Design for Crashworthiness

- Standardized safety test conditions and requirements
  - FMVSS: minimum injury performance
  - NCAP: probability of serious injury using the star scale
  - Impact test: front, side, rear, roll-over
- Front barrier
  - Lower level of acceleration of the vehicle center of mass
- Side impact
  - TTI (Thoracic Trauma Index) < 57
- Rear impact
  - Minimize fuel system leakage
- Roof crush
  - Minimum level of crush force w/o deforming beyond

6.1 Standardized Safety Test

- Primal functions of automobile body
  - Protect occupants in a collision
- Governments
  - Standard crash tests and minimum performance level
  - US: FMVSS (Federal Motor Vehicle Safety Standards)
  - European Union, Japan, Korea, Australia and others
  - NCAP (New Car Assessment Program)
    - Probability of injury for a specific test: star scale (one ~ five)
- Insurance industry and consumer groups
  - Beyond the minimum government standards
  - IIHS (Insurance Institute for Highway Safety)
- Four major groups
  - Front impact, side impact, rear impact, roll-over resistance

Crash-Regulations: Europe, United Nations, USA and China

Instrument panel
UN R21, 32, 33
FMVSS 201

Side windows
UN R43
GTR 6
FMVSS 205, 226

Interior
UN R12, 21, 43
GTR 6
FMVSS 201, 203, 204, 205
GB 11552-2009

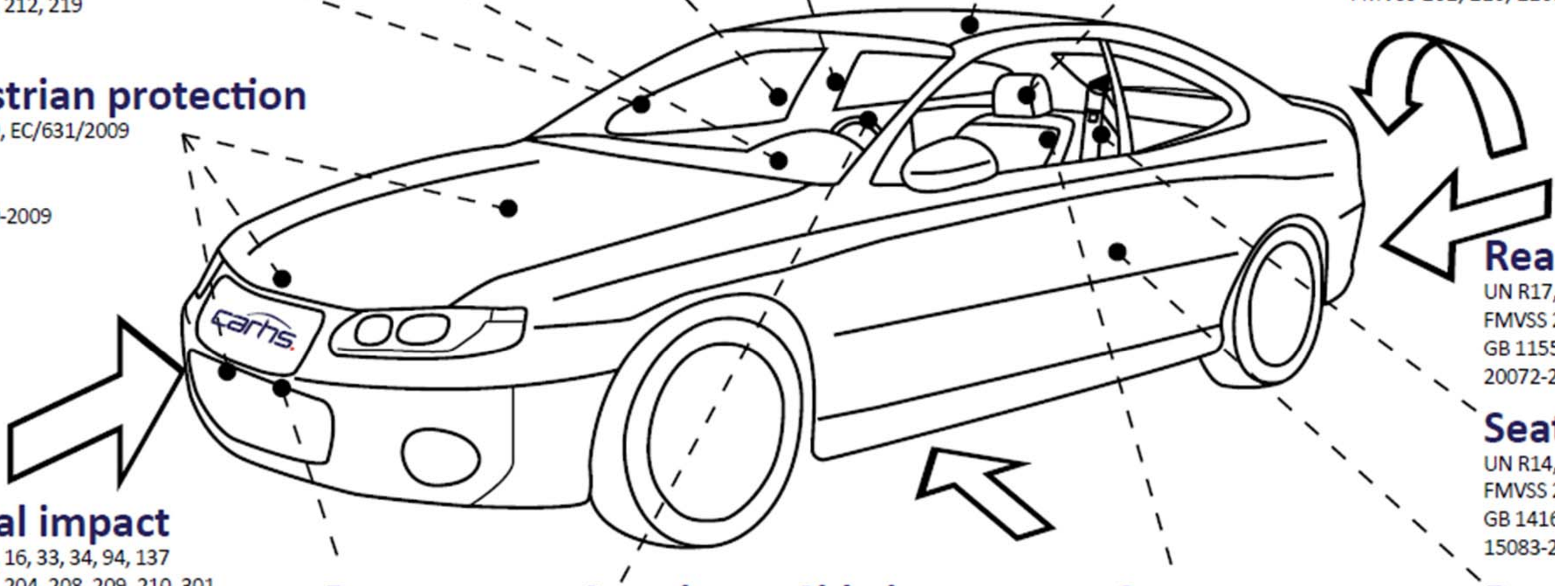
Roof
FMVSS 216, 216a
GB 26134-2010

Headrests
UN R17, 25
GTR 7
FMVSS 202a
GB 11550-2009, GB 15083-2006

Windscreeen
UN R43
GTR 6
FMVSS 205, 212, 219

Rollover
UN R44
FMVSS 201, 216, 216a, 301

Pedestrian protection
EC/78/2009, EC/631/2009
UN R127
GTR 9
GB/T 24550-2009



Rear impact
UN R17, 25, 32, 34, 42, 58
FMVSS 202a, 207, 301, 581
GB 11550-2009, GB 18296-2001
20072-2006

Seat belts
UN R14, 16, 17
FMVSS 208, 209, 210
GB 14166-2013, GB 14167-2013,
15083-2006

Frontal impact
UN R12, 14, 16, 33, 34, 94, 137
FMVSS 203, 204, 208, 209, 210, 301
GB 11551-2014 , 11557-2011 , 14166-2013,
14167-2013
GB/T 20913-2007

Bumper
UN R42
FMVSS 581
GB 17354-1998

Steering wheel
UN R12
FMVSS 203, 204
GB 11557-2011

Side impact
UN R95, 135
GTR 14
FMVSS 214
GB 20071-2006

Seats
UN R16, 17, 21, 44, 129, 145
FMVSS 201, 202a, 207, 213, 225
GB 11550-2009, 14166-2013, 15083-2006, 27887-2011

Doors
UN R11
GTR 1
FMVSS 206
GB 15743-1995, 15086-2013

SafetyWissen by carhs.

Canada CMVSS §
- 208 Frontal 78
- 214 Side............86, 87
- 226 Ejection Mit. ..92

U.S. FMVSS §
- Overview................21
- 126 ESC 140
- 201U 94
- 202a.......................103
- 208 Frontal 76, 79, 80
- 214 Side..... 86, 87, 88
- 216a Roof Crush....74
- 226 Ejection Mitig. 92
- 305 Electric veh......25

U.S. NCAP ★
- Frontal 28, 48
- Side 28, 48, 86
- Pole........... 28, 48, 86
- Rollover / SSF.......128
- CIB.........................152
- FCW 152
- LDW 128
- Rear Auto Brake ..150
- Overall rating 50

IIHS ★
- Frontal........ 28, 52, 80
- Side 28, 53, 86, 87
- Whiplash52, 103, 105
- Roof Crush 53, 74
- Top Safety Pick 53
- Small Overlap...28, 54
- Bumper Test 111
- AEB / FCW... 145, 150
- Advanced Light....128

Latin NCAP ★
- Frontal 28, 57
- Side 28, 57
- Child prot. 57, 109
- Assistance syst.....126

Euro NCAP ★
- Frontal .28, 32, 36, 80
- Side 28, 34, 86, 88
- Far side 44
- Whiplash 103-105
- Pedestrian.....100-102
- Child prot. 108
- Assistance syst.....126
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- LSS.........................148
- Overall rating 46
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Impactors/Dummies
- Size/Weight 120
- Dummies...............116
- THOR 118
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- Upper Legform.....124
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- Flex PLI..................124

RCAR ★
- Whiplash 105
- Bumper 111

EU §
- Overview................21
- 78/2009................100
- 631/2009 100

Bharat NCAP ★
- Test items 69
- Overall rating 69

India AIS §
- 098 Frontal 22
- 099 Side..................23

GTR §
- Overview.................21
- 8 ESC.....................140
- 9 Pedestrian.........100
- 14 Side.....................86

ANCAP ★
- See Euro NCAP

Australia ADR §
- 69/00 Frontal...22, 78
- 73/00 Frontal...22, 78
- 72/00 Side.............23
- 85/00 Pole.............23

UNECE §
- Overview................21
- R21..........................94
- R94 Frtl.22, 26, 78, 80
- R95 Seite ... 23, 26, 86
- R100 26
- R127 .... 96, 100
- R135 Pole.........23, 86
- R137 Frontal 22, 78
- R140 ESC 140
- R.E.3: Veh. classes112

ASEAN NCAP ★
- Frontal 29, 58
- Child prot. 58, 109
- Assistance syst.....126

JNCAP ★
- Frontal 29, 62, 80
- Side 29, 62, 90
- Whiplash 64, 103
- ASV.........................128
- Pedestrian............100
- Overall rating 64

Japan §
- Art. 18/23 Frontal .22
- Art. 18/24 Side.......23
- Art. 18/99 Ped. 100

KNCAP ★
- Frontal 29, 66
- Side 29, 68
- Whiplash 68,103
- Pedestrian............100
- Child prot. 110
- Brakes...................126
- Rollover/SSF.........126
- Assistance syst.....126
- Overall rating 65

Korea KMVSS §
- 102 Frontal 22
- 102 Side..................23
- 102-2 Pedestrian.100

China NCAP ★
- Frontal 29, 60, 80
- Side 29, 61, 90
- Whiplash 61, 103
- Assistance sys.126,154
- Overall rating 61

China GB §
- Overview.................21
- 11551 Frontal 22
- 20913 Frontal 22
- 20071 Side. 23

C-IASI ★
- Small Overlap 29
- Side 29

Rules and Regulations on Occupant Protection

	Full Width Frontal	Offset Frontal	Side Barrier	Side Pole	Pedestrian	Rear	Head Impact	Rollover
USA	FMVSS 208	FMVSS 208	FMVSS 214	FMVSS 214		FMVSS 202a FMVSS 301	FMVSS 201	Roof crush: FMVSS 216a Ejection Mitigation: FMVSS 226
Europe	UN R137[1]	UN R94	UN R95	UN R135[1]	R (EC) 78/2009 R (EC) 631/2009 UN R127	UN R34	UN R21	
Japan	Art. 18 Attachmt. 23[2]	Art 18	Art. 18 Attachmt. 24	UN R135[2]	Article 18 Attachment 99	Article 18 Attachment 34		
China	GB 11551-2014	GB/T 20913-2007	GB 20071-2006		GB/T 24550-2009	GB 20072-2006	GB11552-2009	Roof crush: GB26134-2010
India		AIS-098	AIS-099		AIS-100	AIS-101		
South Korea	KMVSS 102		KMVSS 102		KMVSS 102-2			
Australia	ADR 69/00	ADR 73/00	ADR 72/00	ADR 85/00				

Global NCAP (www.globalncap.org)

한국 및 해외의 자동차안전도평가 기준 비교

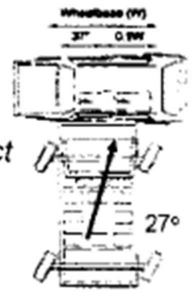
	한국	미국	유럽	호주	일본	중국
고정벽 정면충돌	●	●			●	●
40%부분 정면충돌	●		●	●	●	●
90도 측면충돌	●	●	●	●	●	●
기둥 측면충돌	●		●	●		
좌석	●		●	●	●	●
보행자	●		●	●	●	●
주행전복	●	●				
제동	●	●			●	
유아안전도			●			
홈페이지	🏠	🏠	🏠	🏠	🏠	🏠

www.kncap.org (2017.11.19)

국토교통부 교통안전공단 자동차안전연구원

자동차안전도평가시험 등에 관한 규정

Impact Test

Front Barrier	Side Barrier	Rear Barrier	Roof Crush
FMVSS 208	FMVSS 214	FMVSS 301	FMVSS 216
 *30mph Impact into rigid barrier* *Criterion: Occupant injury*	*33.5 mph Impact by deformable moving barrier* *Criterion: Occupant injury*  	 *30mph Impact by moving barrier* *Criterion: Fuel system integrity*	 *Load 1½ times vehicle weight* *Criterion: Less than 5 inches of deformation*

US-NCAP Front Barrier:
35mph full face rigid barrier

Criterion: Star Rating based on combination of head injury criteria (HIC) and chest acceleration for driver and passenger

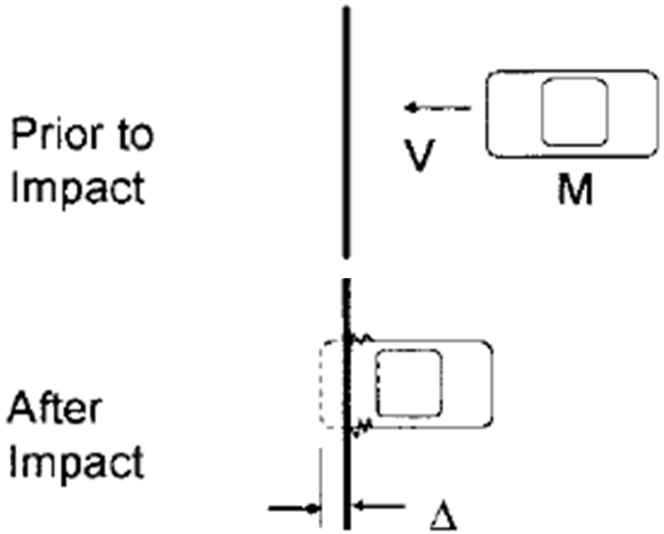
% chance of serious injury

	Frontal 35mph	Side 33mph
★★★★★	<10%	<5%
★★★★	11-20	6-10
★★★	21-35	11-20
★★	36-45	21-25
★	>46	>26

Star Rating System

6.2 Front Barrier (1)

- Test conditions
  - $t = 0$: just touch the rigid, unmovable barrier (speed V_0)
  - As the vehicle deforms, the speed of the vehicle center of mass will gradually reduce
  - $t = t_{final}$: maximum deformation occurs ($V=0$)
- Typical front barrier sequence of events
  - ($t = 0$) ~ ($t = 90$ msec)

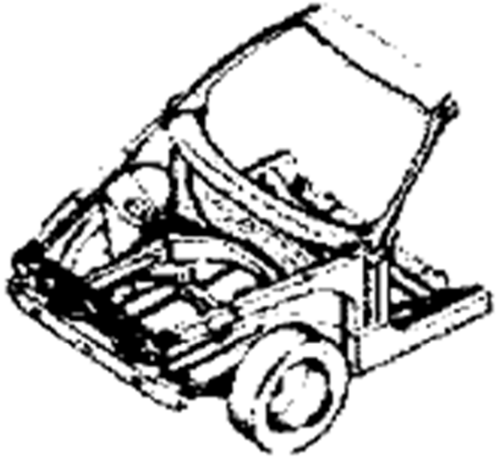


Typical Front Barrier Sequence of Events

- @ t = 0
  - Vehicle: moving at velocity $V=V_0$
  - Front bumper: touching the barrier face
- @ t = 15 msec
  - Bumper: has collapsed
  - Motor compartment midrails and side rails: being loaded
- @ t = 30 msec
  - Midrails: have begun to crumple in an accordion fashion
  - Powertrain: has just touched the barrier, begins to decelerate
- @ t = 45 msec
  - Midrails and upper rails: continue to crumple
  - Powertrain: has decelerated to zero velocity
  - Wheels: have impacted the barrier
- @ t = 90 msec
  - Vehicle: has decelerated to V=0
  - Motor compartment: crumpled by some deformation Δ

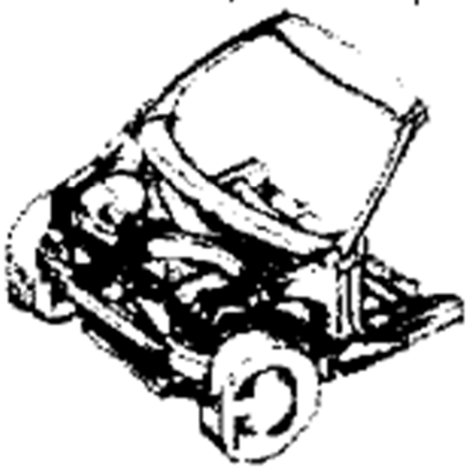
Typical Front Barrier Sequence of Events

t=0msec, v=55kph

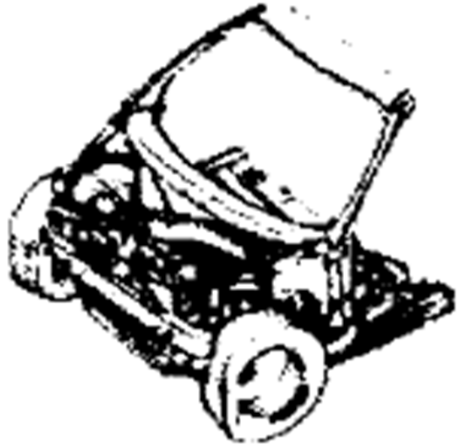


t=15, v=52

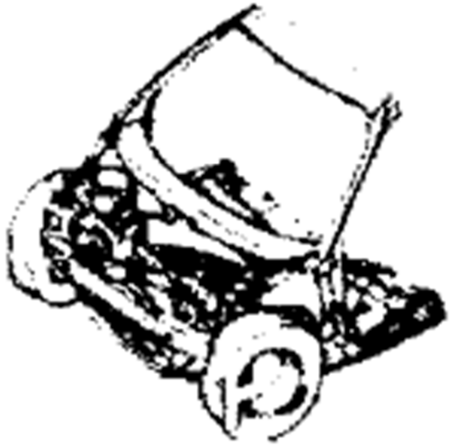
t=30, v=47



t=45, v=34



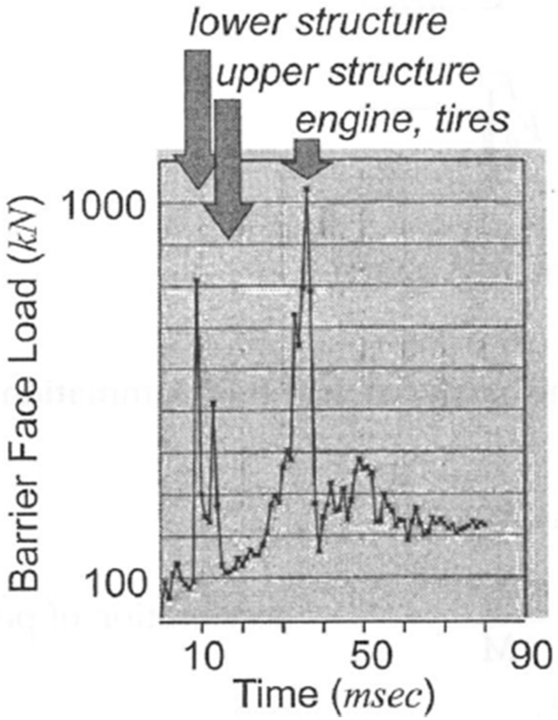
t=60, v=22

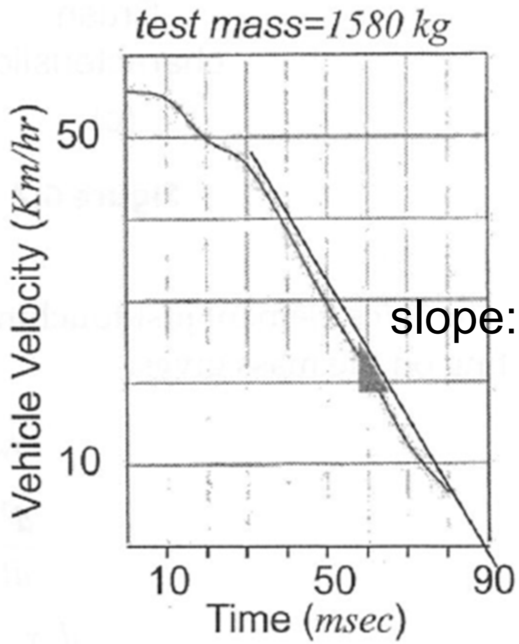


t=75, v=11

Front Barrier (2)

- Primary data
  - Loads applied to the barrier face
  - Acceleration of the vehicle mass center → velocity
- Concern: minimize occupant injury
  - Criterion: acceleration of the vehicle center of mass

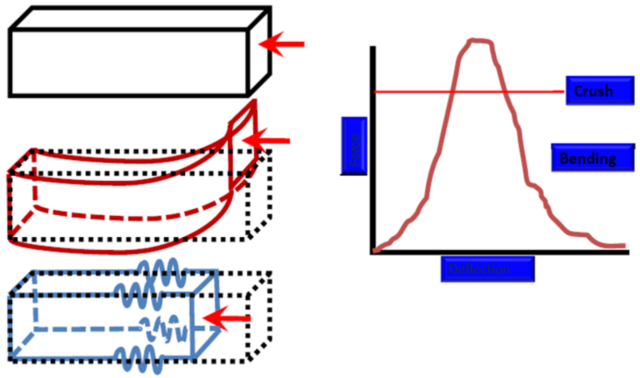




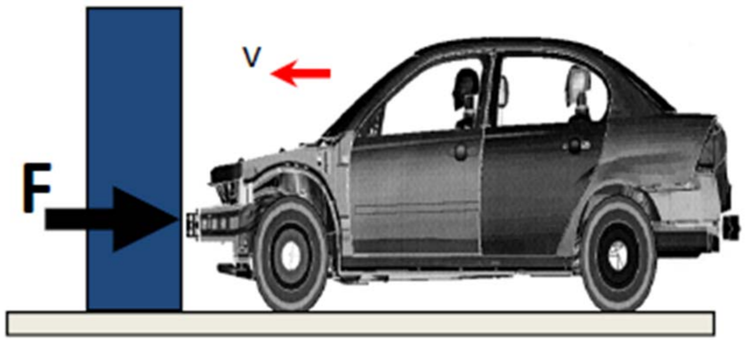
slope: cabin deceleration

Physics of a Crash

- Kinetic Energy = ½mv^2
- Work = F*D
  - F: average force on vehicle by wall
  - D: crush + rebound of vehicle

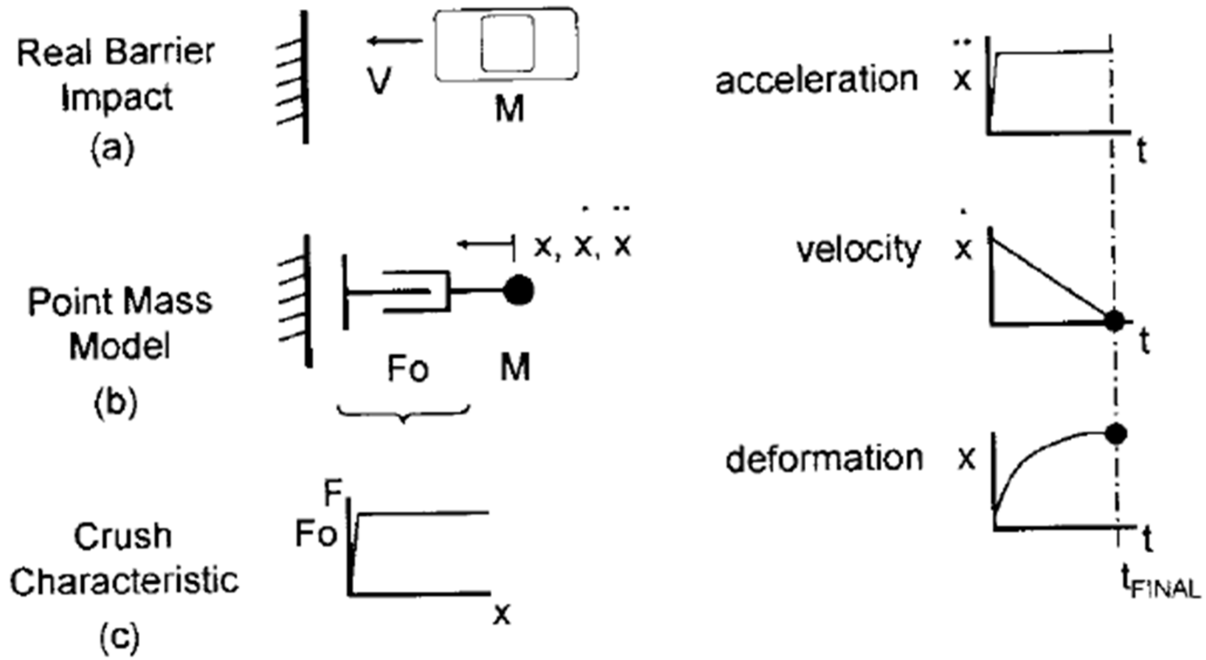


- Dissipate KE into Vehicle Deformation (or Work) but away from occupant
- Energy Dissipation Rate ∝ Injury
- Constant force as “ideal”
- Axial crush as preferred mode
- Maximize crush space
- Minimize intrusion



Basic Kinematic Model

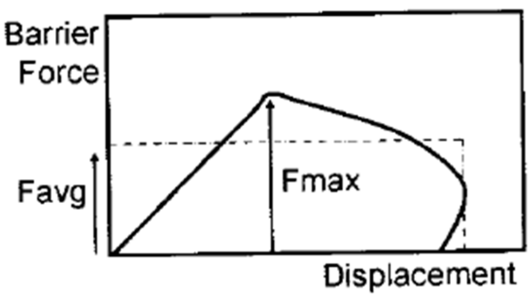
– Ideal structure collapse: point mass, uniform load → t_{FINAL}?

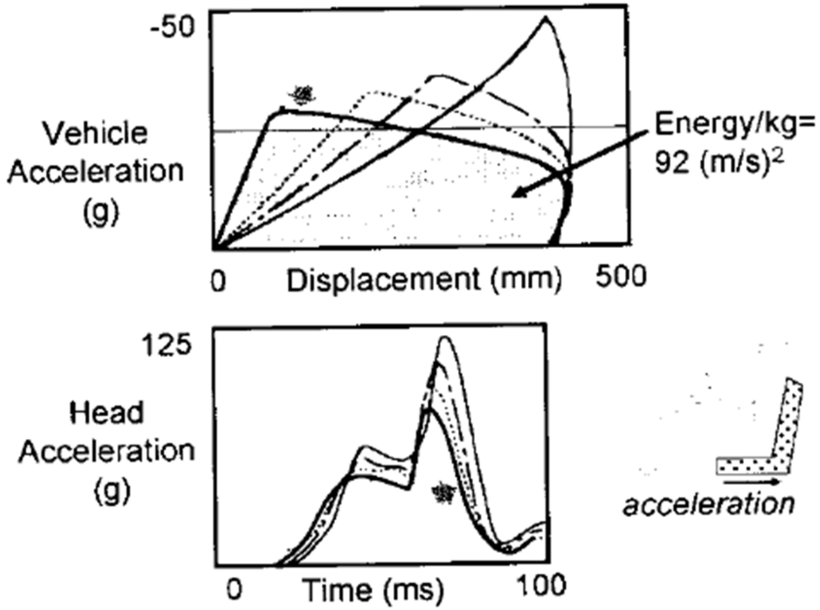


– Consider a vehicle of mass 1580 kg, impacting a rigid barrier at 55 kph and an average motor compartment crush load of 300 kN. → Δ=0.6148m

Refinement: Crush Force

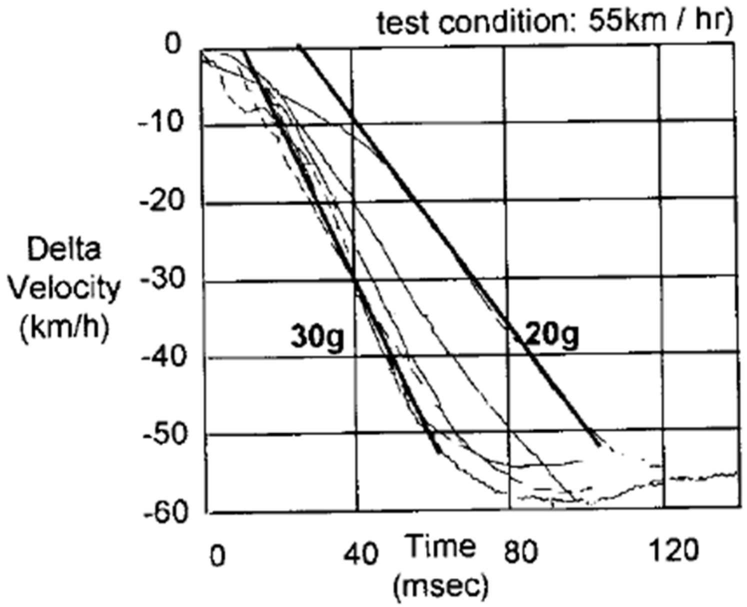
- Refine the model by allowing crush force properties other than uniform
- Crush efficiency factor: $$\eta = \frac{F_{avg}}{F_{max}} = \frac{Ma_{avg}}{Ma_{max}} = \frac{a_{avg}}{a_{max}} \quad (0 < \eta < 1)$$
  - Characterize the load-deflection curves
  - Deformation curve preferable in minimizing occupant injury?
  - The more square shape the curve (η ~ 1), the lower the head injury



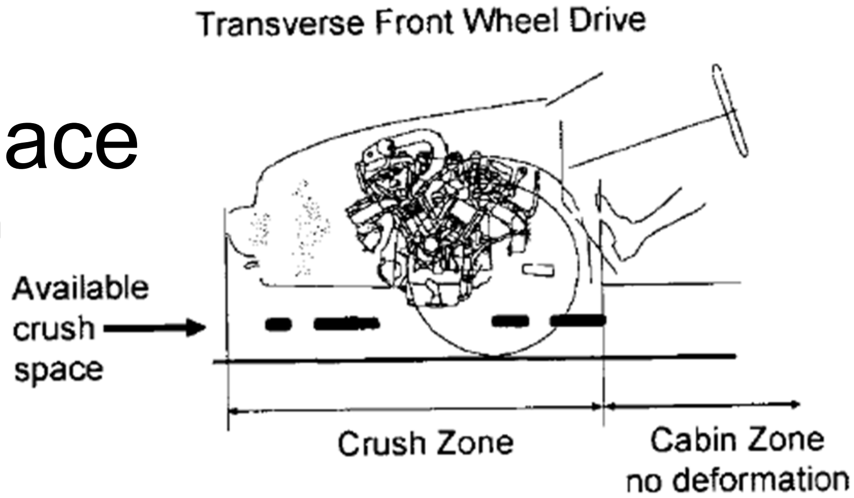


Characteristics for Cabin Acceleration

- Magnitude of the peak acceleration
  - Range of 20 to 30g for peak acceleration
  - Lower peak acceleration: less injurious
- Desirables during impact
  - Limit maximum acceleration to approximately 20g
  - Make this acceleration as uniform as possible



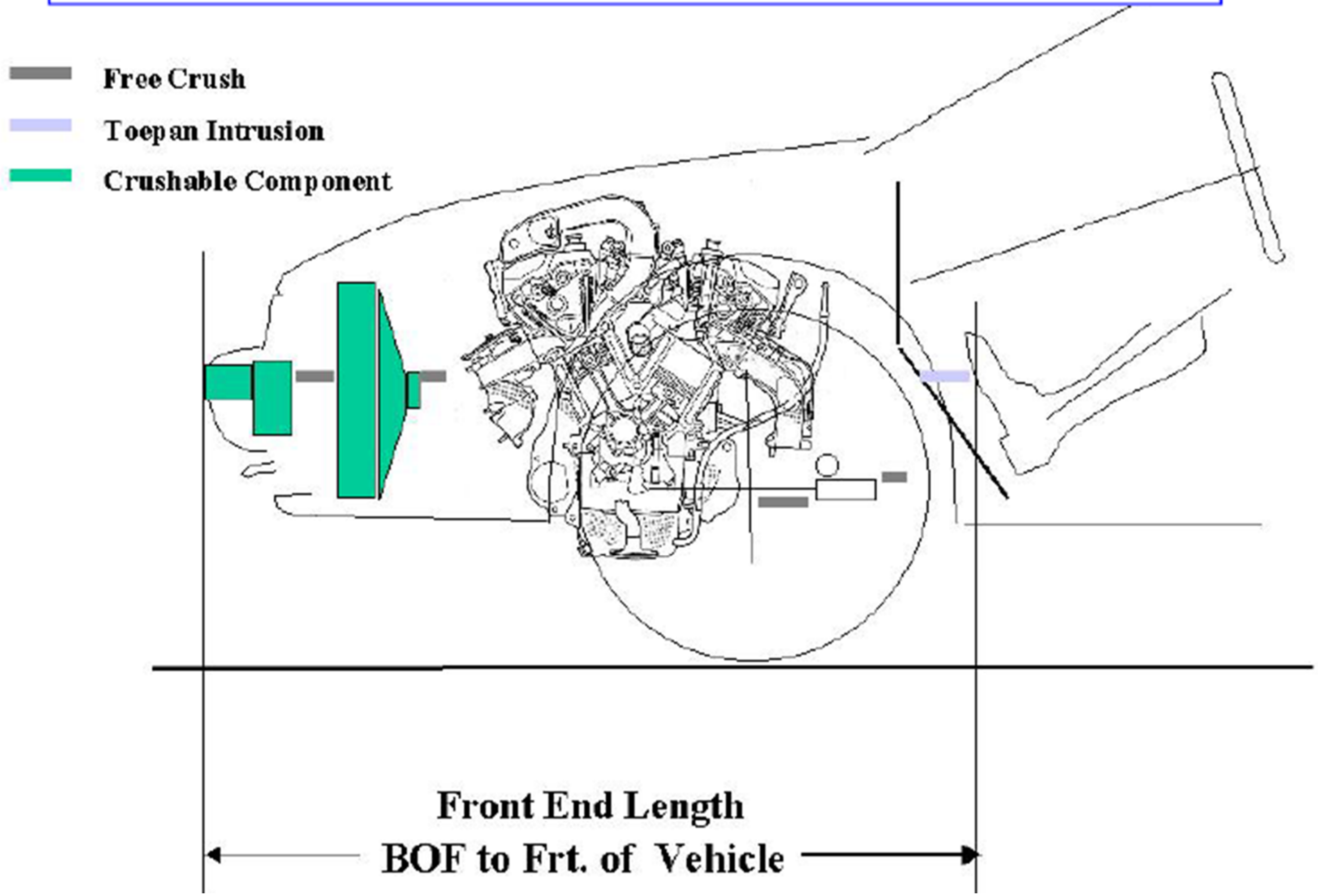
Crush Space



- Crushable space in motor compartment
  - Identify cabin zone we desire to keep from deforming
- Cabin zone
  - Ideally wrap completely around the passengers
  - Practically accept some amount of intrusion into toe pan area
    - Order of 50~120 mm w/o increasing injury
- Crush space Δ
  - Fore-aft dimension of the crush zone
    - Exclude rigid elements: engine block
    - Crushed to some degree: assumption as to final crush dimensions for inclusion (ex, radiator thickness: 50%)

Crush Space Measurement

Static Crush Space = Free Crush + Crushed Components
Dynamic Crush = Static Crush Space + Dynamic Dash Intrusion



(Ball of Foot)

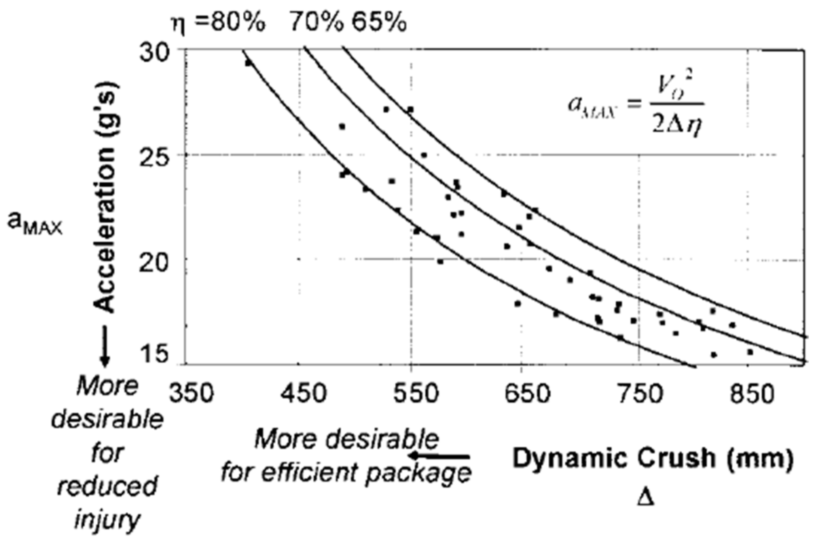
Structural Requirements (1)

  - Maximum cabin acceleration (a_{max}): occupant injury
  - Necessary crushable space (Δ): vehicle styling and packaging
  - Average crush force (F_{avg}): body structure performance
- Work-energy balance
  - Inverse relationship between maximum cabin acceleration during impact and crush space
  - Practical maximum value for crush efficiency: η~0.8

$$\frac{1}{2}MV_0^{\ 2} = F_{avg}\Delta$$

$$\xrightarrow{F_{avg}=\eta F_{\max}}$$

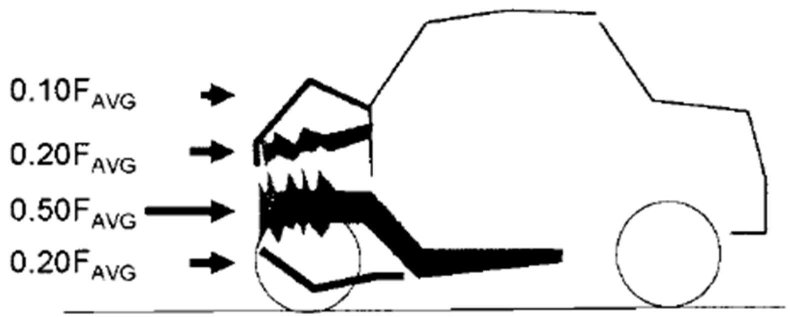
$$a_{\max} = \frac{V_0^{\ 2}}{2\eta\Delta}$$

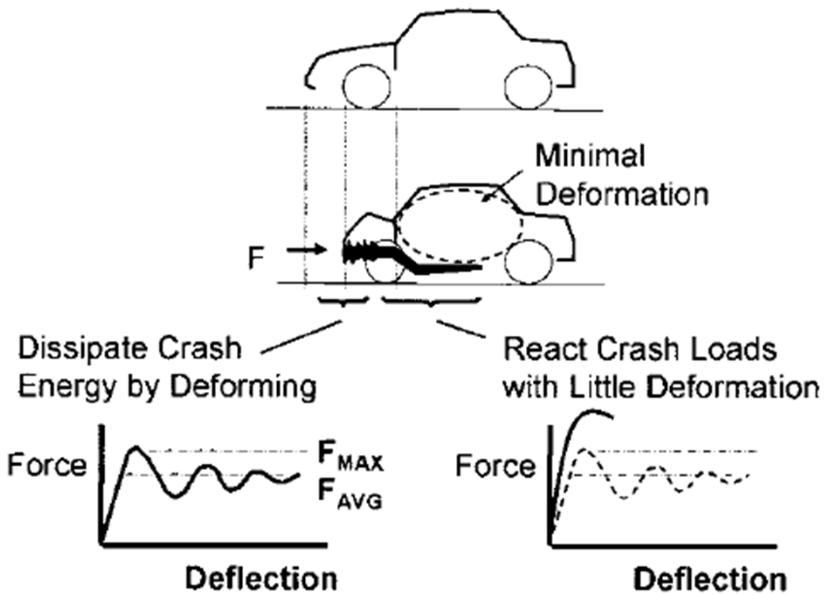


30 mph Barrier Benchmarking

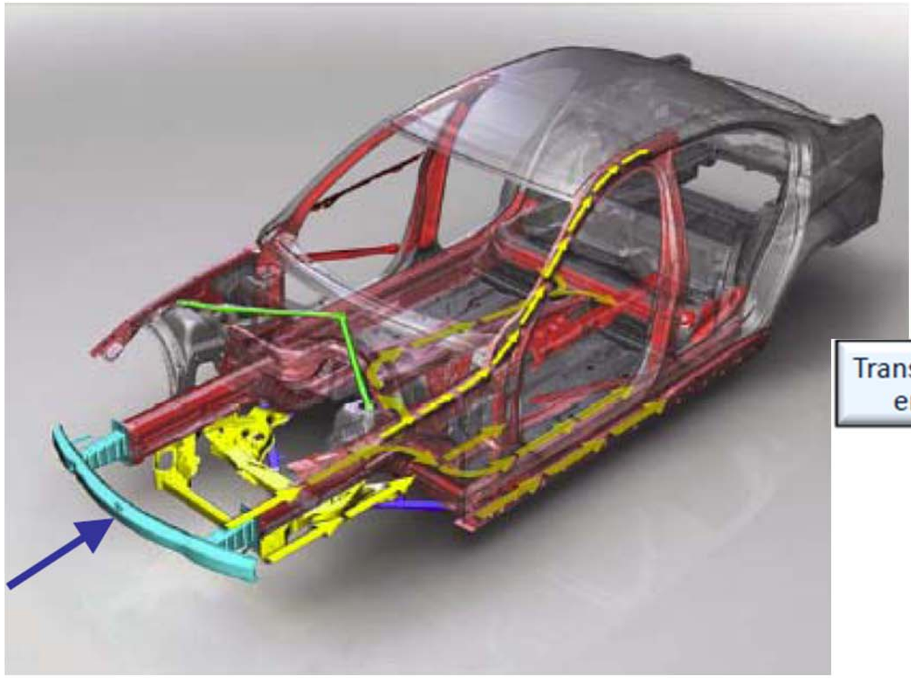
Structural Requirements (2)

– Determine the maximum allowable cabin decelerations based on occupant injury (a_{max})
– Determine a consistent structural efficiency and crush space ($\eta\Delta$)
– Compute the average and maximum allowable crush forces which the vehicle must generate during impact ($a_{max} \rightarrow F_{max}, \eta \rightarrow F_{avg}$)
– Allocate these total forces to the structural elements within the vehicle front end
  - Mid-rail structure: 50%
  - Upper structure load path: 20%
  - Lower cradle: 20%
  - Hood and fender: 10%

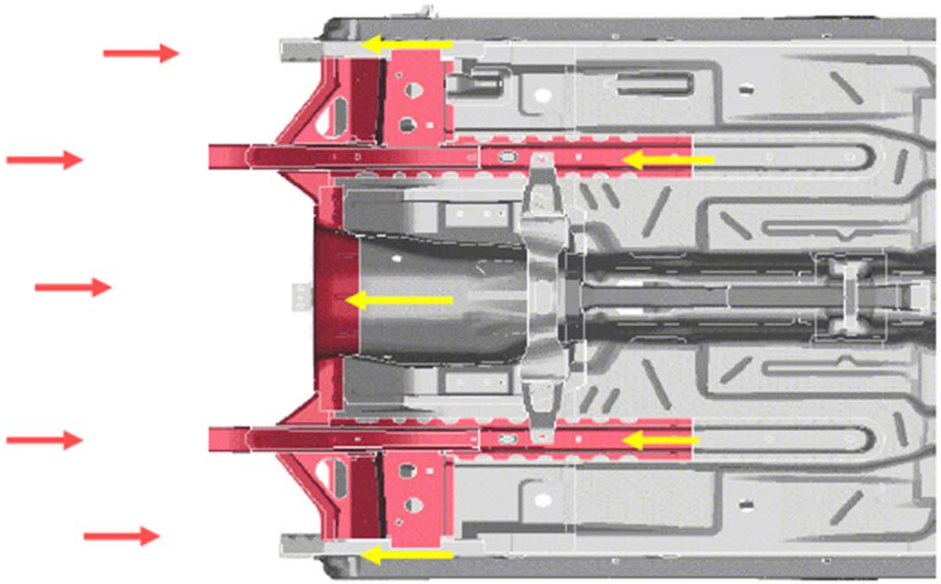




Load Distribution Philosophy

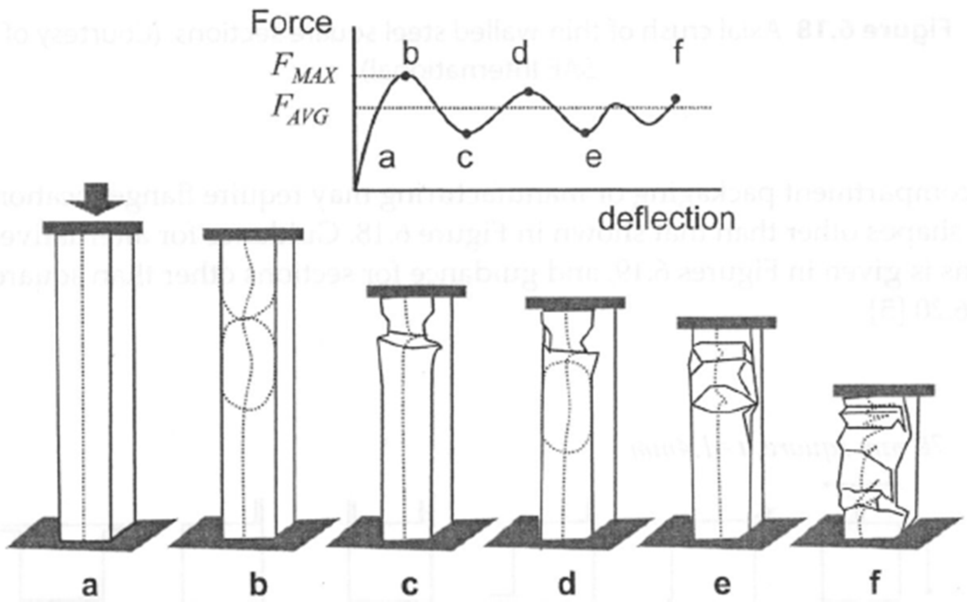


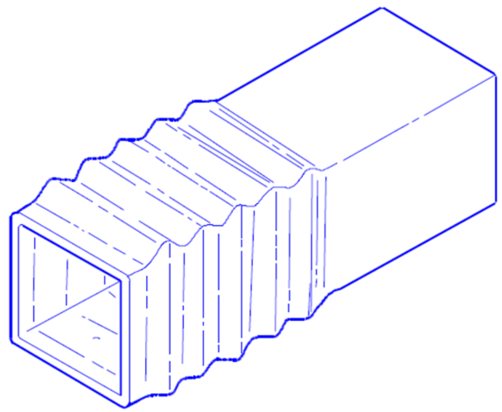
Transition Zone bridges offset between loadpaths in crush zone & safety cage; enables effective load transfer & provides stability control



Beam Sizing for Energy Absorption (1)

- Efficient means to generate an approximately square wave force over a large distance: progressive column crush of a thin walled section
- Thin walled square section under an axial compressive load
  - (b) elastic buckling (c) crippled corner (d) load increase (e) repeat (f) average crush force
- High average crush force: useful for energy absorption

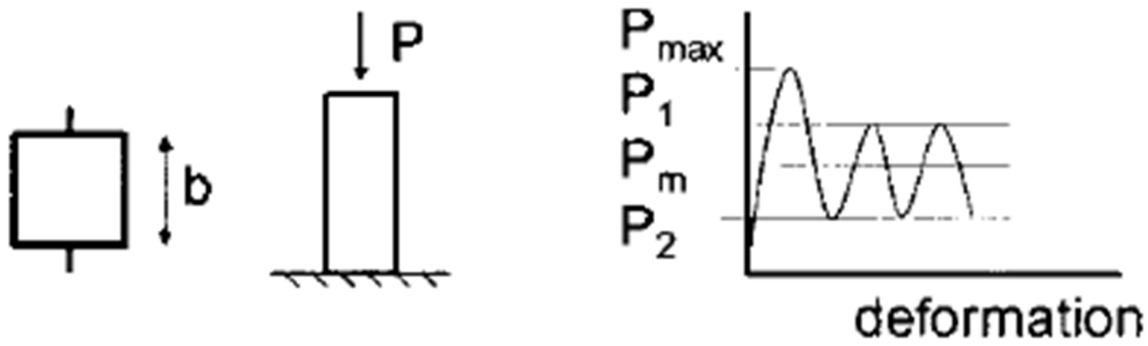




Beam Sizing for Energy Absorption (2)

- Empirical relationship for predicting forces during crush
  - Square steel section loaded by static (very slowly applied) forces

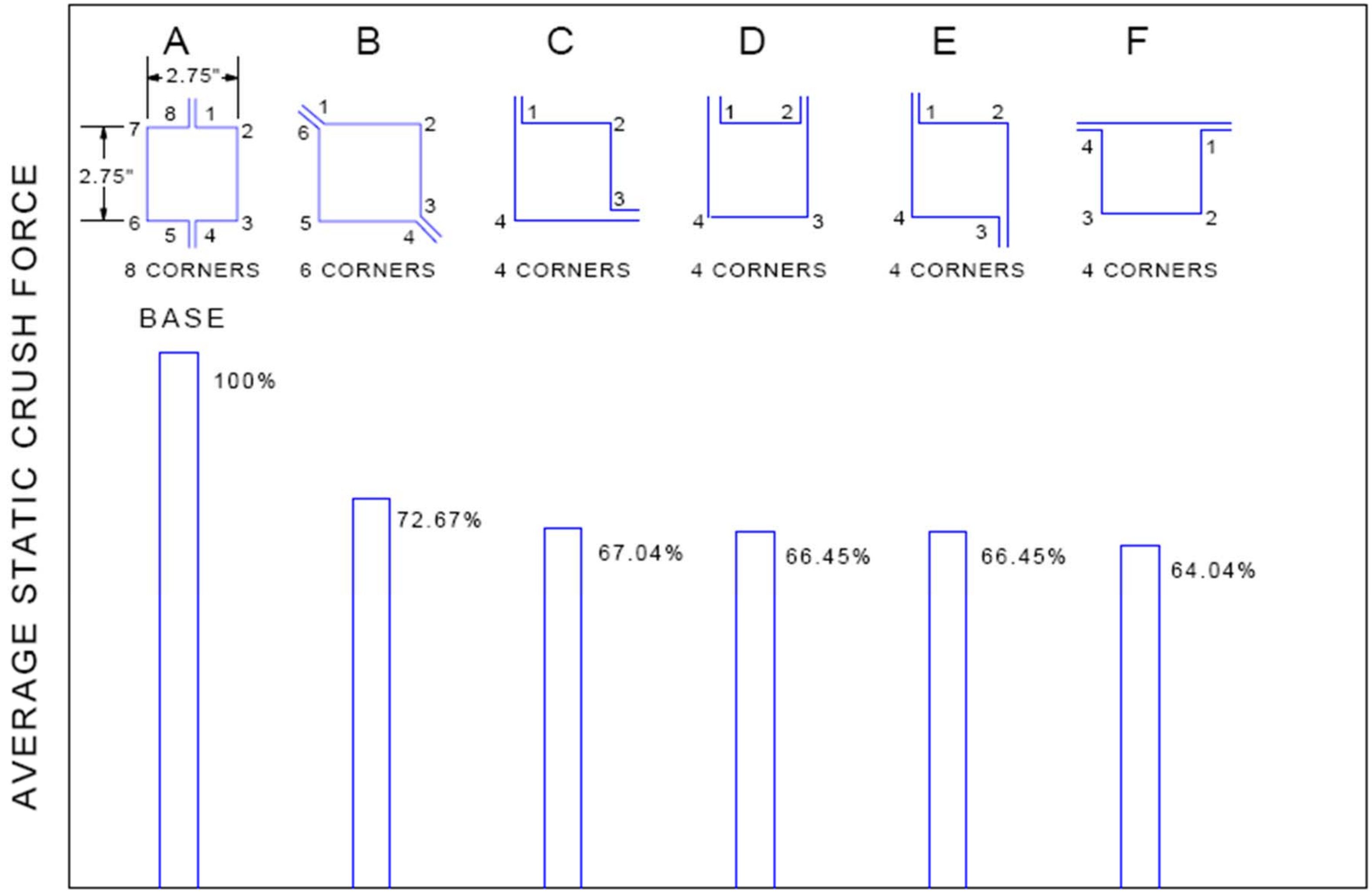
$$\left.\begin{aligned} &P_m : \text{ mean crush force (N)} \\ &P_{\max} : \text{ maximum crush force (N)} \\ &t : \text{ material thickness (mm)} \\ &b : \text{ section width and height (mm)} \\ &\sigma_Y : \text{ material yield stress (N/mm}^2) \end{aligned}\right\} \rightarrow \begin{cases} P_m = 386 t^{1.86} b^{0.14} \sigma_Y{}^{0.57} \\ P_{\max} = 2.87 P_m \\ P_1 = 1.42 P_m \\ P_2 = 0.57 P_m \end{cases}$$



(SAE International)

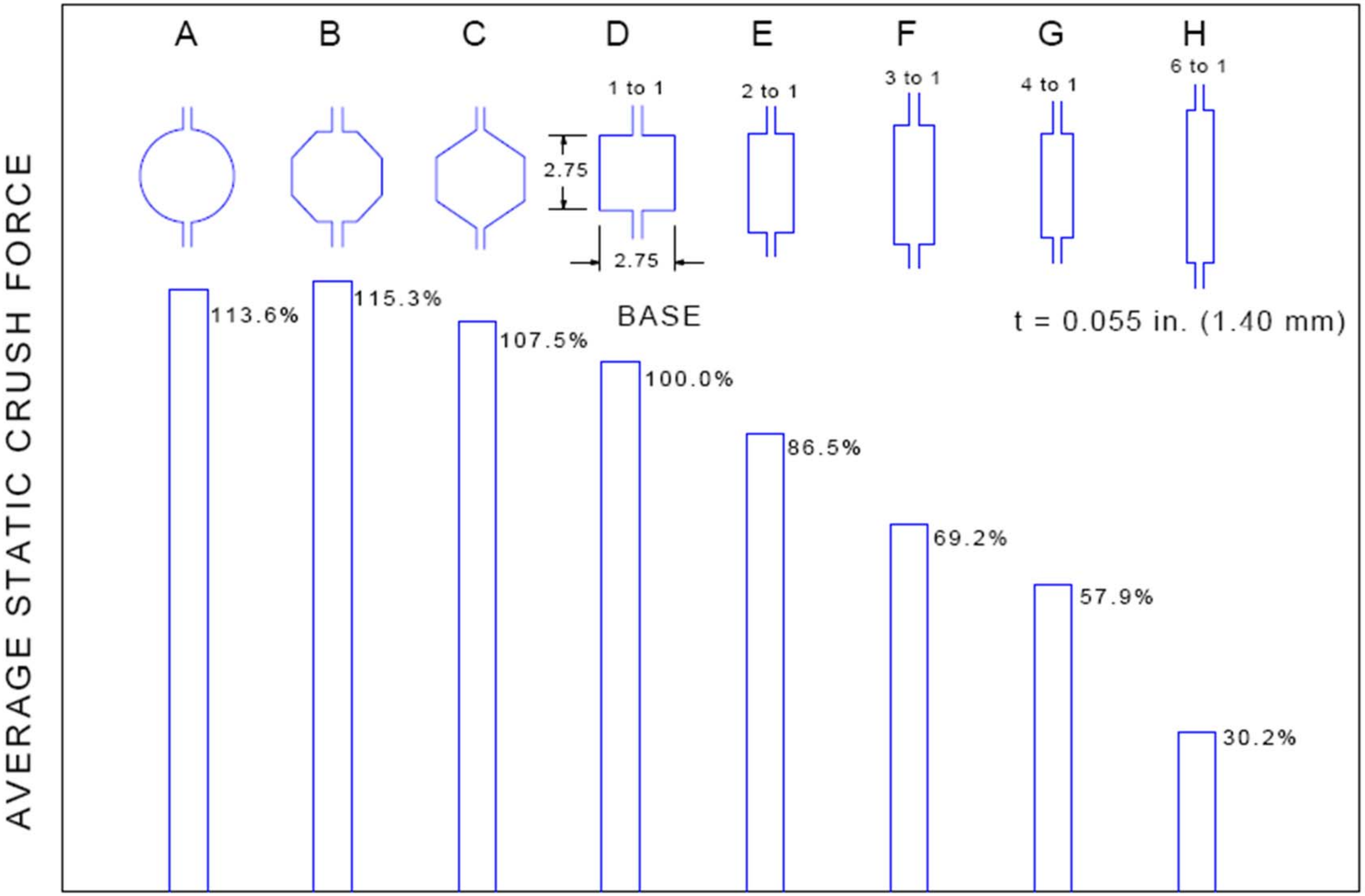
Effect on Average Crush Force: Flange Position

(70mm square, t=1.4mm)



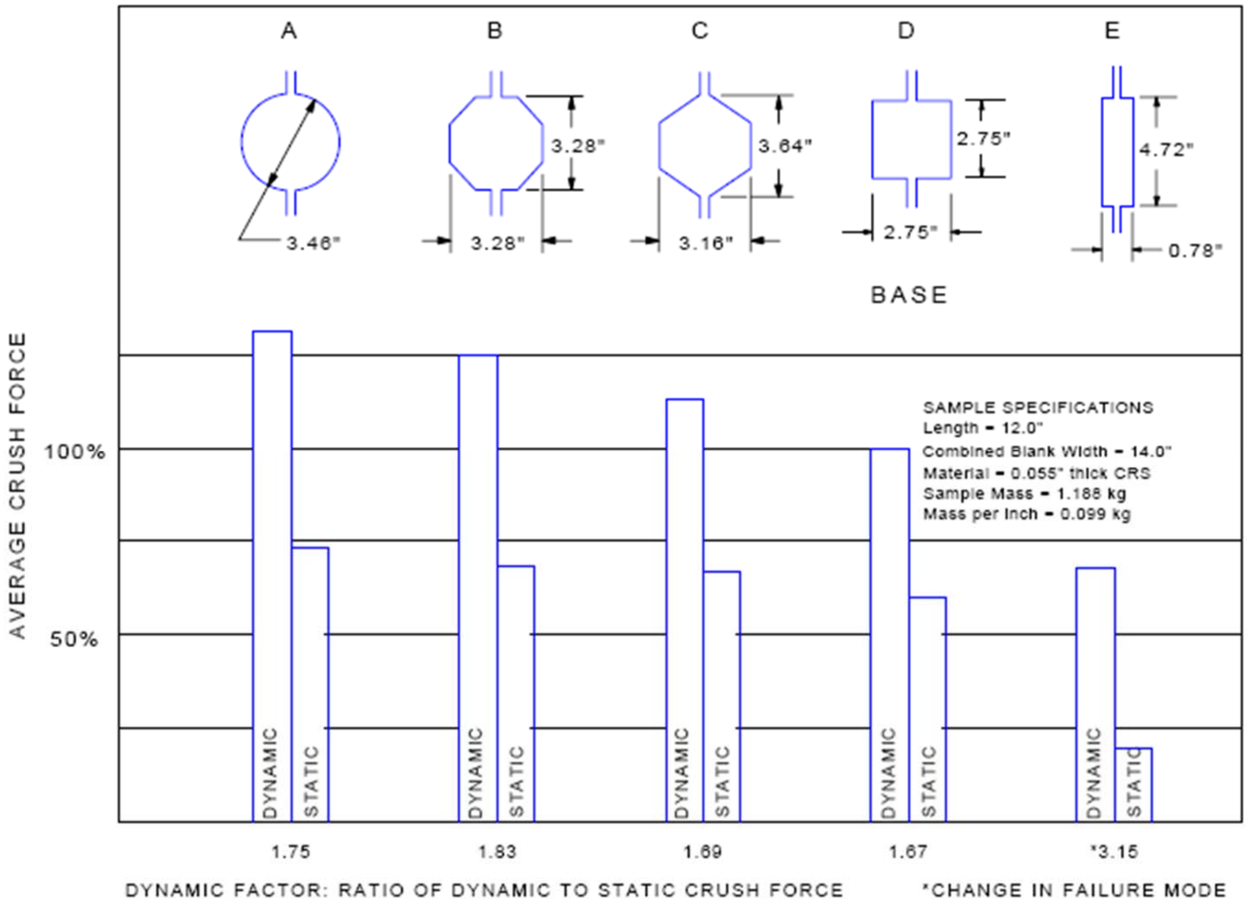
Effect on Average Crush Force: Section Shape

– Constant perimeter excluding flanges



Effect on Average Crush Force: Dynamic Effect

– Drop tower test at 30 mph, perimeter = 280 mm
– Crush of approximately 50% of the initial length



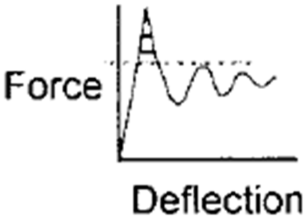
Static vs. Dynamic Loading

- Crush load requirements: dynamic impact
- Many materials including steel when loaded rapidly
  - Strain rate sensitive
  - Generate higher stress
- Reduce the maximum load: η↑
  - Maximum load (P_{max}): initiate the first crippled corner, poor crush efficiency
  - Add darts or beads to initiate the crippling
  - Precise placement and geometry of crush initiators

$$\eta = \frac{F_{avg}}{F_{\max}} = \frac{P_m}{P_{\max}} = \frac{P_m}{2.87 P_m} = 0.35$$

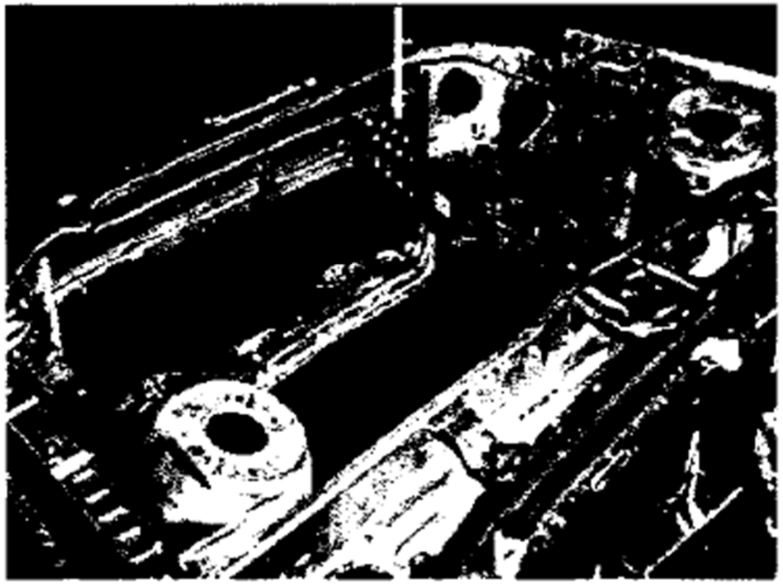
$$\eta = \frac{F_{avg}}{F_{\max}} = \frac{P_m}{P_1} = \frac{P_m}{1.42 P_m} = 0.70$$

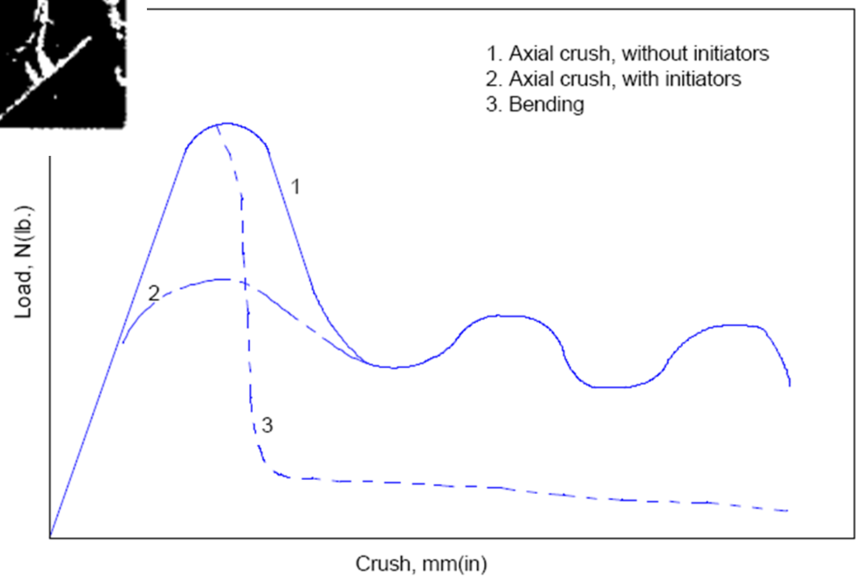
Crush Initiator



Need to Limit Peak Force so Reaction Member is Not Overloaded

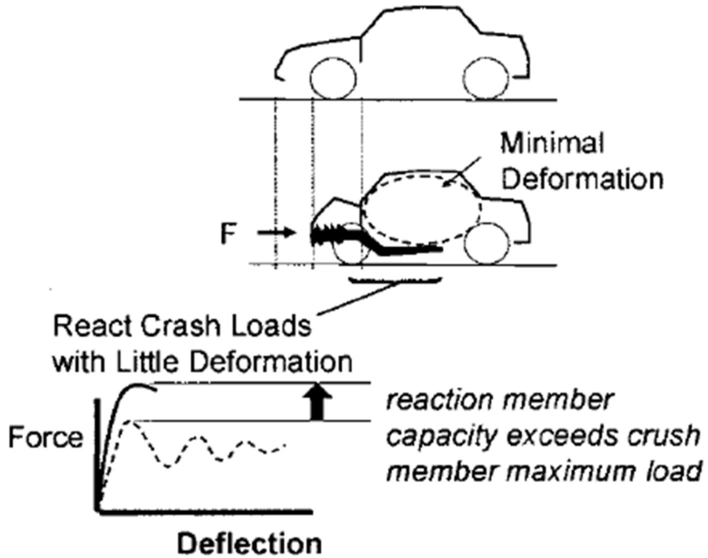
Crush Initiators on Lower Rail

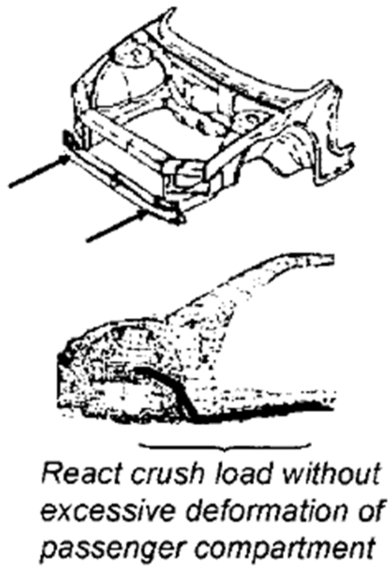


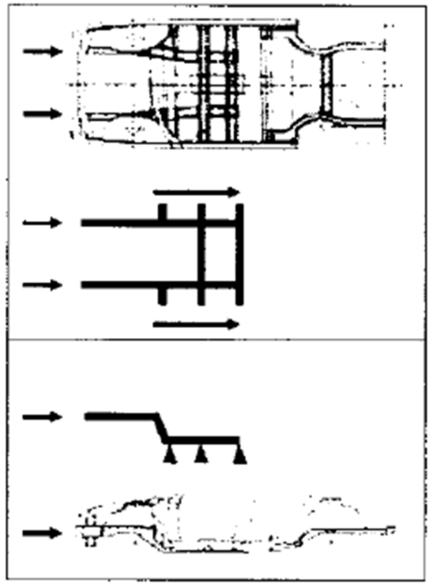


Beam Sizing for Cabin Reaction Structure

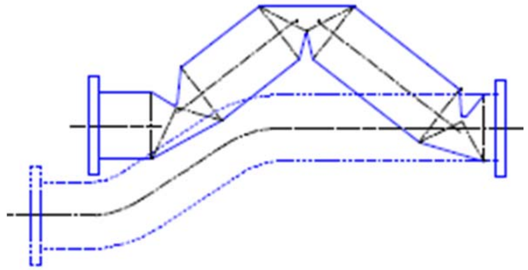
- Structural element in the crush zone
  - Under-floor structure
  - Midrail
  - Deformation which does not influence occupant trajectory during impact and increase injury: 50~120mm
- Failure criterion: yield of the outer fiber → limit analysis



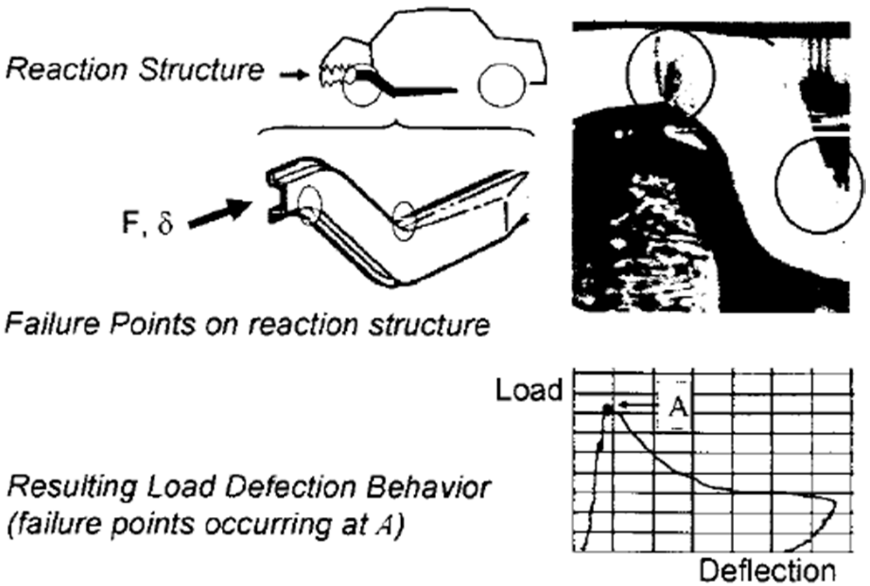


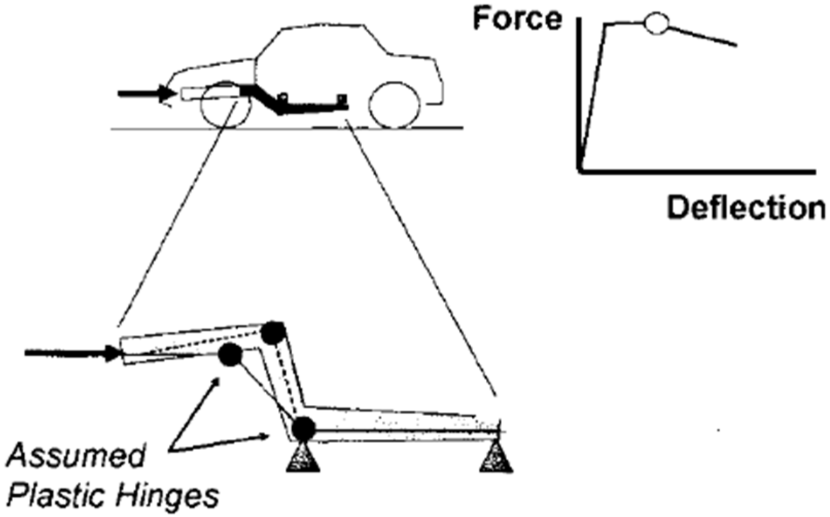


Limit Analysis Design



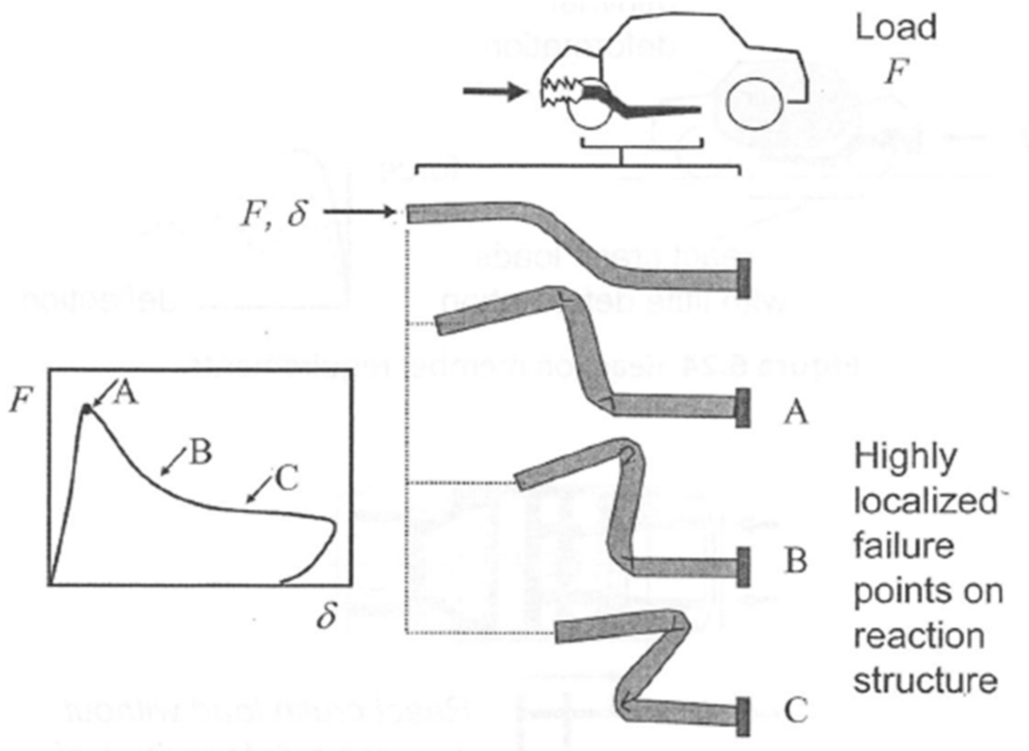
- Reaction structure
  - React applied load elastically
  - Begin to yield: permanent deformation
  - Continue to increase the applied load until yield zones extend across the section: plastic hinges
  - Behave as mechanism with rigid links (plastic hinges)
  - Limit load: ultimate load carrying ability for the structure





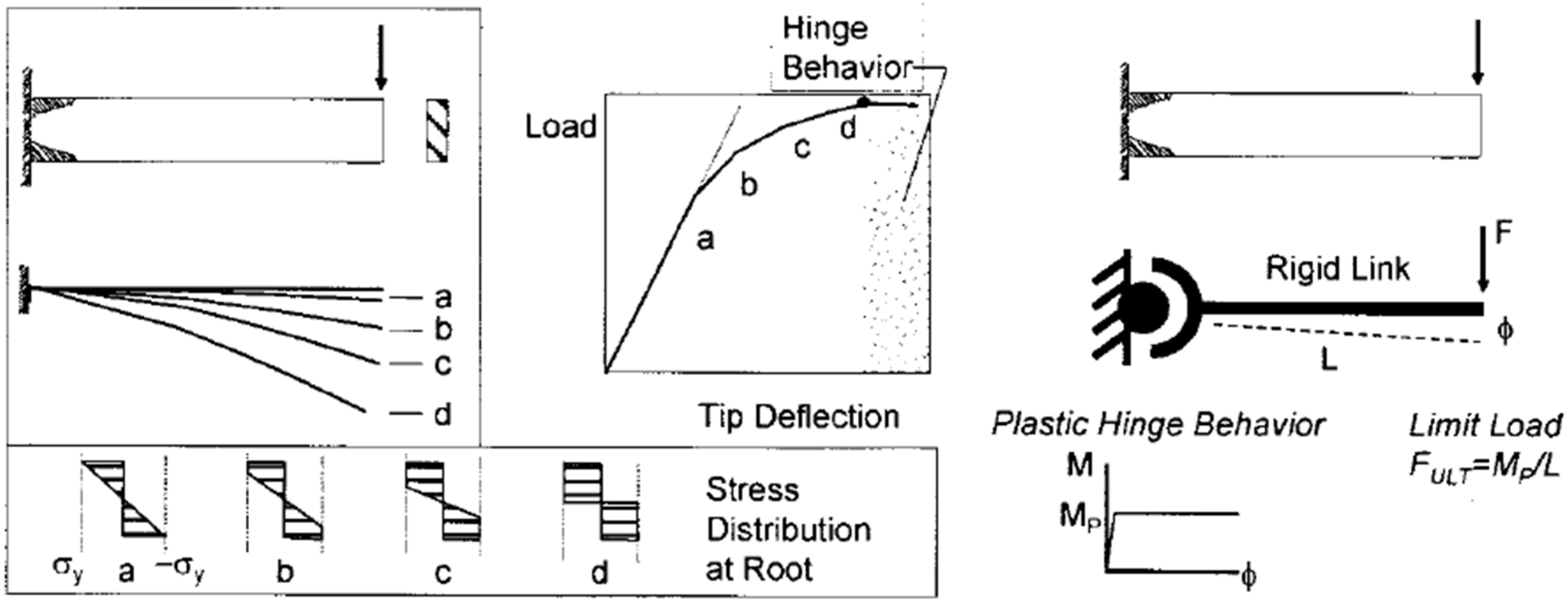
Reaction Member

- Plastic hinge locations

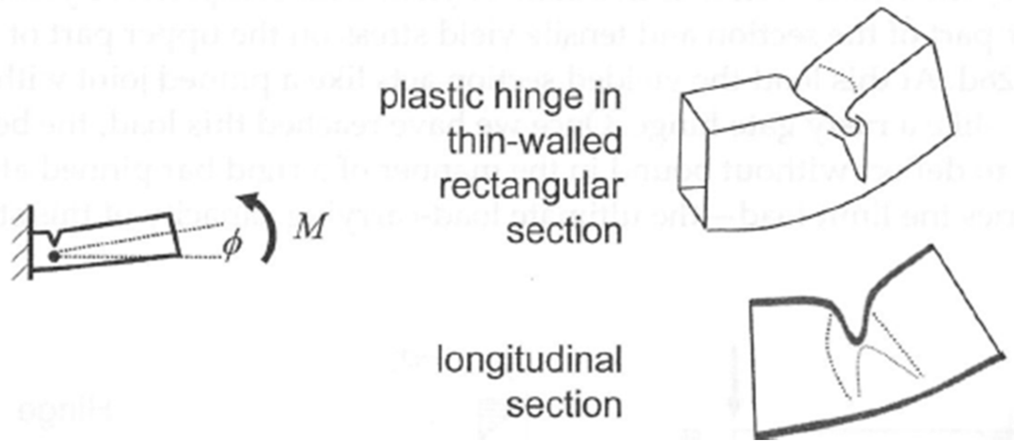


Plastic Hinge Behavior

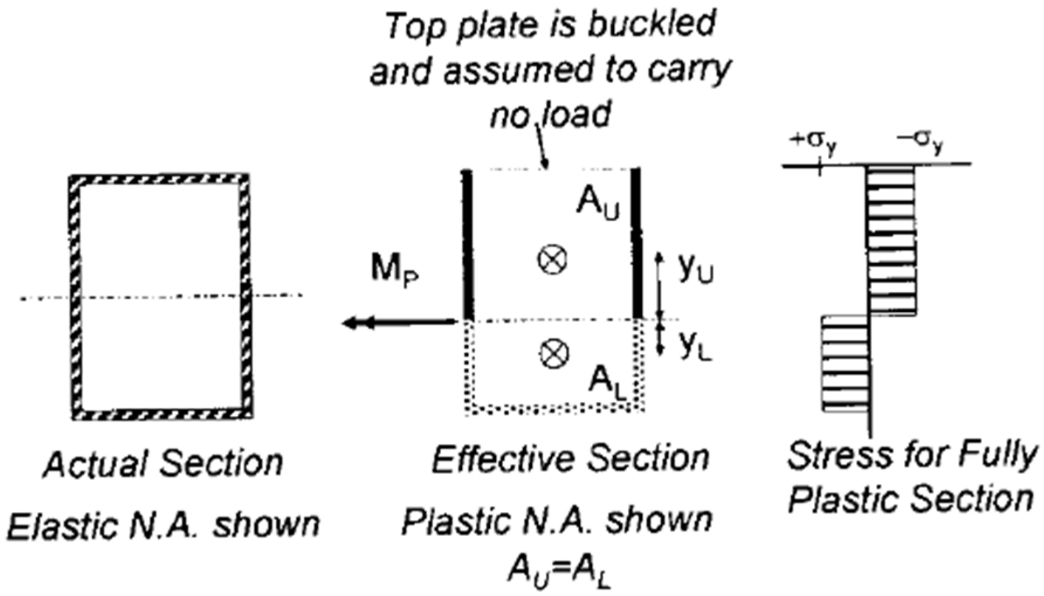
– Cantilever beam with a vertical tip load
– (a) linear and elastic (b) yield at outer fiber (c) increase in yielded region (d) limit load: ultimate load carrying capacity, acts like a pinned joint with a resisting moment



Plastic Moment



- Section dimensions
- Material yield stress

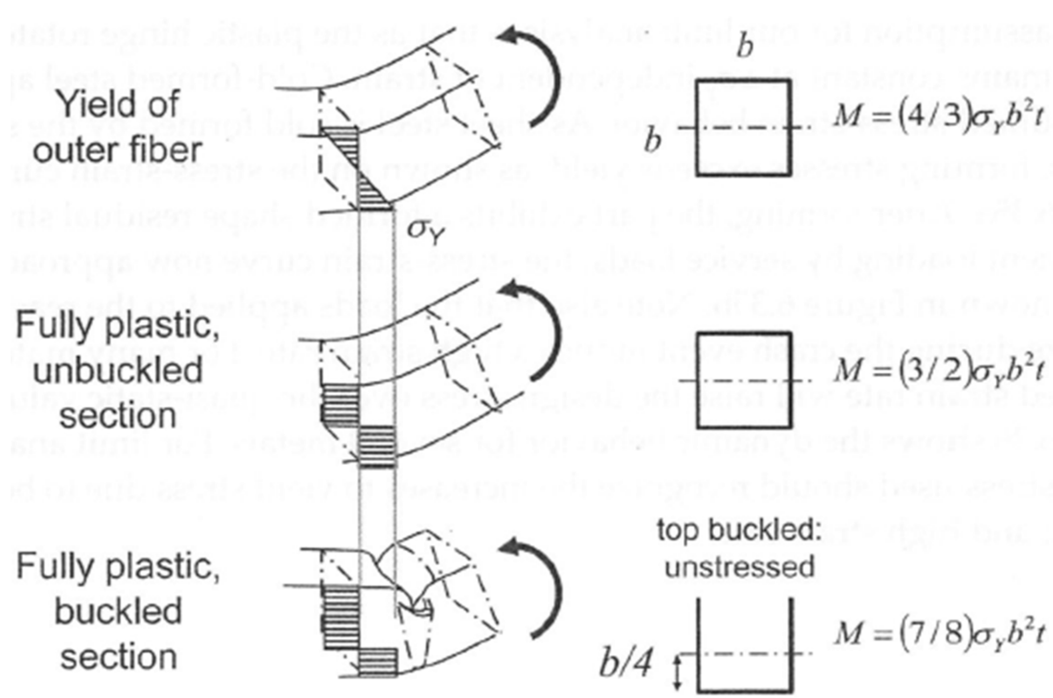


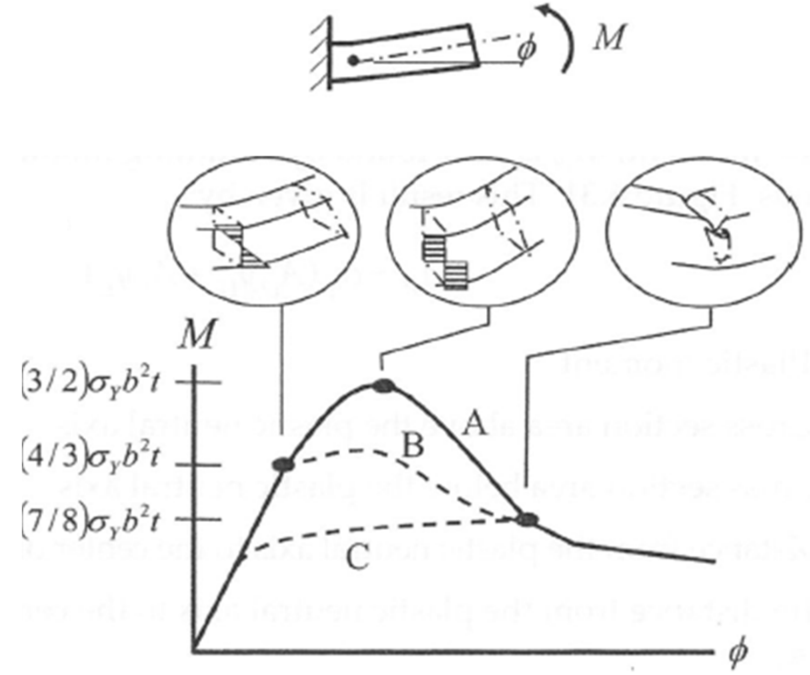
plastic neutral axis? (not necessarily same to the elastic neutral axis)

$$\left(-\sigma_Y\right)A_U + \sigma_Y A_L = 0 \rightarrow A_U = A_L$$

$$M_p = \sigma_Y\left(A_U y_U + A_L y_L\right)$$

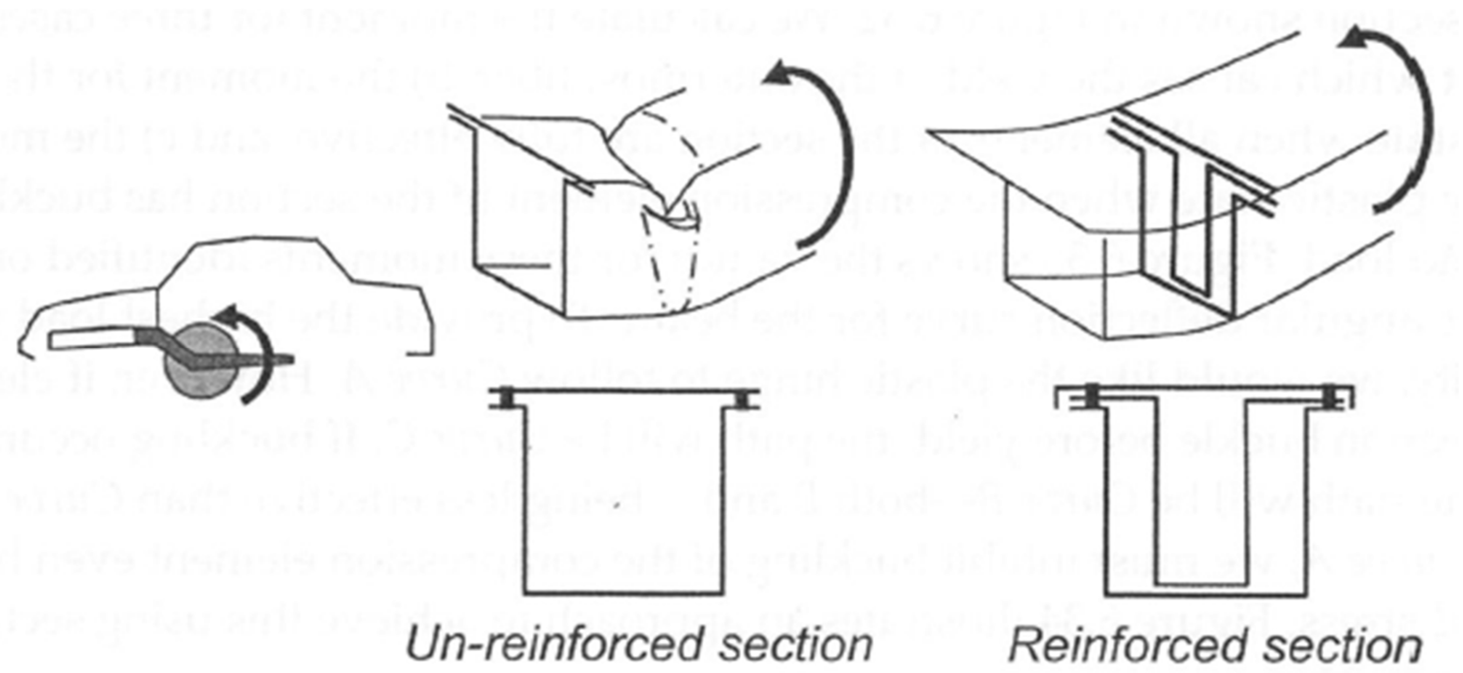
Square Thin-Walled Section





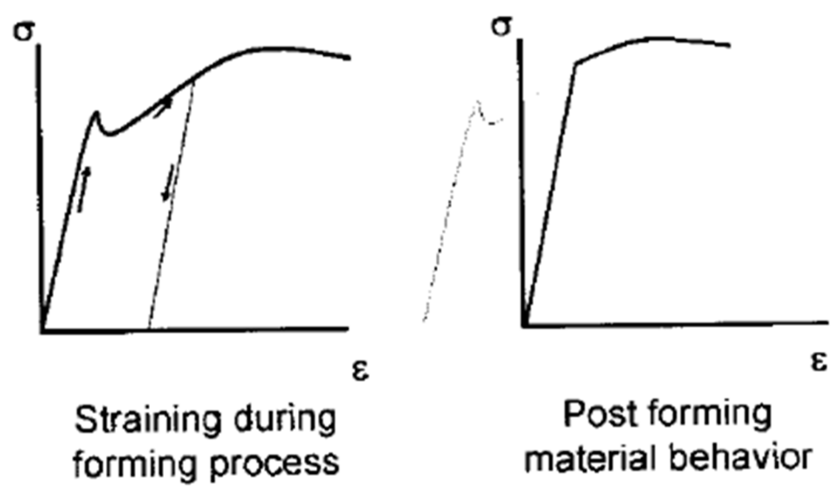
– Curve A: highest load reaction capability (inhibit buckling of the compressed element even beyond the yield)
– Curve B: bucking occurs after yield
– Curve C: bucking occurs before yield

Reinforcement to Increase Mp

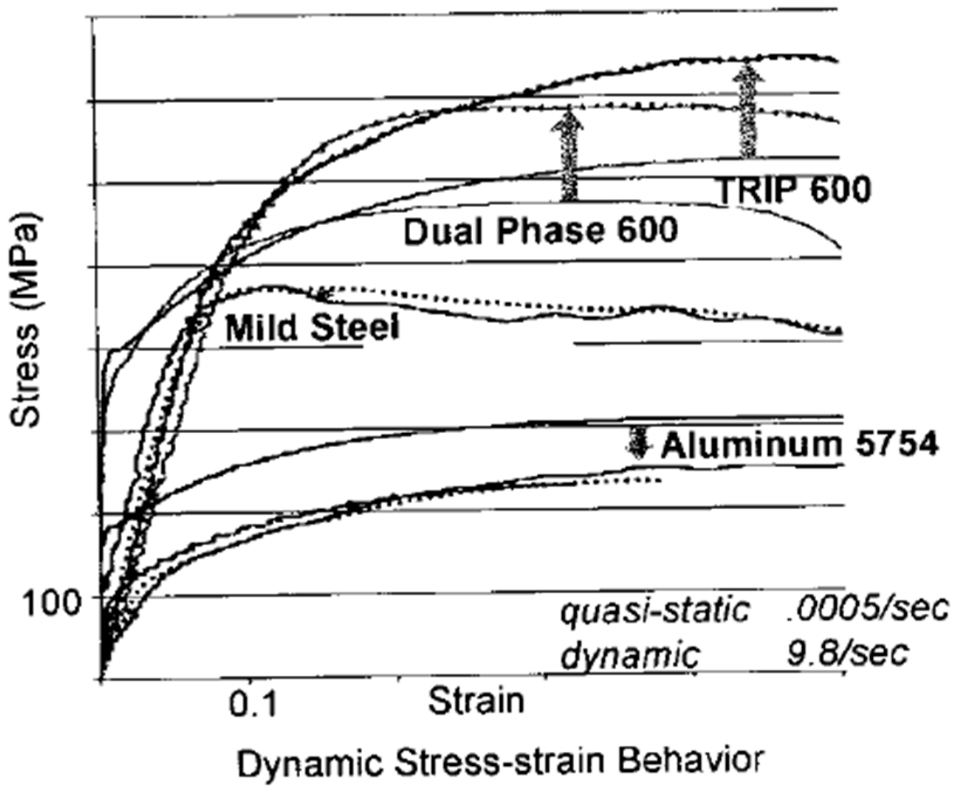


Material Behavior

- Design stress for limit analysis: yield stress
  - Assumption: stress level remains constant independent of strain as the plastic hinge rotates → cold formed steel
  - High strain rate during the crash event

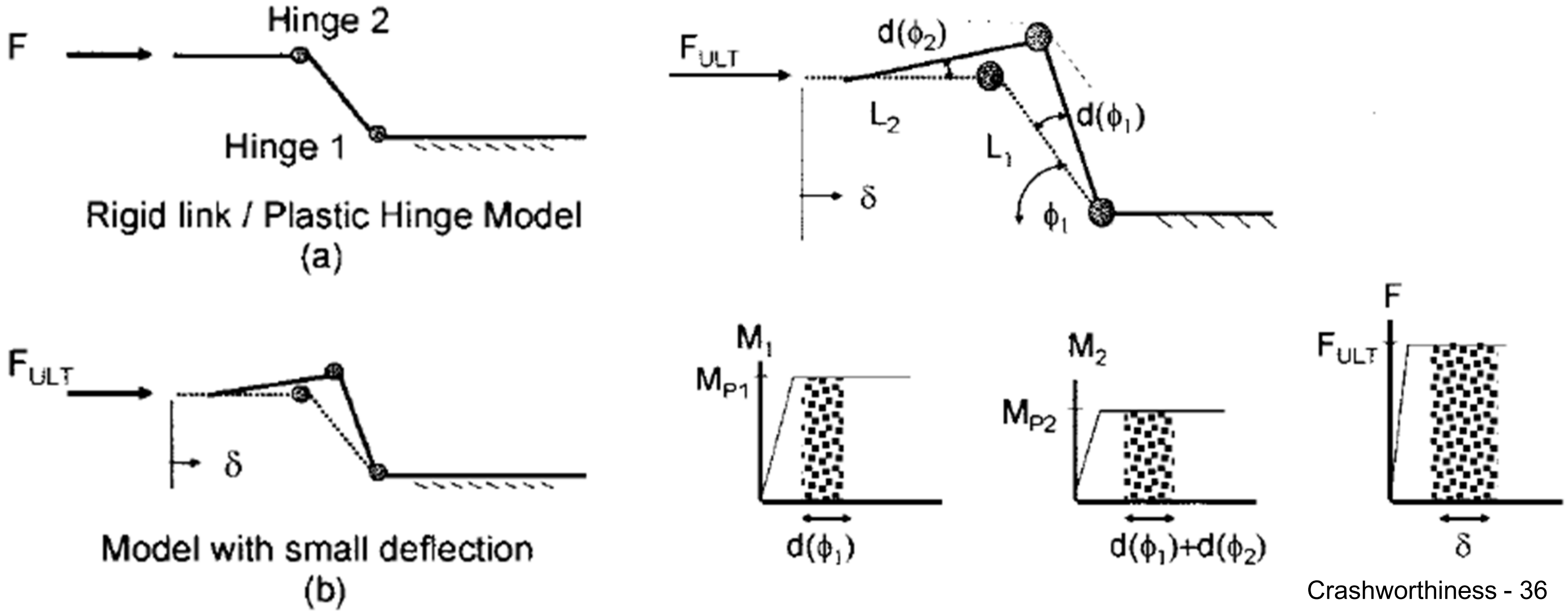


Work hardening



Limit Load Analysis: Midrail

- Objective
  - Identify the limit load capacity of the cabin structure
  - Ensure it is sufficient to react the crush load
- Isolate the longitudinal structure
  - Retain it at the floor pan connection
  - Two rigid beams connected by two plastic hinges

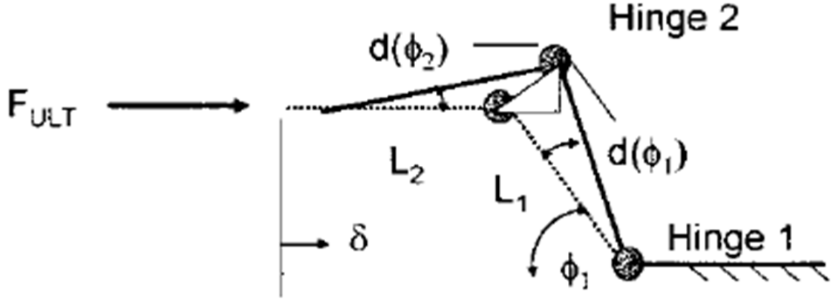


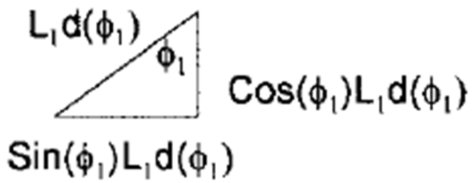
Rigid link / Plastic Hinge Model
(a)

Model with small deflection
(b)

Load Capacity: F_{ULT}?

- Geometry of the longitudinal structure
  - L_1, L_2, ϕ_1
- Plastic moment capacity at the hinge joints
  - M_{p1}, M_{p2}





$$\delta = \sin(\phi_1) L_1 d(\phi_1)$$

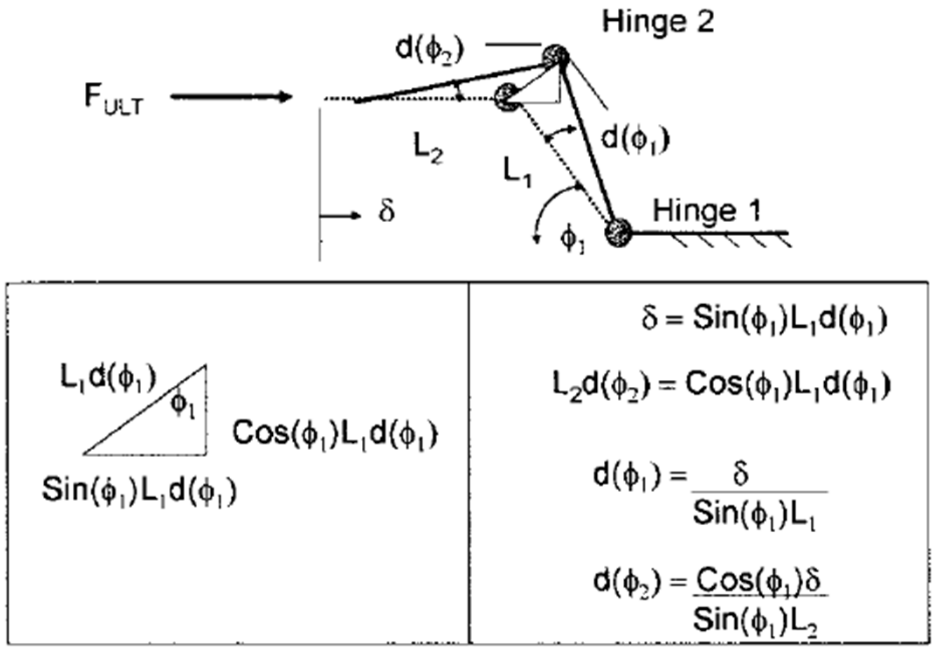
$$L_2 d(\phi_2) = \cos(\phi_1) L_1 d(\phi_1)$$

$$d(\phi_1) = \frac{\delta}{\sin(\phi_1) L_1}$$

$$d(\phi_2) = \frac{\cos(\phi_1)\delta}{\sin(\phi_1) L_2}$$

Load Capacity

- Geometry of the longitudinal structure
  - L_1, L_2, ϕ_1
- Plastic moment capacity at the hinge joints
  - M_{p1}, M_{p2}



$$F_{ULT}\delta = M_{p1}d\phi_1 + M_{p2}\left(d\phi_1 + d\phi_2\right)$$

$$F_{ULT}\delta = M_{p1}\left(\frac{\delta}{L_1 \sin\phi_1}\right) + M_{p2}\left(\frac{\delta}{L_1 \sin\phi_1} + \frac{\delta \cos\phi_1}{L_2 \sin\phi_1}\right)$$

$$F_{ULT} = M_{p1}\left(\frac{1}{L_1 \sin\phi_1}\right) + M_{p2}\left(\frac{1}{L_1 \sin\phi_1} + \frac{\cos\phi_1}{L_2 \sin\phi_1}\right)$$

Design for Reducing Vehicle Pitch

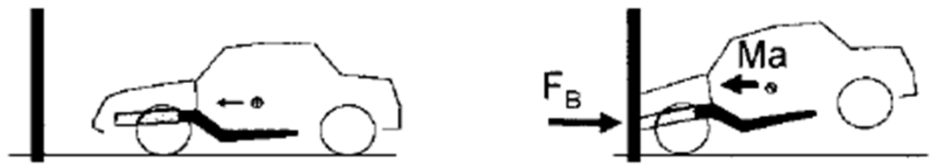
– Some vehicles rotate with rear raising upward: increase the likelihood of neck injuries
– Add another crushable load path above than CG: moments about vehicle CG for two crushable load paths sum to zero

$$\left.\begin{aligned} F_B\left(h-h_L\right) &= I\alpha \\ F_B &= Ma \end{aligned}\right\} \rightarrow \frac{Ma}{I}\left(h-h_L\right)=\alpha$$

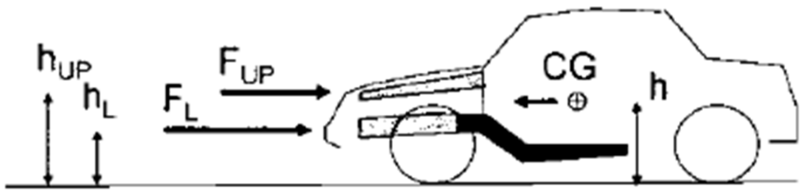
$$\begin{cases} M: \text{ vehicle mass} \\ I: \text{ pitch mass moment of inertia} \\ h: \text{ height of CG above ground} \\ h_L: \text{ height of effective load path above ground} \\ \alpha: \text{ pitch acceleration} \\ a: \text{ acceleration of vehicle during impact} \end{cases}$$

$$F_{UP}\left(h_{UP}-h\right)-F_L\left(h-h_L\right)=0$$

$$\rightarrow \frac{F_{UP}}{F_L}=\frac{h-h_L}{h_{UP}-h}$$



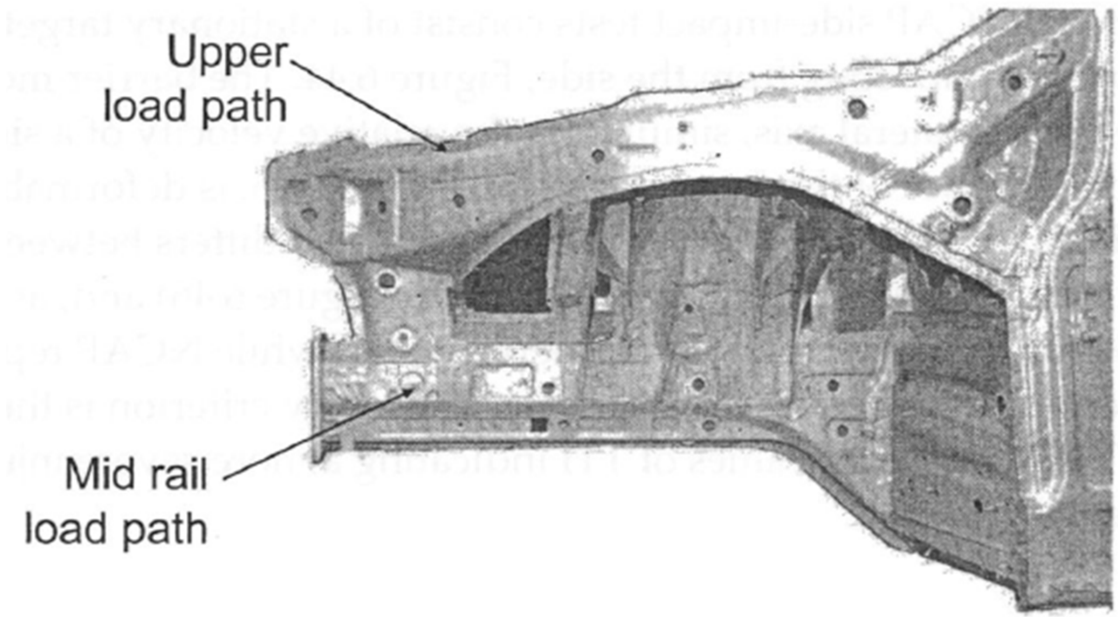
(a) Vehicle pitch without upper load path



(b) Addition of upper load path

Example of Upper Load Path

- Just under the hood
- To the sides of the motor compartment

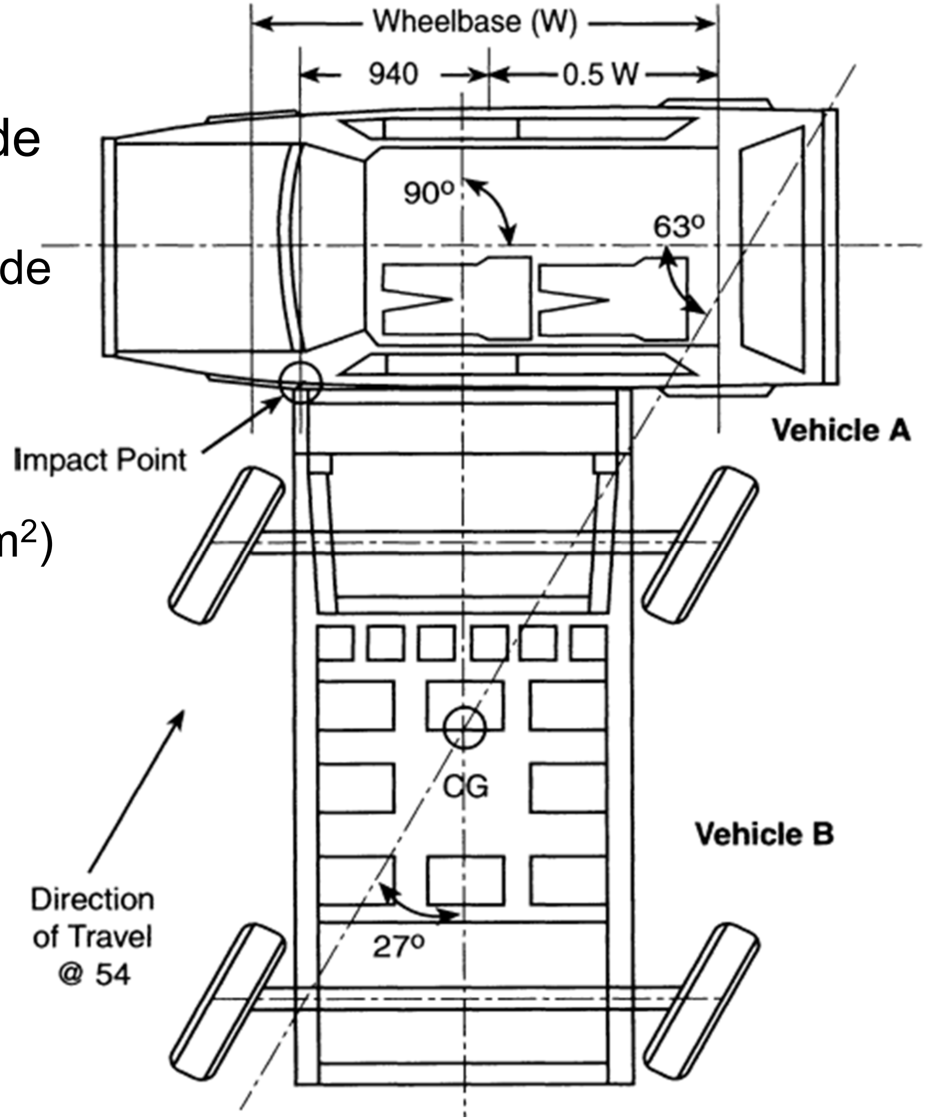


Structure for Front Barrier Impact

- Select the maximum allowable cabin decelerations based on occupant injury (a_{max})
- Determine a consistent structural efficiency and crush space (η, Δ)
- Compute the average and maximum allowable crush forces which the vehicle must generate during impact ($a_{max} \rightarrow F_{max}, \eta \rightarrow F_{avg}$)
- Allocate these total forces to the structural elements within the vehicle front end
- Size the crushable midrail using the average required crush force requirement
- If the peak crush load P_{max} exceeds the maximum load requirement, then consider crush interior designs
- The cabin reaction structure capacity must exceed the maximum midrail crush load. Use limit analysis to determine the required plastic moments for the hinges
- Size the reaction structure sections to generate the hinge moments

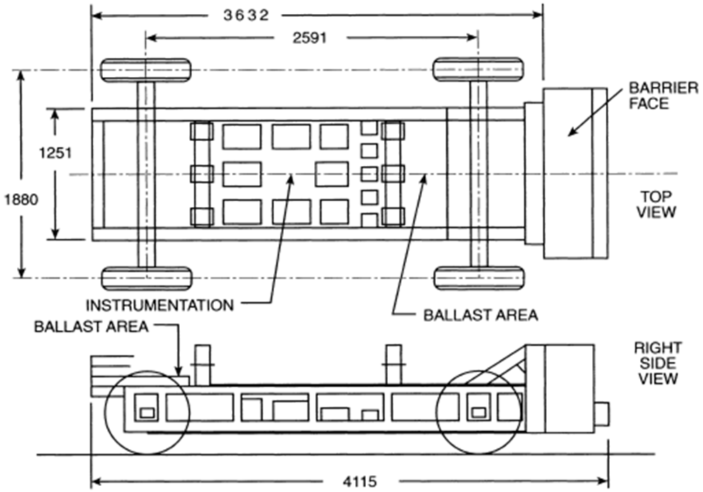
6.3 Side Impact

- Stationary target vehicle
- Moving barrier impacting from the side
  - 27° angle to the vehicle lateral axis simulating the relative velocity of a side impact at an intersection
- Face of moving barrier
  - Deformable
  - Crush at a uniform 45 psi (0.31 N/mm^2)
- Impact speed
  - FMVSS: 33.5 mph (53.6 kph)
  - NCAP: 38.5 mph (61.6 kph)
- Injury criterion
  - TTI (Thoracic Trauma Index) < 57

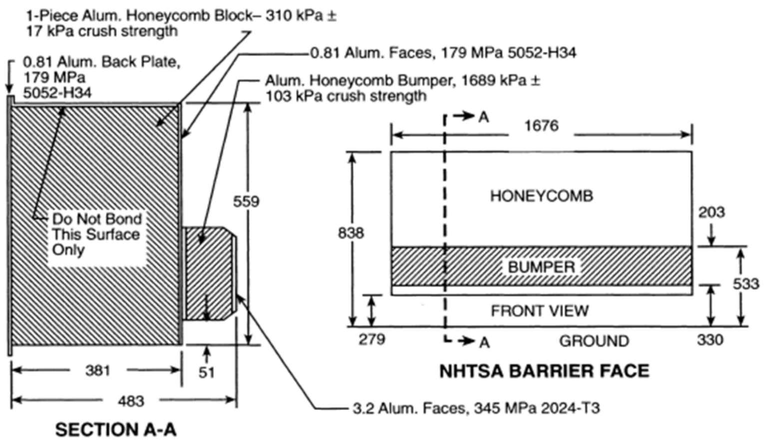


Side Impact

- moving deformable barrier

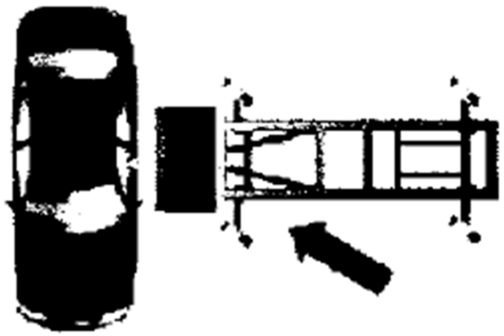


NHTSA VEHICLE SIMULATOR
All dimensions in millimeters (mm)



- NCAP (New Car Assessment Program)

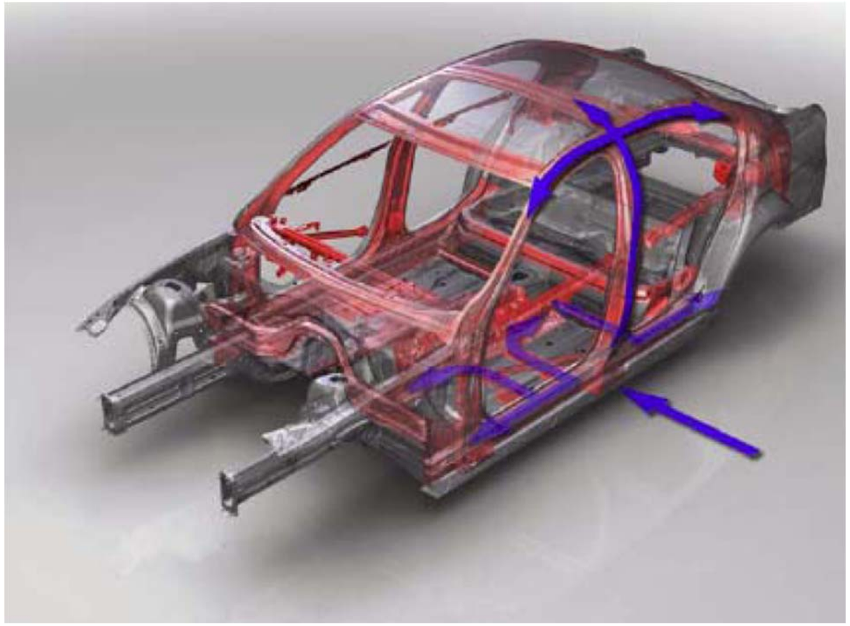
The SINCAP or LINCAP is based on the thoracic trauma index (TTI) using the US-SID dummy. The TTI is defined as the average of the peak accelerations in the rib and lower spine.

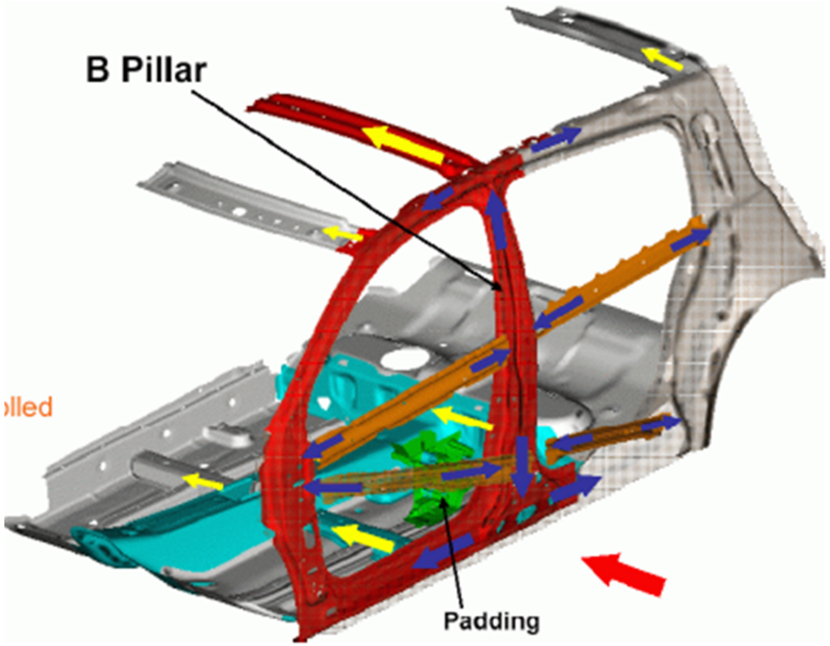


38.5 mph (61.6 km/h) impacted by 1370 kg barrier moving 27° to lateral axis of vehicle

Star Rating	% chance of serious injury
★★★★★	<5%
★★★★	6-10
★★★	11-20
★★	21-25
★	>26

Load Path

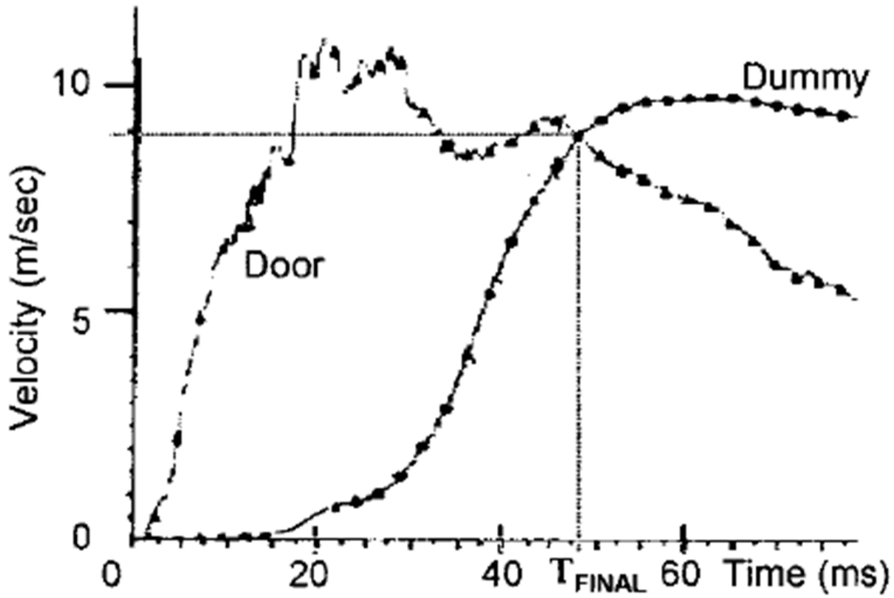


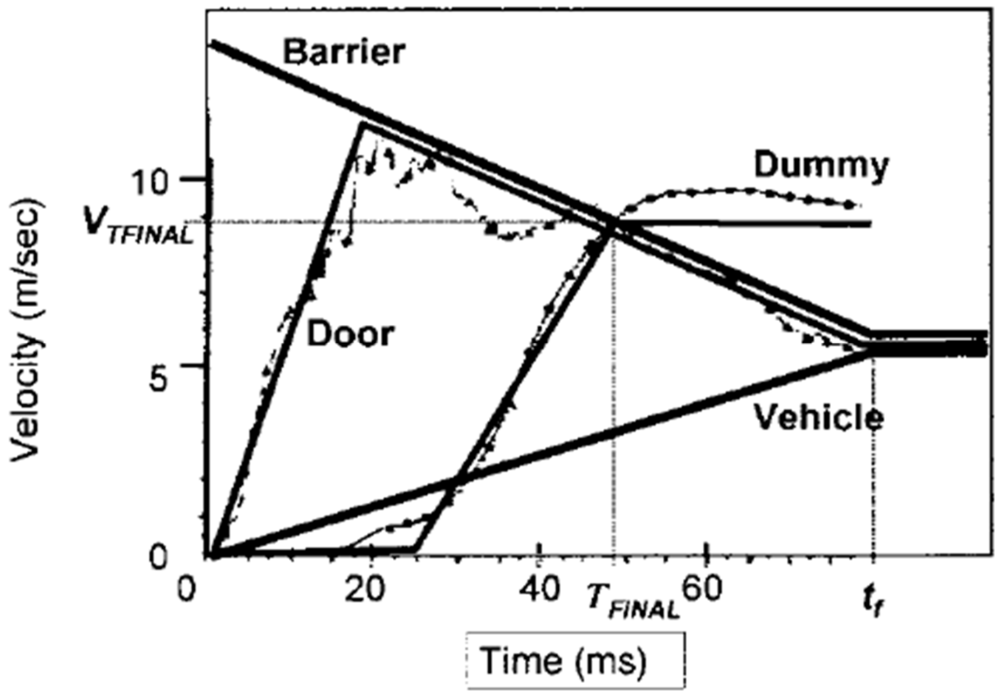


- Structural criteria
  - Load transfer continuity to doors
  - Small relative displacements
  - Small absolute displacements up to t = 40ms for enabling airbag inflation

Velocity-Time History

- Lateral to the vehicle and relative to ground
- Door velocity: at the inside surface of the front door structure
- Dummy velocity: at the torso
- T_{FINAL}: dummy impact event



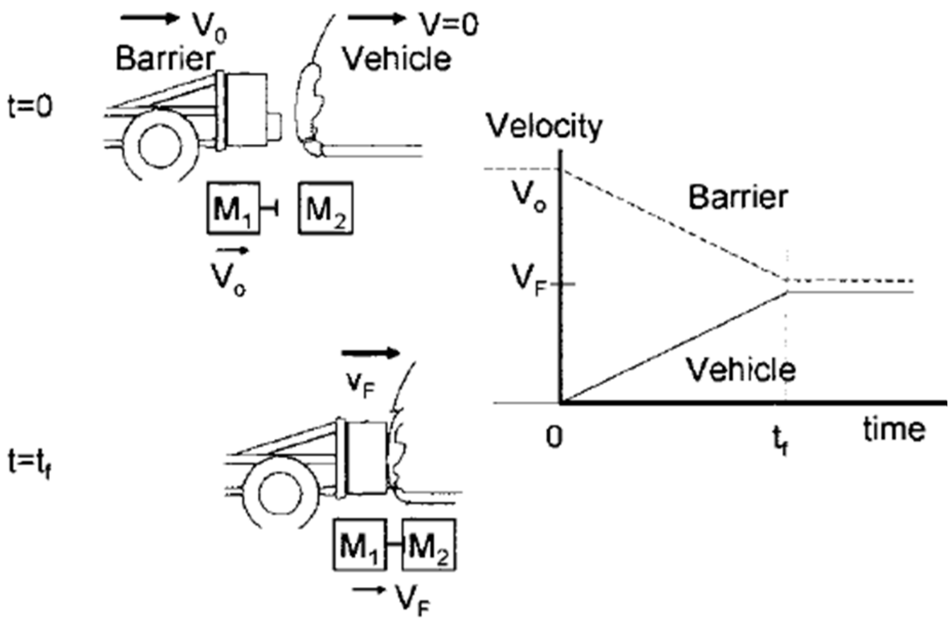


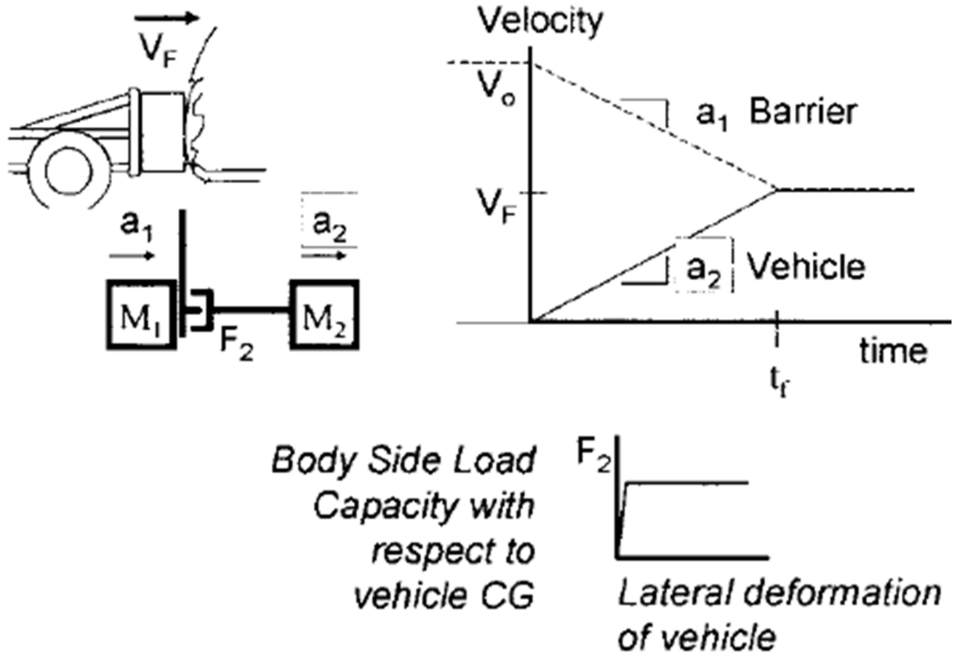
Performance Criterion

- Which characteristics most influence injury?
  - Correlations between observed TTI with measured parameters from the velocity-time history
  - Total change in velocity the dummy undergoes during the impact, V_{FINAL}
- Single performance criterion for preliminary design
  - Minimize $V_{FINAL} \rightarrow$ Minimize TTI

Kinematics & Load Path Analysis

– Model as a point mass with the impact being perfectly plastic





$$M_1 V_0 = \left(M_1 + M_2\right) V_F \rightarrow V_F = \frac{M_1}{M_1 + M_2} V_0$$

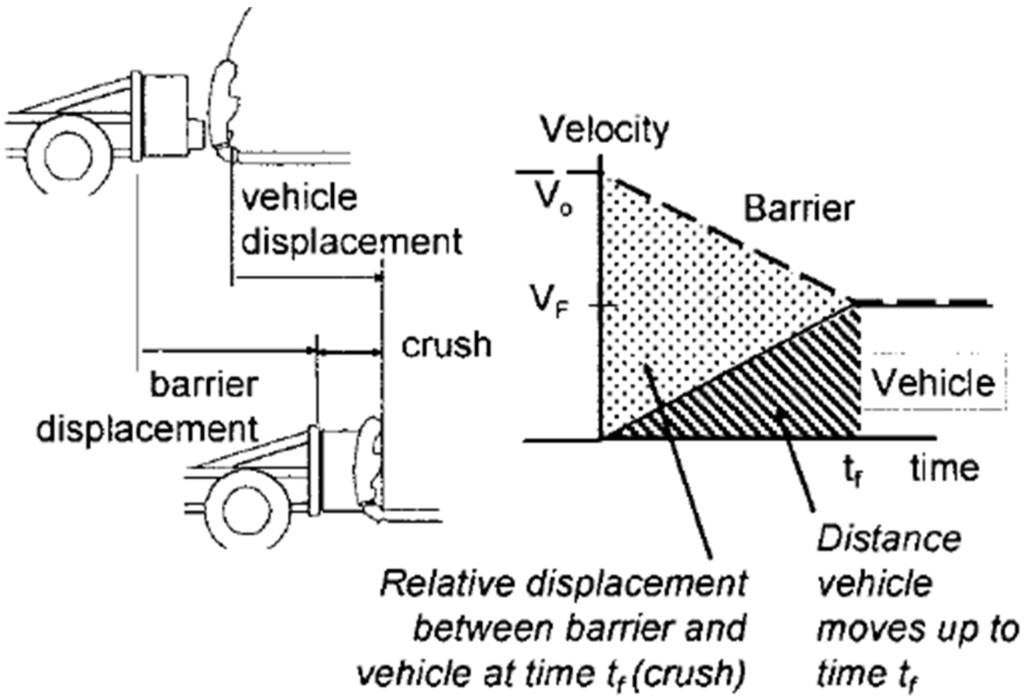
$$\begin{cases} M_1 : \text{ barrier mass} \\ M_2 : \text{ vehicle mass} \\ V_0 : \text{ lateral impact speed } \left(S_{test} \cos\alpha\right) \\ V_F : \text{ final speed of vehicle and barrier} \end{cases}$$

$$-F_2 = M_1 a_1 \rightarrow a_1 = -\frac{F_2}{M_1}, \quad F_2 = M_2 a_2 \rightarrow a_2 = \frac{F_2}{M_2}$$

$$\begin{cases} a_1 : \text{ barrier acceleration} \\ a_2 : \text{ vehicle lateral acceleration} \\ F_2 : \text{ crush load for the vehicle side } \left(\geq 290,000N\right) \end{cases}$$

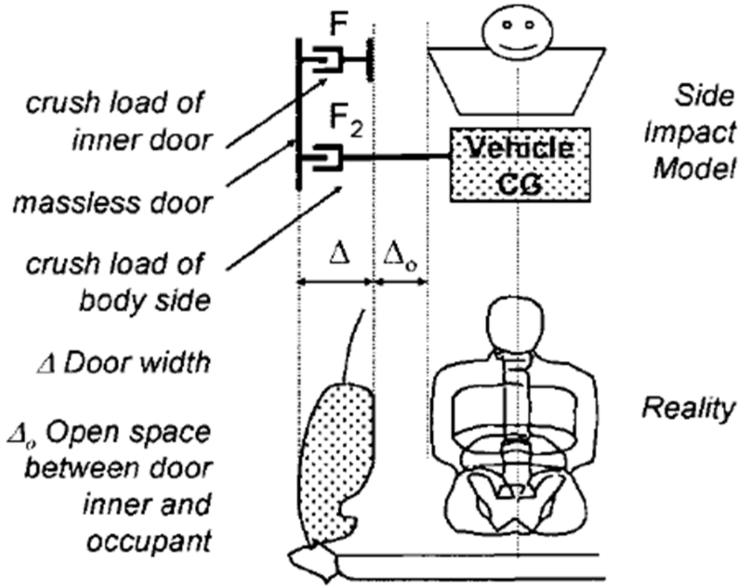
Crush Characteristics

- Final impact time for vehicle and barrier: $a_2 t_f = V_F \rightarrow t_f = \dfrac{V_F}{a_2}$
- Distance traveled relative to ground: $\int_0^{t_f} V dt$
- Relative crush of the vehicle and barrier: $\frac{1}{2} V_0 t_f$
  - Difference of these two distances



Impact Between Occupant and Door

- Interior of vehicle
  - Occupant sitting on the vehicle mass, but not restrained in the lateral direction
  - Massless rigid door side
  - Vehicle crush element: F_2
  - Crush element (F) at the occupant shoulder level: crush characteristics of the door and trim panel

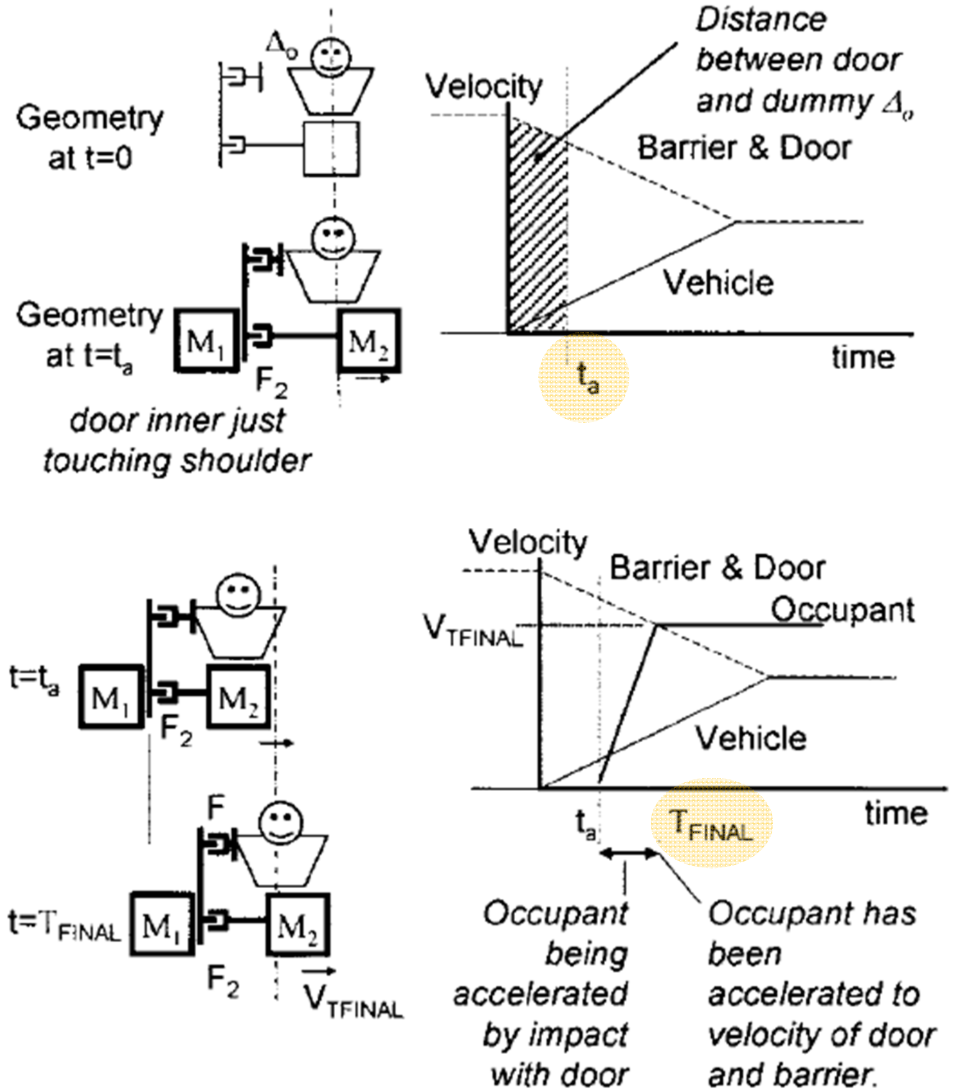


Impact of Vehicle and Barrier (1)

- Vehicle will begin to move to the side
  - Occupant will not move relative to ground
- Vehicle will move through the distance Δ_0 before the inner door will strike the occupant
  - Time at which the door impacts the occupant: t_a
  - Door side begins to load the occupant with force F
- Door side accelerates the occupant laterally
- Impact between the door and occupant is over
  - Velocity of the door and occupant is equal
  - Door inner has crushed through a distance of Δ

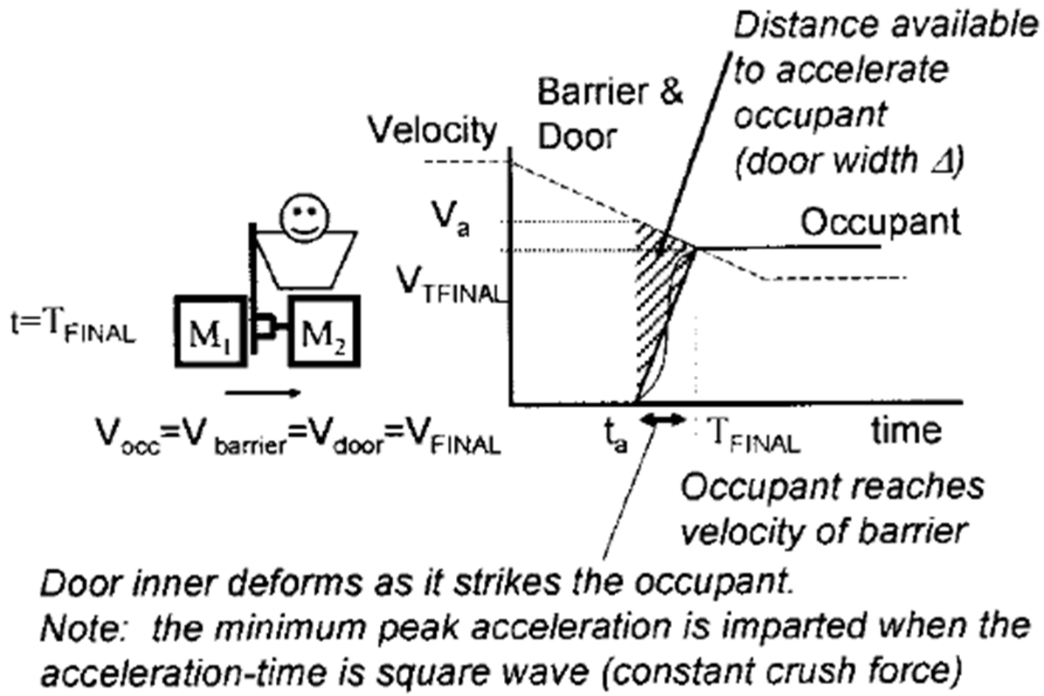
- Objective for kinematic analysis
  - Estimate the change in velocity of the occupant
  - Indicator of injury: V_{TFINAL}

Impact of Vehicle and Barrier (2)



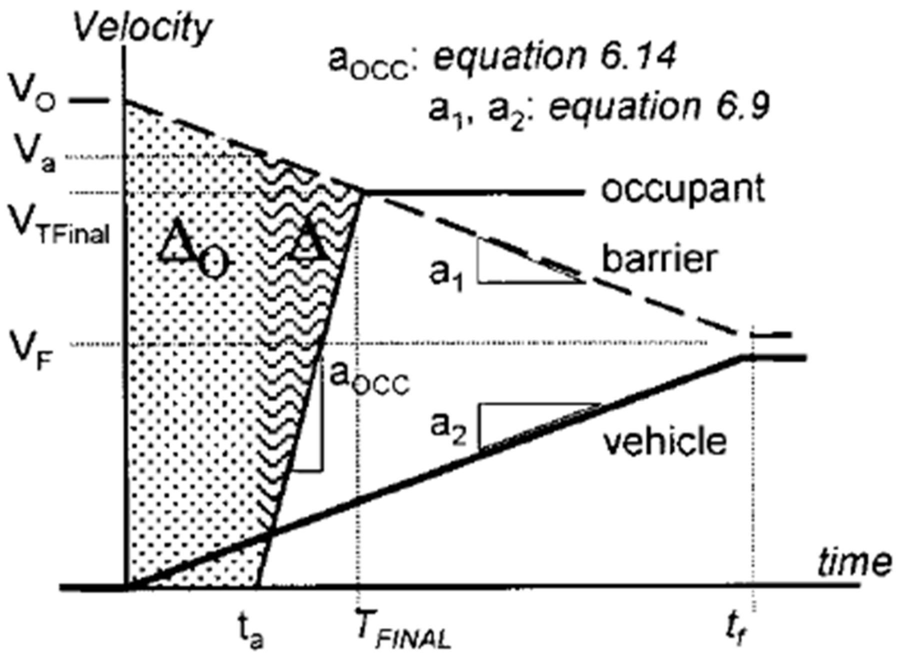
Door Inner Deformation Characteristics

– Assumption: square wave load-deformation crush curve



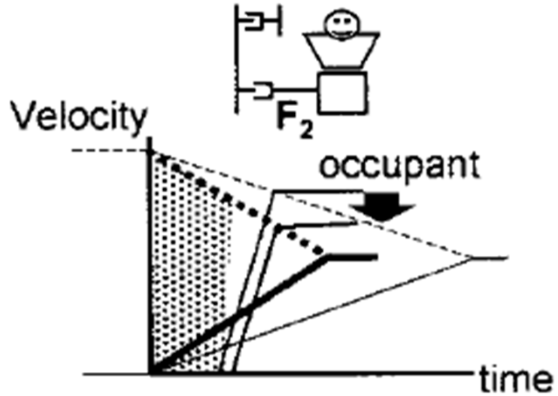
Summary of Kinematic Relationships

– Impact speed: V_0
– Barrier and vehicle masses: M_1 and M_2
– Force characteristics for the body side: F_2
– Dimension for the door crush thickness and space between occupant and door inner: Δ and Δ_0



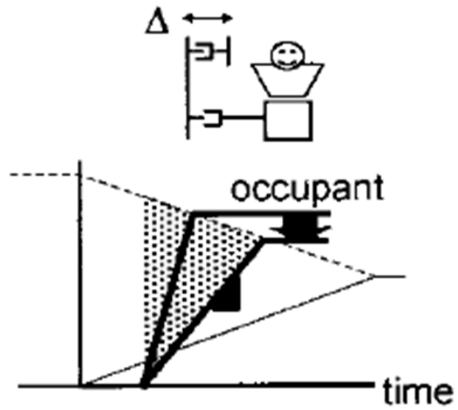
Design Considerations (1)

- High side crush force: F_2
  - Decelerate the barrier quickly before impact with occupant
  - Occupant is struck by the door at a lower velocity
- Rigid side-to-side structural members at the barrier face height
  - Cross member at the B pillar location or at the front of the rear seat pan
  - Rocker, lower B and C pillar



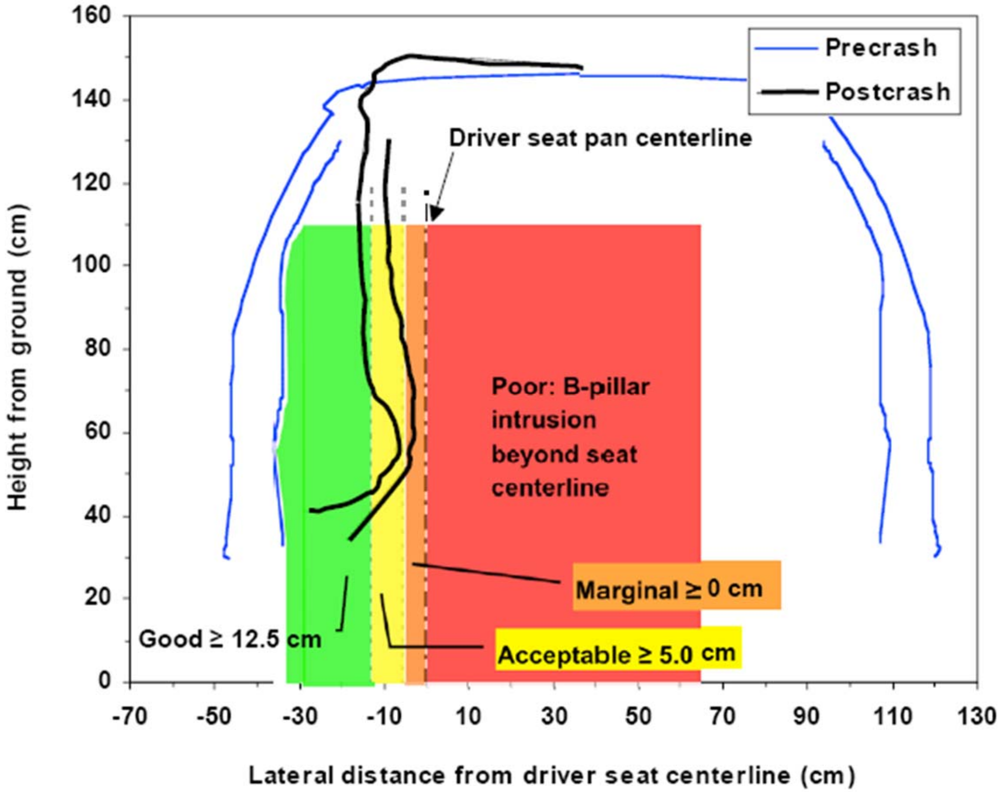
Design Considerations (2)

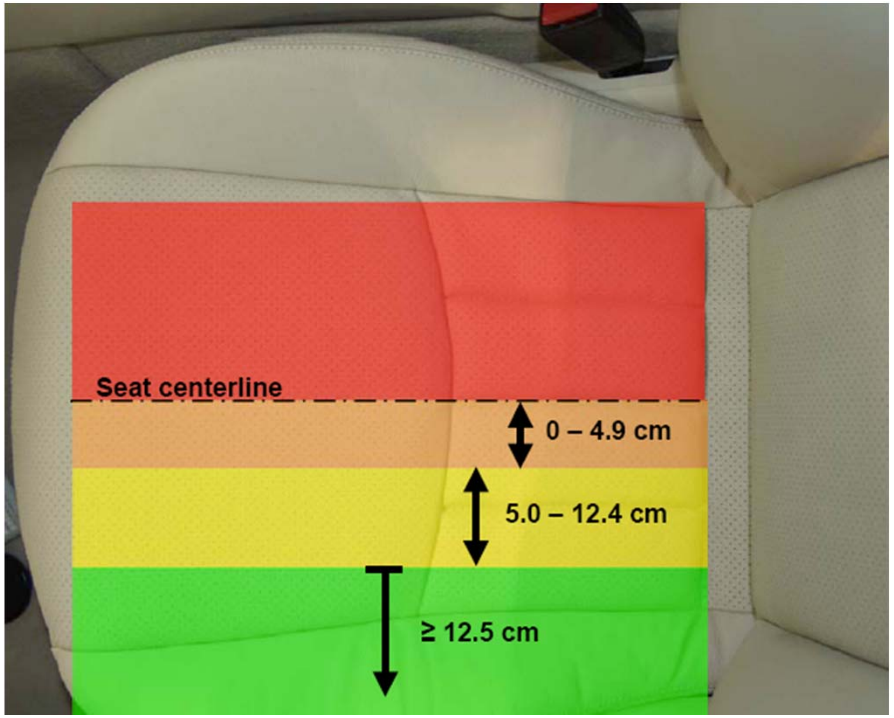
- Clearance between the occupant shoulder and door panel
  - Minimize the impact acceleration of the occupant
  - Increasing this space decreases the average slope of the occupant velocity curve
  - Lower impact force being applied to the occupant
- Door inner crush characteristic: F
  - Minimize the peak acceleration of the occupant
  - Crushable foam placed in the door trim area



IIHS Side Impact: Structural Rating

Boundary line	Good	Acceptable	Marginal	Poor
B-pillar to driver seat centerline distance (cm)	12.5	5.0	0.0	
Structural failures	Downgrade structural rating by one category			





6.4 Rear Impact

  - Stationary target vehicle is impacted by a moving barrier
- Criterion
  - Minimize fuel system leakage (fuel tank integrity)
  - Energy absorption of the barrier by deforming structure rearward of the fuel system
- Front impact case?
  - Replace rear impact with one between a moving vehicle and fixed barrier
  - Identify the equivalent impact velocity which results in the same work of deformation

Moving Barrier Impact Speed

$$M_1(0)+M_2V_0=(M_1+M_2)V_F \rightarrow V_F=\frac{M_2}{M_1+M_2}V_0$$

$$\begin{cases} M_1: \text{ struck vehicle mass} \\ M_2: \text{ moving barrier mass} \\ V_0: \text{ initial moving barrier speed} \\ V_F: \text{ final speed of vehicle and barrier} \end{cases}$$

$$(\text{work of deformation})$$

$$=(\text{change of kinetic energy before and after the impact})$$

$$W=\frac{1}{2}M_2V_0^{\ 2}-\frac{1}{2}(M_1+M_2)V_F^{\ 2}=\frac{1}{2}\left(\frac{M_1M_2}{M_1+M_2}\right)V_0^{\ 2}$$

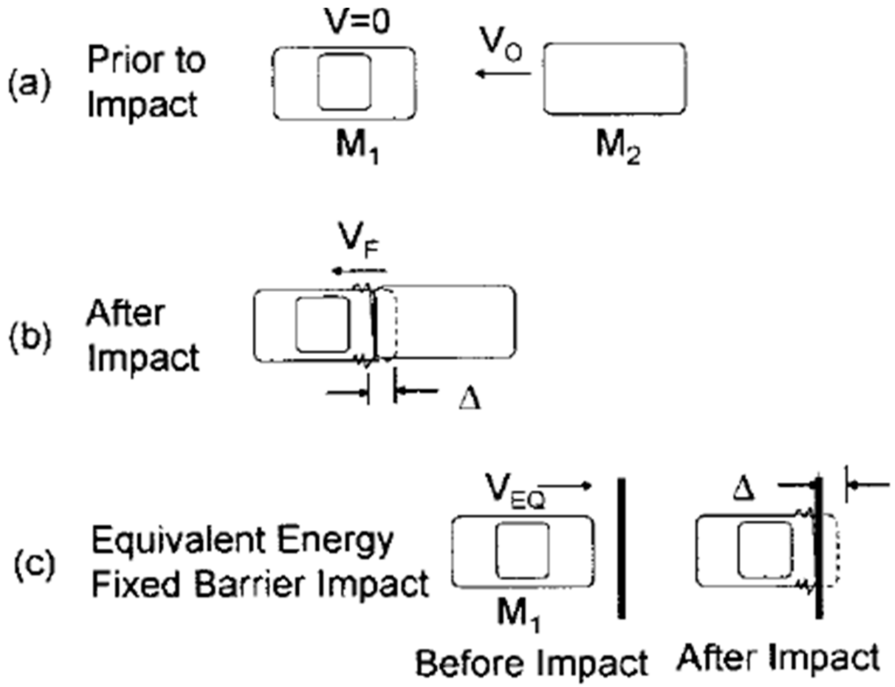
$$\frac{1}{2}M_1V_{EQ}^{\ 2}=W \rightarrow V_{EQ}=V_0\sqrt{\frac{M_2}{M_1+M_2}}$$

$$\frac{1}{2}M_1V_{EQ}^{\ 2}=F_{AVG}\Delta \rightarrow F_{AVG}=\frac{M_1V_{EQ}^{\ 2}}{2\Delta}$$

$$\begin{cases} \Delta: \text{ available crush space between fuel tank and bumper} \\ M_1: \text{ vehicle mass} \\ V_{EQ}: \text{ equivalent impact speed} \end{cases}$$

FMVSS 301

30mph Impact by moving barrier
Fuel system integrity

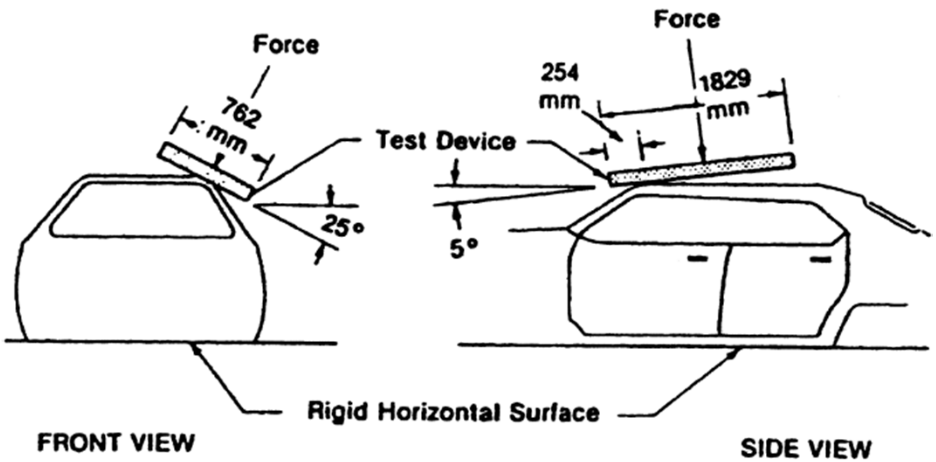


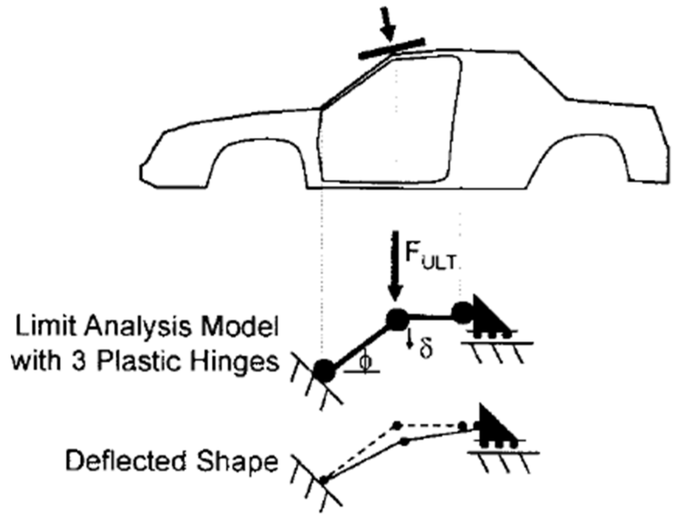
Preliminary Design

- Process to size the rear energy absorbing structure and reaction structure: same as with the front barrier
  - (1) F_{AVG}
  - (2) limit analysis
- Assumption
  - Fuel tank is between rear wheels and extends to the back of rear wheel
- Available crush space Δ
  - Distance from the back of rear wheel to the end of the car

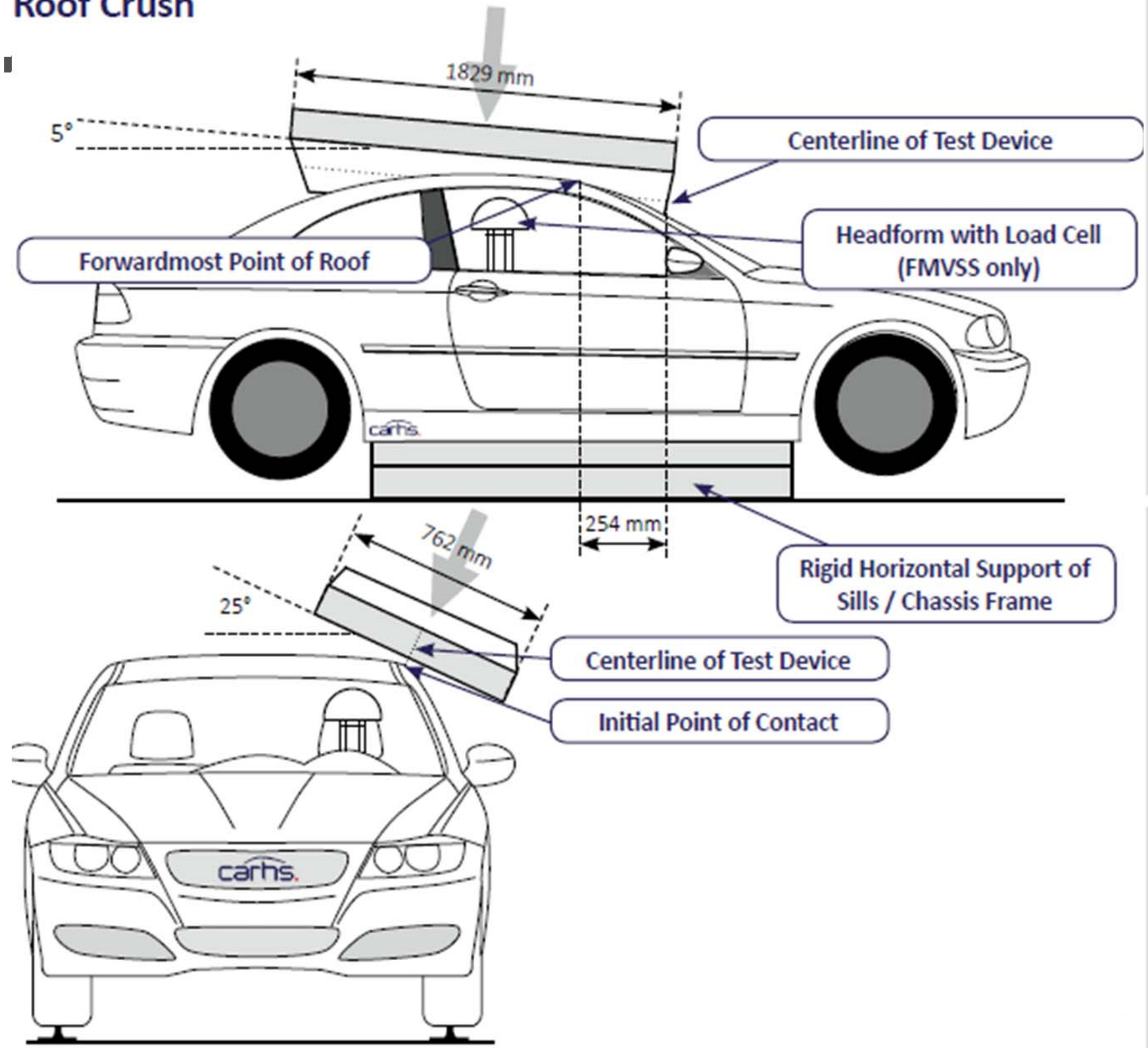
6.5 Roof Crush

- Criterion
  - Develop a minimum level of crush force (1.5 times the vehicle weight) without deforming beyond a set distance (5 inches)
- Limit analysis: first order model
  - Neglect the lateral component of the roof crush load: windshield
  - A pillar beam and roof rail beam connected by three plastic hinges: belt line, top of the windshield, roof rail to B pillar intersection
  - Insure that limit load exceeds crush force requirement





Roof Crush



IIHS

Testing Protocol Version III (July 2016)

Platen Displacement: 127 mm

Feed Rate: 5 mm/s

Single Side Test: Lab selects worst case

Assessment:
based on Strength-to-weight ratio (SWR) = $F_{max} / m \times g$

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

A „Good" rating in the roof crush test is a requirement for the *Top Safety Pick* award.

SafetyWissen by carhs.

FMVSS 216a

TP-216a-00, May 2009

Application:
Vehicles with a GVWR ≤ 4536 kg

Applied Force:
for vehicles with a GVWR ≤ 2722 kg:
F = 3.0 x UVW x 9.8 m/s²
for vehicles with a GVWR > 2722 kg:
F = 1.5 x UVW x 9.8 m/s²

Feed Rate: ≤ 13 mm/s

Double Sided Test

Requirements:
Platen displacement ≤ 127 mm
Load on headform located at head position of 50 % male ≤ 222 N

UVW = Unloaded Vehicle Weight
GVWR = Gross Vehicle Weight Rating

SafetyWissen by carhs.

Overview Dummies

Adult Dummies for Frontal / Rear Impact

	Weight (kg)	Seating Height (cm)	Instruction for Calibration
THOR 50 % Male	76.7	90.7	
THOR 5 % Female	46.9	81.3	
Hybrid II 50 % Male	74.4	90.7	CFR 49 Part 572, Subpart B
Hybrid III 5 % Female	49.1	78.7	SAE J2862, J2878 CRF 49 Part 572, Subpart O
Hybrid III 50 % Male	77.7	88.4	SAE J2779, J2876 CFR 49 Part 572, Subpart E 1999/98/EC
Hybrid III 95 % Male	101.3	91.9	SAE J2860
BioRID II	77.7	88.4	User Manual

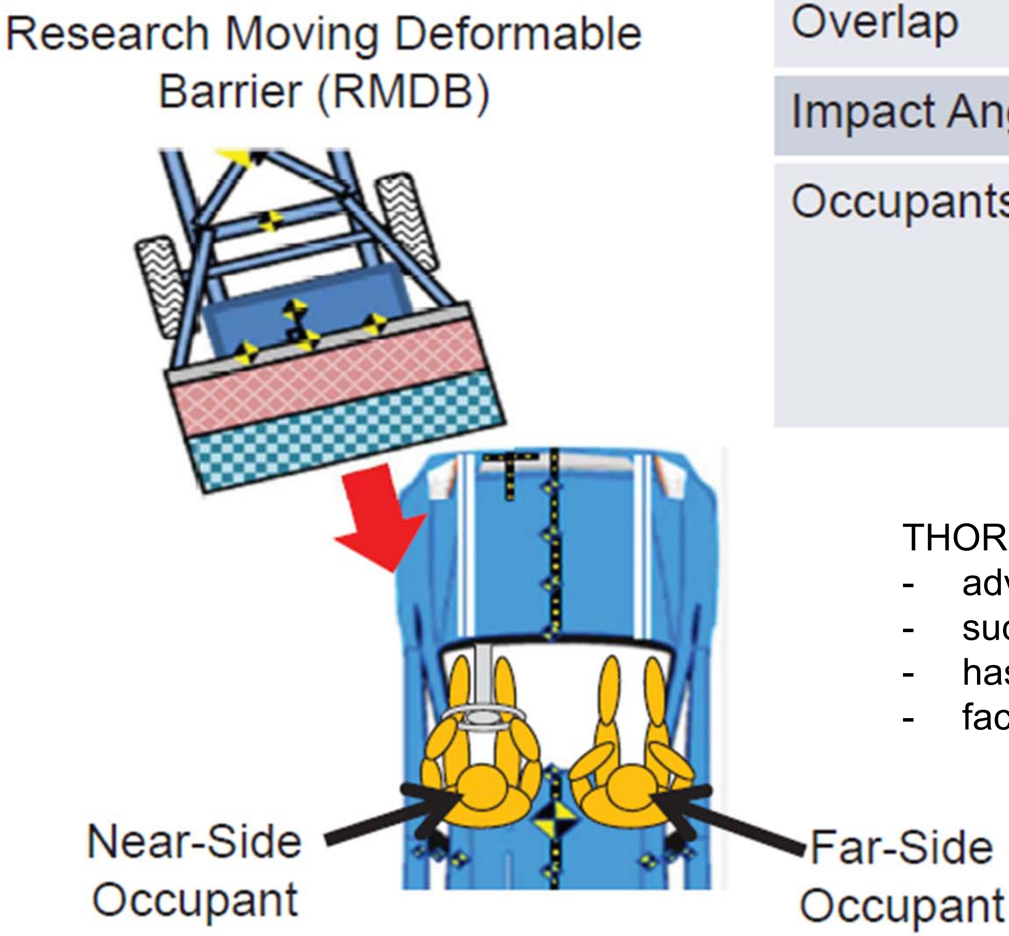
Adult Dummies for Side Impact

	Weight (kg)	Seating Height (cm)	Instruction for Calibration
Eurosid 1	72.0	90.4	Eurosid 1 Certification Procedure 96/27/EC, UN R95
ES-2	72.0	90.9	FTSS- User Manual / UN R95
ES-2 re	72.4	90.9	CFR 49 Part 572, Subpart U
US-SID	76.7	89.9	CFR 49 Part 572, Subpart F
US-SID/Sid-H3	77.2	89.9	CFR 49 Part 572, Subpart M
SID IIs	44.12	78.0	CFR 49 Part 572, Subpart V
WorldSID 5% Female	48.27		User Manual
WorldSID 50% Male	73.91	86.9	User Manual

Child Dummies

	Weight (kg)	Seating Height (cm)	Instruction for Calibration
P0. P¾. P6. P10	3.4 - 32.0	34.5 - 72.5	User Manual
P3	15.0	56.0	User Manual
P1½	11.0	49.5	P1½ User Manual
Q1	9.6	47.9	Q1 User Manual
Q1½	11.1	49.9	Q1.5 User Manual
Q3	14.5	54.4	Q3 User Manual
Q6	23.0	63.6	Q6 User Manual
Q10	35.5	73.4	Q10 User Manual (Rev. A Draft)
CRABI 12 m	10.0	46.4	CFR 49 Part 572, Subpart R
Hybrid II - 3 y/o	15.1	57.2	CFR 49 Part 572, Subpart C
Hybrid II - 6 y/o	21.5	64.5	CFR 49 Part 572, Subpart I
Hybrid III - 3 y/o	16.19	54.6	CFR 49 Part 572, Subpart P
Hybrid III - 6 y/o	23.4	63.5	CFR 49 Part 572, Subpart N
Hybrid III - 6 y/o - weighted	27.92	64.06 - 66.6	CFR 49 Part 572, Subpart S
Hybrid III - 10 y/o	35.2	71.6	CFR 49 Part 572, Subpart T

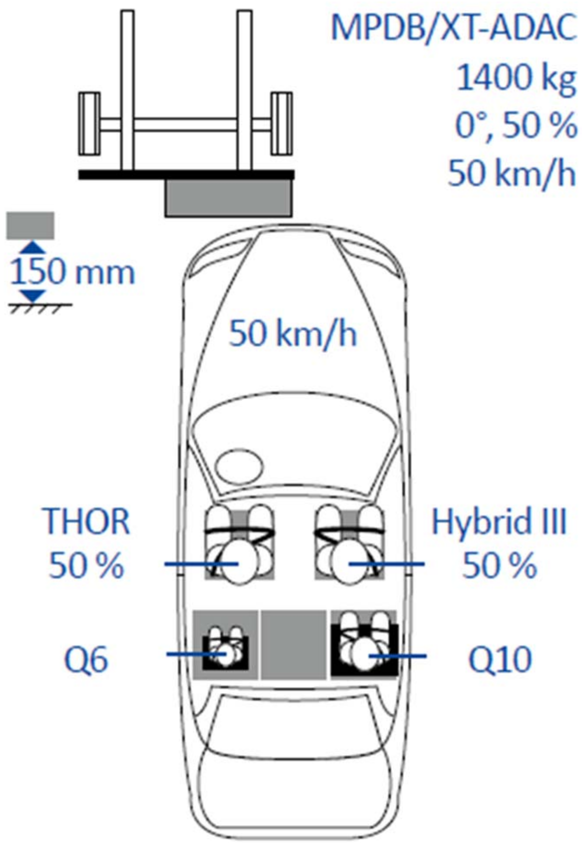
NHTSA Oblique RMDB



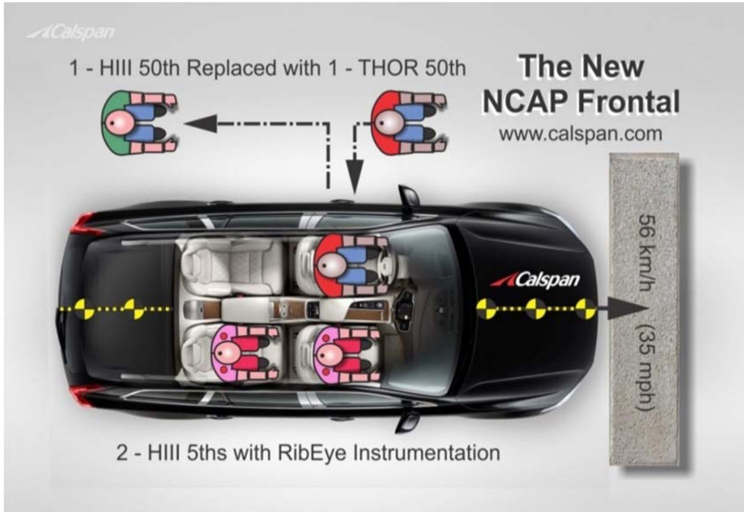
RMDB Speed	56 mph (90 kph)	
Overlap	35 percent	
Impact Angle	15 degrees (PDOF = 345)	
Occupants	Near-side (Driver)	THOR Mod Kit 50th Male
	Far-side (Passenger)	THOR Mod Kit 50th Male

THOR(Test device for Human Occupant Restraint)
- advanced 50th percentile male dummy
- successor of Hybrid III
- has more human-like spine and pelvis
- face contains a number of sensors

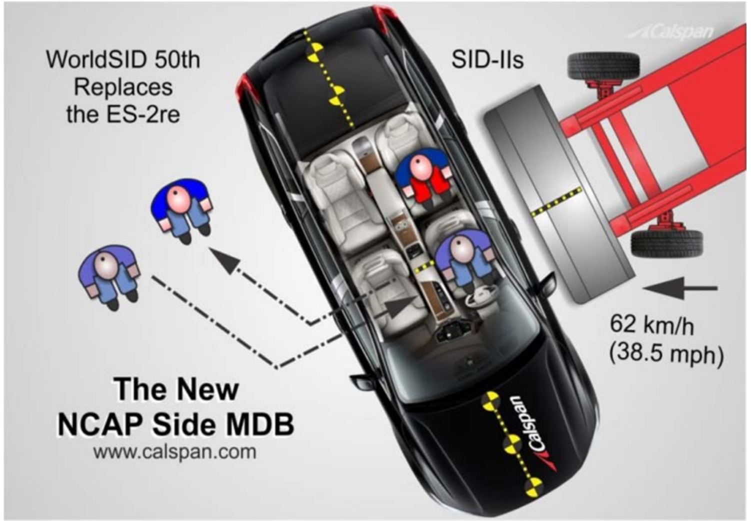
EURO NCAP: MPDB Frontal Impact (2020)



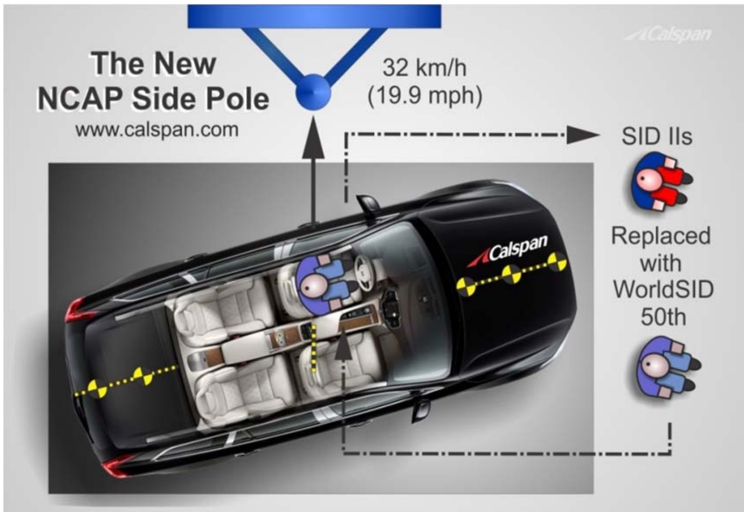
2019 NCAP



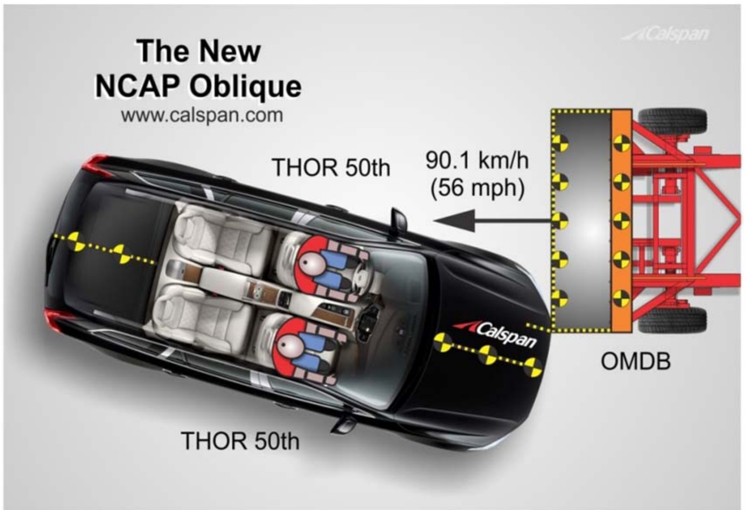
Calspan
1 - HIII 50th Replaced with 1 - THOR 50th
The New
NCAP Frontal
www.calspan.com
56 km/h (35 mph)
Calspan
2 - HIII 5ths with RibEye Instrumentation



Calspan
WorldSID 50th
Replaces
the ES-2re
SID-IIs
62 km/h
(38.5 mph)
The New
NCAP Side MDB
www.calspan.com
Calspan



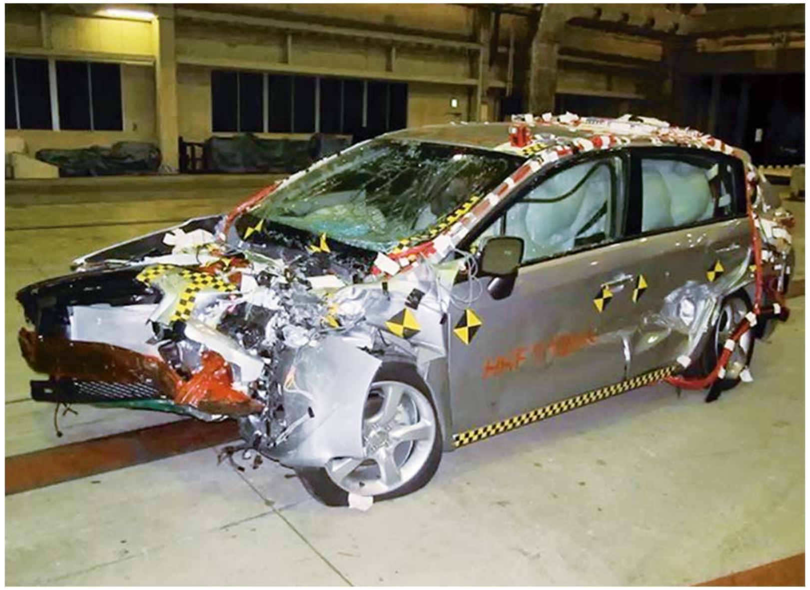
Calspan
The New
NCAP Side Pole
www.calspan.com
32 km/h
(19.9 mph)
SID IIs
Replaced
with
WorldSID
50th
Calspan



Calspan
The New
NCAP Oblique
www.calspan.com
THOR 50th
90.1 km/h
(56 mph)
Calspan
OMDB
THOR 50th

Subaru SGP: oblique충돌 대비책

이상적인 하중 분산의 흐름
(1) 프레임이 부서지면서 충돌시의 하중을 흡수
(2) 흡수하지 못한 하중이 앞 기둥의 밑 부분에 도달하면 프론트 필러의 방향과 사이드 실 및 메인 프레임 등의 방향으로 분산

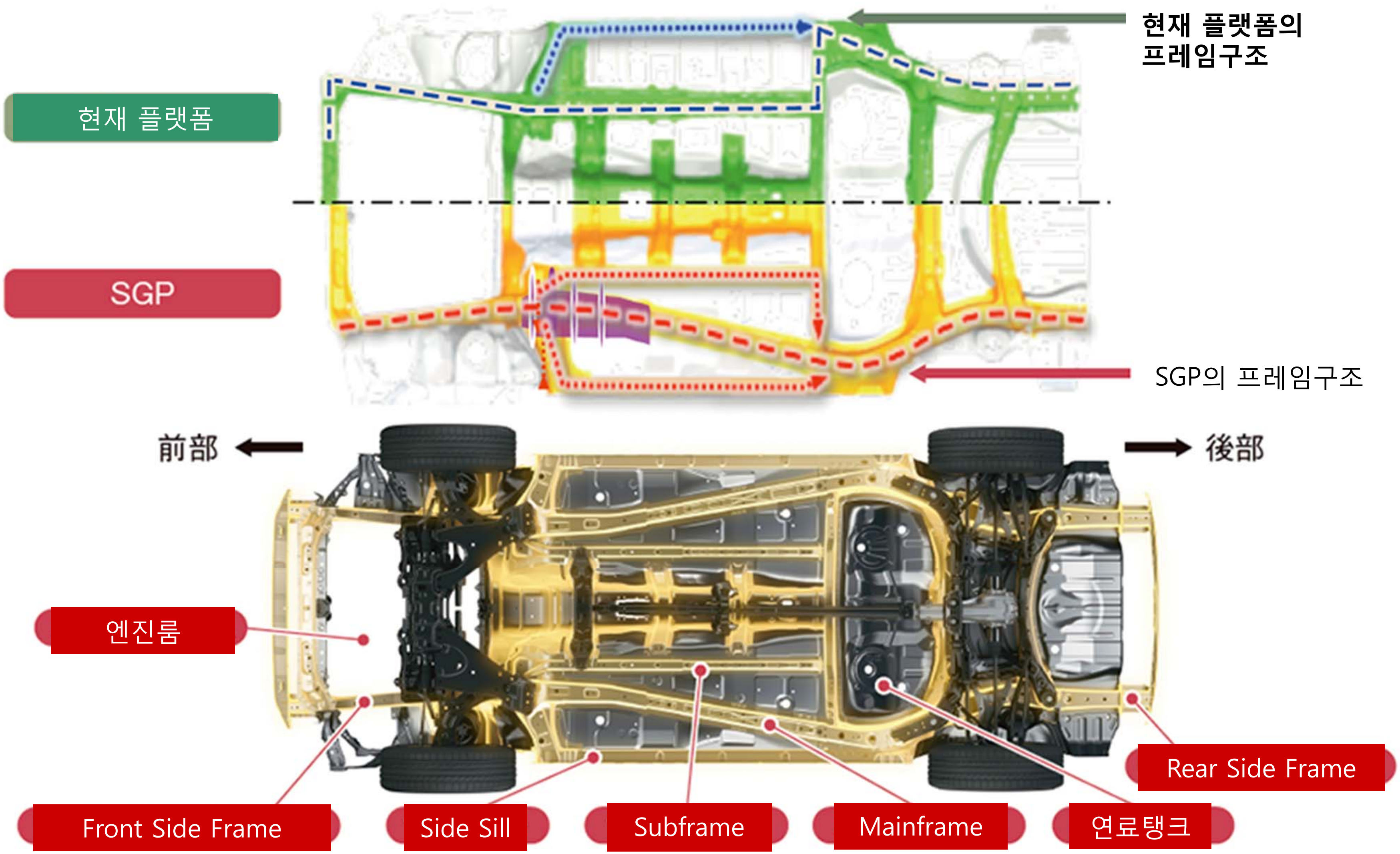


2.5 ton SUV

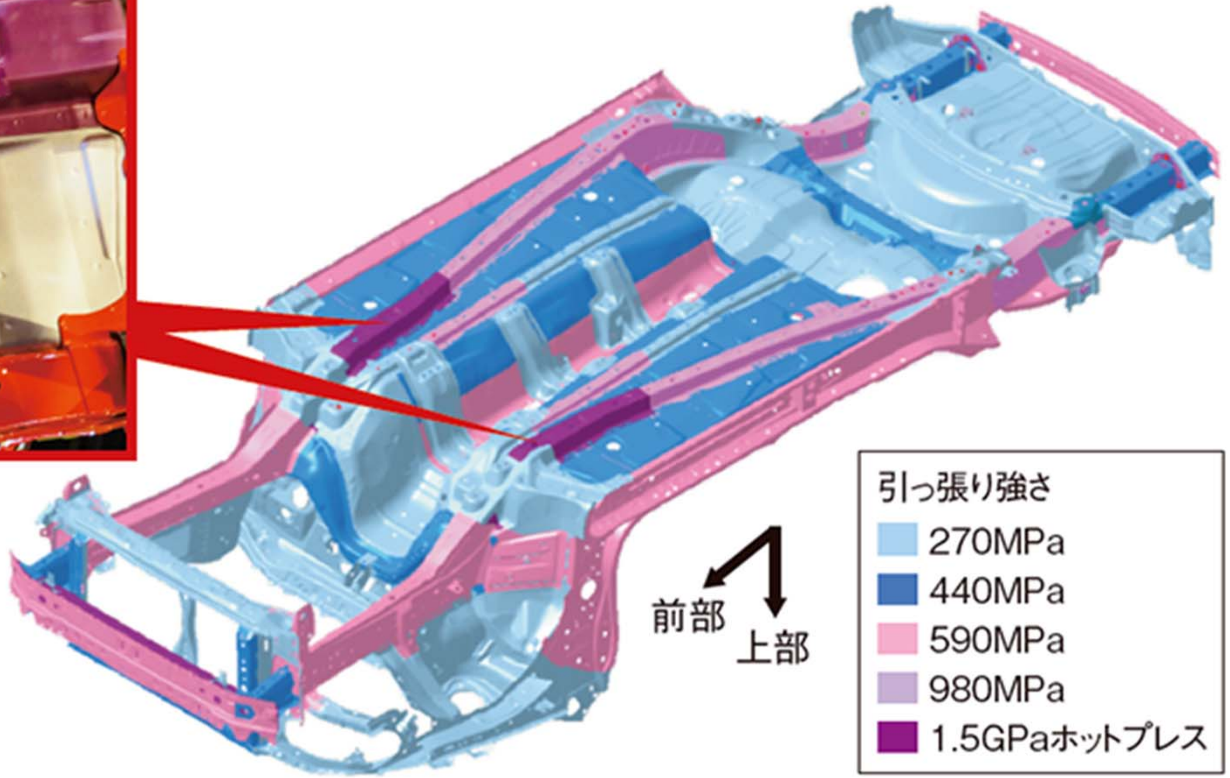
- 프레임구조 개선
- 프런트필러 관절부분의 강도 강화
- 프런트 벌크헤드 주변 결합 강화
  - 엔진룸과 캐빈 사이 격벽
- 플랫폼 전체 강도 강화

Nikkei Automotive 2016년 8월호

충돌 시 하중을 3방향으로 분산

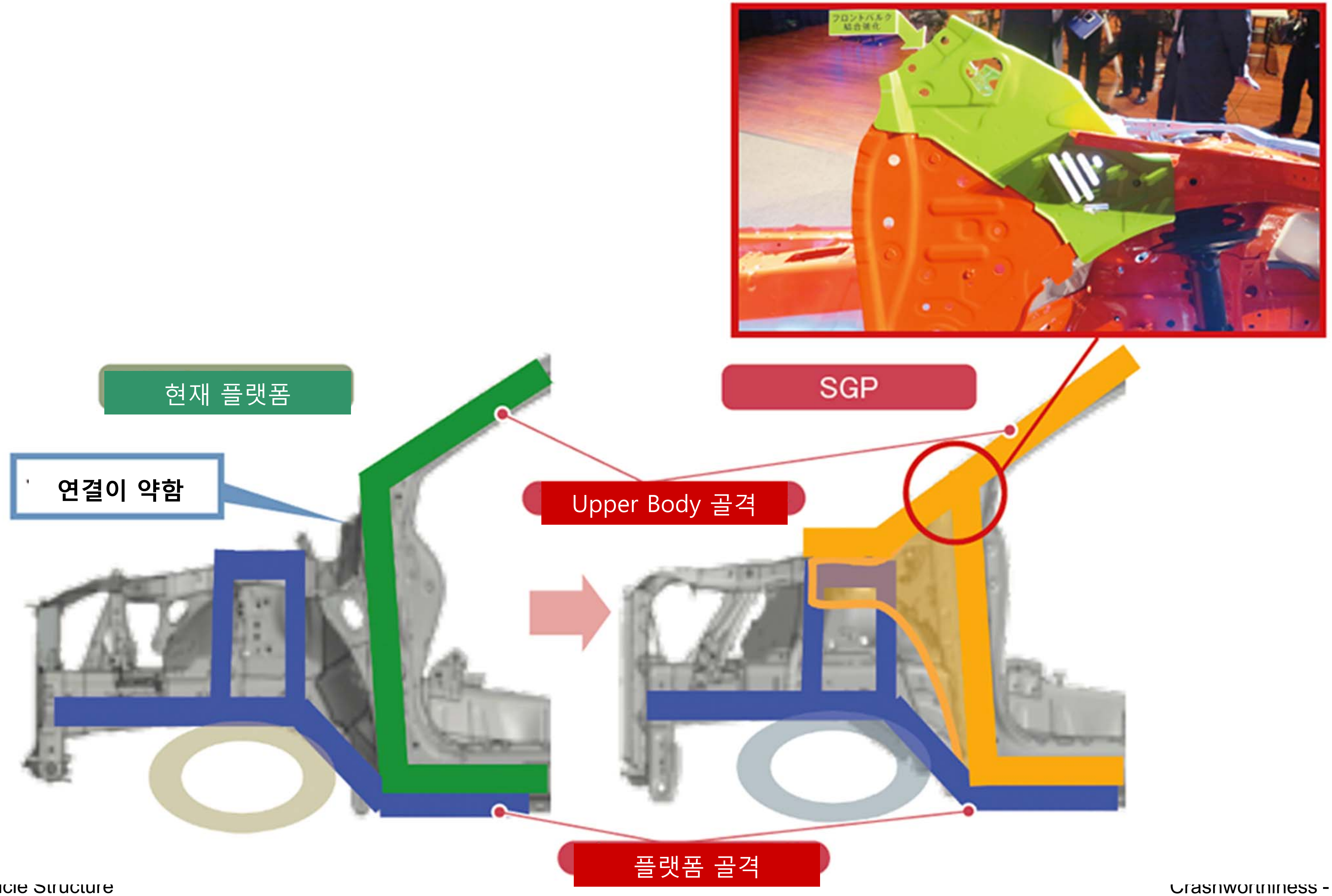


고장력 강판 사용비율 증가

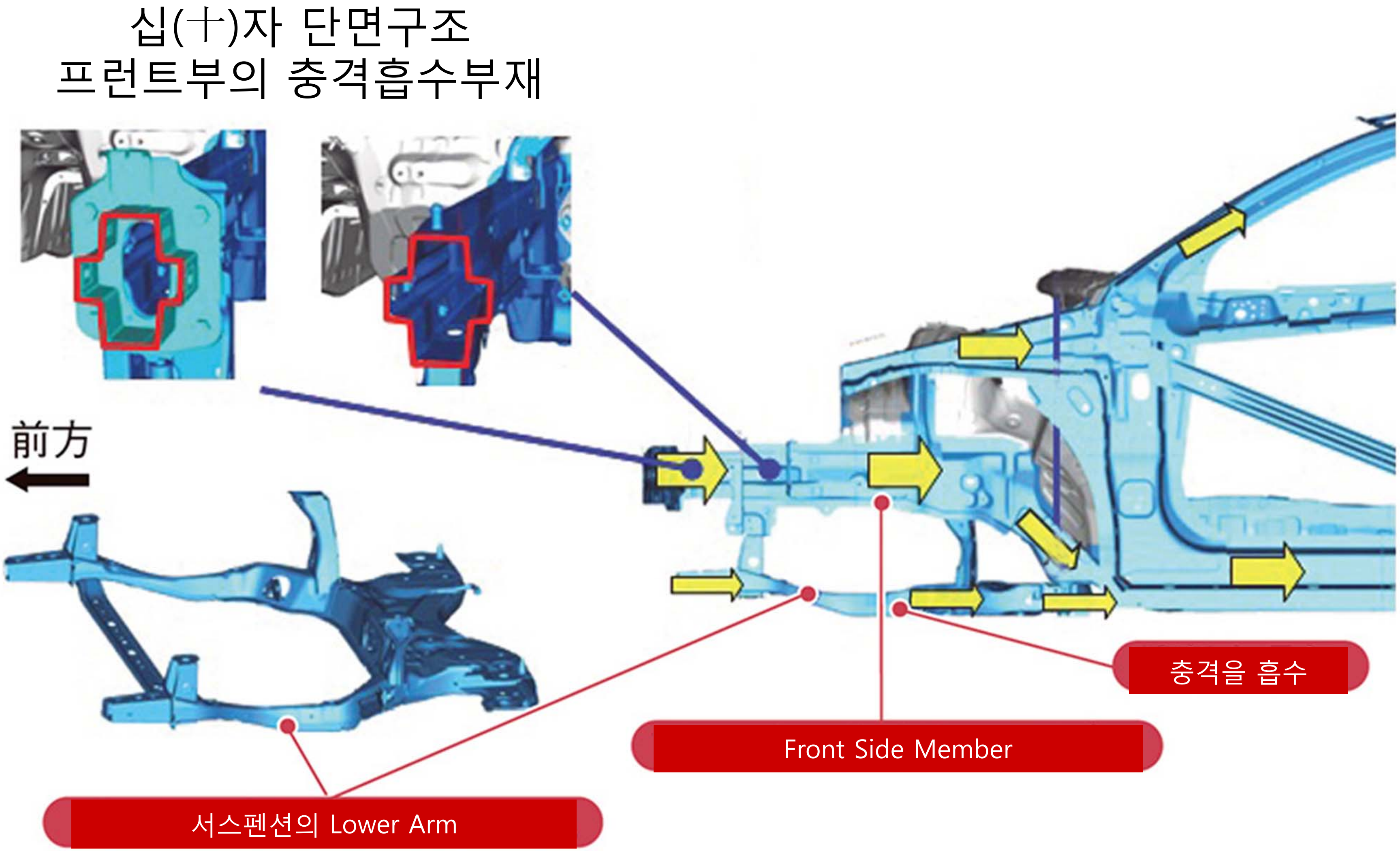


인강강도	이전 플랫폼	SGP
440MPa	11%	15%
590MPa	45%	40%
980MPa		1%
1.5GPa		7%
고장력 강판	56%	63%

SGP와 Upper Body 골격을 Inner Panel로 결합

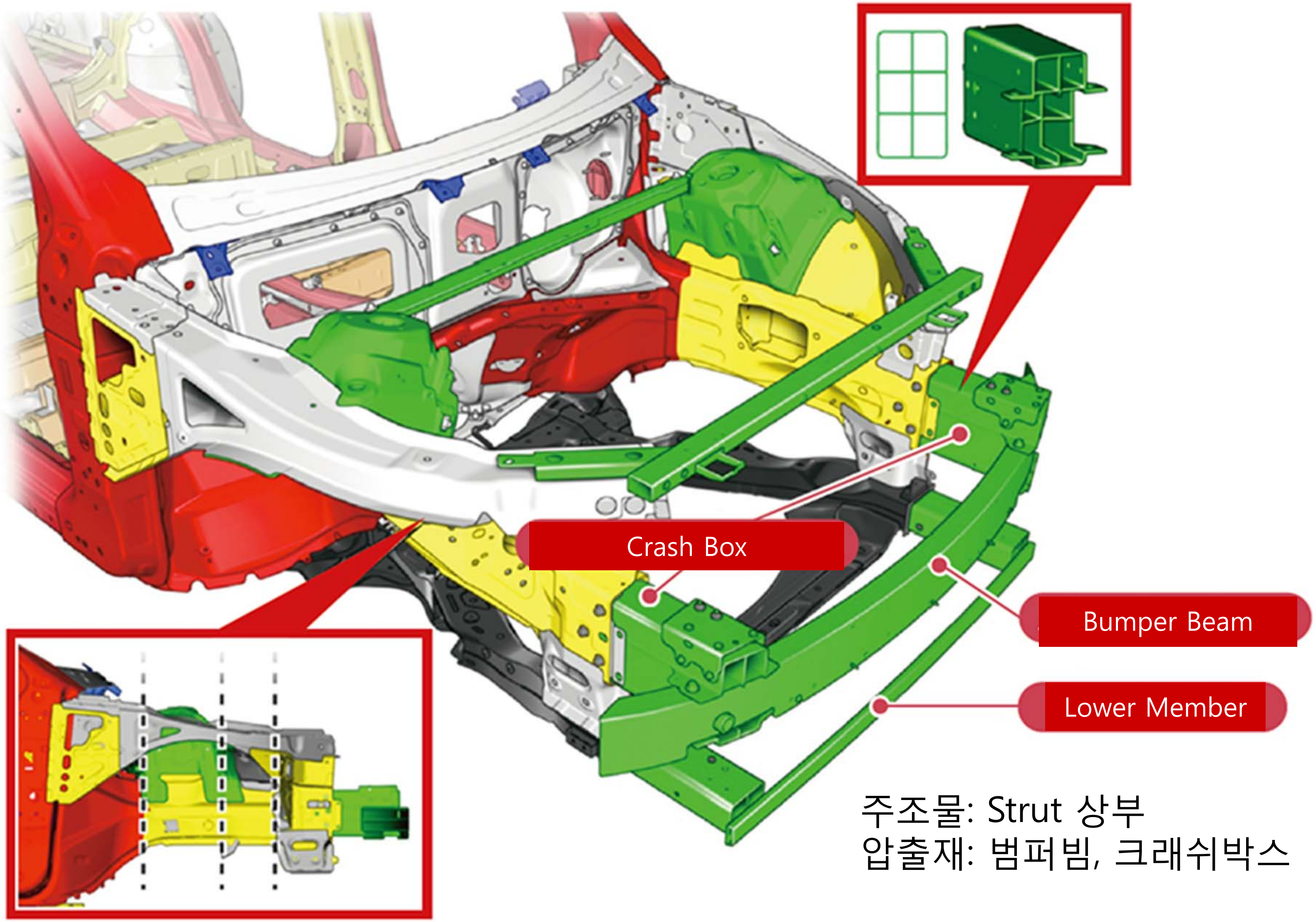


Mazda CX-3 에너지 흡수 구조



Nikkei Automotive 2016년 8월호

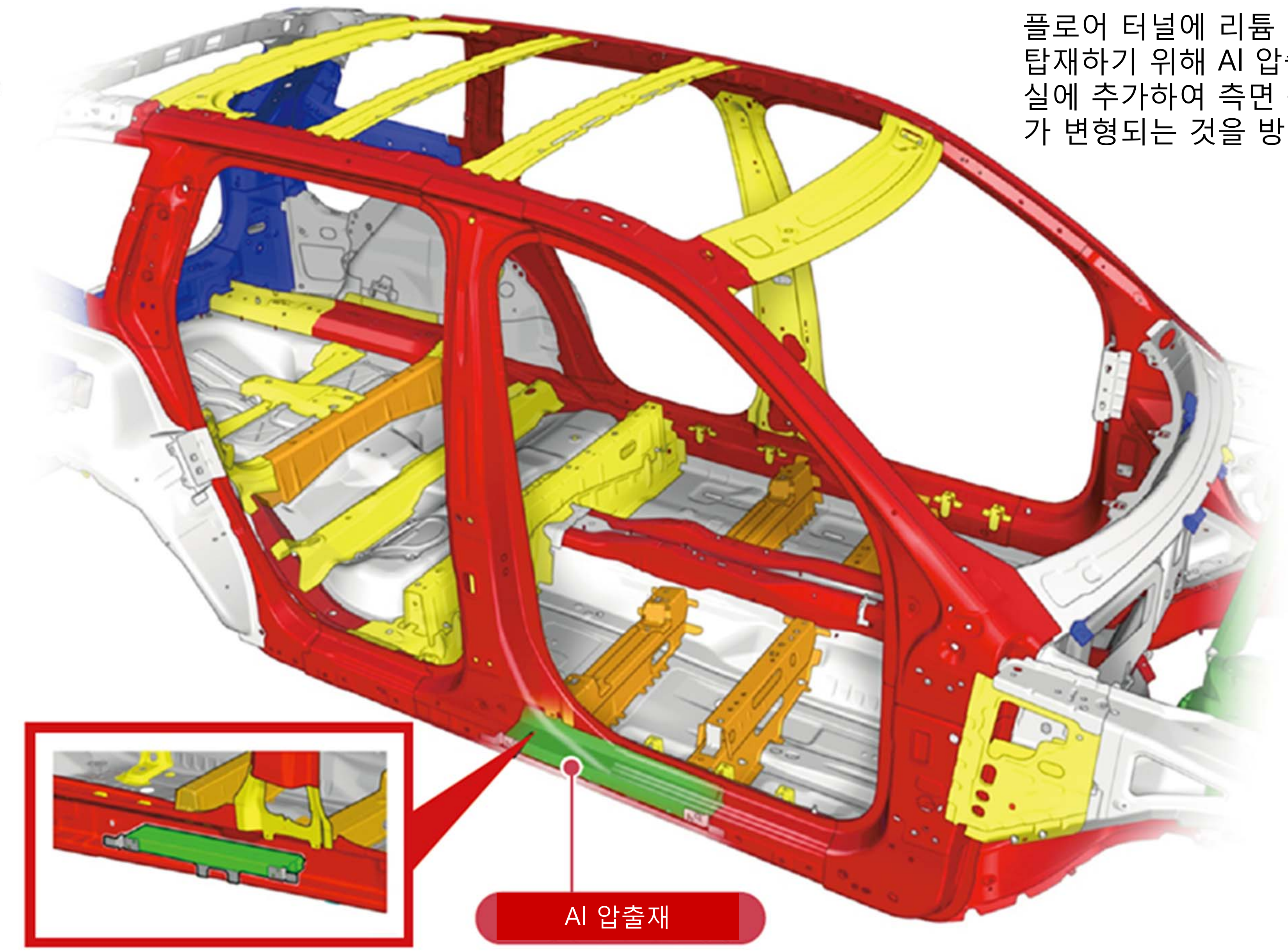
Volvo XC90 (Al합금 사용)



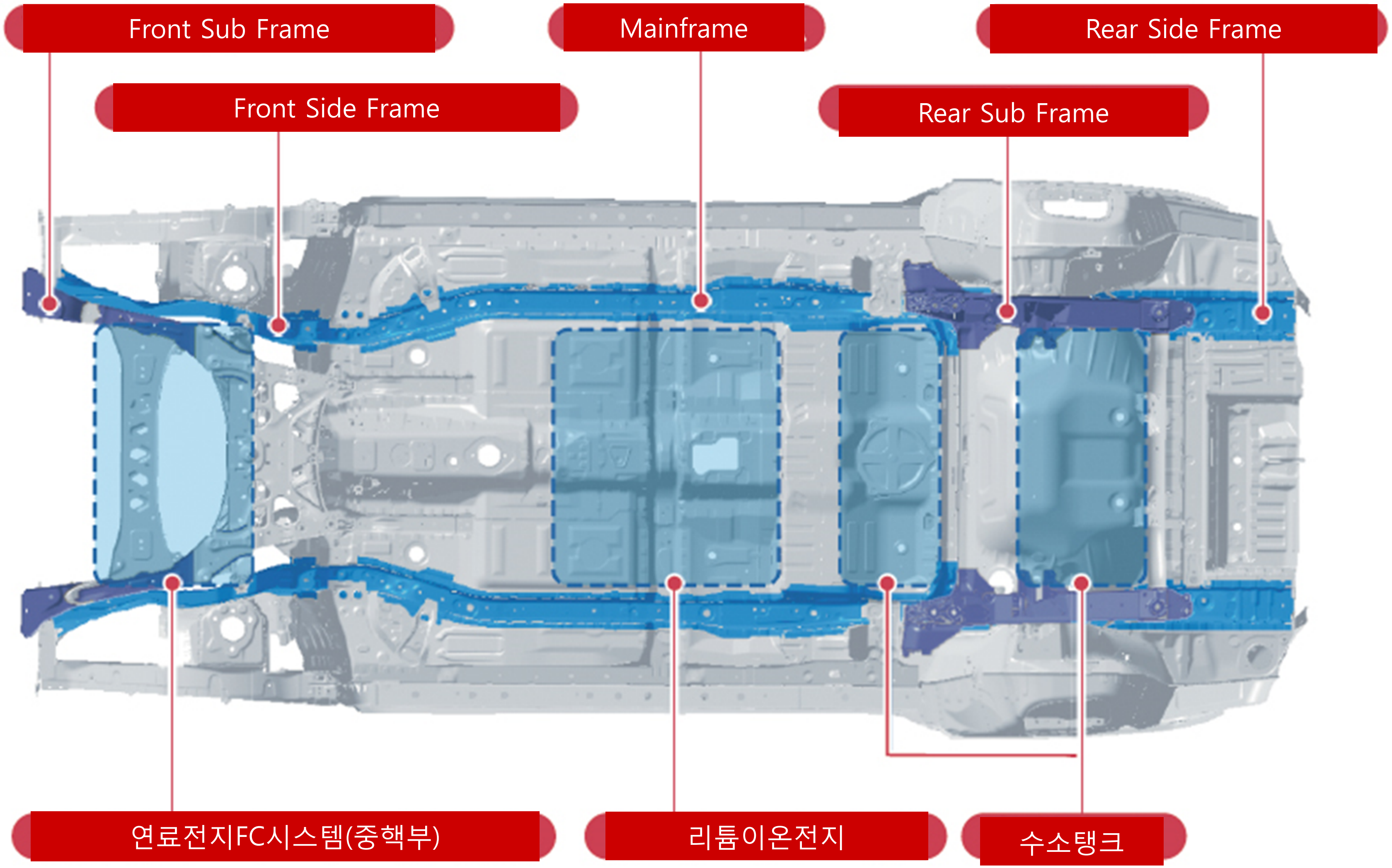
주조물: Strut 상부
압출재: 범퍼빔, 크래쉬박스

Nikkei Automotive 2016년 10월호

플로어 터널에 리튬 이온 배터리를
탑재하기 위해 Al 압출재를 사이드
실에 추가하여 측면 충돌시 배터리
가 변형되는 것을 방지



Honda FCV



Nikkei Automotive 2016년 6월호