Crashworthiness Evaluation
Roof Strength Test Protocol

Version V

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DOCUMENT REVISION HISTORY

Revisions to Version V compared with Version IV:

- Revised the details about positioning the vehicle in our roof strength test system.

  In the *Testing* section, a step was added to minimize the potential for loading the edge of the platen during the test, especially when defining the initial contact point for vehicles with panoramic sunroofs or A-pillars with higher rake angles.

Revisions to Version IV compared with Version III:

- The section detailing our test vehicle selection criteria was removed from this protocol (formerly located in Appendix A). This criteria were updated and placed in a separate document titled *Test Vehicle Selection* (IIHS, 2021).
- For a copy of *Test Vehicle Selection*, visit the Technical Protocols section of the IIHS website.

Revisions to Version III of the protocol compared with Version II:

- Our test vehicle selection criteria were updated to better cover current trends in vehicle sales and production.
- Roof rails will not be removed prior to testing unless requested by the manufacturer.
- The vehicle support system (pinch weld clamping) used for testing has been updated.

Revisions to Version II of the protocol compared with Version I:

- Availability of standard or alloy wheels has been given higher priority in the list of definitions of typically equipped vehicles relative to the seat adjustment type (power vs. manual) and seating surface material.
- Availability of antilock braking system (ABS) and electronic stability control (ESC) has been removed from the definitions of typically equipped vehicles because these features now are standard equipment on all passenger vehicles.

OVERVIEW

This protocol explains how the Insurance Institute for Highway Safety (IIHS) evaluates and rates the roof strength of motor vehicles.

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 U.S. Federal Motor Vehicle Safety Standard (FMVSS) 216 (Office of the Federal Register, 2009). The main differences between the IIHS roof strength test and that specified by FMVSS 216 are that the IIHS test:

- 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.

Supporting documents for the Insurance Institute for Highway Safety (IIHS) roof strength program are available from the *Technical Protocols* section of the IIHS website.

Curb Weight Measurement

Curb weight values used for calculating the SWR are based on IIHS measurements of a vehicle, not the manufacturer's specified curb weight.

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

Test Vehicle Selection

For information on how we select vehicles for our crash test programs, including how we define typically equipped vehicles, see *Test Vehicle Selection* (IIHS, 2021).

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 IIHS definition of a typically equipped vehicle, 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 our typically equipped vehicle 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).

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.

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. Unless the vehicle manufacturer requests otherwise, roof racks and other nonstructural items that may be contacted during the test are left as installed from the factory. 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 (HR A-36, W4X13) for each rocker panel. Each I-beam has a clamping system incorporated on the top that is 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 Laboratory Test Procedure* (2006).

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
Rocker Panel Support System Attached to the Vehicle

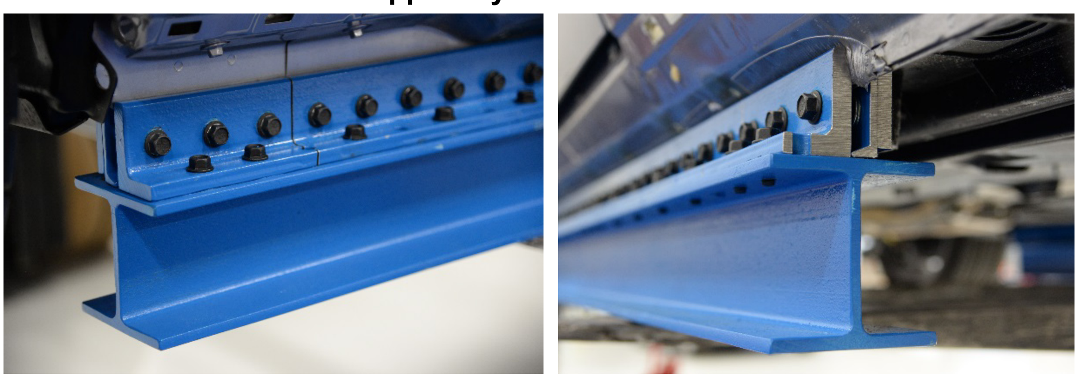


Figure 2
Rocker Panel Support System — Detail

TESTING

Roof strength evaluations are conducted on a quasi-static test system manufactured by MGA Research Corporation (Figure 3).

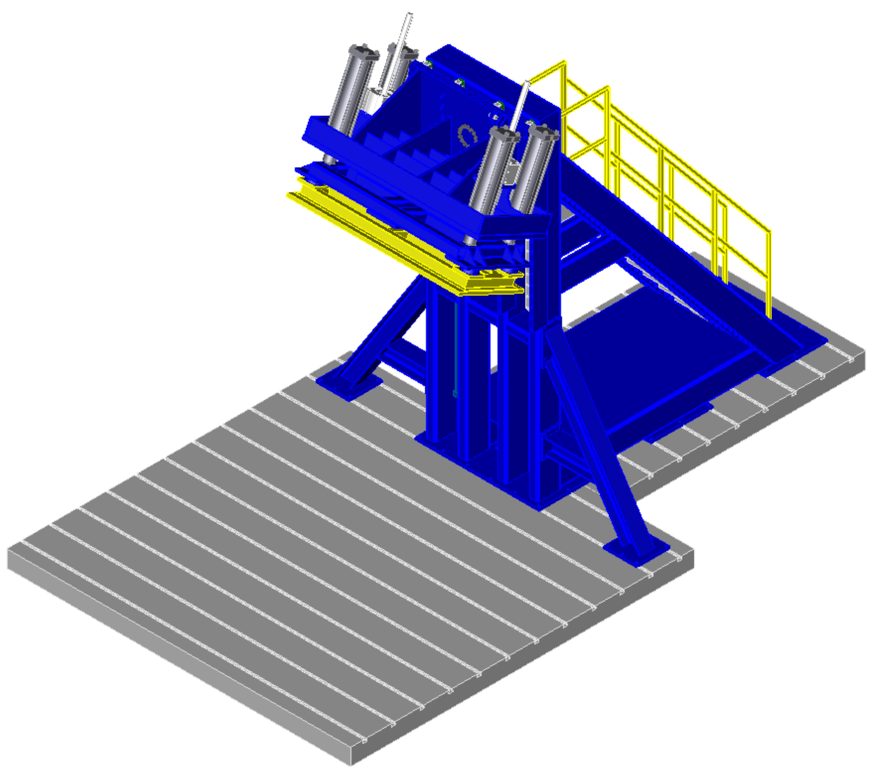
The system consists of an upright assembly and an attached loading head that can be fixed at varying heights from the ground and at pitch angles ranging from −5 to +5 degrees to accommodate testing on the driver or passenger side.

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

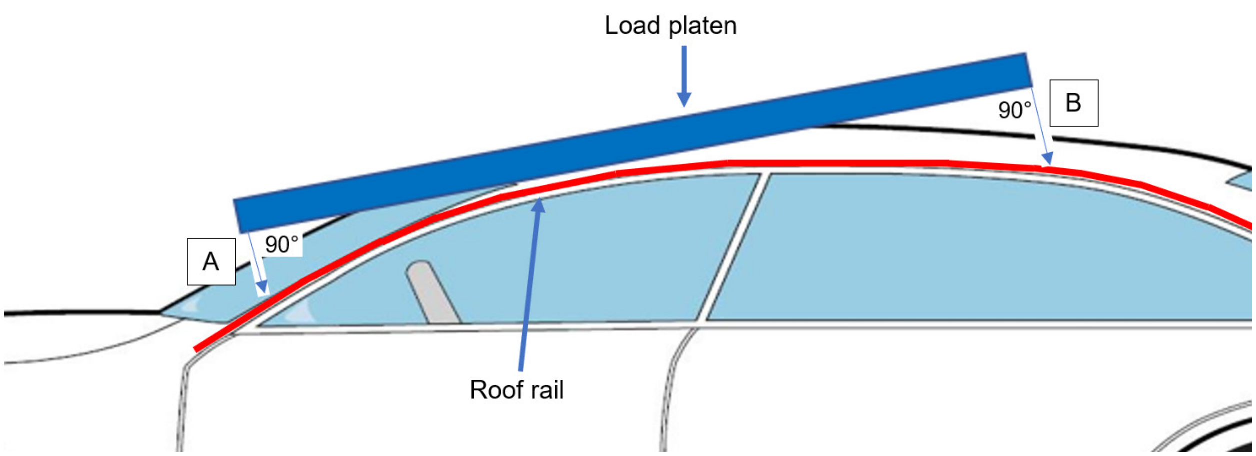
1. The longitudinal centerline of platen is within 10 mm of the initial roof contact point.
2. The yaw angle of the vehicle relative to the longitudinal axis of the platen is 0 ± 0.5 degrees.
3. The midpoint of the platen's forward edge is 254 ± 10 mm beyond the most forward point of the roof (including the windshield trim if it overlaps the roof) lying on the vehicle's longitudinal centerline.

   To minimize the potential for loading the edge of the platen during the test, there should be a minimum clearance of 150 mm between every point along the forward edge of the platen and the structurally significant body components, when measured normal to the platen's face (Dimension "A" in Figure 4).

   Note: Structurally significant body components include the roof, roof pillars, and any glass (windshield, side windows, roof glass) but not the side mirrors, trim, removable roof rails, roof-mounted antennas, and generally any component that consumers can remove.

   If the 150-mm clearance is not achieved, then the vehicle is moved rearward longitudinally until the 150-mm clearance is achieved at the front edge of the platen, or an equal measure of clearance (±20 mm) less than 150 mm at the front and rear edges of the platen is obtained (Dimensions "A" and "B" in Figure 4), whichever occurs first.

Figure 4
Vehicle Position at the Initial Contact Point



Note: The view shown is coplanar to the load face of the platen. The platen is positioned at the first point of contact. "A" indicates the front edge of the platen; "B" indicates the rear edge of the platen.

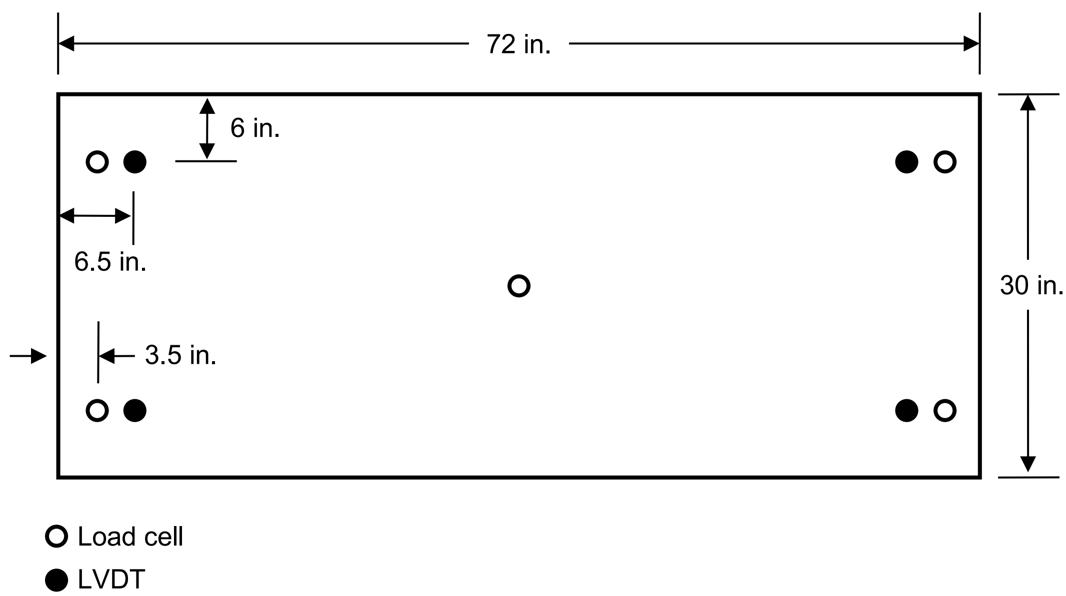
4. The pitch angle of the vehicle matches the on-road angle, while also accounting for any difference between the platen's pitch angle and the nominal −5 degrees.

   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 confirm 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 5 shows the locations of the load cells and LVDTs on the loading platen.

Figure 5
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.

CALCULATING THE STRENGTH-TO-WEIGHT RATIO (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 the 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% 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% 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% 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

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.

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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.