Crashworthiness Evaluation
Roof Strength Test Protocol
(Version I)

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Roof strength evaluations consist of a quasi-static test conducted on a vehicle's roof in a manner similar to tests used to judge compliance with Federal Motor Vehicle Safety Standard 216 (Office of the Federal Register, 2009). The main differences between the procedure specified by the Insurance Institute for Highway Safety (IIHS) and that specified by the US federal government are that the IIHS procedure:

- specifies testing one side of a vehicle's roof,
- does not include a headroom criterion,
- specifies testing to a given displacement instead of a given force level, and
- specifies setting the vehicle's pitch angle during testing based on the measured on-road pitch angle.

An overall rating is assigned based on the peak strength-to-weight ratio (SWR) measured within 127 mm of plate displacement.

Test Vehicle Selection and Curb Weight Measurement

Curb weight values used for calculating SWR are based on IIHS measurements of a vehicle, not the manufacturer's specified curb weight. For each vehicle model, the specific trim level selected for measurement is the one that most closely meets the IIHS definition of a "typical" vehicle of that class. This definition is made for each class by listing the presence or absence of certain features in a prioritized order. As an example, the following were the requirements for small SUVs in 2009:

1. 4-wheel drive
2. Automatic transmission
3. 4-cylinder engine
4. Air conditioning
5. No sunroof
6. No third row seat
7. Manually adjustable front seats
8. Power windows/locks
9. No longitudinal roof racks

When a specific model is not available in a trim level that meets all the requirements, any feature higher on the list takes precedence over all features that follow. In the example above, a model with 4-wheel drive available only in combination with a V6 engine would be selected before a 2-wheel drive trim with a 4-cylinder engine. The various requirements by vehicle class are listed in the Appendix.

Vehicle curb weight is measured with full fluid levels using scales manufactured by Longacre Racing Products (Computerscales DX series 72634).

Whenever possible, the vehicle acquired for testing is the same vehicle used for the curb weight measurement. At times it is necessary to test a vehicle that does not meet the definition of

typically equipped, and the curb weight measurement is applied from another vehicle that does meet the definition. In these cases, the test vehicle does not differ from the typically equipped definition in any way that might influence the roof strength (e.g., a vehicle with a sunroof would not be tested if the typically equipped vehicle lacks this option).

When a given model is available in more than one body type (e.g., hatchback and sedan), the most popular version is tested. Counts of insurance policies from the Highway Loss Data Institute serve as the main source for determining the most popular body type. The rating only is applied to the tested body type. Corporate twins of the same body type and with identical roof structure are assigned the same rating based on the one test.

Once the test vehicle has been acquired, either the driver or passenger side of the vehicle is selected for testing. For most vehicles, the test side is chosen at random. However, for roof designs that appear asymmetrical, engineering judgment is used to select the side of the roof that may result in a lower peak force.

Some of the vehicles evaluated in the roof strength test program have been used in the IIHS bumper test program. Such vehicles have been subjected to an impact on the front and/or rear of the vehicle at either 5 km/h (3.1 mi/h) to the corner or 10 km/h (6.2 mi/h) across the full width (IIHS, 2007). Rear damage to minivans, SUVs, wagons, or hatchbacks pertinent to rollover protection is repaired before the roof strength test. Cosmetic damage is repaired at IIHS discretion. Parts are repaired or replaced as appropriate based on the judgment of professional insurance appraisers.

Test Vehicle Preparation

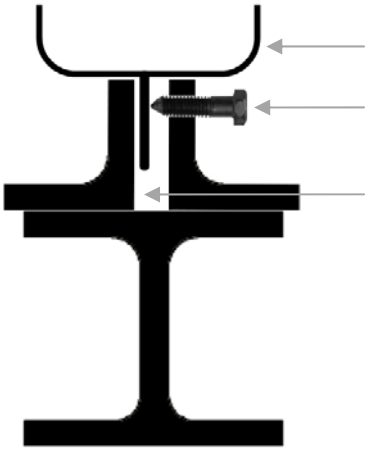
With the vehicle on a level surface, the on-road pitch angle at the front door sill is measured on both sides of the vehicle. All roof racks and other nonstructural items that may be contacted during the test are removed from the vehicle's roof unless the vehicle manufacturer requests otherwise. Any trim or other components are removed if they interfere with supporting the vehicle along its rocker panels.

For vehicles with vertical pinch weld flanges on the bottom of the rocker panels, the vehicle support system consists of one I-beam for each rocker panel, with two lengths of angle iron welded to the top of the I-beam. The angle iron on the outboard side of the vehicle is drilled and tapped to accommodate bolts with cup- or cone-pointed tips. Once the vehicle's rocker panel is supported by the angle iron, the bolts are tightened against the pinch weld flange to clamp the system in place (Figures 1 and 2).

When the pinch weld flange has a bend that prevents supporting the sill with one I-beam, more than one I-beam can be used on each side of the vehicle. For vehicles with no pinch weld flange, or with a nonvertical flange angle that precludes clamping, mounting by another method may be necessary, such as that described in the National Highway Traffic Safety Administration's (2006) Laboratory Test Procedure.

Prior to testing, the front row seat back on the side being tested is reclined to prevent interaction with the crushing roof. Rear seats are latched in their upright position. All windows are closed and doors are locked.

Figure 1
Vehicle Rocker Panel Support System



Vehicle rocker panel with pinch weld flange

Clamping bolts

¾ in. gap between two pieces of angle iron welded to I-beam

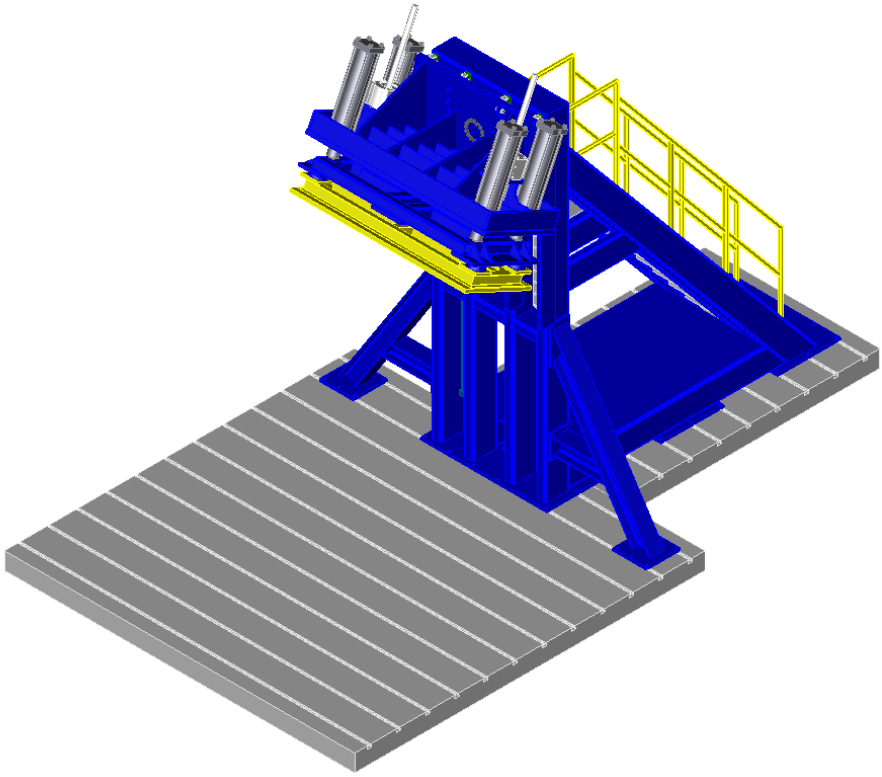
I-beam:	HR A-36 W4x13
Angle iron:	2 × 2 × ⅜ in.
Bolts:	⅜ × 1½ in. spaced 3 in. apart and ⅜ in. down from top edge of angle iron

Figure 2
Rocker Panel Support System Attached to Vehicle
Outboard (top) and Inboard (bottom)

Testing

Roof strength evaluations are conducted on a quasi-static test system manufactured by MGA Research Corporation (Figure 3). The system consists of an upright assembly and attached loading head that can be fixed at varying heights from the ground as well as at pitch angles ranging from -5 to +5 degrees to accommodate testing on the driver or passenger side. The roll angle is permanently fixed at 25 degrees. Four hydraulic actuators control the movement of the platen along two linear guides. The entire system is mounted on a T-slot bed plate anchored to the floor of the test facility.

Figure 3
MGA Roof Crush Test System



Two HR A-36 W10x88 I-beams are mounted on the bed plate perpendicular to the longitudinal axis of the platen. The vehicle, with attached rocker panel support system, is placed on these beams. The vehicle is adjusted so that:

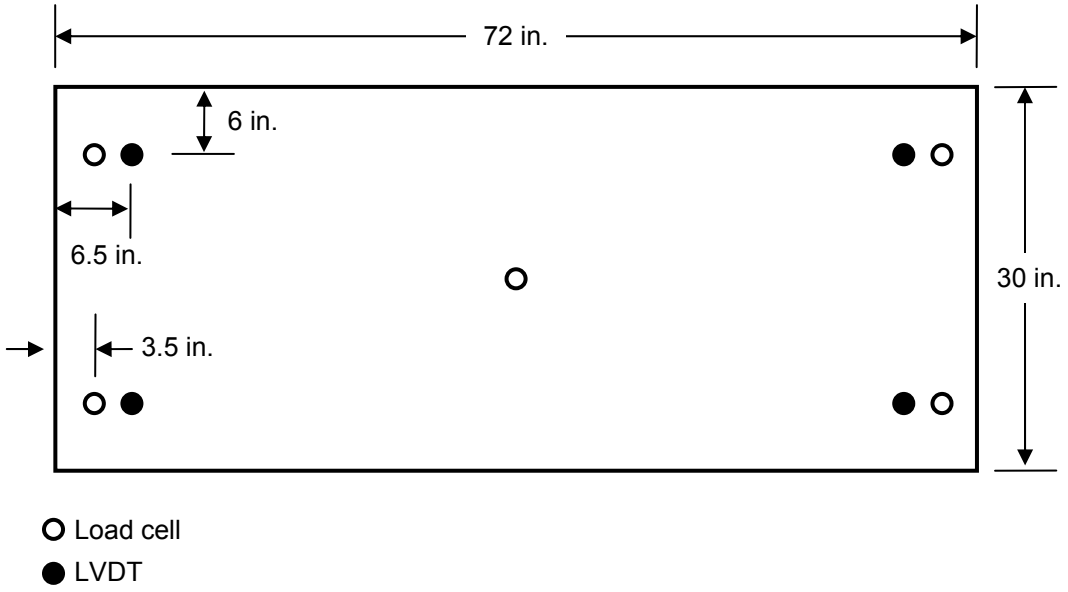
1. The longitudinal centerline of platen is within 10 mm of initial roof contact point.
2. The yaw angle of the vehicle relative to longitudinal axis of the platen is 0 ± 0.5 degrees.
3. The midpoint of the platen's forward edge is 254 ± 10 mm forward of the most forward point of the roof (including windshield trim if it overlaps the roof) lying on the vehicle's longitudinal centerline.
4. The pitch angle of the vehicle matches the on-road angle, while also accounting for any difference between the platen's pitch angle and the nominal -5 degrees. The maximum combined difference of the vehicle and platen pitch angles from their targets is ± 0.5 degrees. (For example, if the on-road vehicle pitch angle is -0.2 degrees and the platen

pitch angle is -5.2 degrees, the target sill angle for the test is -0.4 ± 0.5 degrees.) If necessary to achieve this angle, shims are inserted between the rocker panel supports and the W10x88 I-beams attached to the bed plate.

Once the vehicle is positioned correctly, the rocker panel supports are clamped to the two perpendicular I-beams, and the beams are marked to allow confirmation that the vehicle position is maintained during the test. For body-on-frame vehicles, the frame is supported to prevent the weight of the chassis from stressing the body at the body mounts.

The roof is crushed to a minimum displacement of 127 mm at a nominal rate of 5 mm/second. Some tests are conducted to a greater displacement to collect additional strength data for research purposes. Force data are recorded from five load cells (Interface Inc. model 1220) attached to the loading platen. Displacement data are recorded from four linear variable displacement transducers (LVDTs) (MTS Temposonics model GH) integrated into the hydraulic actuators. Figure 4 shows the locations of the load cells and LVDTs on the loading platen.

Figure 4
Position of Load Cells and LVDTs on Loading Platen



Force and displacement data are collected with a National Instruments USB-6210 data acquisition system and reported at 100 Hz. These data are based on a sampling rate of 2,000 Hz, with every 20 points being averaged to produce the output data at 100 Hz.

The displacement-time histories from the LVDTs are compared to verify that the platen's roll angle and pitch angle (relative to the vehicle's on-road pitch) were maintained at 25 ± 0.5 degrees and -5 ± 0.5 degrees, respectively.

The precrash and postcrash conditions of each test vehicle are documented with still photographs. The position of the vehicle in the test fixture also is recorded. Motion picture photography is made of the test with real-time video cameras.

Calculation of SWR Rating

Force and displacement data are recorded for 5 seconds prior to each test, while the test system holds the loading platen at initial roof contact. The data recorded from 1 to 4 seconds of this hold time are averaged for each channel to produce a measurement offset that is subtracted from the data recorded during the crushing of the roof. After removing the offset for each channel, the force-displacement curve is plotted using the summed output from the five load cells and the average displacement from the four LVDTs.

The maximum force prior to 127 mm of platen displacement is divided by the measured curb weight to obtain the SWR. Both force and curb weight are rounded to the nearest pound prior to performing the calculation, and the resulting SWR is rounded to the nearest one-hundredth of a unit. Displacement is rounded to the nearest 0.1 mm. (The maximum displacement where the load can be used for the vehicle rating is 126.9 mm.) The vehicle's rating is assigned based on the boundaries listed in Table 1.

Table 1
Roof Strength Rating Boundaries

SWR	Rating
≥4.00	Good
≥3.25 to <4.00	Acceptable
≥2.50 to <3.25	Marginal
<2.50	Poor

All trim levels sharing the tested vehicle's body type and roof structure are assigned the same rating as the typically equipped trim level, provided their curb weights do not exceed 110 percent of the selected vehicle's weight. Based on published curb weights from multiple sources, any trim levels that may exceed this weight are identified and weighed. If the weight does exceed 110 percent of the weight of the selected vehicle, a unique SWR is calculated for that trim level. If this SWR results in a lower rating, both ratings are reported for the model, with a split according to trim level. If a trim level weighs more than 110 percent of the typically equipped model, but the lower SWR does not fall in a lower rating band, only the original SWR and rating are reported for the model.

References

Insurance Institute for Highway Safety. 2007. Bumper test protocol (version VI). Arlington, VA.

National Highway Traffic Safety Administration. 2006. Laboratory Test Procedure for FMVSS 216 Roof Crush Resistance. Report no.TP-216-05. Washington, DC: US Department of Transportation.

Office of the Federal Register. 2009. *Federal Register,* vol. 74, no. 90, pp. 22348-22393. National Highway Traffic Safety Administration – Final Rule. Docket no. NHTSA-2009-0093; 49 CFR Parts 571 and 585 – Federal Motor Vehicle Safety Standards, Roof Crush Resistance and Phase-In Reporting Requirements. Washington, DC: National Archives and Records Administration.

Appendix – Definitions of Typically Equipped Vehicles by Class

Microcars and minicars

1. 2-wheel drive
2. Four-door
3. Automatic transmission or CVT
4. Smallest engine (4 cylinders or fewer)
5. Air conditioning
6. No sunroof
7. Manual windows/locks/mirrors
8. ABS
9. No ESC (except where standalone option)
10. Cloth or leatherette seats
11. Manually adjustable seats
12. Standard wheels with above options

Small four-door cars

1. 2-wheel drive
2. Automatic transmission or CVT
3. Smallest 4-cylinder engine
4. Air conditioning
5. No sunroof
6. Power windows/locks/mirrors
7. ABS
8. No ESC (except where standalone option)
9. Cloth or leatherette seats
10. Manually adjustable seats
11. Standard wheels with above options

Midsize moderately priced two-door cars

1. 2-wheel drive
2. Automatic transmission or CVT
3. Base engine
4. Air conditioning
5. No sunroof
6. Power windows/locks/mirrors
7. ESC
8. Cloth or leatherette seats
9. Power adjustable driver seat
10. Standard wheels with above options

Midsize moderately priced four-door cars

1. 2-wheel drive
2. Automatic transmission or CVT
3. Base engine
4. Air conditioning
5. No sunroof
6. Power windows/locks/mirrors
7. ESC
8. Cloth or leatherette seats
9. Power adjustable driver seat
10. Standard wheels with above options

Midsize luxury four-door cars

1. 2-wheel drive
2. Automatic transmission or CVT
3. 3.0- to 4.0-liter 6-cylinder engine
4. Air conditioning
5. Sunroof
6. Power windows/locks/mirrors
7. Power adjustable driver seat
8. Leather seats
9. Alloy wheels

Large family four-door cars

1. 2-wheel drive
2. Automatic transmission or CVT
3. 3.0- to 4.0-liter 6-cylinder engine
4. Air conditioning
5. No sunroof
6. Power windows/locks/mirrors
7. Leather seats
8. Power adjustable driver seat
9. ABS and ESC
10. Alloy wheels

Large luxury four-door cars

1. 2-wheel drive
2. Automatic transmission or CVT
3. 3.0- to 4.0-liter 6-cylinder engine
4. Air conditioning
5. Sunroof
6. Power windows/locks/mirrors
7. Power adjustable driver seat
8. Leather seats
9. Alloy wheels

Small SUVs

1. 4-wheel drive
2. Automatic transmission
3. 4-cylinder engine
4. Air conditioning

5. No sunroof
6. Two rows of seats
7. Manually adjustable front seats
8. Power windows/locks
9. Cloth or leatherette seats
10. No longitudinal roof racks
11. Standard wheels with above options

Midsize SUVs

1. 4-wheel drive
2. Automatic transmission
3. Larger 6-cylinder engine (if two are offered)
4. Air conditioning
5. No sunroof
6. Third row seat
7. Power adjustable driver seat
8. Power windows/locks/mirrors
9. Cloth or leatherette seats
10. Longitudinal roof racks
11. Standard wheels with above options

Midsize luxury SUVs

1. 4-wheel drive
2. Automatic transmission
3. Larger 6-cylinder engine (if two are offered)
4. Air conditioning
5. Sunroof
6. Two rows of seats
7. Power adjustable front seats
8. Power windows/locks/mirrors
9. Leather seats
10. Longitudinal roof racks
11. Alloy wheels

Large SUVs

1. 4-wheel drive
2. Automatic transmission
3. Standard engine (6 or 8 cylinder)
4. Air conditioning
5. Sunroof
6. Third row seat
7. Power adjustable front seats
8. Power windows/locks/mirrors
9. Leather seats
10. Longitudinal roof racks
11. Alloy wheels

Minivans

1. 2-wheel drive
2. Automatic transmission or CVT
3. 3.5- to 4.0-liter 6-cylinder engine
4. Air conditioning
5. No sunroof
6. Power windows/locks/mirrors
7. Power sliding doors (both sides)
8. Power tailgate
9. Cloth seats
10. Power adjustable driver seat
11. ABS and ESC
12. Alloy wheels

Small and large pickups

1. 2-wheel drive
2. Crew cab
3. Short bed (nominal 6 foot)
4. Automatic transmission
5. 3.5- to 4.0-liter V6 (small trucks) or 4.5- to 5.3-liter V8 (large trucks)
6. Air conditioning
7. No sunroof
8. Manually adjustable seats
9. Power windows/locks/mirrors
10. Cloth seats
11. Standard wheels with above options