OFFSET CRASH TESTS - OBSERVATIONS ABOUT VEHICLE DESIGN AND STRUCTURAL PERFORMANCE

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ABSTRACT

Offset frontal crashes can place severe demands on the structure of vehicles. Offset crash tests conducted in the USA, Europe and Australia are revealing that some vehicle models perform exceptionally well in these severe tests. Between them, the authors have been involved in the assessment of more than 45 offset crash tests conducted under the Australian New Car Assessment Program (ANCAP). They have also evaluated data on a similar number of offset crash tests conducted in the USA and Europe.

This paper sets out some general observations about the structural performance of cars, passenger vans and four-wheel-drive vehicles in offset crash tests. The design features which appear to contribute to good structural performance are discussed. Likely reasons for poor performance are noted.

INTRODUCTION

This paper sets out some general observations about the structural performance of cars, passenger vans and four-wheel-drives in the offset crash test conducted by Australian NCAP (New Car Assessment Program), the US Insurance Institute for Highway Safety (IIHS) and Euro-NCAP. The observations are intended to be constructive and should assist vehicle designers improve the crashworthiness of vehicles.

The Offset Crash Test

In the offset crash test the vehicle is travelling at 64km/h when it collides with a crushable aluminium barrier. The barrier initially makes contact with 40% of the width of the front of the vehicle, on the driver's side (Lowne 1996). The resulting crash forces place severe demands on the structure of the vehicle, particularly on the driver's side.

The vehicle structure affects the outcome of an offset frontal crash in two main ways:

i. Absorption and dissipation of crash energy

ii. Integrity of the passenger compartment

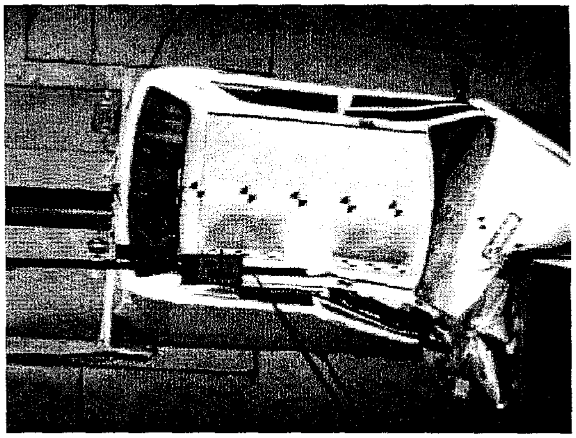

Figure 1. Overhead view of an offset test into a deformable barrier at 64km/h (ANCAP).

ABSORPTION OF CRASH ENERGY

The offset crash test is intended to simulate a collision between two similar-sized vehicles with similar crush characteristics. In these types of crashes it is desirable that most of the crash energy is absorbed and dissipated in the deformation of components within the front metre or so of each vehicle.

The increasing use of engine/suspension cradles has allowed designers to better control this deformation and to by-pass very rigid components such as engine blocks which are not effective energy absorbers.

To avoid load concentrations it is important that the crash forces are spread across the face of the deformable barrier. In several cases it has been observed that box-section structures at the front of the vehicle have punched through the barrier and relatively little energy is absorbed through deformation of the barrier. These box section structures appear to be designed to achieve better performance during a full-frontal crash into a rigid barrier but they can be much less effective during offset crashes into deformable objects, including other motor vehicles. Conversely, some box sections which crush efficiently in a full-frontal crash do not perform as well under the asymmetric loads of an offset crash - they tend to buckle rather than concertina.

Some four-wheel-drive recreational vehicles have relatively stiff front structures. This can result in a very high deceleration of the passenger compartment and high loads on the occupants. A stiff front structure can also place excessive demands on the deformable barrier, causing the barrier to bottom out early in the crash sequence. In a collision between two vehicles the occupants of the heavier vehicle would generally be better off, due to the physics of the collision. In the case of four-wheel-drive vehicles colliding with passenger cars, however, this advantage can be diminished by a stiff front structure. Analysis of crashes in Australia have shown that, on average, the driver of a four-wheel-drive vehicle has a greater likelihood of being killed or seriously injured in a crash than the driver of a large car (Newstead et al , 1997).

Aggressivity

The front structure of a vehicle also has a strong influence on aggressivity - the degree to which individual vehicle models cause injuries to occupants of other vehicles. The Monash University Accident Research Centre (MUARC) has recently conducted an analysis of aggressivity in more than 300,000 on-road crashes (Cameron et al 1998). Key results related to front structure are set out below:

- There is the expected trend of increased aggressivity with increased vehicle kerb mass but there is a large amount of scatter, with some high-mass vehicles showing low (good) aggressivity.
- Four-wheel-drives generally show high aggressivity but there is a large amount of scatter and some commendable exceptions. Some of the lighter four-wheel-drives are no more aggressive than cars of the same mass.
- Passenger vans and commercial vans tend to have high aggressivity for their kerb mass.

The cases where, in the offset crash test, the front structure imposed concentrated loads on the deformable barrier could also be expected to be hazardous to the occupants of other vehicles due to increased penetration and intrusion. This might partly explain the adverse result for vans. Other factors might be the very high proportion of these vehicles fitted with "bull bars" in Australia (estimated at 50% or higher - Traffic and Transport Surveys, 1994) and the higher laden mass, compared with cars (the analysis was based on kerb mass).

One criticism of consumer offset crash tests is that they are claimed to push manufacturers towards building stiffer vehicles, in order to protect their own occupants, and that these stiffer vehicles are more aggressive to other vehicles. The MUARC study, and results of recent offset crash tests suggest that this criticism is unfounded. Some vehicles performed exceptionally well at protecting their occupants in the offset test while apparently having low aggressivity towards the occupants of other vehicles. Evidently this was achieved by efficiently absorbing crash energy in the front structure while retaining the integrity of the passenger compartment.

Occupants of other vehicles should be at less risk in collisions with these low-aggressivity vehicles. Vehicle design is therefore a crucial factor in achieving good crashworthiness *and* low aggressivity.

If the all-vehicle average aggressivity observed in the MUARC study had been reduced to the average for small cars then it is estimated there would have been a 30% reduction in fatal/serious injuries to the occupants of "other" vehicles. Since aggressivity is not a quality easily affected by consumer pressure this may be an area which requires legislation.

INTEGRITY OF THE PASSENGER COMPARTMENT

The passenger compartment should keep its shape in the crash test. The steering column, dash, roof, roof pillars, pedals and floor panels should not be pushed excessively inwards, where they are more likely to injure the occupants. Doors should remain closed during the crash and should be able to be opened after the crash to assist quick rescue.

There is a temptation, when observing a frontal crash test, to concentrate on what is happening at the front of the vehicle, since this is where most of the deformation is occurring. This might give the impression that the front of the vehicle is being forced back into the passenger compartment. While this is an important source of passenger compartment intrusion it is only part of the story.

At the height of a frontal crash test the front of the vehicle has come to a halt but the remainder of the vehicle is still undergoing a high deceleration - typically around 40g (up to 60g with some four-wheel-drive vehicles). Substantial compression forces are generated between the front and rear of the vehicle at this time.

Consider a transverse vertical plane in line with the dash. The resulting cross-section might include the a-pillars, side doors, door sills and floor. About 50% of the vehicle's weight will usually be rearward of this plane. The compression forces arising in these components due to a 40g deceleration are therefore equivalent to about 20 times the weight of the vehicle. This places a severe demand on the structure. Furthermore, there is usually very little structural redundancy in the design and if any one of these components has a major failure then catastrophic collapse can occur (and has been observed).

For commercial vehicles and four-wheel-drives the proportion of mass in the rear is usually greater than with passenger cars, particularly when laden. This, combined with a stiffer front structure, can place a very severe demand on the structure of the passenger compartment .

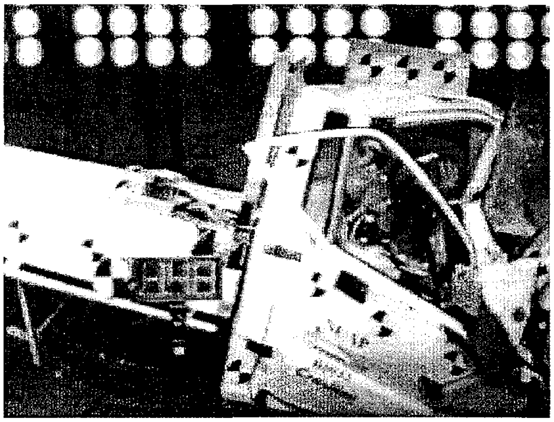

Figure 2. *Unladen* light commercial vehicle during an offset crash test at 64km/h (ANCAP).

During the 56km/h full-frontal test of several four-wheel-drive vehicles there was a noticeable sleeving effect, where the sides of the passenger compartment tended to slide around the engine compartment, resulting in substantial firewall and dash intrusion at the height of the crash (figure 3). The deformation usually appears to be elastic and therefore the post-crash residual movement of the firewall and dash might not indicate a problem.

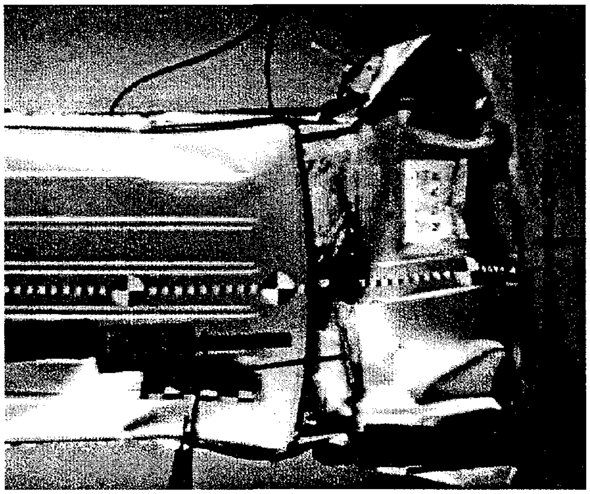

Figure 3. Overhead view of a full-frontal crash test into a solid barrier at 56km/h (ANCAP).

Footwell intrusion

Front suspension components such as lower control arm pivots are commonly located on, or just ahead of, the footwell toepan area and above the floor level. The suspension components which are attached to these points are usually rigid in a longitudinal direction and therefore, during the crush of the front of the vehicle, they tend push the mounting points rearwards into the toepan. In addition to the risk of lower leg injury due to intrusion, dynamic movement of the toe-pan can cause the legs to lift suddenly, sometimes resulting in a violent head to knee strike.

The better designs tend to locate the suspension mounting points below floor level. In this configuration longitudinal structural members mounted under footwell area can effectively transmit the crash forces past the footwell area and reduce intrusion - this has been observed on several vehicles. However, in some cases such structures have insufficient strength to cope with forces during a 64km/h offset crash test. One possible weakness is the location of joints or welds at a bend or change in cross-section.

These observations also apply where engine and/or suspension components are mounted on a cradle under the front of the vehicle. These cradles are usually attached to the body just ahead of the toepan. Their height and method of attachment can have a significant influence on footwell intrusion.

Road wheels and tyres are relatively rigid when compared with footwell panels and they can contribute to intrusion into the footwell area or separation of footwell panels. Failure of the seams between the floor and door sill or the firewall and a-pillar can greatly reduce the strength of this region.

Seat movement

Another factor associated with floorpan deformation is the movement of seats. In some cases seats have tilted forward and/or to the side by substantial amounts when the floorpan or transmission tunnel deforms. This can have an adverse effect on occupant kinematics. This is particularly a concern where the seat belt buckle is mounted on the seat because it can result in extra forward movement of the occupant - thereby defeating the advantage of mounting the buckle on the seat (better adjustment of the seat belt to suit the occupant).

With seat-mounted seat belt buckles the loads on seat components are much higher. Seat runners have been observed to bend, seat mounting frames have rocked forward and floor panels have deformed. All these problems have contributed to excessive forward movement of the occupants.

Upward movement of the steering wheel

Several of the crash-tested passenger vans and utilities experienced a large upward movement of the steering column during the crash test. In some cases the whole dash appeared to rotate upwards taking the steering column with it. In other cases the vehicle structure near the bottom end of the steering column was pushed rearwards, causing the column to rotate and move upwards. Where an airbag is fitted this movement can adversely affect its performance (this is evident in several of the IIHS tests of passenger vans).

The upward motion of the steering column often coincides with the forward and downwards motion of the occupant's head. Where no airbag is fitted this can cause an increase in the severity of the head strike. In one case, this effect contributed to a head deceleration of 250g - one of the highest ever recorded.

In the absence of an airbag, steering wheel hub design plays an important role in reducing head injuries. Considerable research has been undertaken into effective, energy-absorbing hub designs but these do not appear to have been put into production. In some cases the hub cover has flown off just before the head impact, exposing the head to metal components.

Sideways movement of the steering wheel

In several offset crash tests the driver dummy rolled off the outboard side of the airbag. Although some outboard motion of the dummy can be expected due to the non-symmetrical crash forces, in most of these cases it is likely that the steering wheel had moved inboard, relative to the driver's seat. One possible factor is that components in the engine bay push the steering column to one side, causing it to pivot about its mounting points. Another possible factor can be gauged from an overhead view at the height of the crash (figures 1 & 4). In many cases there is a substantial angular difference between the front part of the vehicle, containing the dash and steering column, and the rear part containing the passenger compartment - a "jack-knife" effect. The steering wheel therefore moves inboard, relative to the passenger compartment

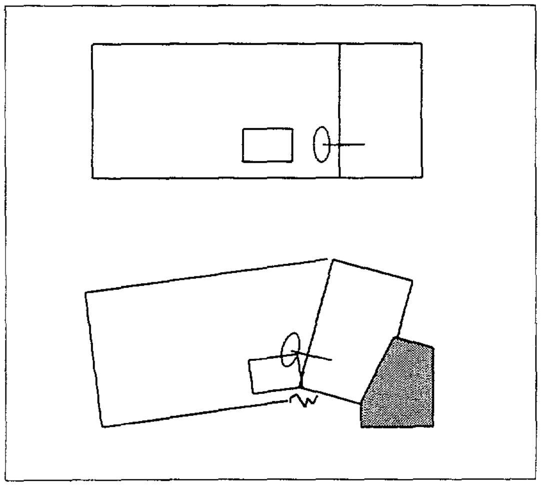

Figure 4. Diagram showing possible relative movement of steering wheel

This effect usually results from excessive deformation in the region of the a-pillar on the driver's side. Rupture of the join between the dash and the a-pillar, and collapse of the door and door sill can also contribute to this problem.

Seat belt upper anchorages

Adjustable upper seat belt anchorages improve the fit of the seat belt. However, some designs deform under the severe loads of the crash test and allow additional forward movement of the occupants.

With the trend towards b-pillars which curve substantially inwards between the door sill and the roof there is another source of seat belt "slack". The webbing follows the curved path between the retractor unit and the D-ring and is usually held in place by the trim. During the crash the plastic trim can give way due to tensile forces in the webbing, which then straightens and feeds through the D-ring.

CONCLUSIONS

The 64km/h offset crash test places severe demands on the structure of the vehicle. Some vehicles perform exceptionally well during this crash test but many exhibit excessive structural collapse and other undesirable characteristics. The better designs appear to have the following structural features:

- a front structure which absorbs crash energy through controlled deformation and avoids load concentrations on the impacted object,
- structural components which bridge the front footwell area so that compression forces are transmitted directly between the front and rear of the vehicle, resulting in minimal footwell deformation,
- structural components which channel crash forces into the a-pillars, side doors and door sills rather than into the firewall area,
- the join between the top of the a-pillar and the roof is smooth and strong so that upwards buckling of the roof is resisted,
- side doors and door sills which offer resistance to longitudinal compression forces (measures to improve side impact protection appear to have assisted in this regard),
- a steering column designed and mounted to minimise the amount of rearward and upward movement at the height of the crash,

It is evident that these issues are now being taken into account during the early stages of vehicle design. Powerful Computer Aided Engineering (CAE) packages are now able to determine vehicle structural deformation and occupant kinematics during a variety of crash situations, including a simulated offset crash test (Loo and Brandini 1998).

Recent research in Australia indicates that the better designs can provide good protection for their occupants, while having low aggressivity towards the occupants of other vehicles.

ACKNOWLEDGMENTS

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