

Crashworthiness 101

Crash standards, crush zones, load paths, frontal and side impact kinematics

Crash Standards

Test	What it covers
FMVSS 208	Frontal impact: 30 mph into a fixed barrier; head, neck, chest, leg injury
FMVSS 214	Side impact: moving deformable barrier at 33.5 mph (53.6 km/h), 27° angle; barrier face crushes at 45 psi
FMVSS 301	Rear impact
FMVSS 216	Rollover / roof crush resistance
NCAP (NHTSA)	1-5 stars beyond FMVSS minimums; side test at 38.5 mph (61.6 km/h)
IIHS	Private, insurer-funded: moderate and small overlap front, roof strength, driver-assist features
Euro NCAP	European frontal, side and pedestrian ratings

FMVSS were endorsed by NHTSA in 1966 and apply to passenger vehicles under 10,000 lb GVWR.

Key Concepts

Crashworthiness	A structure's ability to reduce fatal and serious injuries in an impact. Assessed by FEA (LS-DYNA, RADIOSS, PAM-CRASH, MADYMO), physical tests or crash records.
Passive vs active	Passive (BIW, airbags, belts) protects after a crash; active (ACC, lane keep, ESC) tries to avoid it.
Crush zone (Δ)	Area ahead of the cabin. Rigid parts (engine, transmission) and partly rigid parts (radiator ≈ 50% crush).
Crush initiators	Features in the mid-rails that force a predetermined, accordion-style collapse.
Load path	Good BIW geometry matters more than material; stronger isn't always better in the crush zone.
HIC / TTI	Head Injury Criterion; Thoracic Trauma Index (TTI < 57 desirable in side impact).

Crash Physics (standard relations)

Kinetic energy	$E = \frac{1}{2} m v^2$	Mostly absorbed as work by the BIW; some heat and sound.
Avg deceleration	$a = v^2 / (2\Delta)$	e.g. 55 km/h at 20 g needs $\Delta \approx 0.6$ m of crush.
Crash force	$F = m a$	Newton's 2nd law; momentum change sums to zero.
Side impact contact	$\int (v_{veh} - v_{occ}) dt = \Delta_0$	Area between velocity curves = gap before door hits occupant.

Frontal Barrier Load Split & Targets

50% Mid-rail (impact beam)	20% / 20% Upper load path / lower cradle	10% Hood and fenders	< 20 g Occupant deceleration target
50-120 mm Toe-pan intrusion that can occur without higher injury risk	~20 ms Occupant keeps moving until belt or airbag engages	~25 / 50 ms Side impact: vehicle slides, then door and occupant reach same speed	~30 ms Frontal: powertrain engages, biggest velocity drop

Design Rules

- Size crush-zone beams for an accordion collapse that oscillates around an average crush force (near-square acceleration pulse).
- Center weld flanges on box sections where packaging allows; cross-section shape changes load capacity.
- Keep all four wheels down and pitch low to cut neck injuries.
- Side impact: load path through the BSI (hot-stamped boron B-pillar, rocker, roof rails); push load into the underbody; align rocker, lower B and C pillars with barrier height; add a B-pillar or seat-pan cross member.
- A poor BIW architecture can't be fixed by material choice alone, but good materials make a good design great.