

Body-on-Frame: Truck Design

BOF vs unibody, ladder frames, chassis natural frequencies and an FEA lightweighting study

Chassis vs Frame vs Body

Frame	Structural skeleton. A ladder frame uses two parallel rails joined by crossmembers.
Chassis	Frame plus suspension, steering, powertrain and axles (a rolling chassis).
Body	Sheet-metal shell around the passenger compartment.
Body-on-frame (BOF)	Body bolted to a separate frame during the body drop ("marriage").
Unibody	Body and frame welded into a single load-bearing structure.

Body-on-Frame vs Unibody

Factor	Body-on-Frame	Unibody
Weight / fuel economy	Heavier / lower	Lighter / higher
Towing & hauling	Higher	Lower
Off-road	Better: ground clearance, twist tolerance	Lower
Ride & handling	Less refined, more roll	More refined, sharper
NVH isolation	Better	More vibration to cabin
Rollover resistance	Lower (higher CG)	Higher
Crash energy	Separate front sub-frame / crush structure	Dedicated crumple zones, generally better
Repair cost	Usually cheaper	Usually pricier
Typical vehicles	Pickups, BOF SUVs	Cars, crossovers

Unibody pickups: Honda Ridgeline (mid-size), Ford Maverick and Hyundai Santa Cruz (compact). Univ. of Washington study: 18% lower death risk for occupants struck by compact unibody vs BOF SUVs.

Natural Frequency

Natural frequency	$f_n = (1/2\pi) \sqrt{k / m}$	Change stiffness k or mass m to move f_n .
Design goal	Keep f_n away from engine and road excitation	Avoids resonance, noise and premature failure.

Example Truck Frame Modes

Mode	Type	Frequency
1 (global)	Torsion: both ends translate most	7.219 Hz
2 (global)	Vertical bending: front translates most	17.153 Hz
3 (local)	Local bending at top-hat crossmember	29.612 Hz
4 (local)	Local bending	33.517 Hz
5 (local)	Local torsion at gearbox-mount crossmember	n/a

Modes 1, 2 and 6 are global; the rest are local.

FEA Study (HyperMesh / OptiStruct, steel $E = 210 \text{ GPa}$, $\nu = 0.3$, $\rho = 7.9 \times 10^{-6} \text{ kg/mm}^3$)

Trial	Change	f_n	Mass
Baseline	Ladder frame as designed; pivots about crossmember 4; peak strain at crossmembers 1 and 5	15.3 Hz	122.8 kg
Trial 1	Crossmember 2: 4→6 mm; 3 and 4: 5→6 mm; lightening holes in 1 and 5	9.32 Hz	122.4 kg
Trial 2	Crossmember 2 back to 5 mm; holes added to 3 and 4	9.30 Hz	120.2 kg

Crossmember 2 had little effect on frequency. Lightening holes in low-stress areas cut mass without a proportional loss of performance (they do add local stress concentrations).

Ladder Frame Design Notes

- Must carry max load, absorb engine/driveline torque, withstand shock and twist on uneven ground.
- Torsional flexibility (gearbox crossmember to rear-suspension crossmember) helps the frame "weave" instead of failing and reduces suspension loads.
- Lighter frames are more prone to vibration from engine, transmission and road; adding crossmembers or brackets adds parts, mass, welds and cost.