8 | Right ankle failed |
| G2/P | Thermoplastic | 3.5 | 2.5 | Right knee fa |
| G3/P | none | 4.1 | 3.2 | - |
| G4/P | none | 3.2 | 2.6 | - |
| G5/P | Tubular steel | 3.3 | 2.8 | Left ankle fa |
| G6/I | Tubular steel | 5.2 | 3.3 | |
| G7/I | Tubular steel | 2.6 | 2.5 | Arm caught on bull-bar |
| G8/I | Thermoplastic | 2.2 | 1.7 | |
| G9/I | Thermoplastic | 4.9 | 3.9 | |
| G10/I | none | 3.4 | 3.0 | |

4.1.3 Selected Detailed Results from High-Speed Photography

The results of experiments G2, G3 and G5 were selected for comparison and discussions.

The series of photographs on the subsequent pages show the positions of the dummy and the car at selected times measured from the moment of the impact. At the end of the series, the final position of the dummy is displayed.

4.2 LARGE CAR - HOLDEN HZ SEDAN

4.2.1 General Information

The development of a reliable and consistent experimental methodology in the Gemini tests enabled integration of the photographic and data recording segments in the experiments with the Holden HZ sedan.

Three types of bull-bars were selected for HZ Sedan tests:

1) Aluminium bull-bar

| | |
|--------------|--|
| Material | : Aluminium 2" diameter |
| Manufacturer | : Baron Engineering Pty. Ltd., 57 Cambro Road, Clayton, Victoria. 3168. |
| Mass | : 10 kg |
| Price | : \$120 |

2) Tubular Steel bull-bar

Data as for Gemini tests

3) Truck type bull-bar

| | |
|--------------|--|
| Material | : Steel |
| Type | : Tubed 2" diameter |
| Manufacturer | : O.R.E. Manufacturing, 39 Barry Street, Bayswater, Victoria. |
| Mass | : 32 kg |
| Price | : \$140 |

FIGURE 4.3 Gemini Tests

nominal impact speed 20 km/h

Fifty percentile adult male pedestrian dummy

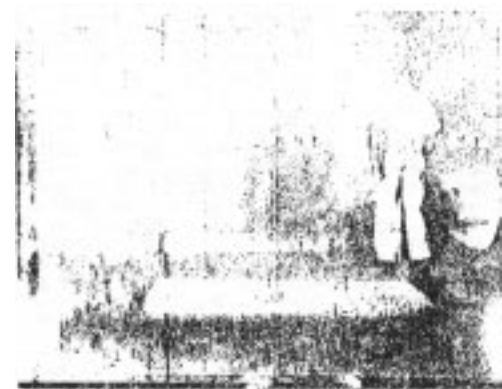
Car: Gemini Coupe, curb weight 930 kg, wheelbase 2404 mm

Time
(ms)

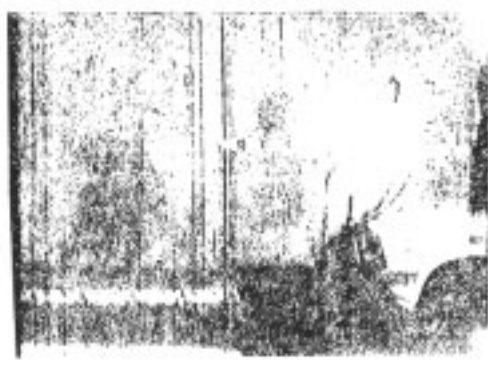
TEST G 4
no bull-bar

TEST G 2
thermoplastic bull-bar

TEST G 5
Tubular steel bull-bar



40

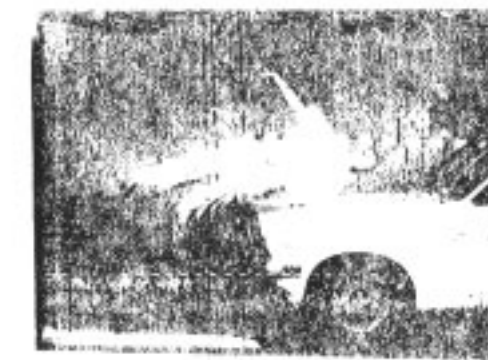


80



10

150
Time
(ms)



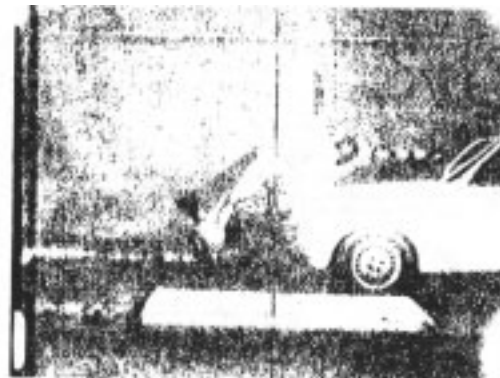
no bull-bar

thermoplastic bull-bar

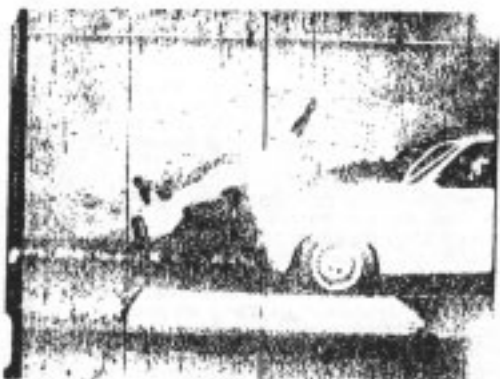
tubular steel bull-bar

FIGURE 4.3 (Continued)

250



300



360
Time
(ms)



no bull-bar

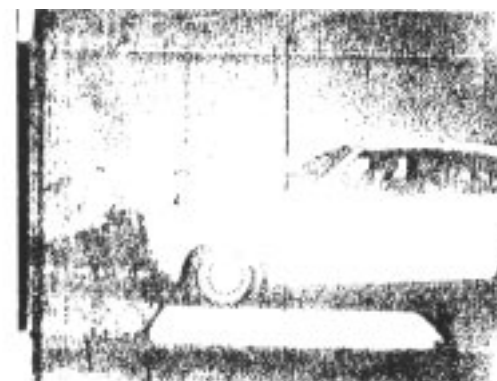
thermoplastic bull-bar

tubular steel bull-bar

600



720



920

Time
(ms)

no bull bar

thermoplastic bull-bar

tubular steel bull-bar

FIGURE 4.3 (Continued)

The special configuration of the bull-bars with respect to the test car was similar to that shown in Figures 3.5, 4.4 and 4.5.

The same vehicle-pedestrian collision configuration as in the Gemini tests was maintained in the HZ sedan runs. As before the nominal speed of impact was 20 km/h.

4.2.2 Overall Results

Table 4.2 yields details of the pedestrian simulation results.

TABLE 4.2 COLLISION EXPERIMENTS USING HOLDEN HZ SEDAN
(P - PHOTOGRAPHY, I - INSTRUMENTATION)

| Test No. | Bull-Bar Type | Throw Distance (m) | Braking distance (m) | Impact Speed (km/h) |
|----------|---------------|-----------------------|-------------------------|------------------------|
| K1/P,I | Aluminium | 4.7 | 2.5 | 18.3 |
| K2 | Tubular steel | 4.9 | 3.8 | - |
| K3/P,I | Tubular steel | 4.1 | 3.1 | 20.0 |
| K4/P,I | none | 4.1 | 2.7 | 18.0 |
| K5/P,I | Truck type | 5.0 | 3.2 | 18.5 |
| K6 | Aluminium | 4.6 | 1.7 | 19.5 |
| K7 | Aluminium | 4.5 | 2.9 | 20.8 |
| K8 | none | 3.5 | 2.3 | 20.0 |



FIGURE 4.4 Tubular steel bull-bar used in experiments with HZ sedan



FIGURE 4.5 Truck-type bull-bar used in experiments with HZ sedan

4.2.3 Selected Detailed Results from High-speed Photography

The subsequent positions of the dummy and the car are shown on the next few pages in figure 4.6. The times are measured from the instant of the impact. The final position of the dummy after impact is shown at the end of the individual series in figures 4.7 - 4.9.

4.2.4 Acceleration-time Data

Table 4.3 provides details of the peak acceleration values together with respective duration times and the severity indices for four accelerometer locations. The acceleration data for head, pelvis and knee are absolute values calculated from the three axis components.

TABLE 4.3 HOLDEN HZ SEDAN TESTS - MAXIMUM ACCELERATIONS AND SEVERITY INDICES

| Bull-bar Type | None | Aluminium | Tubular steel | Truck Type |
|----------------------------------|----------------|-----------|----------------|----------------|
| Test number | K4 | K1 | K3 | K5 |
| Vehicle velocity (km/h) | 18.7 | 18.3 | 20.0 | 18.5 |
| Head-peak Accel. g's / ms * | 65/5 | 84/5 | 45/50 | 206/10 |
| Head-Severity Index | 850 | 1350 | 1050 | 2350 |
| Pelvis-Peak Accel. g's / ms * | 280/2 | 310/3 | 230/7 | 275/10 |
| Knee-Peak Accel. g's / ms * | 146/1 | 75/4 | 225/1 | 132/7 |
| Foot-peak Accel. g's / ms * | signal lost | 63/4 | signal lost | signal lost |

The acceleration-time histories are given in Appendix D.

* g's/ms records acceleration in g's averaged over time

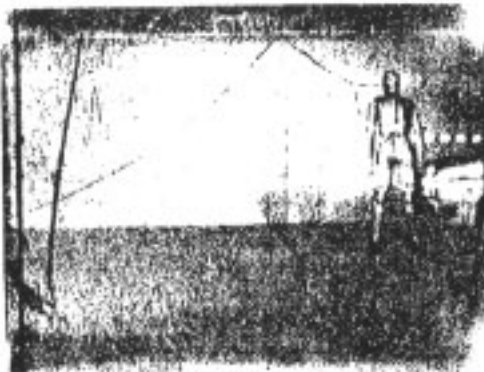
FIGURE 4.6 - HZ Sedan Tests

nominal impact speed 20 km/h

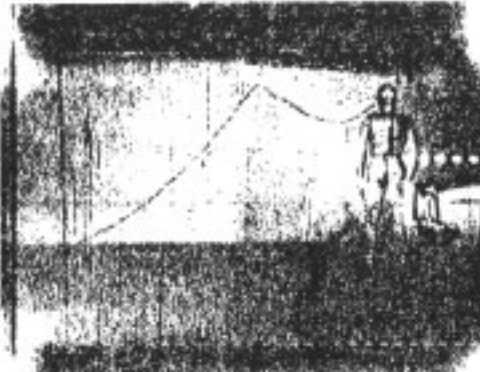
Fifty percentile adult male pedestrian dummy

Car: Holden HZ Sedan automatic, curb weight 1370 kg, wheelbase 2819 mm

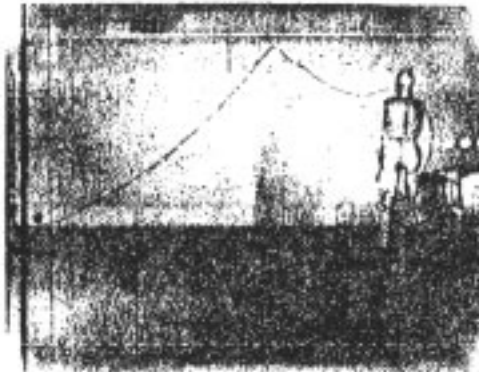
Test K 4
no bull-bar



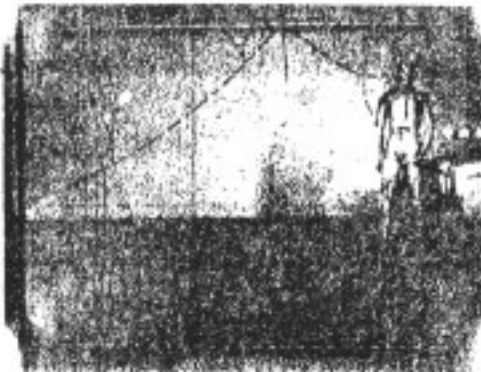
Test K 1
aluminium bull-bar

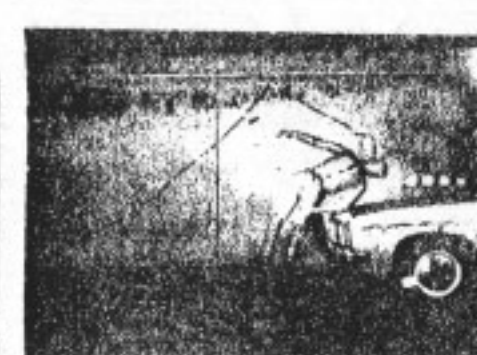
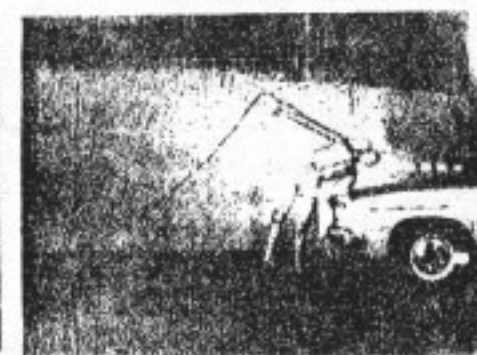
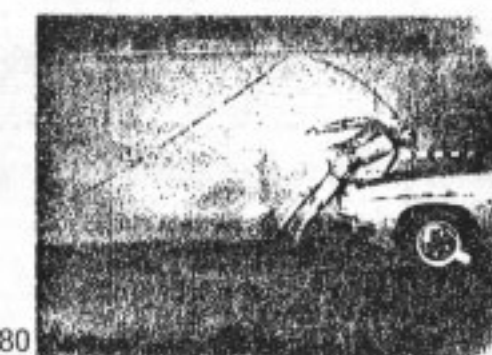
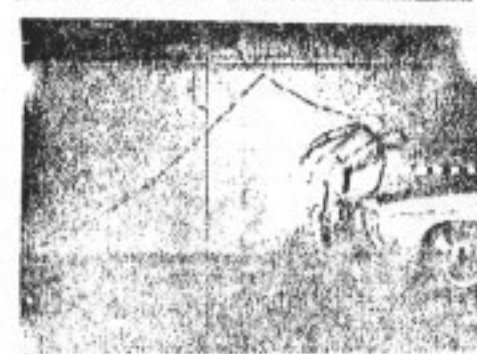
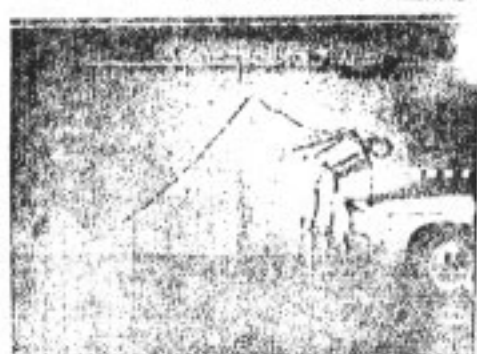
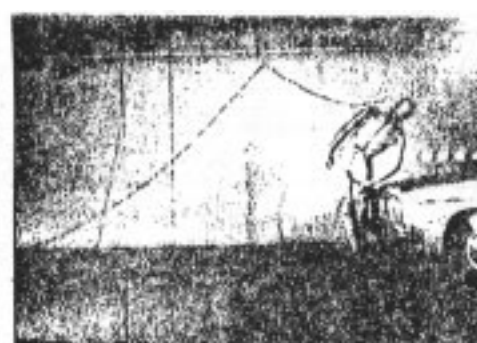
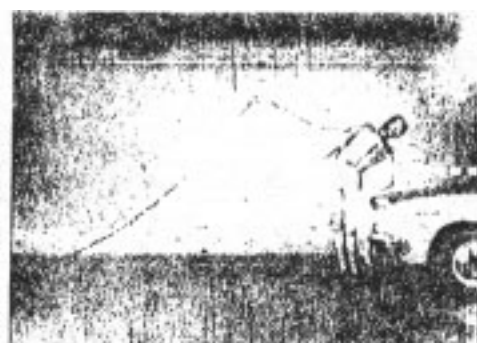
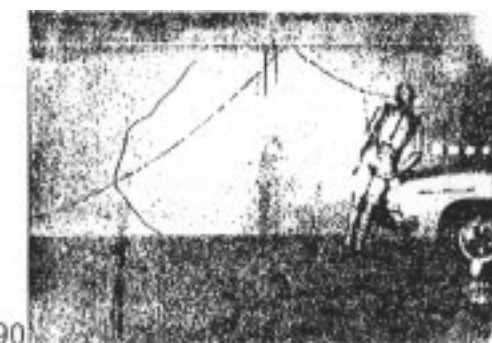


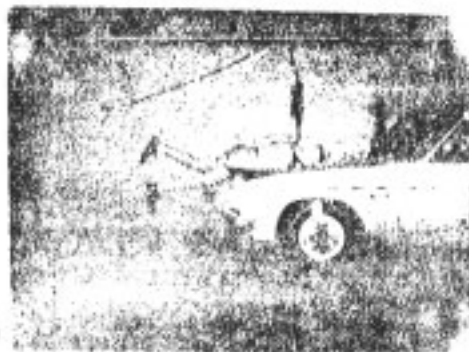
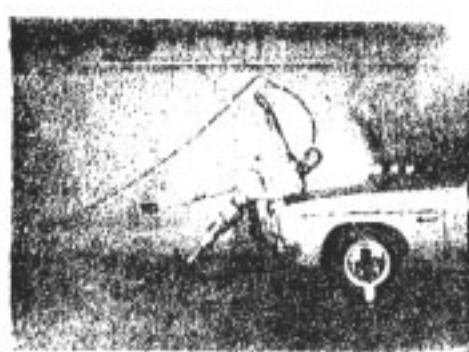
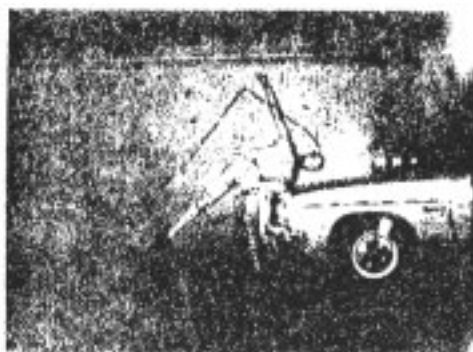
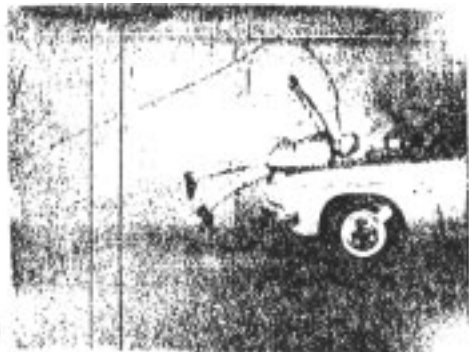
Test K 3
Tubular steel bull bar



Test K 5
truck type bull-bar







time
(ms)

no bull-bar

aluminium bull-bar

tubular steel bull-bar

truck type bull-bar

FIGURE 4.6 (Continued)



no bull-bar

aluminium bull-bar

tubular bull-bar

truck type bull-bar

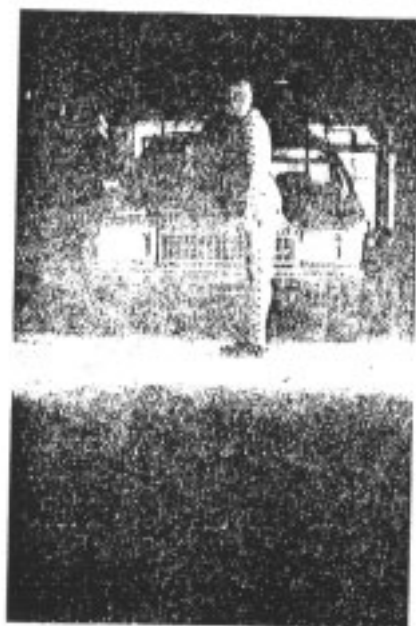


FIGURE 4.7 - 20 km/h impact - no bull-bar



FIGURE 4.7 (Continu

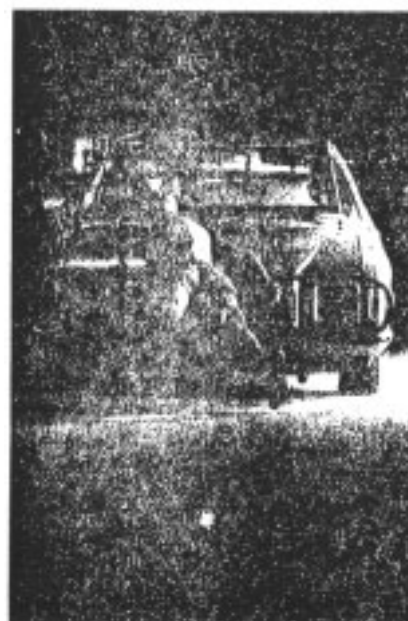


FIGURE 4.8 20 km/h impact - Tubular steel bull-bar





FIGURE 4.9 - 20 km/h impact - Truck type bull-bar



CHAPTER 5

EVALUATION OF RESULTS5.1 GENERAL ASPECTS OF PEDESTRIAN DYNAMICS IN COLLISIONS
WITH SEDAN CARS

The motion of a pedestrian after the first impact by the car is a complex sequence of events influenced by the following parameters (20 km/h impact speed):

- (a) Road: friction between shoes and road surface
- (b) Bumper: height above the road
horizontal distance relative to the bonnet
leading edge (bumper lead or lag)
width
stiffness
- (c) Bonnet edge: height above the road
- (d) Bonnet: stiffness
free space below the bonnet

During the last decade extensive research programs on aspects of pedestrian dynamics in car-pedestrian collisions were initiated with the objectives of determining optimum values of the above parameters for minimum injury.

The findings of this research can be summarised as follows:

- (a) The first contact between the car and the pedestrian should occur between the bumper and the lower leg. It should also be located between the knee and the ankle and as close as possible to the road. In this way, the moment of the friction force between the shoes and the road with respect to the contact point on the bumper can more easily be overcome by the moments of the inertia forces of the body above the same contact point.

These facts can be explained on a simple analytical model

- (b) The bumper must not be too soft. A soft bumper acts as a spring. Hence, it takes time to deform sufficiently so that the contact force F is large enough to accelerate the lower torso and develop inertia forces in the upper leg to overcome the opposing moment of the friction force (Pritz et al, 1975). See also Appendix B.
- (c) The leading edge of the bonnet can be positioned with respect to the bumper to minimize the rotational acceleration of the body and the intensity of the primary impact of the head with the car. The bonnet contact point should be the upper leg between the knee and the hip to reduce the probability of the damage to those joints. A soft leading edge is desirable for this purpose (Sarraihe and Hearn, 1971).
- (d) The bonnet surface should deform plastically to absorb as much energy as possible. The contact area between the upper torso and the hood should also allow maximum energy absorption.
- (e) The leading edge of the bonnet should not be sharp in order that the body can slide smoothly over it. A sharp edge could catch part of the body thereby inducing rotation forwards so that the road is hit from a substantially higher level than in the case of a smooth motion over the leading edge.

The results from the bull-bar tests as presented in Chapter show the importance of the mentioned parameters in a quite pronounced way because the bull-bar substantially changes the frontal profile of the vehicle. The main difference between the HZ Sedan and the Gemini is the bumper projection ahead of the bonnet leading edge. It is negligible in the Gemini's design but is more ideal on the HZ Sedan.

5.2 COMPARISON OF SMALL CAR TESTS

The differences between the results with and without bull-bars in the Gemini tests are not as pronounced as in the tests with the HZ Sedan. Nevertheless, the photographs in section 4.1.3 demonstrate how the fitting of a bull-bar can change the frontal profile of the car.

The Gemini without a bull-bar is not an example of a good structure with respect to pedestrian safety because the bumper and leading edge of the bonnet are almost in the same vertical plane. Nonetheless, the bumper is relatively stiff and the bonnet edge is relatively soft so that the lower legs are forced from the road after approximately 100 ms. The upper body starts rotating about the bonnet edge after another 40 ms and contacts a large area of the bonnet. The dummy then slides along the bonnet, contacts the road with its knees and hits the ground with the soft front part of the head from a low height.

The plastic bull-bar demonstrates the problem caused by an extremely 'soft' bumper. The almost negligible rigidity of the lower bar results in rotation of the body about the road contact point (the right foot being locked) during the first 50 ms. Compare the position of the right lower leg at 40 ms for the car without a bull-bar and that with the plastic bull-bar. In the first case the foot has slid on the road; in the second case it is still not moving. The photograph at 150 ms shows that the knee has fractured (the ankle had been stiffened after the previous test).

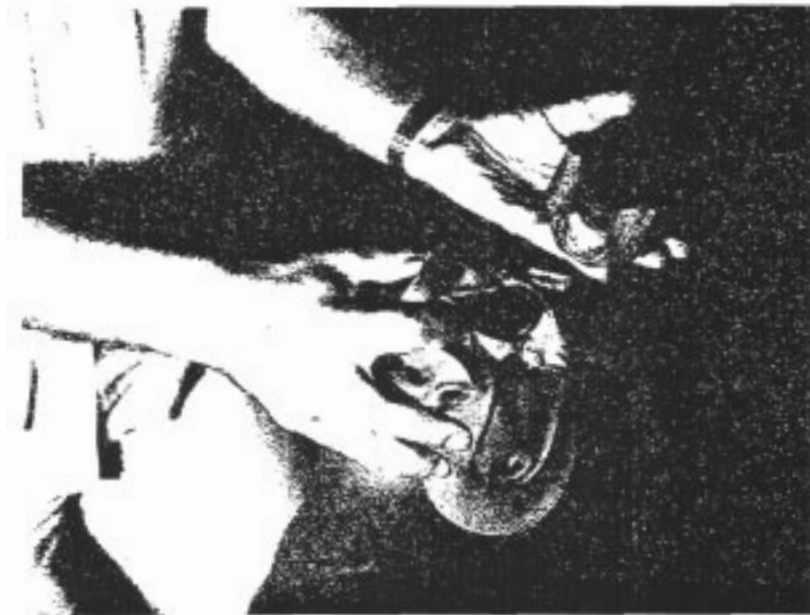


FIGURE 5.1 The broken right "knee" after impact with a plastic bull-bar

The effect of the elasticity of the upper bar can be seen from the frames at 300 and 360 ms. The rebound of the bar causes larger angular acceleration and a harder impact with the bonnet.

The steel bull-bar demonstrates the effect of a small contact area with the bonnet and of the position of a sharp contact point above the bonnet edge. The rebound energy is higher than in the two other cases and the dummy's torso turns about the upper bar during the back slide and hits the road from a higher level (frame at 920

5.3 COMPARISON OF LARGE CAR TESTS

The effect of bull-bars on pedestrian kinematics is more pronounced in the HZ Sedan tests than the Gemini tests.

The feet of the dummy in the test without a bull-bar are forced from the road after 90 ms. The aluminium bull-bar caused the right foot to be locked throughout the accident, the other two bull-bars effected release after 180 ms. The right ankle would have fractured in all the experiments with the bull-bars. (Note: The ankle and knee of the right leg had been stiffened after repeated damage had been experienced in tests with bull-bars, to save repair time).

The difference in utilization of the contact area with the hood is clearly demonstrated by frames at 360 ms.

The effect of the bonnet edge on the severity of the secondary impact with the road is demonstrated by the last frames and by the final position of the dummy. The head severity index from Table 4. for the truck type bull-bar would cause a severe injury to a pedestrian at impact of 20 km/h when there would be no injury if the car had no bull-bar.

CHAPTER 6

CONCLUSIONS

The attachment of a bull bar to a car can change certain performance characteristics of the vehicle of relevance in a collision with a pedestrian. These characteristics have resulted from extensive and costly research programs including analysis of accidents, experimental impact tests, computer simulation and theoretical studies.

Most modern cars have:

- (a) smooth overall shape without protruding components;
- (b) non-aggressive geometrical configuration and material of the individual parts of the front structure;
- (c) special shapes of some sections to allow a controlled deformation sequence during various types of collisions.

The idea that the front of a car could be improved to decrease substantially pedestrian trauma in accidents was initially met with scepticism. However, experiments with modified front structures have demonstrated that substantial reduction of severity of pedestrian trauma (up to 50%) is attainable for low speed impacts and can be achieved by simple and inexpensive means (Pritz 1977, Kuehnel and Appel 1978).

Studies are currently under way in the USA on compliance test procedures for the front of sedan cars to satisfy proposed standards for pedestrian safety (Eppinger, Pritz 1979).

Although the research program was of a pilot nature only, the results indicate the influence of the front structure of a car on the pedestrian collision kinematics and on the severity level of pedestrian trauma.

Certain aspects of the frontal car structure cited by overseas researchers as contributory to car aggressiveness in collisions with pedestrians were amplified by bull-bars as they include:

- (a) softening the bumper by application of a plastic bar as demonstrated by the Gemini tests;
- (b) shifting the first impact point upwards as introduced by almost all bull-bars;
- (c) placing a rigid bar above the bonnet leading edge so that the pedestrian is -
 - (i) hindered from maximising his contact area with the bonnet surface;
 - (ii) prevented from sliding smoothly along the bonnet during the braking period; and
 - (iii) caused to be overturned during the final phase of his motion.

The improvements already achieved in frontal design were demonstrated in the Holden HZ tests, where the frontal configuration was more ideal (Pritz 1977). The pedestrian's legs in the Holden HZ tests are forced from the road by the low positioned, protruding and relatively stiff bumper so that the probability of braking the ankle or knee is reduced. The pedestrian then rotates about the bonnet edge and lands on a large area of the relatively soft bonnet. He slides down along the now stationary car unhindered to land with his knees on the road and subsequently hits the road surface with the front part of his head from a low height. The head severity index at an impact speed of 20 km/h is about 850 which is below the accepted tolerance threshold of 1000.

Compare this motion with the case when a bull-bar had been attached to the car. The head severity index is in some cases substantially above the threshold of 1000 - aluminium bull-bar 1130, heavy steel 2320 - so that a light injury is converted to a serious casualty. A broken ankle or knee can be expected in almost all cases. The high-speed photography prints in the report clearly indicate the collision kinematics.

CHAPTER 7

RECOMMENDATIONS

Conclusions arrived at from this research are based on a relatively small number of experimental tests conducted with moderate controllability of conditions. Nonetheless, the following statements of recommendation are made:

- (i) The fitment of bull-bars in metropolitan areas to other than heavy vehicles should be controlled and the manner of such control should be investigated.
- (ii) A sociological survey on the motives of car owners for using bull-bars is recommended. *
- (iii) The previous survey of cars travelling in the Melbourne metropolitan area with bull-bars should be repeated under similar conditions to assess the change of bull-bars usage over time.
- (iv) Should further information be required in regard to controlling the fitment of bull-bars, impact tests with a pedestrian dummy using various speeds should be undertaken and include tests with delivery vans.
- (v) The adverse effects of bull-bars on pedestrian safety should be conveyed to motorists via appropriate publicity campaign in order to discourage their indiscriminate use.

* A student project subsequently conducted indicated that the major reason for the fitment of bull-bars may be purely to prevent damage in minor collisions, which may be preventable by changes in bumper design.

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