

Roof Strength and Occupant Protection in Rollover Crashes

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Abstract

A fundamental principle of protecting vehicle occupants in crashes is to minimise the deformation of the passenger compartment. This principle should also apply to rollover crashes but the issue has been clouded by opposing arguments in litigation cases - mostly in the USA.

The US government introduced a regulation for static roof strength in 1973 and recently reviewed the regulation. In its submission to the review, the Insurance Institute for Highway Safety found a correlation between static roof strength and risk of occupant injury in a rollover crash for compact sports utility vehicles (SUVs). Further research on passenger cars convinced IIHS that a consumer rating based on a static roof strength test was worthwhile, at least as an interim measure while a suitable dynamic test was developed. The IIHS method rates vehicles by strength-to-weight ratio as measured in the regulation test, with value of four needed for a good rating.

This paper sets out the results of a review of the IIHS rating method and its applicability to Australia.

Keywords

Vehicle safety, Occupant protection, Roof strength, FMVSS, NCAP

Introduction

Around a quarter of Australian light vehicle occupant fatalities occur in crashes involving rollover crashes. These crashes tend to be more severe than most other types of crashes (Grzebieta [1], Richardson [2]).

One factor associated with the risk of injury in a rollover crash is roof strength (Brumblelow *et al.* [3]). Although there is no Australian Design Rule for roof strength, it is likely that all cars marketed in Australia would meet the requirements of US Federal Motor Vehicle Safety Standard 216 (FMVSS 216). Henderson *et al.* [4] found that there was little point introducing an ADR based on FMVSS 216 - mainly because most cars already complied with the FMVSS.

FMVSS 216 was introduced in 1973 and required the front corner of the roof to withstand a quasi static force equal to at least 1.5 times the weight of the vehicle, up to 127mm of deflection. This is known as a strength-to-weight ratio (SWR) of 1.5. Figure 1 shows an FMVSS 216 test rig.

An enhanced roof crush test is being introduced by National Highway Traffic Safety Administration (NHTSA) in the USA (NHTSA [5]). This is the current FMVSS 216 test, followed by a similar load applied to the roof on the previously untested roof pillar on the other side of the vehicle. The minimum SWR required in FMVSS 216 will increase from 1.5 to 3.0 for light vehicles (gross mass under 2,700kg). Phase-in begins in September 2012, and all vehicles must comply by September 2016.



Figure 1. FMVSS 216 roof crush testing by IIHS

Some road safety advocates in the USA have proposed that a dynamic rollover test be introduced such as the Jordan Rollover System (JRS) (Friedman *et al.* [6], Berg [7], Richardson *et al.*[8]). This test involves spinning the car about an approximately longitudinal axis and dropping it so that a corner of the roof contacts the ground (simulated by a moving platform).

There has been considerable debate in the USA and elsewhere about the usefulness of the JRS for determining occupant protection. This appears to be partly because JRS test results have been used in litigation cases. It is likely to be several years before a dynamic test is available that is suitable for either regulatory or consumer rating purposes.

In 2008 the US-based Insurance Institute for Highway Safety provided detailed comment on NHTSA's proposed changes to FMVSS 216 (Brumblelow *et al.* [9]). IIHS made the following comments about dynamic rollover tests:

"A dynamic rollover test using instrumented test dummies would be a gold standard for assessing occupant protection in rollover crashes. However, we are not certain that the procedures for dynamic test are reasonably repeatable, and we are not sure how to conduct such a test to obtain the most relevant information. Real-world rollover crashes vary widely. They often are preceded by violent events as vehicles leave the road and begin to roll over. The positions of occupants at the time a rollover begins are uncertain, so it is difficult to position test dummies to represent where occupants would be in real-world rollover crashes. Current dummies designed for front, side, and rear testing have not been shown to behave in a human-like manner in rollover crashes."

Roof strength and injury risk

The concept of a strong passenger compartment is not new:

"... The iconic Pininfarina and Ferrari companies then combined to build a race safety concept car, the Sigma Grand Prix. Based on a 1967 Ferrari F1, it was first shown in 1969 and brought into the real world several ground-breaking concepts that have since formed the basis of nearly all race vehicle design and rule-making, including:

- Comprehensive built-in fire protection
- Six-point harness restraint system
- Head and neck restraint system
- *Driver's safety cell and rollover protection*, with surrounding collapsible structures to front, rear and side
- Crash data recording ..."

(from Australian Institute for Motor Sport Safety (AIMSS) brochure, [10]).

Hu [11], in a retrospective study of USA crashes, concluded "Age, the number of quarter-turns, rollover initiation type, maximum lateral deformation adjacent to the occupant, A-pillar and B-pillar deformation are significant predictors of head-face-neck injury odds for belted occupants..."

Strashny [12] conducted a statistical analysis of NASS data for NHTSA and concluded that "the relationship between injury severity and [intrusion or headroom] was statistically significant". This analysis was based on data from 24 car models.



Figure 2. Jordan rollover system (from Friedman [5])

IIHS conducted static roof crush tests of several SUV style vehicles and compared the results with real-world crash data on the risk of serious injury in a rollover crash. IIHS found good correlation between SWR and risk of injury:

"IIHS's study [of compact sports utility vehicles] clearly shows the relationship between increased roof strength and reduced injury risk in rollover crashes. We support the continued use of the current roof crush procedures set forth in the existing federal standard on roof crush resistance. However, our study supports requiring vehicles to have a strength-to-weight ratio of at least 3.0. We estimate that a 1-unit increase in peak strength-to-weight ratio — for example, from 1.5 times vehicle weight, as specified in the existing federal standard, to 2.5 times, as proposed by the National Highway Traffic Safety Administration — would reduce the risk of serious or fatal injury in a rollover crash by 28 percent. Increasing roof strength requirements beyond 2.5 times vehicle weight would reduce injury risk even further." (Oesch [13])

More recent IIHS research with cars found similar results, with an estimated 22% reduction in the risk of incapacitating or fatal driver injury for a one-unit improvement in SWR [3].

Possible NCAP rating based on roof crush resistance

IIHS research [3] over the past 12 months included measurement of the SWR for numerous vehicle models. This identified a wide range in performance for vehicles in similar categories. In March 2009 IIHS published the first results of its new roof strength rating system. This simply assigns a rating of Good (SWR greater than 4.0), Acceptable (SWR greater than 3.25 and up to 4.0), Marginal (SWR greater than 2.5 and up to 3.25) or Poor (SWR less than 2.5), depending on the SWR, as illustrated in Figure 3.

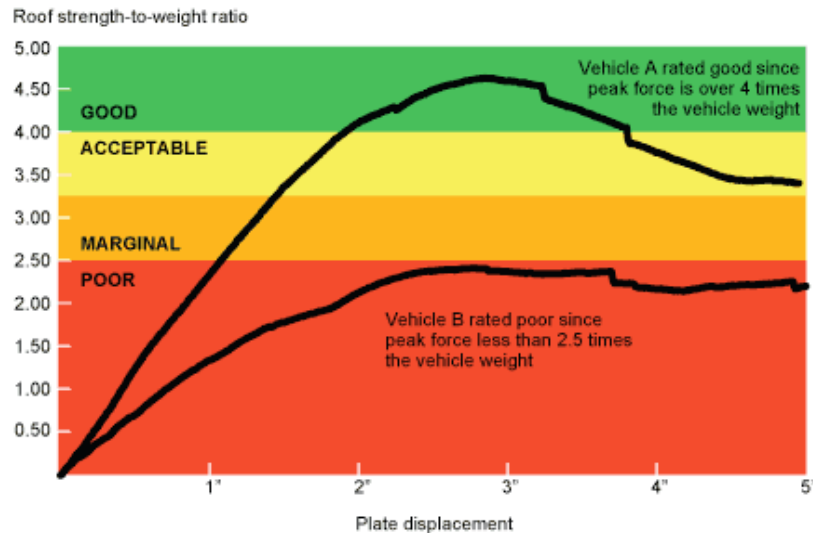


Figure 3. IIHS Rating System of Strength-to-Weight Ratio

NHTSA [5] reports the results of static roof-crush tests for a wide range of vehicles. Figure 4, derived from the published NHTSA and IIHS data (IIHS website), shows the Strength-to-Weight Ratio (SWR) plotted against unladen mass. Also shown on the graph is the IIHS rating system, with a "good" rating for an SWR of 4 or more. The X-axis is set at the current FMVSS 216 SWR requirement of 1.5.

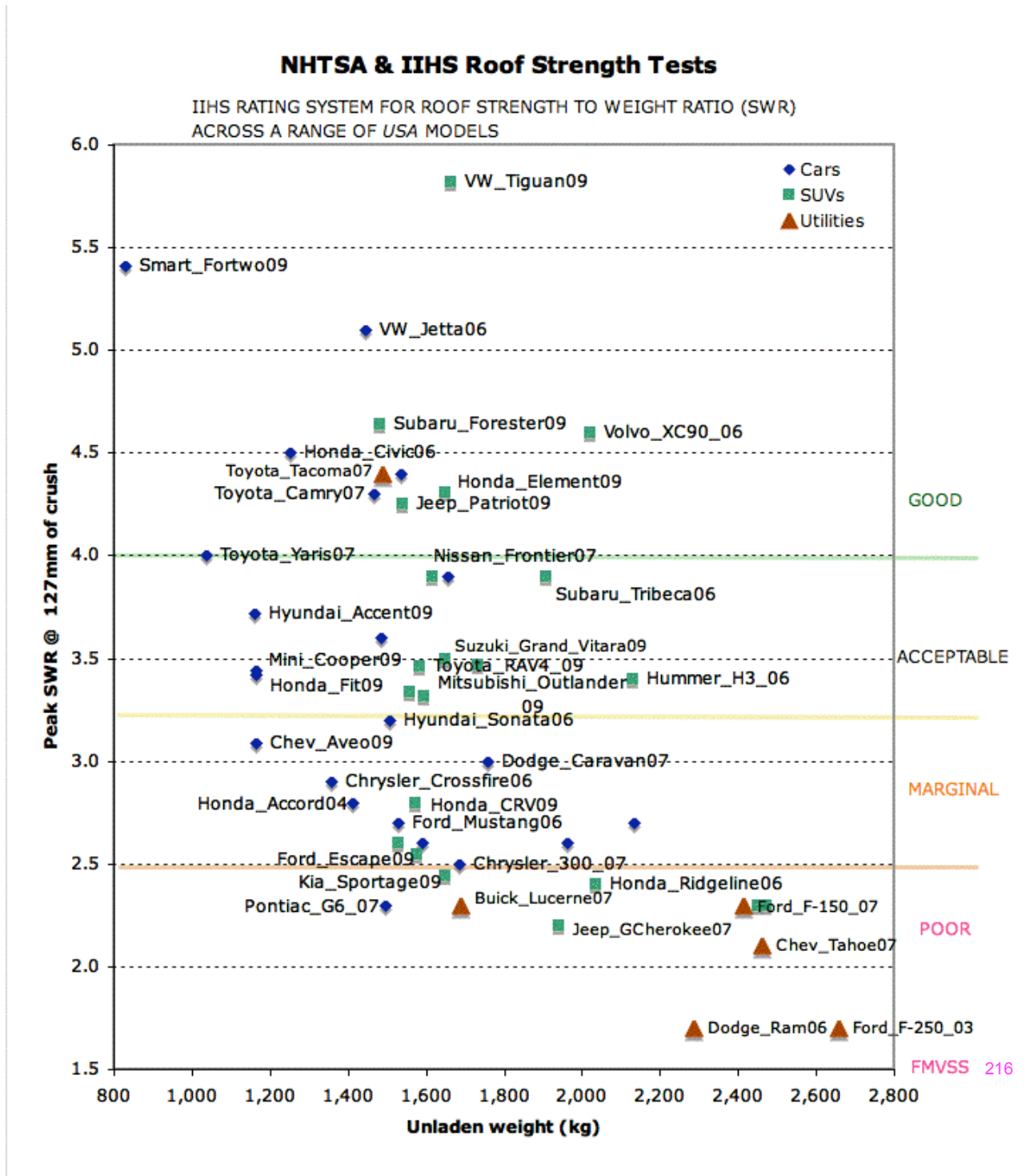


Figure 4. Strength-to-weight ratio for a range of USA vehicle models

From Figure 4, it is evident that there is a large spread of SWR for vehicles in the same class and size. This suggests that vehicles of any type can be designed to have a high SWR (Figure 5).



Figure 5. Snapshot from IIHS video comparing roof crush of Volkswagen Tiguan and Kia Sportage

Consumer information programs such as New Car Assessment Programs (NCAPs) could provide comparative information to consumers regarding the roof strength of different vehicle models.

In addition to a rating based on SWR, there may be an opportunity for NCAPs to encourage inflatable side curtains and seat belt pre-tensioners that are deployed in a rollover event. These should also be required to protect outboard rear-seat occupants (eg pre-tensioners and curtains for rear outboard seats). For example, there could be a "gold" rating that is an SWR of 4 or more and suitable curtains and pre-tensioners. In these cases manufacturers may need to supply evidence of the deployment of this equipment in a rollover event.

Conclusions

Occupant injury in rollover crashes is a substantial road safety problem in Australia. Roof strength has been shown to be an important indicator of injury risk in USA crash studies.

Based on the IIHS initiative, a consumer rating system for occupant protection in rollover crashes is feasible and could be based on the current single static roof crush test of FMVSS 216.

There has been considerable debate in the USA about proposed changes to FMVSS 216. There are no signs of the introduction of roof strength regulations outside North America.

An NCAP rating system can side-step this debate because it would not be compulsory for all vehicles to meet minimum requirements - the rating system simply spreads the field and leaves it to consumers to decide whether to buy vehicles that perform well.

Disclaimer

This document represents the views of the authors and does not necessarily represent ANCAP policy.

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