**STRUCTURAL ENERGY ABSORPTION TRENDS IN NCAP CRASHED VEHICLES.**

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## ABSTRACT

The ANCAP (Australian New Car Assessment Program) have been conducting offset frontal crash tests into a deformable barrier since 1995. During this time the results of the ANCAP tests have shown significant improvements in occupant protection measured via reduction in dummy injury measurements, i.e. HIC, chest 'g', etc.

Occupant protection has improved with manufacturers designing structures to minimise the occupant space intrusion with the aim to have the crash energy absorbed by deformation of the frontal vehicle structure. Also new restraint technology has been included along with the vehicle structure designed to optimise the restraint technology.

Previous analyses have questioned whether changes in the vehicle structures and restraint technology have changed the loads either in the occupant compartment or on the front seat belts. The previously analysis of 'B' pillar accelerations and also the front seat occupant seat belt loads for frontal crash tests performed by ANCAP from 1995 through to 2003 showed that while the dummy injury measurements have reduced there has not been a corresponding reduction in either 'B' pillar accelerations or seat belt loads.

This result was surprising given the occupant gains made through this period. It is possible that the regulatory and consumer crash tests and scoring parameters are such that vehicle engineers find it more efficient to optimise the restraint systems without significantly engineering the crumple zone.

However, the previous study did show small improvements in 'B' pillar decelerations in the small car segment (i.e. kerb weight of up to 1250kg). This study used data from other consumer crash test programs to add to ANCAP data to allow for analysis of a greater number of vehicles. This will be used to identify trends in energy absorption performance in the small car fleet.

The 'A' pillar displacement was used as an indication of load paths and also occupant cell structural integrity. The longitudinal acceleration time traces for driver side 'B' pillar will be used to represent the loads on the vehicle structure and correlated with seat belt loads and dummy acceleration measurements. It is intended to determine if crumple zones have been optimised with respect to the restraint system timing.

## INTRODUCTION

From 1995 ANCAP included a 40 % offset frontal crash into a deformable barrier in accordance with the test protocols developed by the EEVC in 1993. This test was initially conducted at 60 km/hr, which was the speed for the proposed European regulations.

However, ANCAP increased the crash test speed to 64 km/hr to be consistent with both the US IIHS who also started conducting consumer crash tests at this speed in 1995 and the developing Euro NCAP program.

This study has used the results of 128 passenger vehicles crash tests from both ANCAP and the US IIHS. Unfortunately, Euro NCAP data was not able to be obtained in time to be included in this analysis.

During the time of the offset frontal crash tests conducted by ANCAP (and other NCAP groups) there have been significant improvements in the level of occupant protection in passenger vehicles. This has been shown by the driver dummy injury measurements that have improved from over 1000 HIC and 44 mm of chest deflection to less than 300 HIC and 21 mm of chest deflection.

The benefits of a consumer crash test program has been demonstrated through both the introduction of vehicles with safety technology that exceeds the minimum regulatory requirement and also through international studies showing cars that perform better in crash tests provide better occupant protection than vehicles that perform poorly in crash tests.

The improvements in occupant protection shown in laboratory crash tests have also been experienced in the real world. A study by Farmer [5] in 2004 found "a driver is 74% less likely to die in cars rated good than cars rated poor in car to car head on crash of two cars of similar mass."

Similarly Lie and Tingvall [6] found "cars with three or four stars are approximately 30% safer than cars with two stars."

Studies conducted by Monash University Accident Research Centre [7] concluded that vehicles that performed well in crash tests provided higher levels of safety on Australian roads.

## B-PILLAR PEAK ACCELERATIONS

Gradual changes have occurred B-pillar peak deceleration have occurred in NCAP crashed vehicles over the last 12 years. The driver's side B-pillar accelerations are used for an indication of the acceleration experienced by the occupant compartment. The driver's side is chosen because this side impacts the deformable barrier in the offset frontal test, generating higher loads than the passenger's side.

In the offset frontal test a tri-axial accelerometer is mounted on both the driver's and passenger side of the vehicle at the base of the B-pillar near the seat belt anchorage.

For the assessment of B-pillar performance the longitudinal acceleration, Gx, was chosen as this was consistently measured by ANCAP since 1995. Additionally, Gx should give an indication of the performance of the vehicle's structure.

To determine if there was any variation in vehicle structural performance that may result in any significant variation in driver's side B-pillar peak acceleration an analysis of the results was undertaken. Gx was plotted against both year of manufacture of the tested vehicle and also the test mass.

The graph of vehicle test mass vs. Gx, Figure 1, showed a scatter around a line that trended upwards from approximately 30g at 1050kg to approximately 37g at 2050kg.

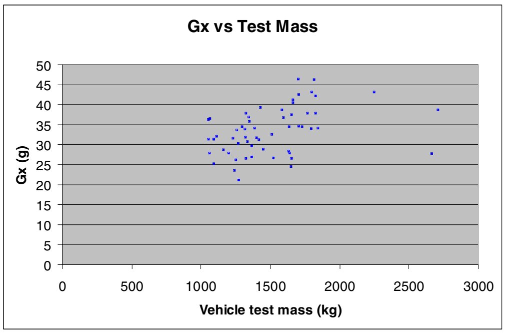


**Figure 1. Driver's side Gx verses test mass – all vehicles**

Similarly, the plot of YOM against Gx, Figure 2, also showed a small upward trend.

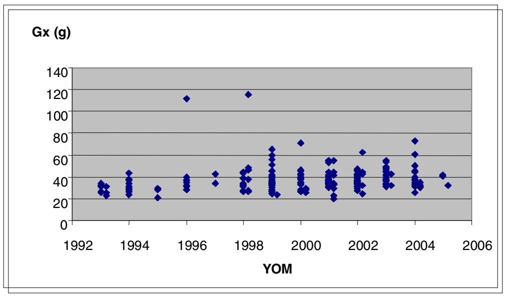


**Figure 2. Driver's side Gx verses Year of Manufacture – all vehicles**

A regression analysis was conducted with the following results:

- Gx vs. YOM y = 0.6047x - 1170.9
- $r^2 = 0.0259$

A review of the high-speed film of some tests indicates that the Gx occurred when the test vehicle bottomed out on the barrier. This is more prevalent with the larger cars.

The analysis conducted did not show any significant change in B-pillar accelerations, or time of maximum acceleration with either YOM or mass of test vehicle.

## VEHICLE CATEGORIES

As there was not any significant change due to either year of manufacture or test mass when considering all vehicles, the data was reviewed by vehicle category, i.e. large, medium and small. These are the test categories used by ANCAP and are based on vehicle mass.

Below are the plots of year of manufacture verses Gx for small (Figure 3), medium (Figure 4) and large cars (Figure 5).

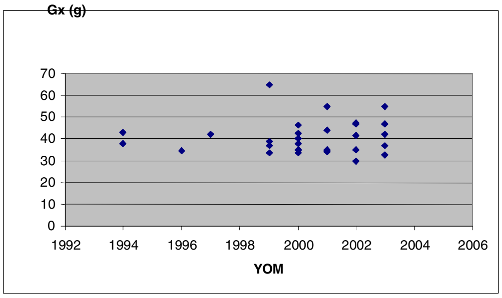


**Figure 3. Drivers Gx verses Year of Manufacture - Large Cars**

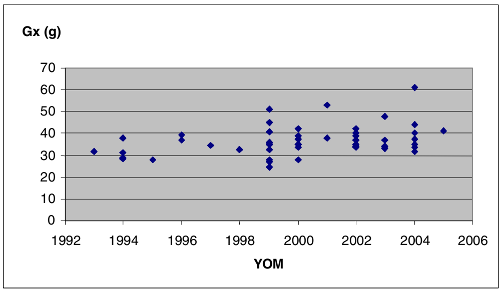


**Figure 4. Driver's side Gx Vs Year of Manufacture - Medium Cars**

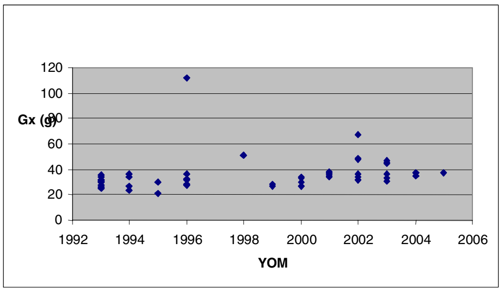


**Figure 5. Drivers side Gx Vs Year of Manufacture – Small Cars**

Each of these categories showed an increase in maximum Gx with Year of Manufacture. The regression analysis showed the following trends and correlations.

Large cars: $y = 0.2027x - 365.03$
$r^2 = 0.0039$
Medium cars
$y = 0.778x - 1519.5$
$r^2 = 0.1304$

$y = 0.6239x - 1210.8$
$r^2 = 0.0357$

It is likely that the increasing average weight of the vehicles has an effect on these results.

Both the small and medium car segments showed a discernable trend towards increased Gx with later model vehicles.

## A-PILLAR DISPLACEMENT

The second part of the paper examines the driver's side A-pillar displacement. Again vehicles from both ANCAP and IIHS tests have been used for this analysis. A total of 128 results were used; 19 large cars, 63 medium cars and 44 small cars.

The A-pillar displacement is used as a measure of structural integrity in vehicles post crash. Vehicle design since the beginning of consumer crash test programs have focused on improving the integrity of the occupant compartments.

Due to lack of data in some tests results from all tests are not able to be used and consequently the number of vehicles analysed in this section will not directly correspond to the number of vehicles analysed in the first part of the paper.

### Passenger Cars

The analysis began with considering the A-pillar displacement of all passenger cars against both test mass and year of manufacturer (YOM).

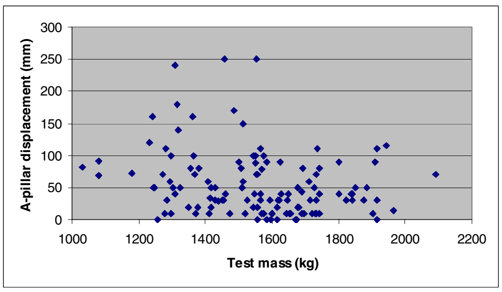


**Figure 6 Test mass verses A-pillar displacement for all passenger cars.**

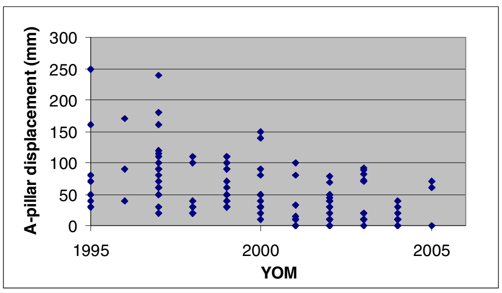


**Figure 7 Year of Manufacture vs A-pillar displacement for all passenger cars.**

The above graphs show while there is a downward trend with reducing A-pillar displacement with YOM there is no discernable trend between test mass and A-pillar displacement.

A correlation analysis was undertaken with the following results;

- test mass; $r^2 = -0.24$
- YOM; $r^2 = -0.49$

Similar analysis was conducted for large, medium and small passenger cars to consider if these same trends were throughout the range of vehicles tested or if the trend was more prominent in one particular vehicle category.

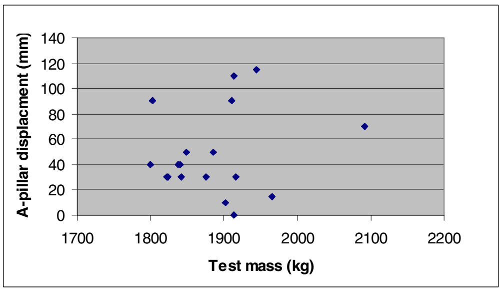


**Figure 8 Test mass verses A-pillar displacement for large passenger cars.**

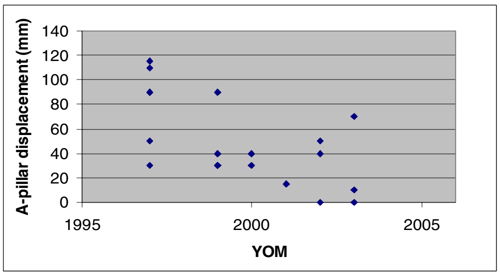


**Figure 9 Year of Manufacture verses A-pillar displacement for large passenger cars.**

Correlation analysis results;

- test mass; $r^2 = 0.17$
- YOM; $r^2 = -0.61$

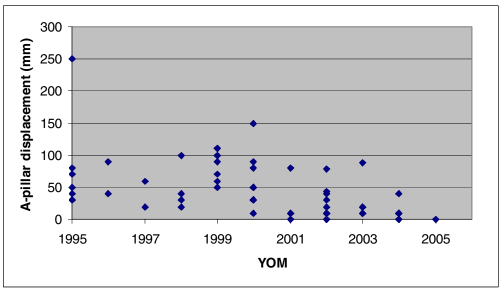


**Figure 10 Test mass verses A-pillar displacement for medium passenger cars.**

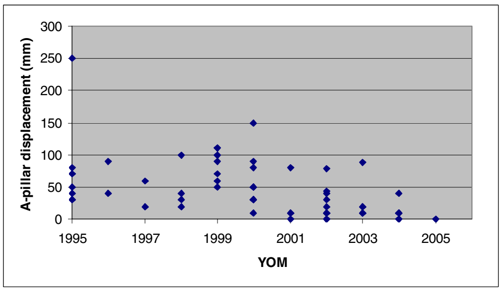


**Figure 11 Year of Manufacture verses A-pillar displacement for medium passenger cars.**

Correlation analysis results;

- test mass; $r^2 = -0.27$
- YOM; $r^2 = -0.49$

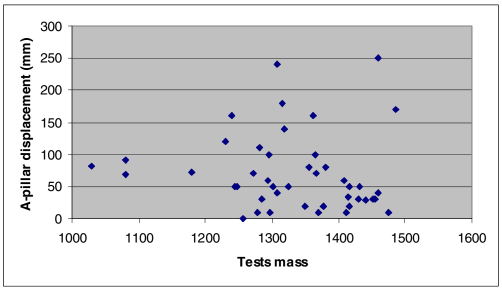


**Figure 12 Test mass vs A-pillar displacement for small passenger cars.**

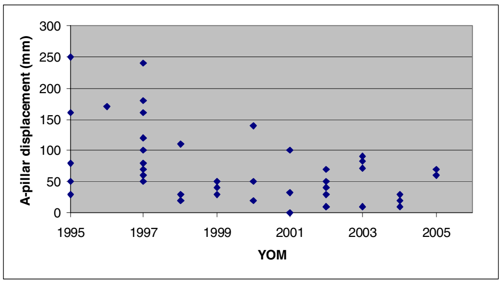


**Figure 13 Year of Manufacture vs A-pillar displacement for small passenger cars.**

Correlation analysis results;

- test mass; $r^2 = -0.10$
- YOM; $r^2 = -0.48$

This analysis showed the trend for a reduction in A-pillar displacement with newer cars, i.e. increasing YOM, was consistent across all vehicle classes.

There were no trends between A-pillar displacement and test mass, either when considering all passenger cars or when considering individual car categories.

**Sports Utility Vehicles**

A similar analysis was conducted for SUVs results from both ANCAP and IIHS. A total of 69 results were used; 23 large SUVs, 18 medium SUVs and 26 small SUVs.

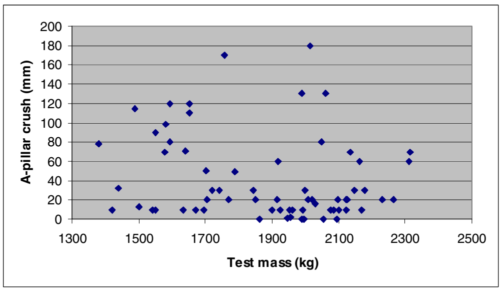


**Figure 14 Test mass verses A-pillar displacement for all SUVs.**

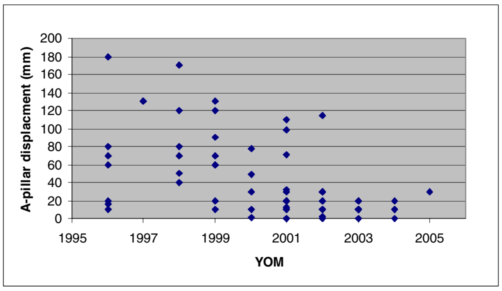


**Figure 15 Year of Manufacture verses A-pillar displacement for all SUVs.**

Correlation analysis results;

- test mass; $r^2 = -0.21$
- YOM; $r^2 = -0.55$

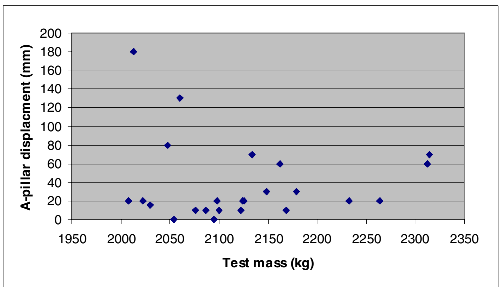


**Figure 16 Test mass verses A-pillar displacement for large SUVs.**

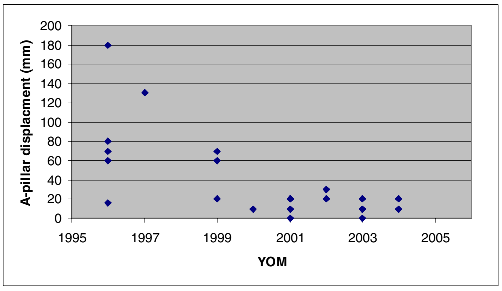


**Figure 17 Year of Manufacture verses A-pillar displacement for large SUVs.**

Correlation analysis results;

- test mass; $r^2 = -0.07$
- YOM; $r^2 = -0.68$

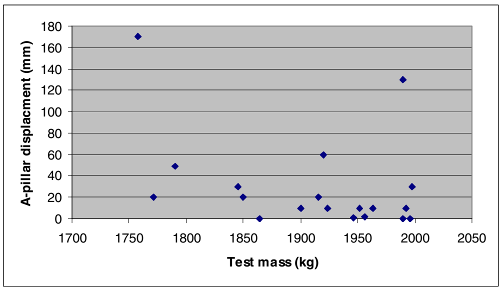


**Figure 18 Test mass verses A-pillar displacement for medium SUVs.**

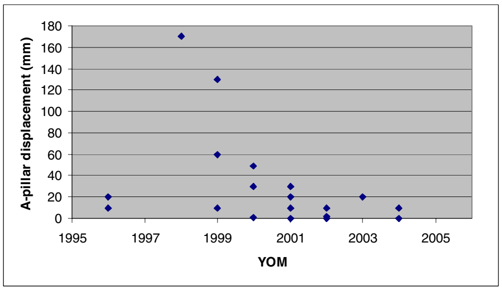


**Figure 19 Year of Manufacture verses A-pillar displacement for medium SUVs.**

Correlation analysis results;

- test mass; $r^2 = -0.01$
- YOM; $r^2 = -0.39$

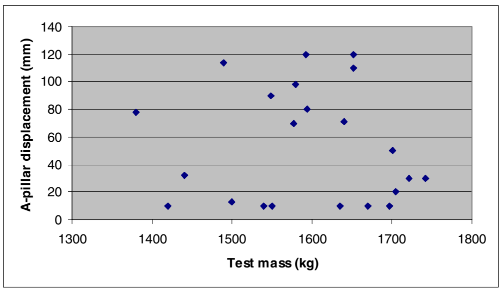


**Figure20 Test mass verses A-pillar displacement for small SUVs.**

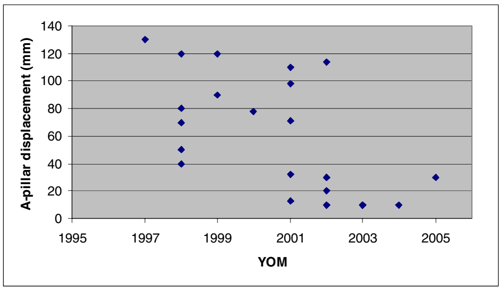


**Figure 21 Year of Manufacture verses A-pillar displacement for small SUVs.**

Correlation analysis results;

- test mass; $r^2 = -0.08$
- YOM; $r^2 = -0.66$

Similarly to the passenger cars, this analysis showed a trend for a reduction in A-pillar displacement for newer SUVs while test mass did not appear to influence A-pillar displacement.

## DISCUSSION

The analysis of peak B-pillar longitudinal acceleration, Gx, showed an upward trend with increased test mass and also for newer vehicles. However, the regression analysis did not show any significant correlation with either YOM or mass of the test vehicle.

The analysis did show that for increasing Gx on the driver's B-pillar a corresponding decrease in A-pillar displacement. An increase in B-pillar deceleration is a good indicator of the deceleration of the vehicle in crash test and gives an indication of the stiffness profile of the vehicle.

The stiffness of the front end of a vehicle is obviously a key aspect of design not the least when a design is considered against the offset crash test. However, optimal performance in an offset crash requires a rigid front end and a strong occupant compartment that effectively absorbs crash forces.

The trend witnessed in the compiled tests indicate that, particularly in the case of small cars, that overall vehicle deceleration may be compensated for by an increased stiffness of the occupant compartments. Essentially the crumple zones are constructed less stiff than the occupant compartments they are designed to protect.

The IIHS have contended that 'manufacturers don't simply stiffen the front ends of their vehicles to perform well in offset tests. Good performance in offset crashes requires strong, or stiff compartments and front ends that effectively absorb crash forces. To achieve this result, the crumple zones need to be less stiff than the compartments' [8]. It may be that we are observing improvements in structural design to optimise for frontal stiffness to achieve desired occupant compartment rigidity.

This observation of increasing vehicle deceleration in parallel with decreasing A-pillar displacement was particularly marked in the small car category. In this case the increase in Gx may be in some way attributed to the stiffness provided to the structure to ensure that the occupant compartments where able to withstand the forces applied by impacts with larger vehicles.

The lack of correlation and variation in both Gx a could be due to limitations of the offset frontal test at 64 km/h. Offset test assesses performance of structure, i.e. how well passenger compartment retains survival space.

The offset test at 64 km/hr may result in vehicles bottoming out on the barrier prior to all the crash energy being absorbed by the frontal vehicle structure. Alternatively, this could indicate there have been only limited changes to the front vehicle structure to manage the crash energy.

This corresponds to research conducted by both the US IIHS and also NHTSA. In their 2001 study, the IIHS found no correlation between stiffness and offset structural performance of vehicles. Similarly, a 1999 NHTSA study on the US NCAP results for light trucks and vans (LTVs) found that during the 14 years of US NCAP frontal crash testing, on average, LTVs have become less stiff.

Additionally, the ANCAP crash tests have shown significant improvements in occupant protection as measured by the test dummies and also through analysis of the vehicle deformation.

The ANCAP crash tests have demonstrated that while the integrity of the vehicle passenger compartment has improved with reduction in intrusion the HIC and chest deflection measures have also reduced.

## CONCLUSIONS

This paper reviewed driver side peak longitudinal acceleration and the A-pillar deformations during consumer crash tests over the period between 1993 and 2005.

This analysis showed that the deceleration levels affected on the vehicle as shown by the B-pillar decelerations is increasing. This effect is most significant in the small car segment. The fact that this corresponds also to the most dramatic reduction in A-pillar displacement reduction may indicate a reaction to compatibility issues.

These effects are likely to be still at the lower order of influence on injury outcomes at regulatory and consumer crash test speeds. It seems likely that the occupant restraint systems remain the most significant factor in reducing serious head and chest injury.

However, optimisation of front stiffness profiles and occupant compartment rigidity by vehicle mass categories may have further potential as a design approach.

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[8] IIHS Status Report, Vol 39, No. 8, Aug 28, 2004.

[9] IIHS Offset Frontal Crash Test Reports, various, from 1995 to 2004.