EVALUATING 'REAL WORLD' ROOF STRENGTH THROUGH INVERTED DROP TESTING

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ABSTRACT

The only federal standard that addresses vehicle roof strength is Federal Motor Vehicle Safety Standard FMVSS) 216. To pass this standard a vehicle must resist an intruding plate with a load of 1.5 times the weight of the vehicle and is designed to offer protection to occupants in rollovers. The conditions under which FMVSS 216 is applied are significantly less stringent than those experienced in actual rollover accidents. When vehicles are tested in a way that is consistent with actual rollover accidents, they will often crush significantly under loads that are 30 to 50% of the published FMVSS 216 peak loads. As our series of inverted drop tests will show, many vehicles will crush catastrophically when tested under these 'real world' conditions.

The three major factors that lead to diminished roof strength in the real world are 1) high angle effect, 2) glass effect and 3) variation between prototype and production vehicles. The three factors leading to diminished roof strength are discussed in detail below.

'High Angle' Effect

In the 1980s, General Motors conducted field accident analysis and determined that real world rollover loads occurred at a more lateral orientation (commonly referred to as 'high angle') than that applied in FMVSS 216 [1]. They conducted static tests of multiple vehicles with loads applied more laterally than specified in the FMVSS 216 configuration. The results indicate that vehicles designed primarily to pass FMVSS 216 have diminished roof strength in this lateral loading environment. The reductions in roof strength are on the order of 27%. Therefore, in realistic rollover impacts, the roof is often only able to resist intrusion with 73% of the roof strength it produces in FMVSS 216.

Glass Effect

There are many FMVSS 216 data traces where significant amounts of roof strength are lost when the windshield (or other glass) breaks. The loss in strength is from a low of 10% to a high of 50%. Many vehicles would fail FMVSS 216 (and some by a considerable margin) if the windshield were broken prior to the test. The maximum load achieved in an FMVSS 216 test is often determined by the timing of the windshield failure, as shown in a series of FMVSS 216 plots in Figure 1. The maximum load is typically reached just before the windshield breaks after which the load on the roof begins to decrease rapidly. Prior to fracture, the glazing acts as a temporary structural reinforcement for the roof structure by providing a shear panel that distributes loads.

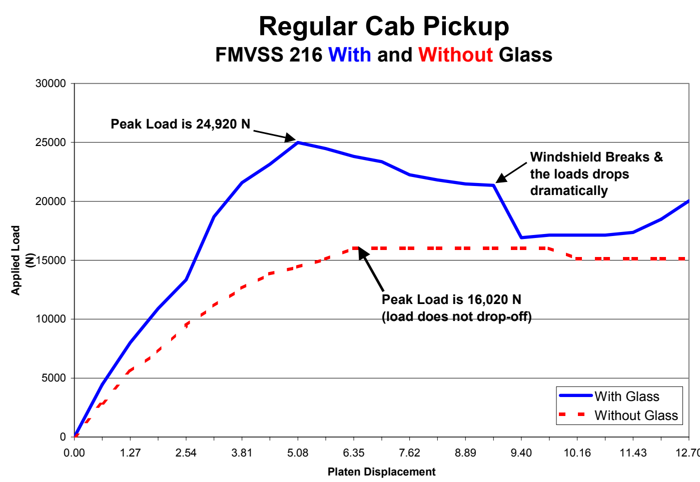

Figure 1: FMVSS 216 Plots Illustrating Glass Effect

In real world rollovers, one of the first things to be damaged is typically the windshield or other glass. Therefore, it is unreasonable to rely on the strength of the windshield to achieve the required FMVSS 216 force level. Glass may provide an additional source of roof crush resistance, but cannot be relied upon unless its integrity can be guaranteed.

Prototype v. Production Body Variation

When manufacturers certify vehicles for FMVSS 216, they typically run tests on prototype vehicles. Prototype vehicles are one-of-a-kind vehicles that are carefully built for the purposes of certification testing. It is known that prototype vehicles are typically on the order of 5% to 15% stronger than production vehicles, based on actual studies conducted by auto manufactures. In order to account for prototype/production body variation, most manufactures include a 10% to 25% factor of safety that is applied to the FMVSS 216 requirement, in order to ensure that any production vehicle will meet the standard.

INVERTED DROP TESTING

Two inverted drop test studies were conducted on various vehicles in order to evaluate each roof's structural performance in a real world environment (see Figure 1). Numerous technical papers have been published on the subject of inverted drop testing [2-7]. The various test set-ups are shown in Table 1. Results are shown in Table 2.

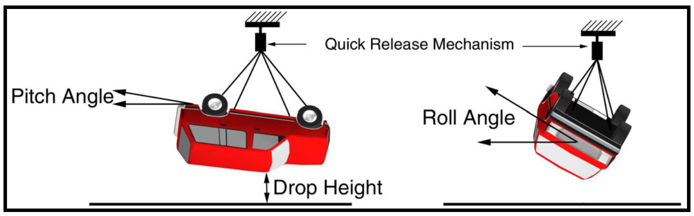

Figure 2: Inverted Drop Testing Procedure

Table 1: Inverted Drop Testing Set-Ups

Test Vehicle	Windshield Condition	Drop Height	Roll Angle	Pitch Angle	Test Weight
INVERTED DROP TEST STUDY #1					
Small SUV	Intact	30.5 cm	25°	5°	14,955 N
Small SUV	Removed	30.5 cm	25°	5°	15,622 N
INVERTED DROP TEST STUDY #2					
2-dr Hatchback	Removed	0 cm	37.5°	5°	11,285 N
Large SUV*	Removed	0 cm	36°	16°	26,422 N
Reg Cab Pickup	Broken	0 cm	25°	5°	15,489 N
Midsize SUV	Broken	0 cm	31°	5°	14,510 N

*The Large SUV was lowered slowly onto the test surface.

Inverted Drop Test Study #1

Two equivalent small SUVs were subjected to inverted drop testing in order to analyze the effect of the windshield. The first vehicle was equipped with the original windshield while the windshield of the second vehicle was removed.

After undergoing identical inverted drop testing procedures, the stock vehicle without windshield exhibited approximately 30% more roof crush than the vehicle with OEM windshield. This demonstrates that the windshield alone can have a substantial effect on roof strength.

Inverted Drop Test Study #2

Four different vehicle types were subjected to zero drop height inverted drop testing at the SAFE facility. Prior to being released, each vehicle's windshield was either broken or removed. In three of the four tests, the vehicles were released while having a roll angle such that the vehicle's center of gravity was located approximately above the contact point ('high angle'). All four vehicles were released with the top of the A-pillar in contact with the ground (0" drop height), with a 5° pitch angle.

All four vehicles sustained significant damage to the roof structure over the occupant compartment, due to the failure of headers, pillars and critical junctions/transitions. The maximum deformation at the top of the loaded A-pillar during the primary contact ranged from 0.17 to 0.26 m. This illustrates the fact that many production vehicle roofs cannot withstand their own weight when inverted. FMVSS 216 requires that vehicles withstand 1.5 times their own weight within 12.7 cm (5") of roof crush. However, when loaded in a more realistic way, at a high angle with broken glass, vehicles can crush significantly more than 12.7 cm (5") under their own weight.

Table 2: Inverted Drop Testing Results

Test Vehicle	Drop Height	A-Pillar Crush
INVERTED DROP TEST STUDY #1		
Small SUV (stock)	30.5 cm	24.1 cm
Small SUV (no windshield)	30.5 cm	31.2 cm
INVERTED DROP TEST STUDY #2		
2 dr Hatchback	0 cm	17.0 cm
Large SUV	0 cm	20.3 cm
Reg Cab Pickup	0 cm	24.6 cm
Midsize SUV	0 cm	26.4 cm

CONCLUSIONS

- The tests conditions of FMVSS 216 are not representative of 'real world' loading conditions;
- Vehicles that pass FMVSS 216 can fail under their own weight when inverted and released at a high angle and without glass;
- Prior to fracture the windshield (and other glass) can have a significant effect on roof strength;
- Vehicles roofs demonstrate diminished roof crush resistance at higher or more lateral load application angles.

REFERENCES

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