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, China and India

Instrument Panel
UN R21, 32, 33
US FMVSS 201
IN IS 15223

Side Windows
UN R43, GTR 6
US FMVSS 205, 226

Interior
UN R12, 21, 43, GTR 6
US FMVSS 201, 203, 204, 205
CN GB 11552-2009
IN IS 15223, AIS 096

Roof
US FMVSS 216, 216a
CN GB 26134-2010

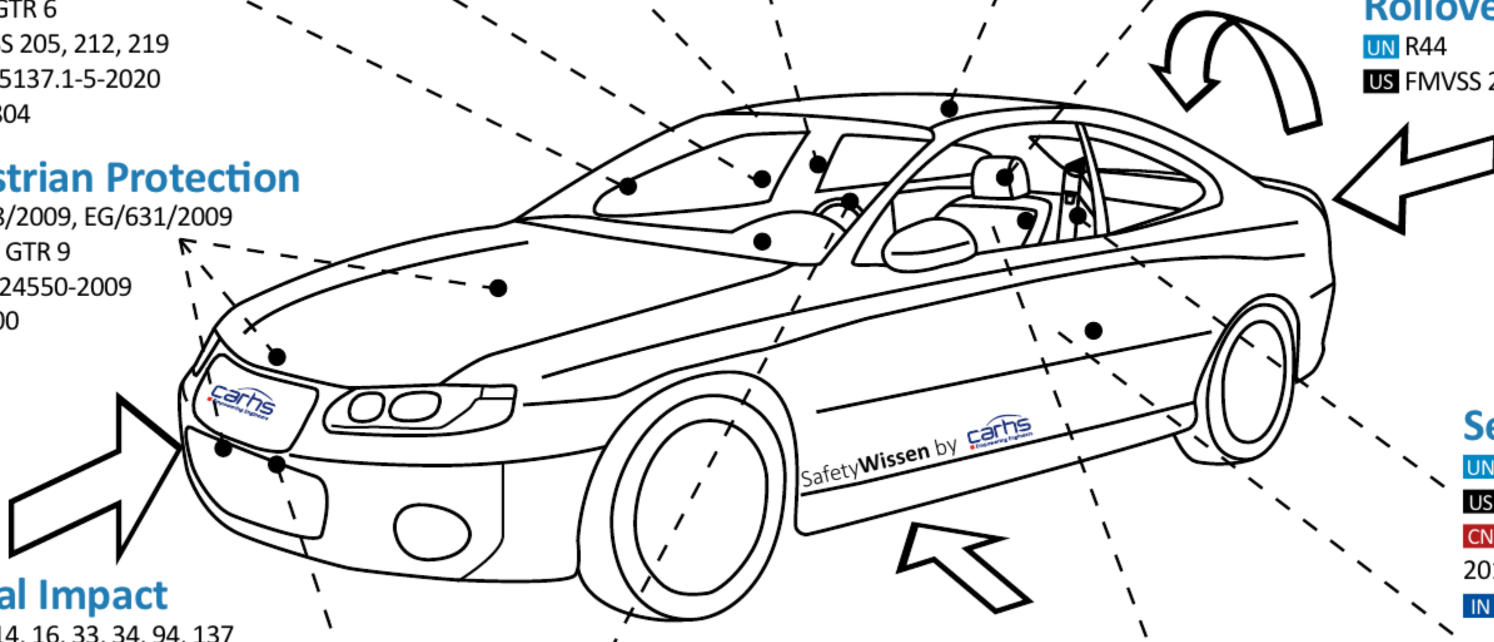
Headrests
UN R17, 25, GTR 7
US FMVSS 202a
CN GB 11550-2009, GB 15083-2006
IN IS 15546

Windscreeen
UN R43, GTR 6
US FMVSS 205, 212, 219
CN GB/T 5137.1-5-2020
IN IS 15804

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

Pedestrian Protection
EU EG/78/2009, EG/631/2009
UN R127, GTR 9
CN GB/T 24550-2009
IN AIS 100

Rear Impact
UN R17, 25, 32, 34, 42, 58
US FMVSS 202a, 207, 301, 581
CN GB 11550-2009, 18296-2019, 20072-2006
IN AIS 101



Seat Belts
UN R14, 16, 17
US FMVSS 208, 209, 210
CN GB 14166-2013, GB 14167-2013, 15083-2006
IN IS 15139, 15140

Frontal Impact
UN R12, 14, 16, 33, 34, 94, 137
US FMVSS 203, 204, 208, 209, 210, 301
CN GB 11551-2014 , 11557-2011 , 14166-2013, 14167-2013 GB/T 20913-2007, 37437-2019
IN IS 15139, 15140, AIS 096, 098

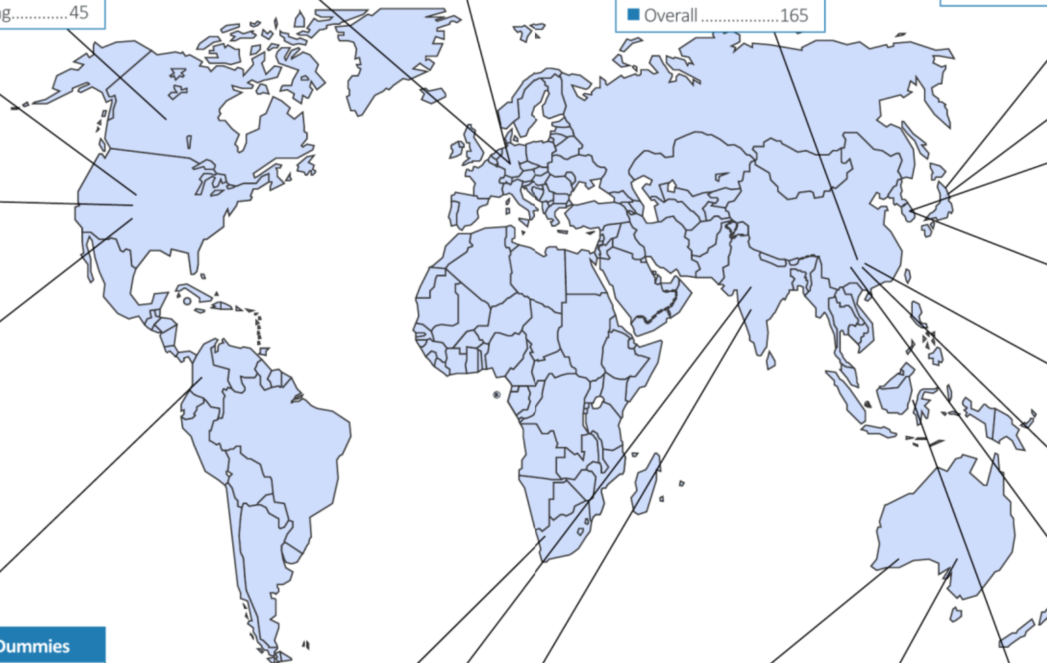
Bumper
UN R42
US FMVSS 581
CN GB 17354-1998
IN IS 15901

Steering Wheel
UN R12
US FMVSS 203, 204
CN GB 11557-2011
IN IS 11939, AIS 096

Side Impact
UN R95, 135, GTR 14
US FMVSS 214
CN GB 20071-2006, GB/T 37337-2019
IN AIS 099

Seats
UN R16, 17, 21, 44, 129, 145
US FMVSS 201, 202a, 207, 213, 225
CN GB 11550-2009, 14166-2013, 15083-2019, 27887-2011
IN IS 15546, 15139, 15532, AIS 072

Doors
UN R11, GTR 1
US FMVSS 206
CN GB 15743-1995, 15086-2013
IN IS 14225



Rules and Regulations on Occupant Protection

Ground clearance of the lower edge of the deformable barrier

	Full Width Frontal	Offset Frontal	Side Barrier	Side Pole	Pedestrian	Rear	Head Impact	Rollover
USA	FMVSS 208 (0° 56 km/h, H III 50 % / H III 50 %; 0° / ± 5° 56 km/h, H III 5 % / H III 5 %; 0° / ± 5° 32-40 km/h, H III 5 % / H III 5 %; 0° / ± 30° 32-40 km/h, H III 50 % / H III 50 %)	FMVSS 208 (ODB 40 %, 200 mm, 0° 40 km/h, H III 5 % / H III 5 %)	FMVSS 214 (ES-2 re, 54 km/h 27°, 48 km/h, MDB, 1368 kg, SID IIs)	FMVSS 214 (SID IIs / ES-2 re, 0-32 km/h 75°, 254 mm Pole)		FMVSS 202a FMVSS 301	FMVSS 201	Roof Crush: FMVSS 216a Ejection Mitigation: FMVSS 226
Europe	UN R137[1] (0° 50 km/h, H III 50 % / H III 5 %)	UN R94 (ODB 40 %, 200 mm, 0° 56 km/h, H III 50 % / H III 50 %)	UN R95 (300 mm, ES-2, 50 km/h 90°, MDB EEVC, 950 kg)	UN R135[1] (WS 50 %, 32 km/h 75°, 254 mm Pole)	R (EC) 78/2009[2] R (EC) 631/2009[2] UN R127 R (EU) 2019/2144	UN R34	UN R21	
Japan	Art. 18 (0° 50 km/h, H III 5 % / H III 50 %)	Art 18 (ODB 40 %, 200 mm, 0° 56 km/h, H III 50 % / H III 50 %)	Art. 18 (ES-2, 300 mm, 50 km/h 90°, MDB EEVC, 950 kg)	Art. 18 (32 km/h 75°, WS 50 %, 254 mm Pole)	Article 18	Article 22-4	Article 20	
China	GB 11551-2014 (0° 50 km/h, H III 50 % / H III 50 %)	GB/T 20913-2007 (ODB 40 %, 200 mm, 0° 56 km/h, H III 50 % / H III 50 %)	GB 20071-2006 (300 mm, ES-2, 50 km/h 90°, MDB EEVC, 950 kg)	GB/T 37337-2019 (WS 50 % / ES-2 re, 32 km/h 75°, 254 mm Pole)	GB/T 24550-2009	GB 20072-2006	GB11552-2009	Roof Crush: GB26134-2010
India		AIS-098 (ODB 40 %, 200 mm, 0° 56 km/h, H III 50 % / H III 50 %)	AIS-099 (ES-1/ ES-2, 300 mm, 50 km/h 90°, MDB EEVC, 950 kg)		AIS-100	AIS-101	IS15223	
S. Korea	KMVSS 102-3 (0° 50km/h, H III 50 % / H III 50 % 5 %[2])		KMVSS 102 (300 mm, ES-1/ ES-2, 50 km/h 90°, MDB EEVC, 950 kg)	KMVSS 102-4 (WS 50 %, 32 km/h 75°, 254 mm Pole)	KMVSS 102-2		KMVSS 88	
Australia	ADR 69/00 (0° 48 km/h, H III 50 % / H III 50 %)	ADR 73/00 (ODB 40 %, 200 mm, 0° 56 km/h, H III 50 % / H III 50 %)	ADR 72/00 (ES-2, 300 mm, 50 km/h 90°, MDB EEVC, 950 kg)	ADR 85/00 (32 km/h 75°, WS 50 %, 254 mm Pole)			ADR 21	

SafetyWissen by carhs

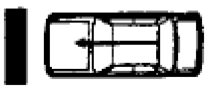
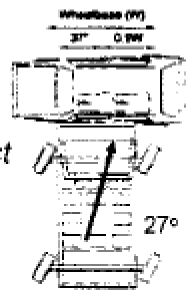
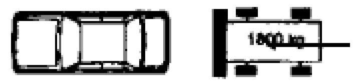
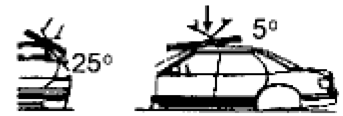
[1] Mandatory as part of the EU type approval for new types from July 6, 2022, for new registrations from July 7, 2024.

SafetyWissen by carhs

[1] Mandatory as part of the EU type approval for new types from July 6, 2022, for new registrations from July 7, 2024.

[2] Expires on July 5, 2022

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

신차안전도평가(NCAP)

- 자동차 안전도에 관한 객관적 정보를 제공하고 업계의 기술개발을 촉진하기 위한 제도
  - 자동차 충돌시험 및 안전기능 평가를 통해 별점(0~5 star) 등의 등급을 부여하는 제도

▌주요국 NCAP 개요(左) 및 '78년 NCAP 도입 이후 美 자동차 사고 사망률 변화(右)▐

지역	제도	도입시기	주관기관
미국	US NCAP	1978	도로교통안전국(NHTSA)
	IIHS Test	1995	고속도로안전보험협회(IIHS)
유럽	Euro NCAP	1996	자체 수행(EU 회원국 지원)
일본	JNCAP	1995	자동차사고대책기구(NASVA)
한국	KNCAP	1999	한국교통안전공단(TS)
중국	C-NCAP	2006	자동차기술연구센터(CATARC)

* 출처: 국가별 NCAP 주관기관 홈페이지(左) 및 IIHS Fatality Facts 2018(右)

신차안전도평가(NCAP): 평가항목

❙ 각국 NCAP의 주요 평가항목 소개(‘19년 기준, 파란색은 최근 신규 항목) ❙

평가항목	한국	미국		유럽	일본/중국
	KNCAP	US NCAP	IIHS	Euro NCAP	JNCAP/C-NCAP
정벽 정면 충돌	●	●	●	●	●
40% 부분 정면 충돌	●	●	●	●	●
측면/기둥 측면 충돌	●/●	●/●	●/	●/●	●/
좌석 안전성	●	●	●	●	●
보행자 안전성	●			●	●
유아/어린이 안전도	●			●	
주행 전복/제동	●/●	●/			
사고예방 안전성(AEB)	●	●	●	●	●

* 출처: KIAT 글로벌 산업기술 주간브리프(‘20.02) 및 美 IIHS 웹사이트

신차안전도평가(NCAP) 변화

- 최근 자동차 안전도가 상향평준화되면서 NCAP 실효성에 대한 비판 제기
  - 최근 US NCAP에서 98%가 4~5 star를, Euro NCAP에서 75%가 5 star를 받았으며, 한국 KNCAP도 '19년도 평가차량 10종 모두 종합 1등급 획득
- 주요 평가기관은 능동안전 평가 및 사고 시나리오 다양화로 변화 모색
  - 세계 NCAP 변화를 주도하는 Euro NCAP은 '20년 개편안을 통해 전방 자동긴급제동(AEB)기능 평가 확대 및 후방 AEB, 운전자 피로도 감지·경고 등을 평가항목에 추가
  - 대형차·소형차 간 충돌, 움직이는 선행차량에 대한 추돌, 운전자·탑승객 간 충돌 등 보다 현실적인 사고 시나리오 반영
    - 美 IIHS는 '20년 이후 SUV 등을 활용하여 실제 상황에 가까운 측면 충돌 평가 예정

Global NCAP (globalncap.org)

- 주요 자동차 생산국인 미국, 유럽, 일본, 한국, 중국 및 호주(ANCAP), 동남아(ASEAN NCAP), 중남미(Latin NCAP) 등이 제도 시행 중

- 국토교통부 교통안전공단(TS) 자동차안전연구원(KATRI)
- kncap.org
- 자동차안전도평가시험 등에 관한 규정
- IIHS (Insurance Institute for Highway Safety)

www.kncap.org KNCAP

2020 자동차안전도평가 Korean New Car Assessment Program

머리말

국토교통부는 자동차의 충돌시험 등을 통해 자동차의 안전성을 평가하여 소비자에게 정보를 제공하고 제작사로 하여금 보다 안전한 자동차를 제작하도록 유도하며 교통사고로 인한 인명 피해를 줄이기 위해 자동차안전도평가(NCAP, New Car Assessment Program)를 실시하고 그 결과를 발표하고 있다.

제네시스 GV80 평가결과

1등급 92.5점

충돌안전성

100.0% 60.00점 ★★★★★

정면충돌	15.75 /	16점
부분정면충돌	15.96 /	16점
측면충돌	16.00 /	16점
어린이 안전성	8.00 /	8점
좌석안전성	3.07 /	4점
기둥측면충돌(+)	1.98 /	2점
좌석안전띠경고장치(+)	0.20 /	0.5점
첨단에어백장치(+)	0.50 /	0.5점
합 계	60.00 /	60점

보행자안전성

69.8% 13.96점 ★★★★

보행자안전성	13.96 /	20점
합 계	13.96 /	20점

사고예방안전성

92.9% 18.57점 ★★★★★

주행전복안전성	1.80 /	2점
첨단안전장치	14.77 /	18점
첨단안전장치 가점	+2.00 /	2점
합 계	18.57 /	20점

시험평가자 의견

제네시스 GV80의 안전도평가결과 충돌안전성 분야 만점 및 사고 예방안전성에서 높은 점수를 기록하였으나 보행자안전성에서 저조한 결과를 나타냈다

2020년 자동차안전도평가 대상 차종인 제네시스 GV80의 평가결과 안전도 종합등급 1등급을 받았으며, 차종별, 평가항목별 상세결과는 안전도평가 홈페이지(www.kncap.org)를 통해 공개하고 있다.

2020년 자동차안전도평가 대상 차종

평가분야 및 항목 총 3분야 20항목 평가

분야	평가항목	분야	평가항목	
충돌 안전성	정면충돌	사고예방 안전성	주행전복	
	부분정면충돌		비상자동제동장치 (AEBS)	고속
	측면충돌			시가지
	기둥측면충돌			보행자
	어린이			자전거
				야간 보행자
	좌석		최고속도제한장치-조절형(SLD)	
	좌석안전띠경고장치		차로유지지원장치(LKAS)	
	첨단에어백		후측방접근경고장치(RCTA)	
보행자 안전성	보행자		최고속도제한장치-지능형(ISA)	
			사각지대감시장치(BSD)	

국토교통부 TS 자동차안전연구원 2020 Korean New Car Assessment Program Newsletter www.kncap.org KNCAP

구 분			평 가 분 야			안 전 도 종합등급 (100점)
차 명			충돌안전성 [60점]	보행자안전성 [20점]	사고예방안전성 [20점]	
승용	세단 (중대형)	기아 K5	54.7 (91.2%,★★★★)	13.7 (68.7%,★★★★)	16.8 (83.9%,★★★★)	1등급 85.2점
		현대 아반떼	59.8 (99.7%,★★★★★)	12.4 (62.0%,★★★)	17.8 (89.1%,★★★★★)	1등급 90.1점
		제네시스 G80	60.0 (100.0%,★★★★★)	18.6 (93.0%,★★★★★)	18.7 (93.7%,★★★★★)	1등급 97.3점
		벤츠 A220	59.7 (99.5%,★★★★★)	14.8 (74.0%,★★★★)	13.7 (68.3%,★★★)	1등급 88.1점
	레저용 (중형)	르노삼성 XM3	60.0 (100.0%,★★★★★)	14.8 (74.0%,★★★★)	13.4 (66.9%,★★★)	1등급 88.2점
		쉐보레 트레일블레이저	59.5 (99.2%,★★★★★)	15.3 (76.3%,★★★★)	16.1 (80.4%,★★★★)	1등급 90.8점
		르노삼성 캡처	59.7 (99.5%,★★★★★)	14.7 (73.7%,★★★★)	15.0 (75.2%,★★★★)	1등급 89.5점
	레저용 (대형)	기아 쏘렌토	60.0 (100%,★★★★★)	12.9 (64.7%,★★★★)	17.1 (85.3%,★★★★★)	1등급 90.0점
		제네시스 GV80	60.0 (100.0%,★★★★★)	13.9 (69.7%,★★★★)	18.6 (92.9%,★★★★★)	1등급 92.5점
		아우디 Q7	41.3 (68.8%,★)	14.7 (73.7%,★★★★)	14.4 (72.0%,★★★★)	5등급 70.4점
승용·승합		기아 카니발	60.0 (100.0%,★★★★★)	14.3 (71.3%,★★★★)	18.2 (91.2%,★★★★★)	1등급 92.5점

[종합등급 산정기준]

구분	종합등급 산정기준
1등급	82.1 ~
2등급	75.1 ~ 82.0
3등급	**68.1 ~ 75.0**
4등급	61.1 ~ 68.0
5등급	~ 61.0

[평가분야별 등급조정기준]

구분	충돌안전성[%]	보행자안전성[%]
1등급	90.1 ~	60.1 ~
2등급	83.1 ~ 90.0	50.1 ~ 60.0
3등급	76.1 ~ 83.0	40.1 ~ 50.0
4등급	69.1 ~ 76.0	35.1 ~ 40.0
5등급	**~ 69.0**	~ 35.0

[평가분야별 별등급 산정기준]

구분	충돌안전성[%]	보행자안전성[%]	사고예방안전성[%]
★★★★★	93.1 ~	83.1 ~	84.8 ~
★★★★	90.1 ~ 93.0	63.1 ~ 83.0	70.5 ~ 84.7
★★★	87.1 ~ 90.0	43.1 ~ 63.0	55.4 ~ 70.4
★★	84.1 ~ 87.0	23.1 ~ 43.0	40.2 ~ 55.3
★	~ 84.0	~ 23.0	~40.1


2021년 자동차안전도평가 평가대상 차종
구분
승용10
승합1
SUV 6
세단 4
중형
대형
중형
내연기관
전기차
기아 스포티지
현대 투싼
폭스바겐 제타
기아 K8
현대 스타리아
폭스바겐 티구안
아우디 A6
현대 아이오닉5
테슬라 모델3
기아 EV6
벤츠 EQA
이후 평가가 완료된 차종에 대해 순차적으로 자동차안전도평가 홈페이지(www.kncap.org)
유튜브와 뉴스레터를 통해 공개할 예정이다.
국토교통부
TS 자동차안전연구원
2021 Korean New Car Assessment Program
www.kncap.org
KNCAP

현대 아이오닉5

종합등급

1등급 (92.1점)

충돌안전성

98.8%

59.29점 ★★★★★

정면충돌안전성	15.10 / 16.00점
부분정면충돌안전성	14.44 / 16.00점
측면충돌안전성	16.00 / 16.00점
좌석안전성	3.10 / 4.00점
어린이충돌안전성	8.00 / 8.00점
기둥측면충돌안전성(가점)	1.95 / 2.00점
좌석안전띠경고장치(가점)	0.20 / 0.50점
첨단에어백장치(가점)	0.50 / 0.50점
합계	59.29 / 60.00점

보행자안전성

68.2%

13.64점 ★★★★

보행자안전성	13.64 / 20.00점
합계	13.64 / 20.00점

사고예방안전성

95.9%

19.17점 ★★★★★

비상자동제동장치(고속)	2.95 / 3.00점
비상자동제동장치(시가지)	2.70 / 3.00점
비상자동제동장치(보행자)	2.72 / 3.00점
비상자동제동장치(자전거)	2.00 / 2.00점
비상자동제동장치(야간)(가점)	2.00 / 2.00점
차로유지지원장치	4.00 / 4.00점
사각지대감시장치	0.50 / 1.00점
후측방접근경고장치	0.30 / 2.00점
조절형최고속도제한장치	0.50 / 0.50점
지능형최고속도제한장치	1.50 / 1.50점
합계	19.17 / 20.00점

시험평가자 의견

해당 차종은 종합등급 1등급을 받아 우수한 결과를 보였다.
충돌안전성분야에서 전반적으로 우수한 결과를 거두었고, 보행자안전성분야에서는 양호한 결과를 나타냈다. 사고예방안전성분야에서는 후측방접근경고장치 평가를 제외하고 높은 점수를 획득하여 우수한 결과를 기록했다.

테슬라 Model3

종합등급

2등급 (83.3점)

충돌안전성

99.6%

59.77점 ★★★★★

정면충돌안전성	15.36 / 16.00점
부분정면충돌안전성	15.55 / 16.00점
측면충돌안전성	16.00 / 16.00점
좌석안전성	1.99 / 4.00점
어린이충돌안전성	8.00 / 8.00점
기둥측면충돌안전성(가점)	1.87 / 2.00점
좌석안전띠경고장치(가점)	0.50 / 0.50점
첨단에어백장치(가점)	0.50 / 0.50점
합계	59.77 / 60.00점

보행자안전성

58.4%

11.68점 ★★★

보행자안전성	11.68 / 20.00점
합계	11.68 / 20.00점

사고예방안전성

59.5%

11.89점 ★★★

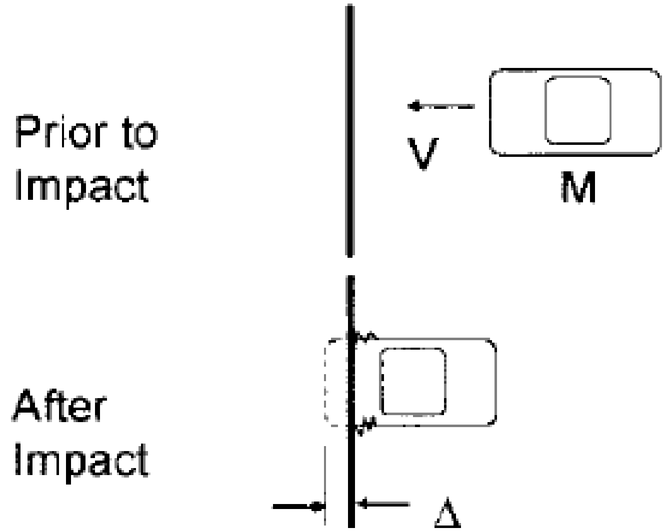
비상자동제동장치(고속)	2.64 / 3.00점
비상자동제동장치(시가지)	3.00 / 3.00점
비상자동제동장치(보행자)	2.35 / 3.00점
비상자동제동장치(자전거)	0.90 / 2.00점
비상자동제동장치(야간)(가점)	2.00 / 2.00점
차로유지지원장치	0.00 / 4.00점
사각지대감시장치	1.00 / 1.00점
후측방접근경고장치	- / 2.00점
조절형최고속도제한장치	0.00 / 0.50점
지능형최고속도제한장치	0.00 / 1.50점
합계	11.89 / 20.00점

시험평가자 의견

해당 차종은 종합점수로는 1등급에 해당하나, 보행자 점수 과락으로 종합등급 2등급을 받아 양호한 결과를 보였다.
충돌안전성분야 전반에 걸쳐 우수한 점수를 획득하였고, 상대적으로 낮은 머리충격 평가점수로 보행자안전성분야에서 보통의 결과를 기록했다. 비상자동제동장치(자전거)와 차로유지지원장치 평가시험에서의 일부 성능 부족 등으로 사고예방안전성분야에서 보통 수준의 결과를 나타냈다.

6.2 Front Barrier (1)

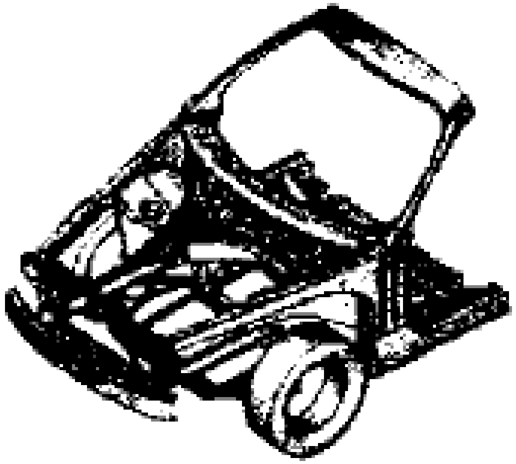
- Test conditions
  - t = 0: just touch the rigid, unmovable barrier (speed V_0)
  - As the vehicle deforms, the speed of the vehicle center of mass will gradually reduce
  - t = t_{final}: maximum deformation occurs (V=0)
- Typical front barrier sequence of events
  - (t = 0) ~ (t = 90 msec)



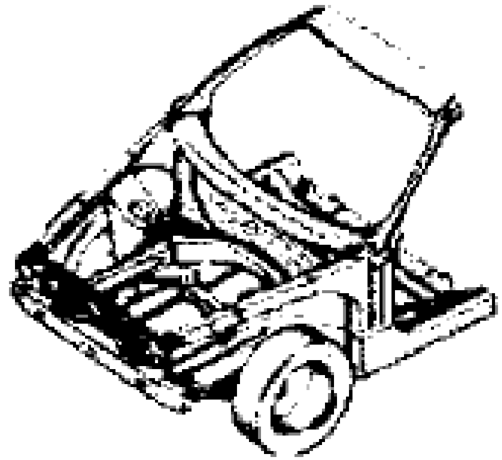
Typical Front Barrier Sequence of Events

- @ 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

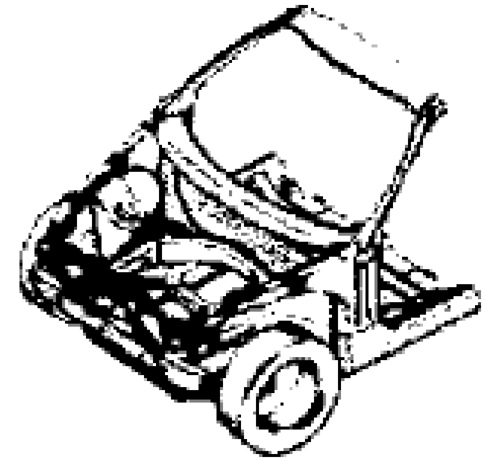
Typical Front Barrier Sequence of Events



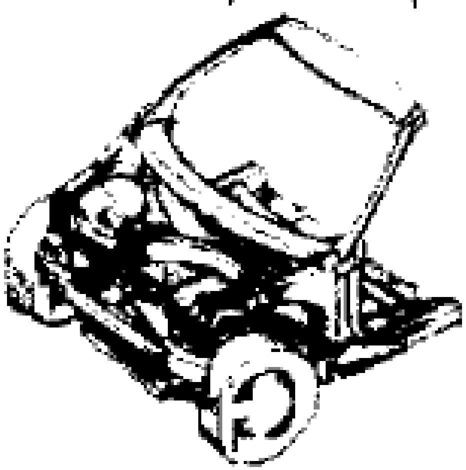
t=0msec, v=55kph



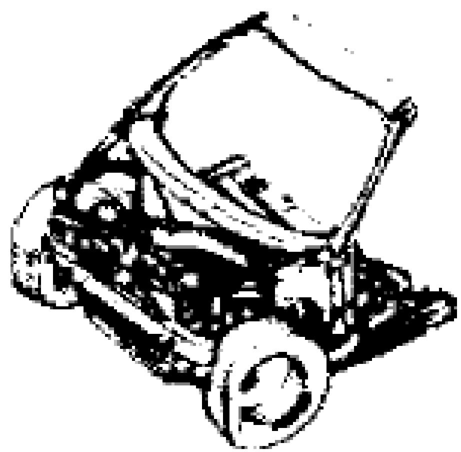
t=15, v=52



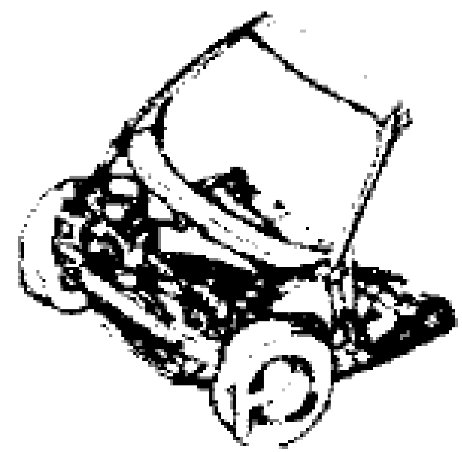
t=30, v=47



t=45, v=34



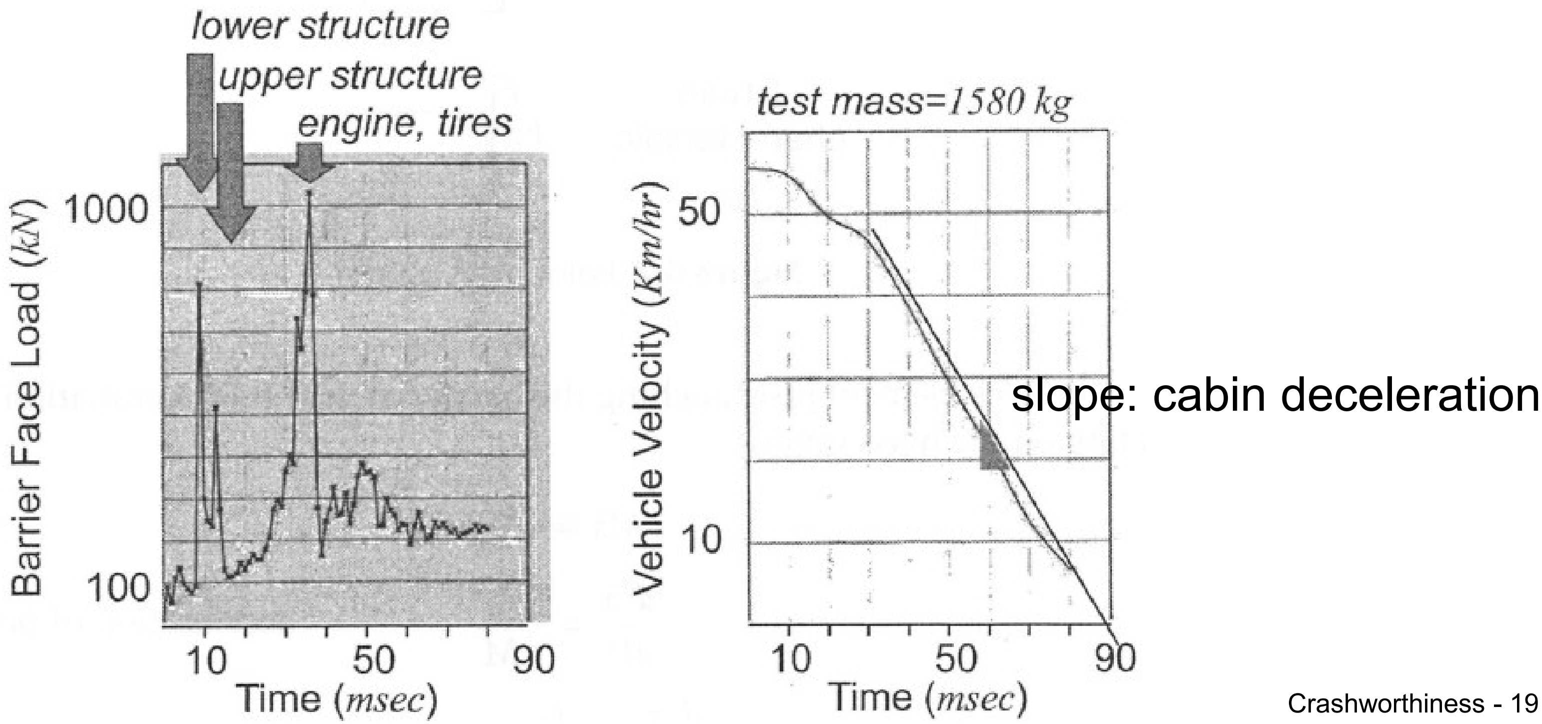
t=60, v=22



t=75, v=11

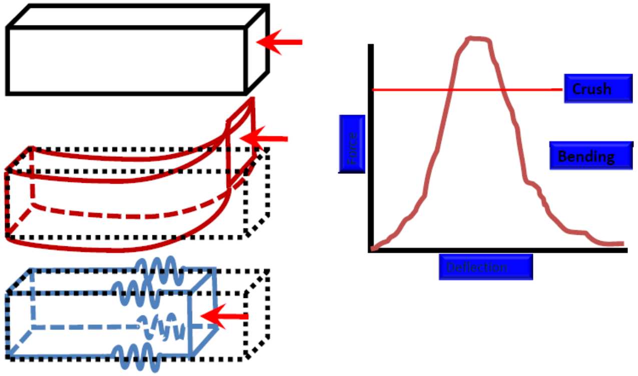
Front Barrier (2)

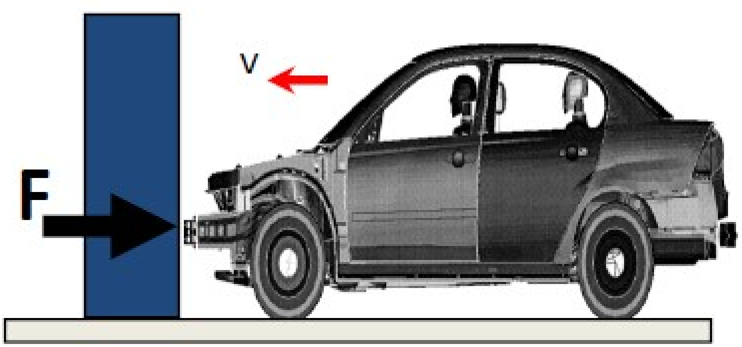
- Primary data
  - Loads applied to the barrier face
  - Acceleration of the vehicle mass center → velocity
- Concern: minimize occupant injury
  - Criterion: acceleration of the vehicle center of mass



Physics of a Crash

- Kinetic Energy = $\frac{1}{2}mv^2$
- 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 $\propto$ Injury
- Constant force as “ideal”
- Axial crush as preferred mode
- Maximize crush space
- Minimize intrusion

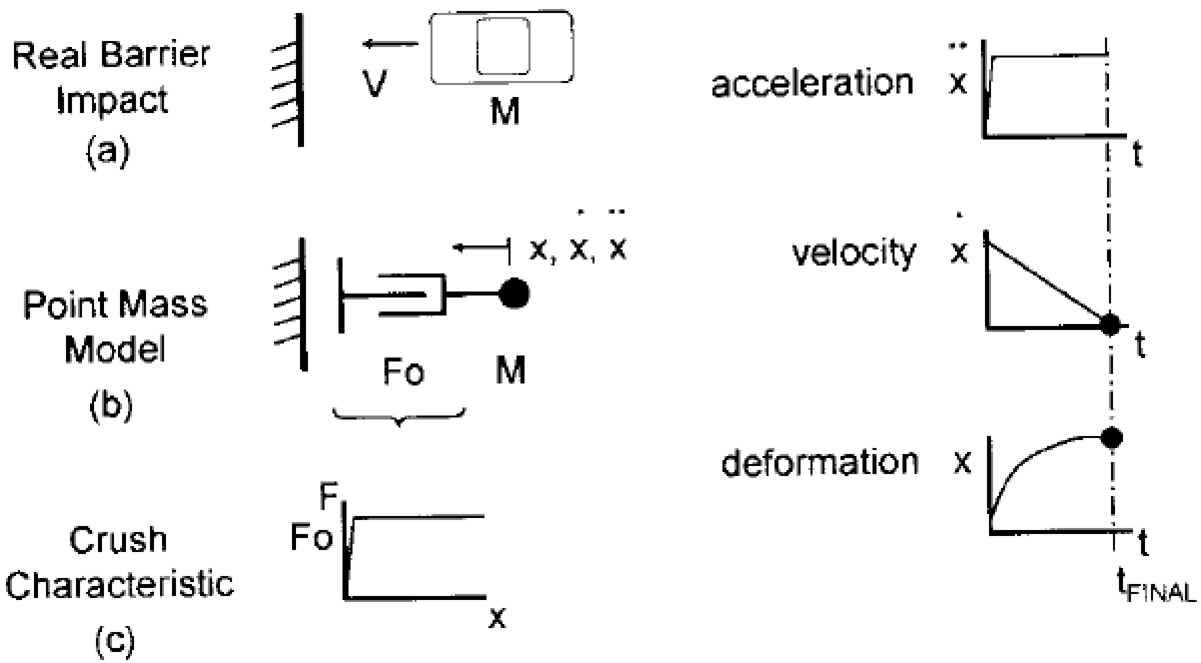




Basic Kinematic Model

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

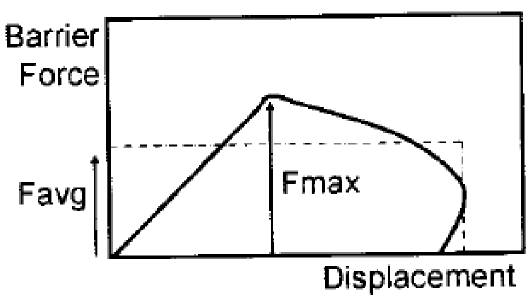
$$M\ddot{x} = -F_0$$

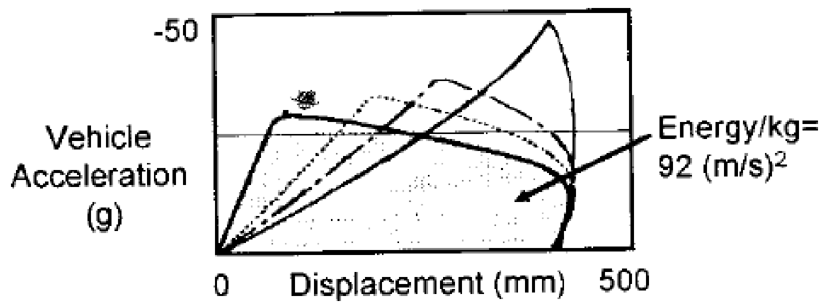


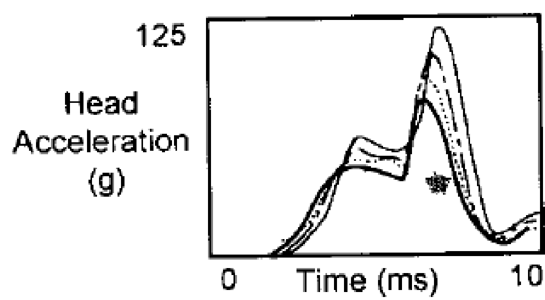
– Consider a vehicle of mass 1580 kg, impacting a rigid barrier at 55 kph and an average motor compartment crush load of 300 kN. → Δ=0.6148m

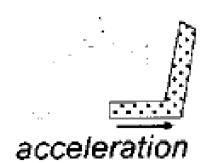
Refinement: Crush Force

- 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 ($\eta \sim 1$), the lower the head injury



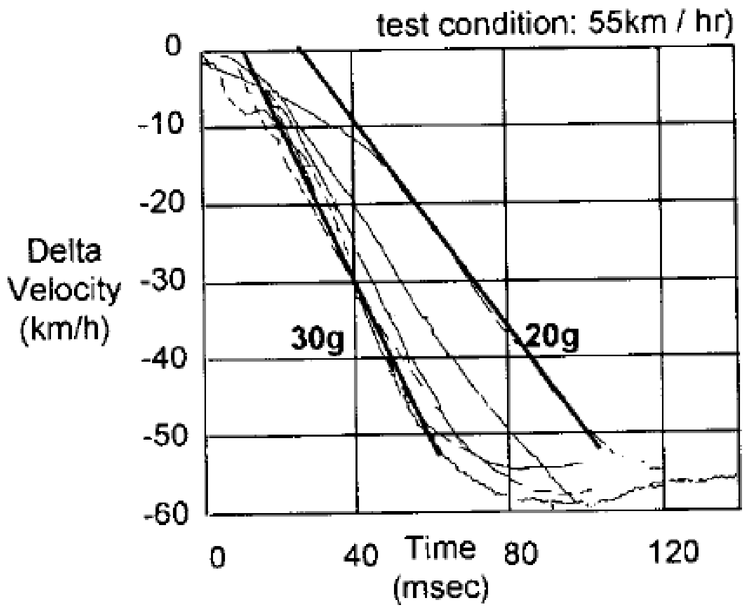




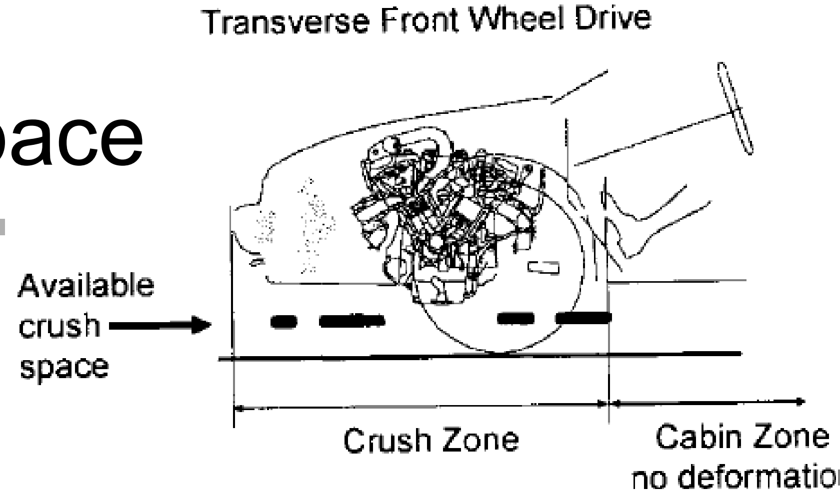


Characteristics for Cabin Acceleration

- 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



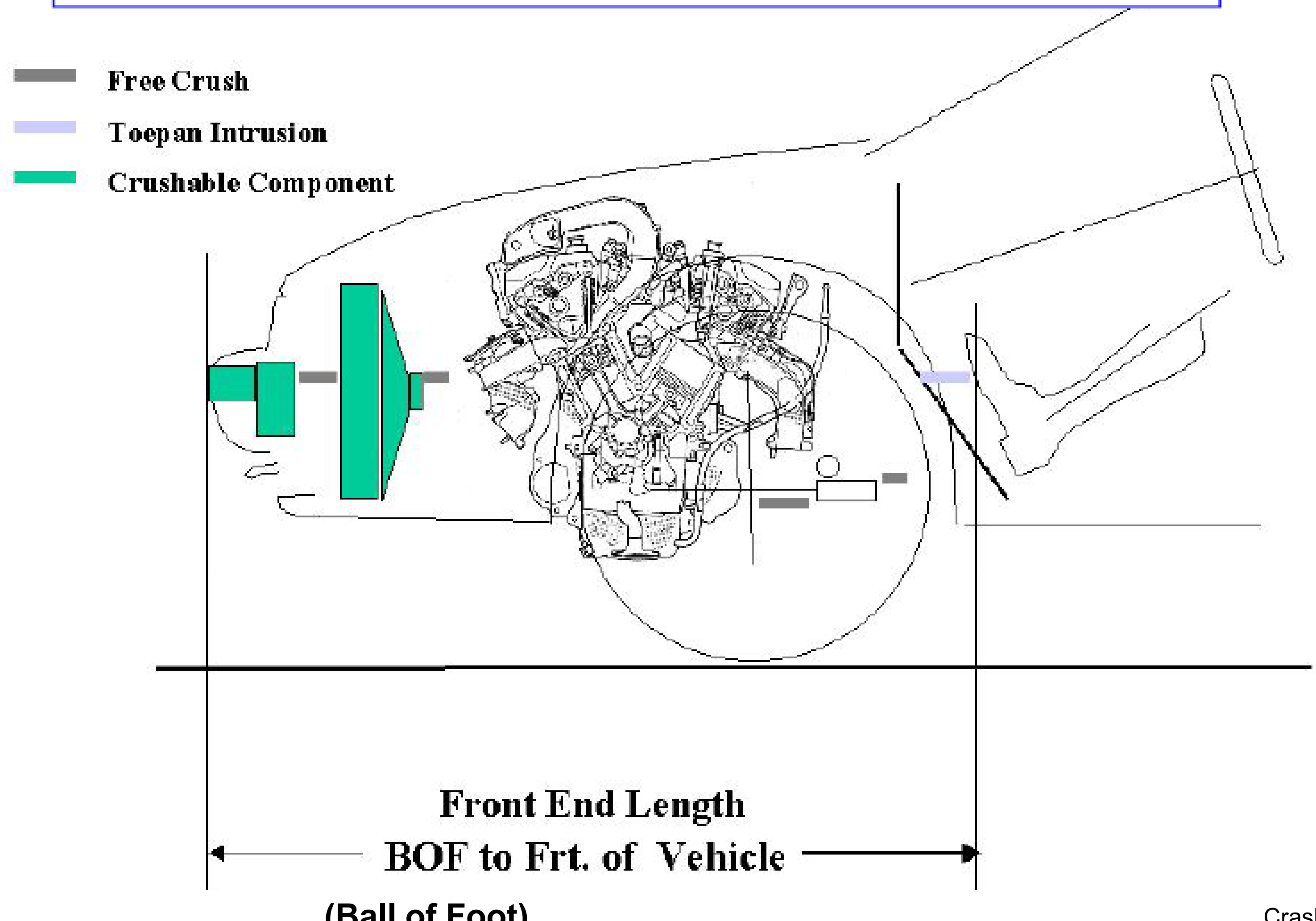
Crush Space



- 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



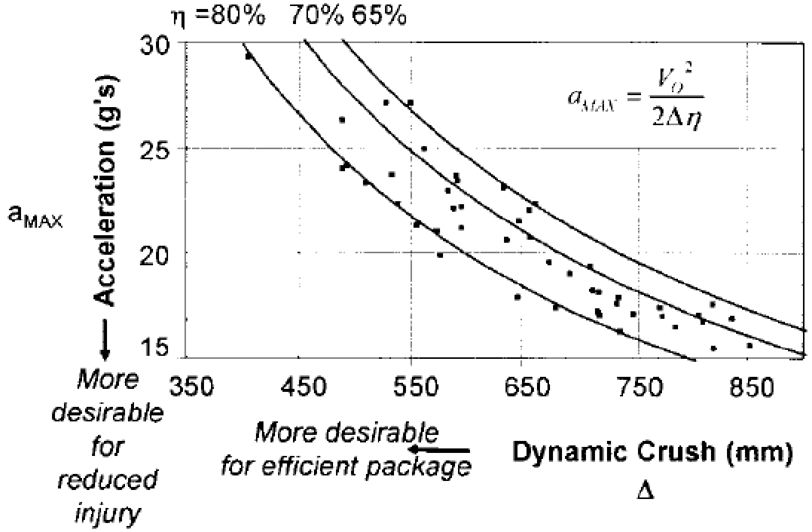
Structural Requirements (1)

  - 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

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

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

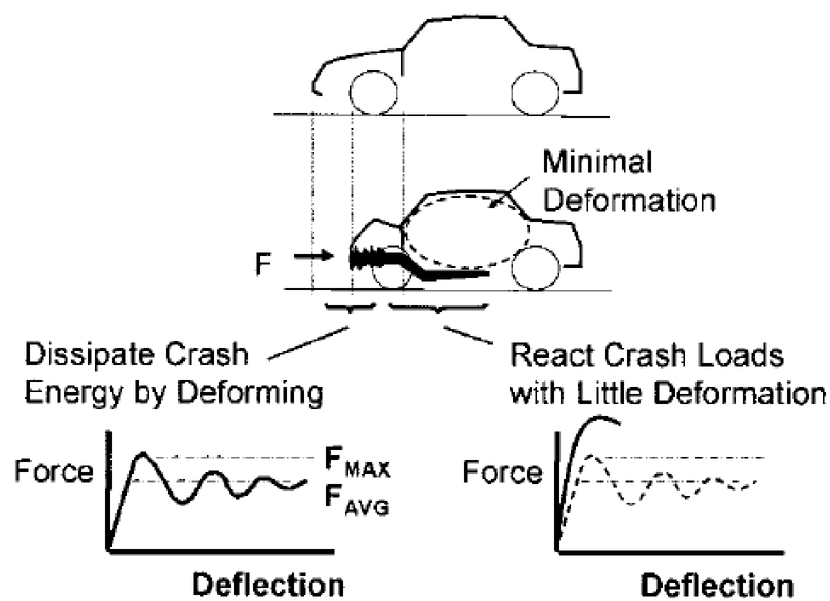
$$a_{\max} = \frac{V_0^{\,2}}{2\eta\Delta}$$

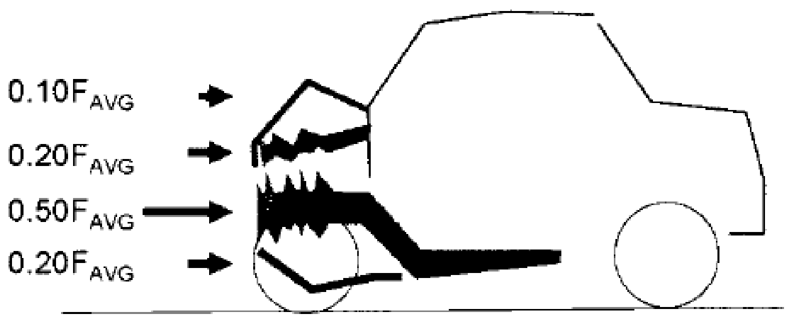


30 mph Barrier Benchmarking

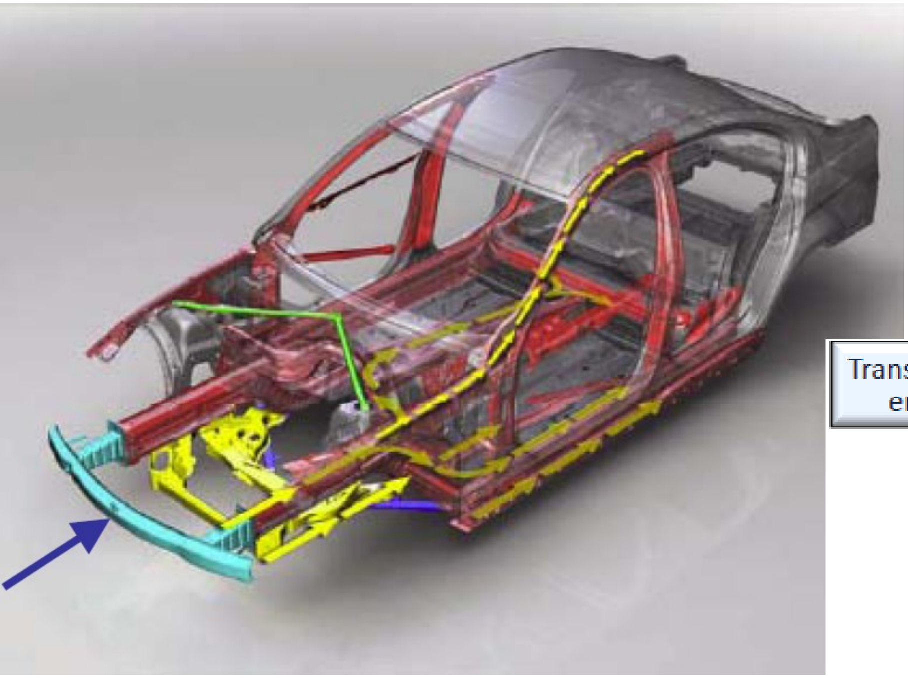
Structural Requirements (2)

- 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%

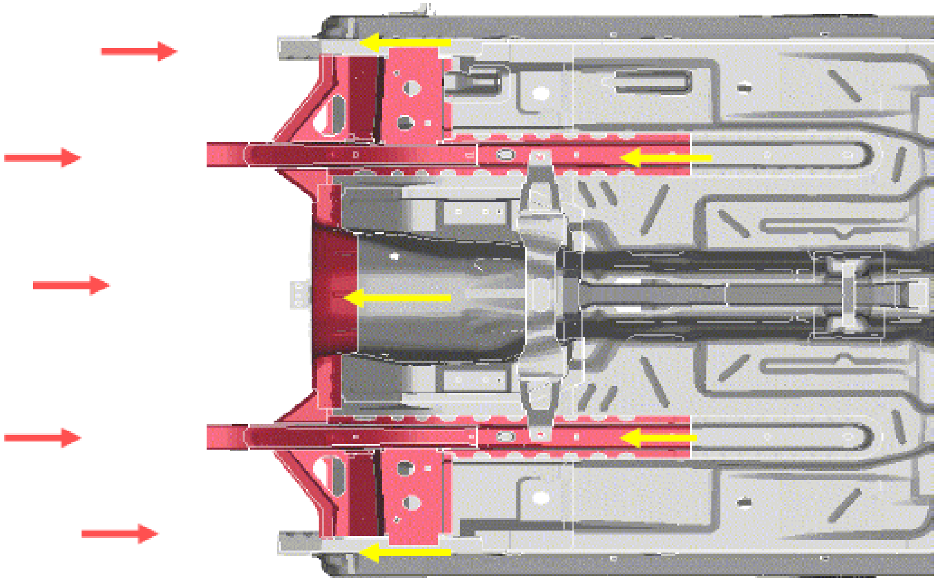




Load Distribution Philosophy

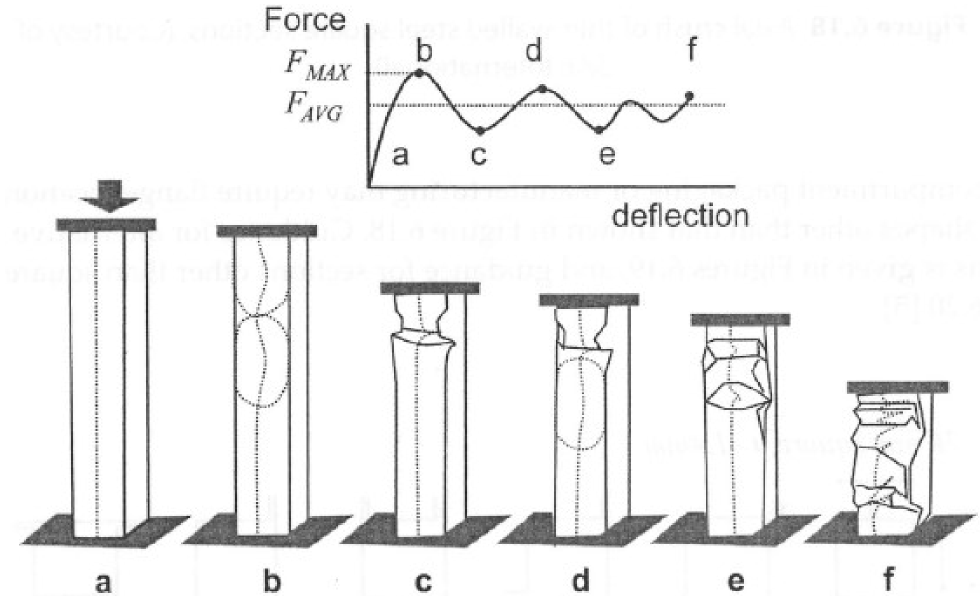


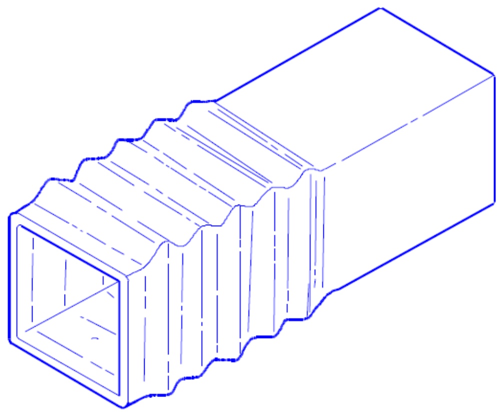
Transition Zone bridges offset between loadpaths in crush zone & safety cage; enables effective load transfer & provides stability control



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

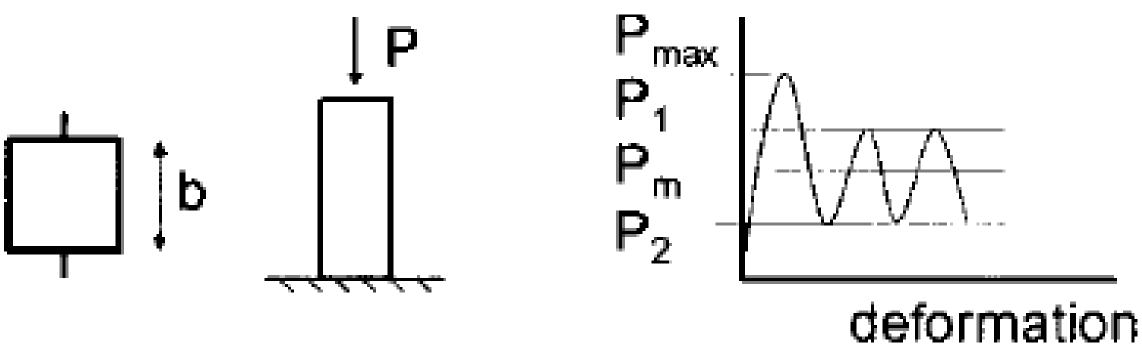




Beam Sizing for Energy Absorption (2)

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

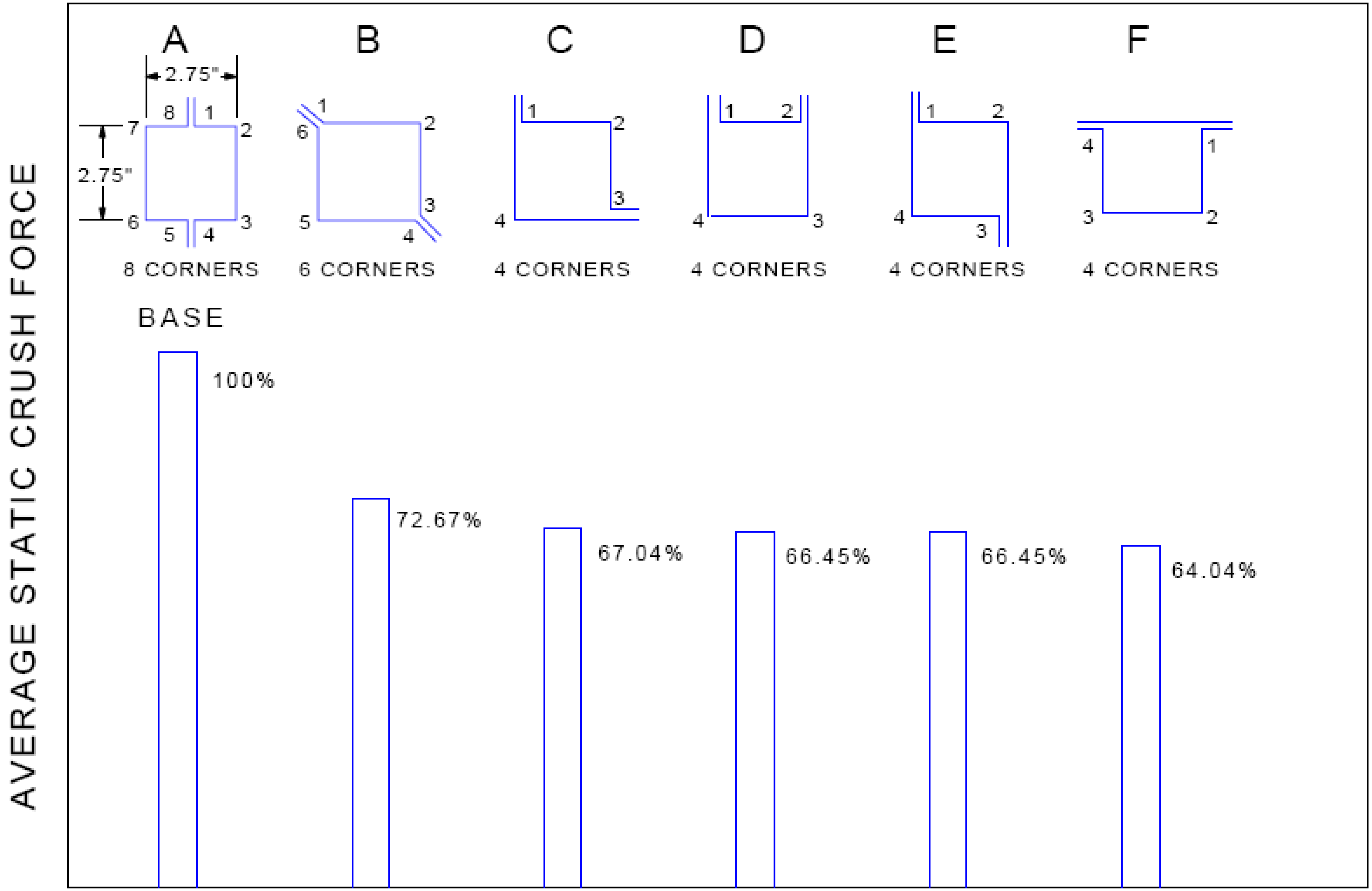
$$\left.\begin{array}{l} P_m : \text{ mean crush force (N)} \\ P_{\max} : \text{ maximum crush force (N)} \\ t : \text{ material thickness (mm)} \\ b : \text{ section width and height (mm)} \\ \sigma_Y : \text{ material yield stress (N/mm}^2\text{)} \end{array}\right\} \rightarrow \begin{cases} P_m =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



(SAE International)

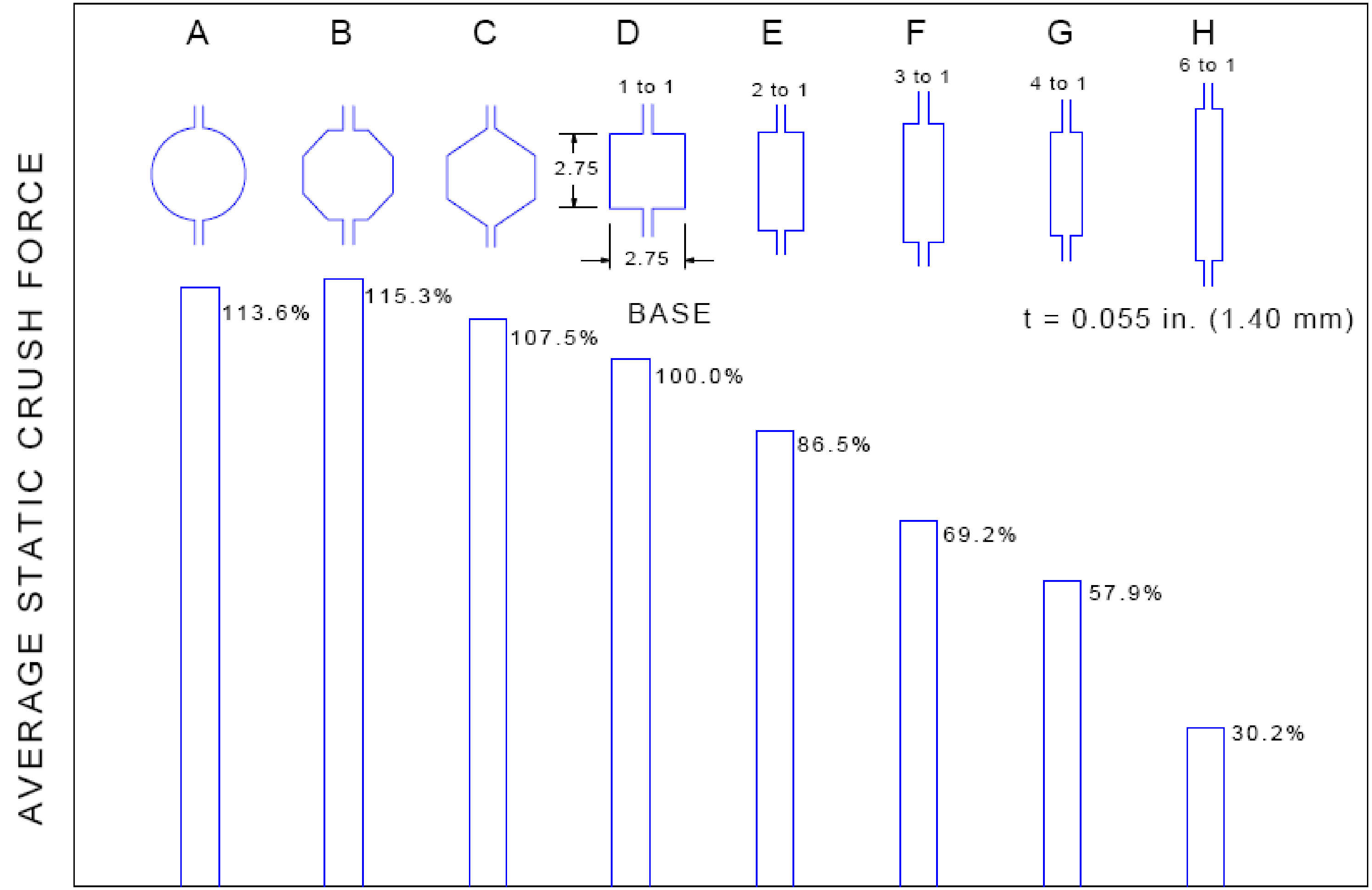
Effect on Average Crush Force: Flange Position

(70mm square, t=1.4mm)



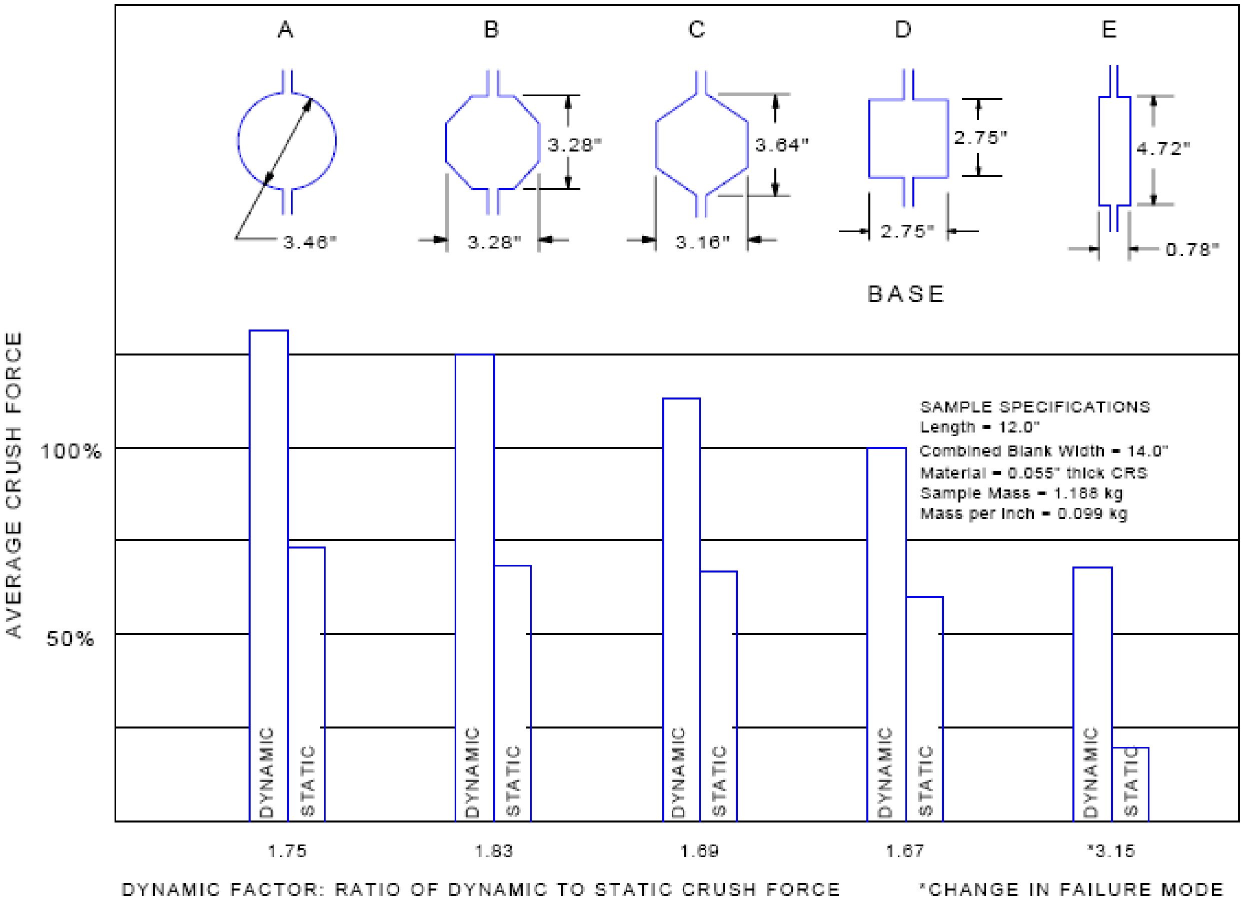
Effect on Average Crush Force: Section Shape

– Constant perimeter excluding flanges

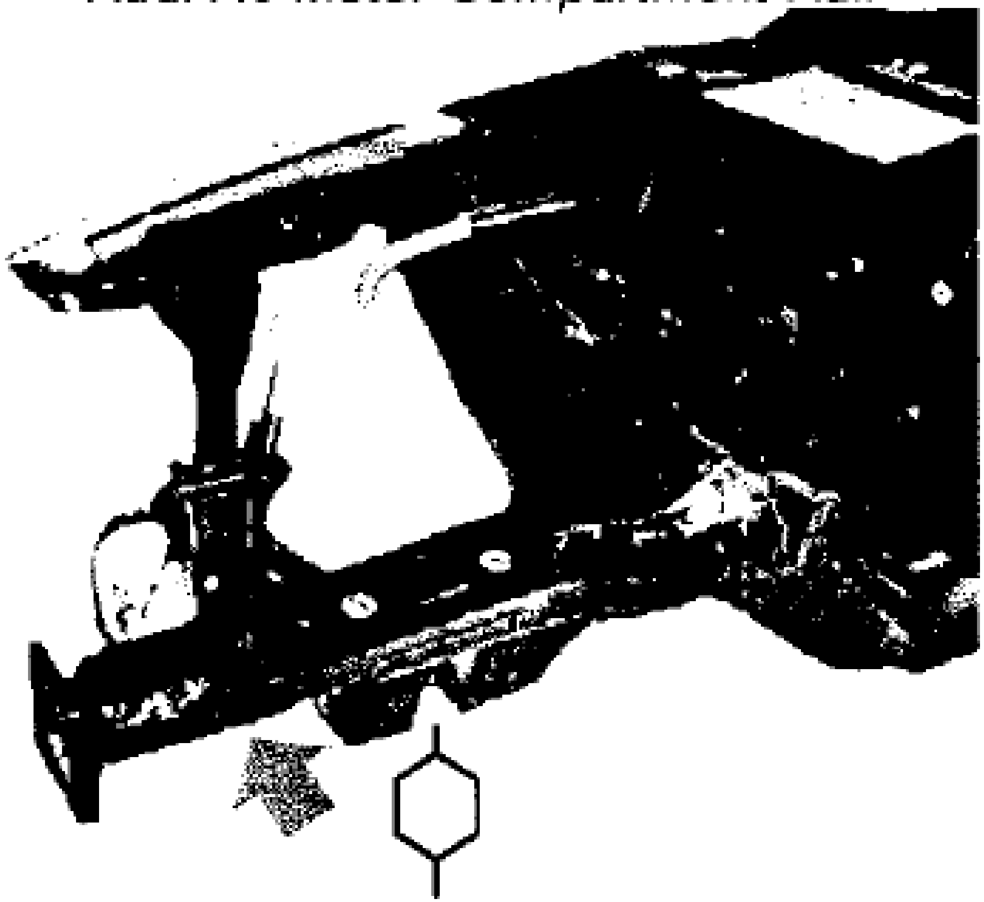


Effect on Average Crush Force: Dynamic Effect

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



Audi A6 Motor Compartment Rail



Use of Hexagonal Sections

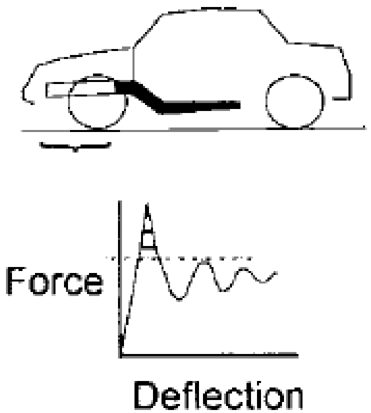
Static vs. Dynamic Loading

- 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

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

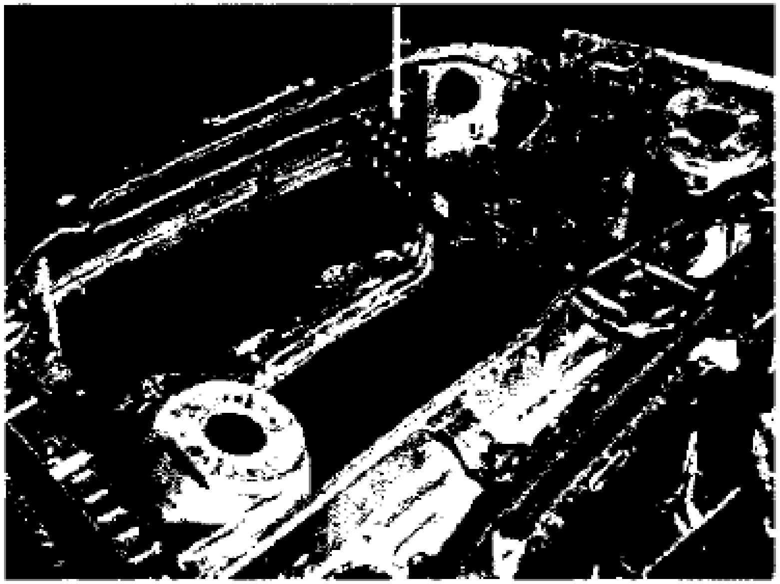
$$\eta = \frac{F_{avg}}{F_{\max}} = \frac{P_m}{P_1} = \frac{P_m}{1.42P_m} = 0.70$$

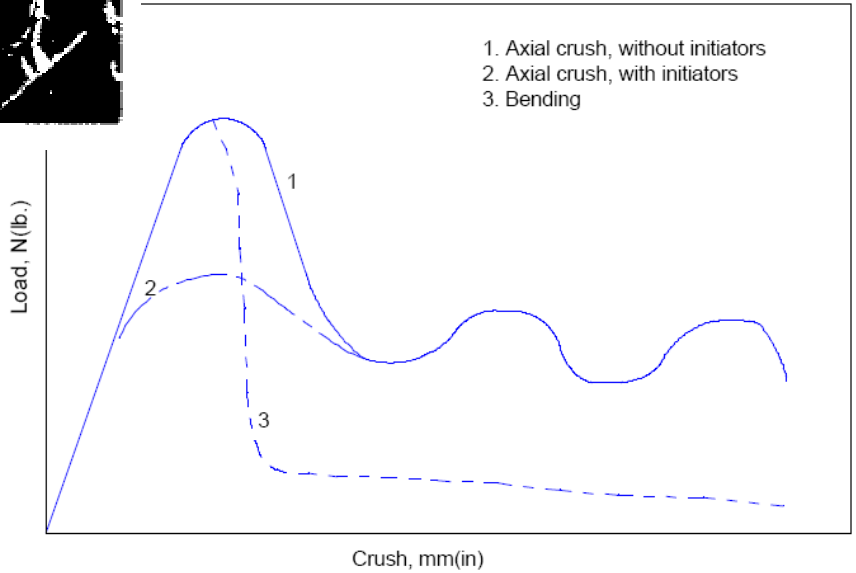
Crush Initiator



Need to Limit Peak Force so Reaction Member is Not Overloaded

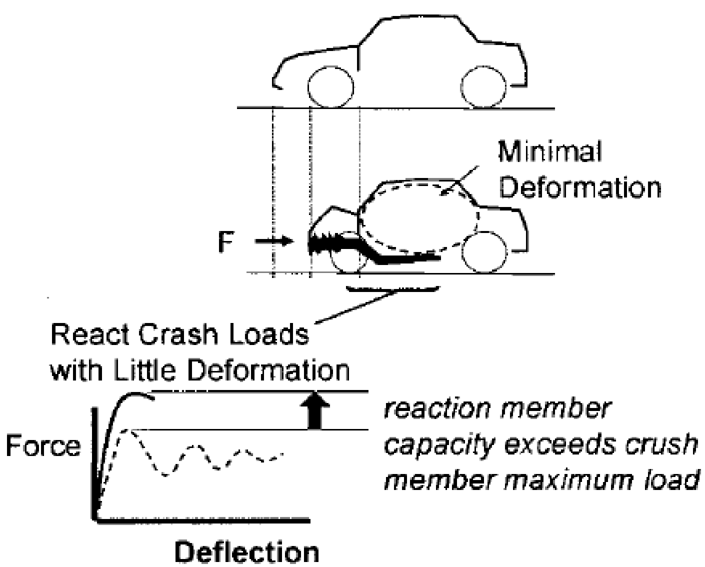
Crush Initiators on Lower Rail

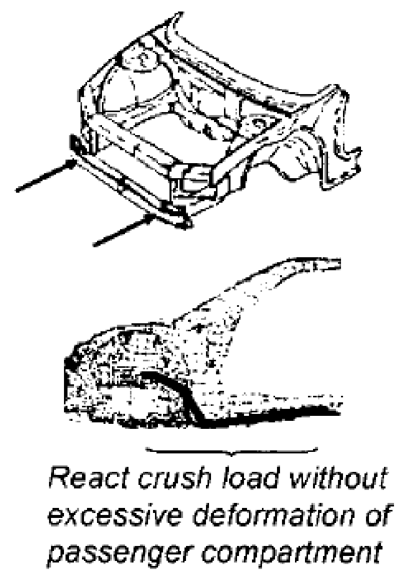


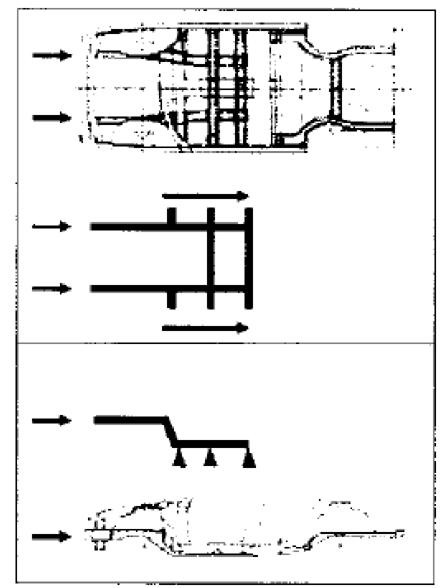


Beam Sizing for Cabin Reaction Structure

- 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

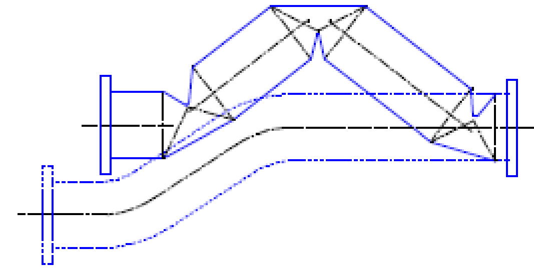


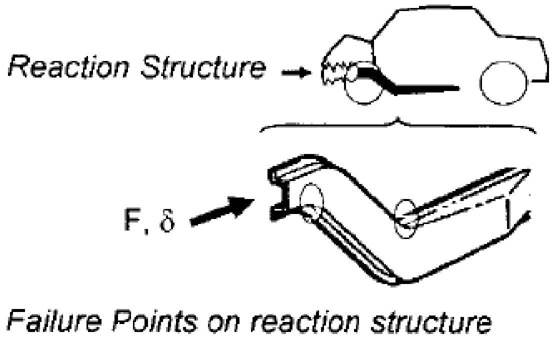


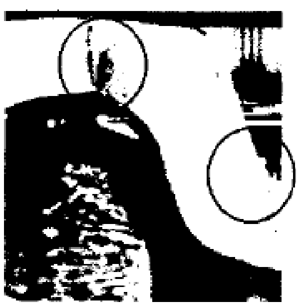


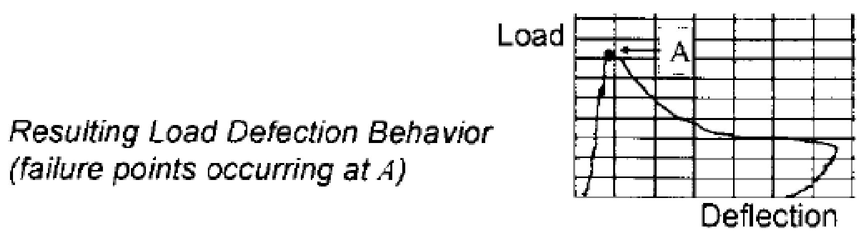
Limit Analysis Design

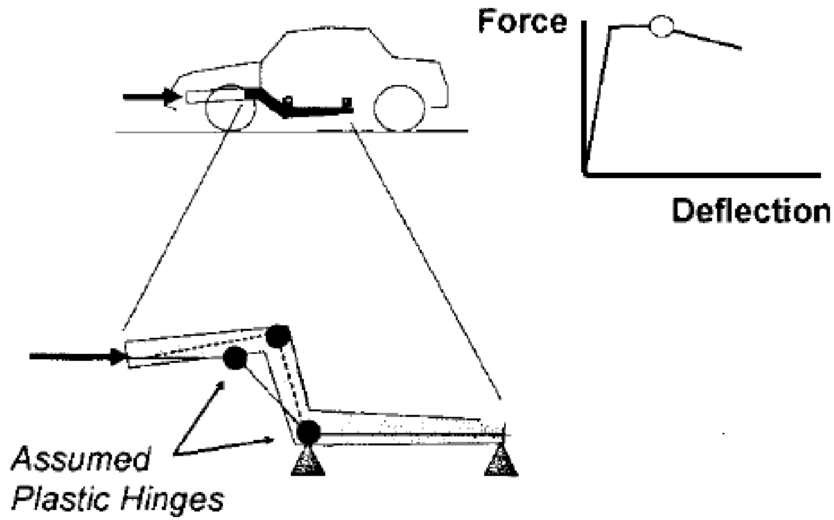
- Reaction structure
  - React applied load elastically
  - Begin to yield: permanent deformation
  - Continue to increase the applied load until yield zones extend across the section: plastic hinges
  - Behave as mechanism with rigid links (plastic hinges)
  - Limit load: ultimate load carrying ability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





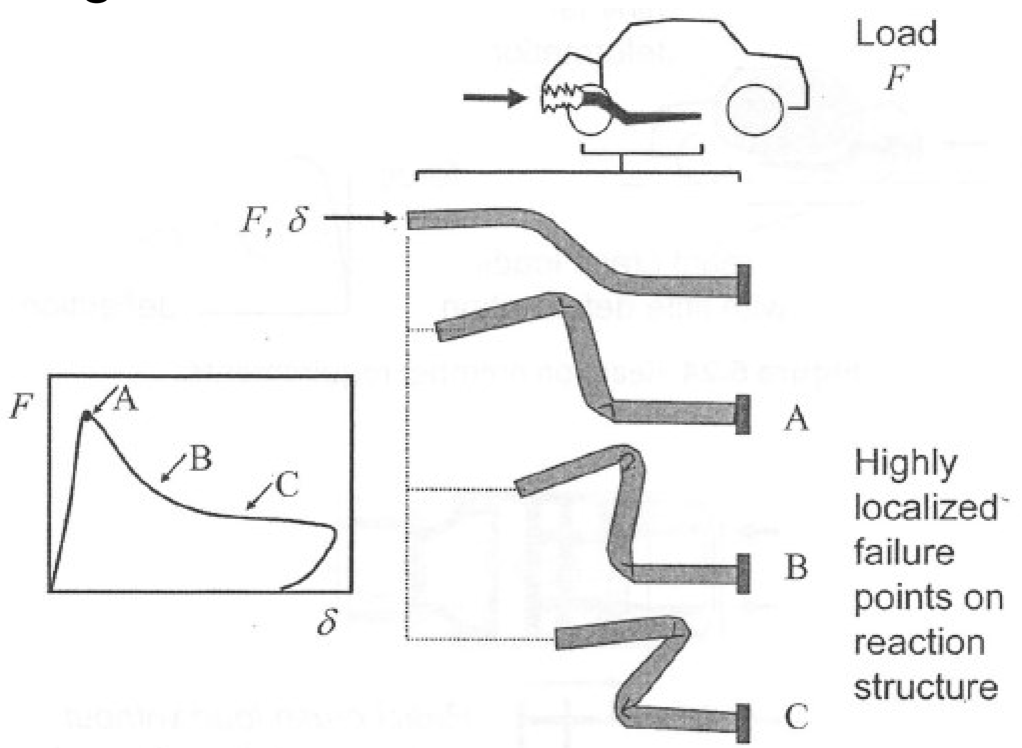






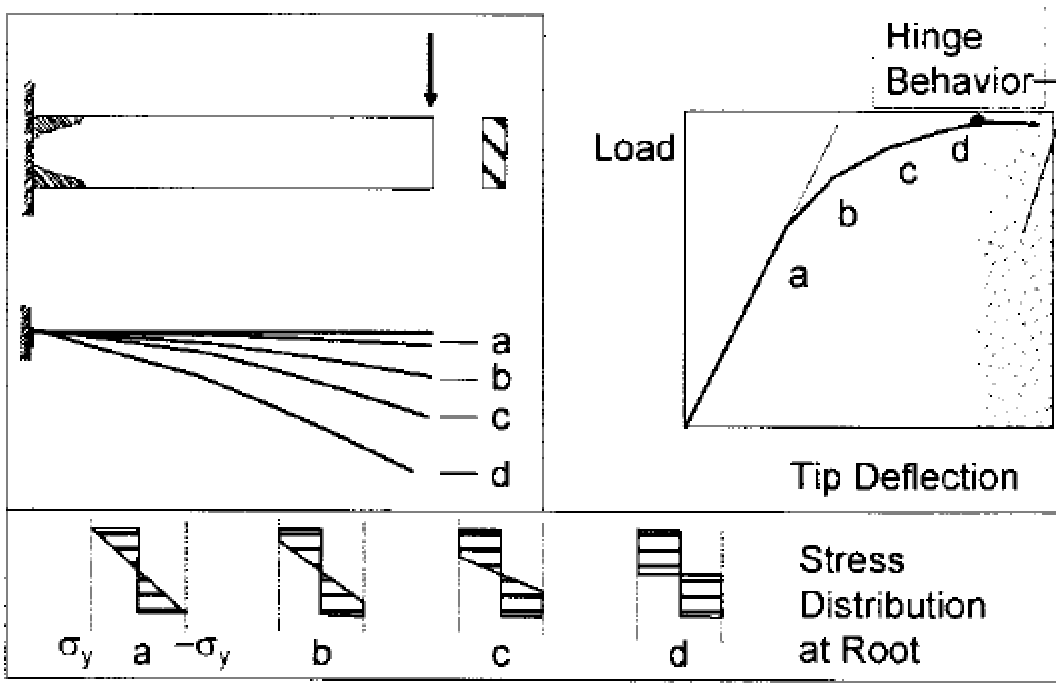
Reaction Member

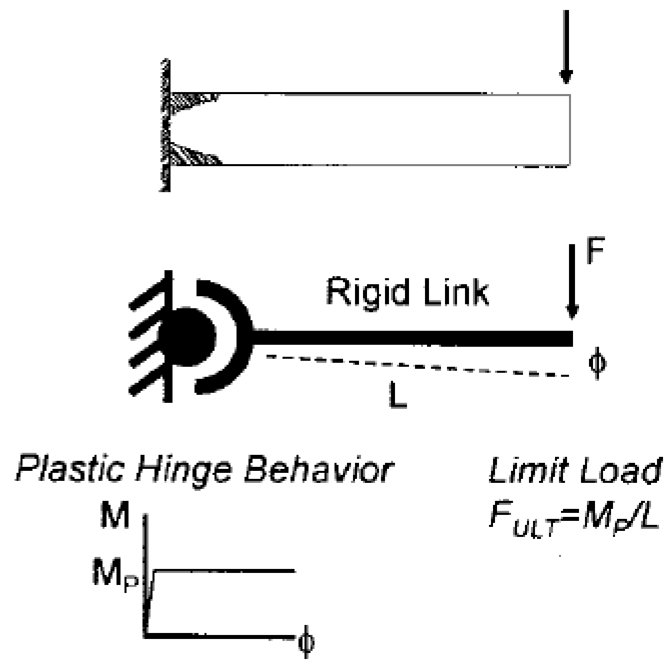
- Plastic hinge locations



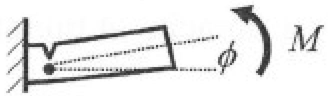
Plastic Hinge Behavior

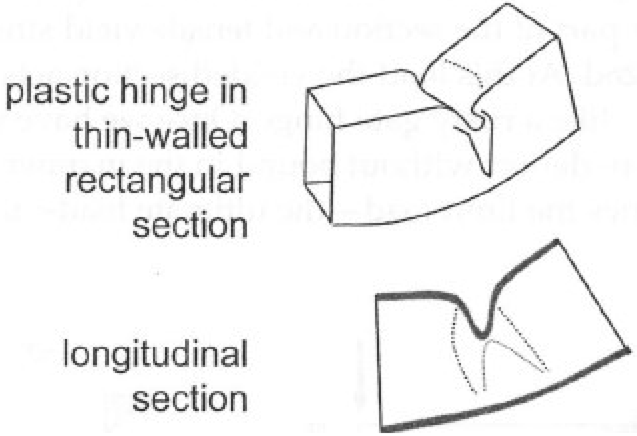
– Cantilever beam with a vertical tip load
– (a) linear and elastic (b) yield at outer fiber (c) increase in yielded region (d) limit load: ultimate load carrying capacity, acts like a pinned joint with a resisting moment



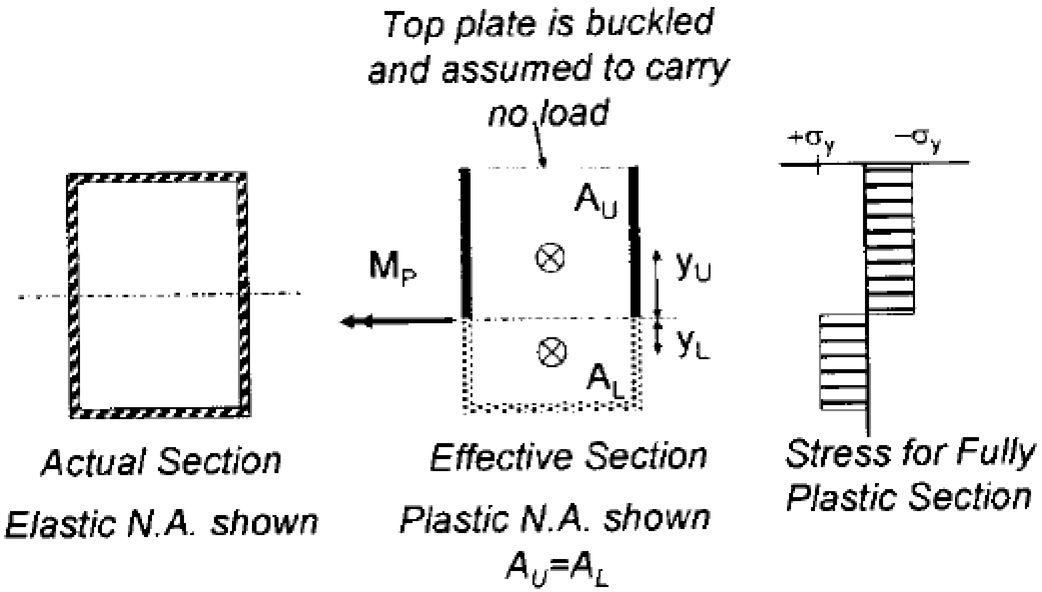


Plastic Moment





- Section dimensions
- Material yield stress

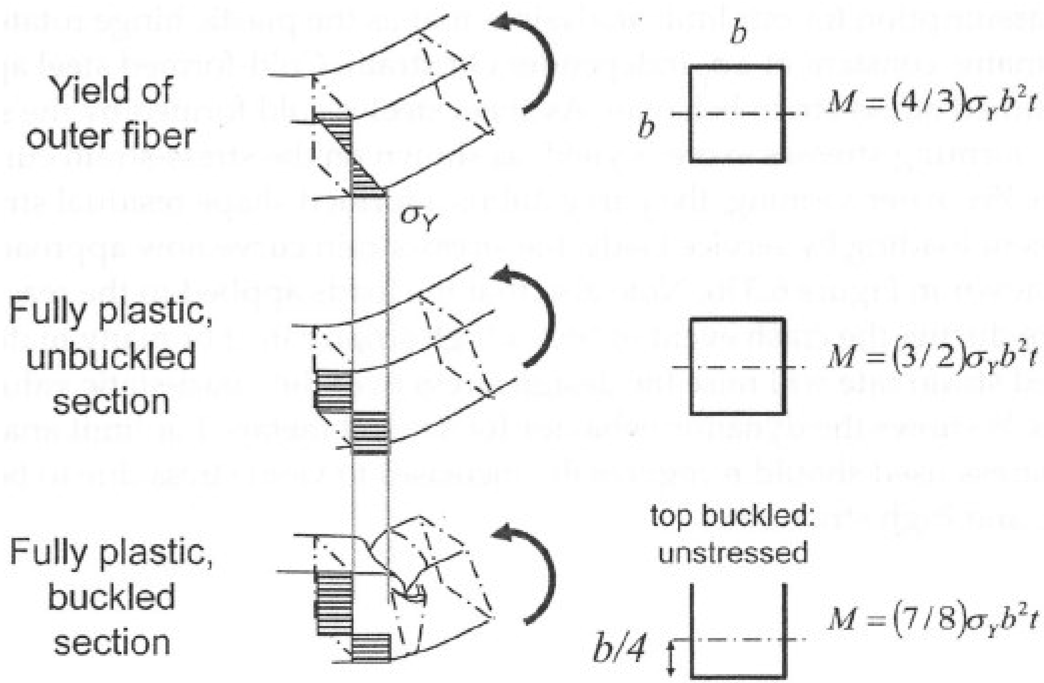


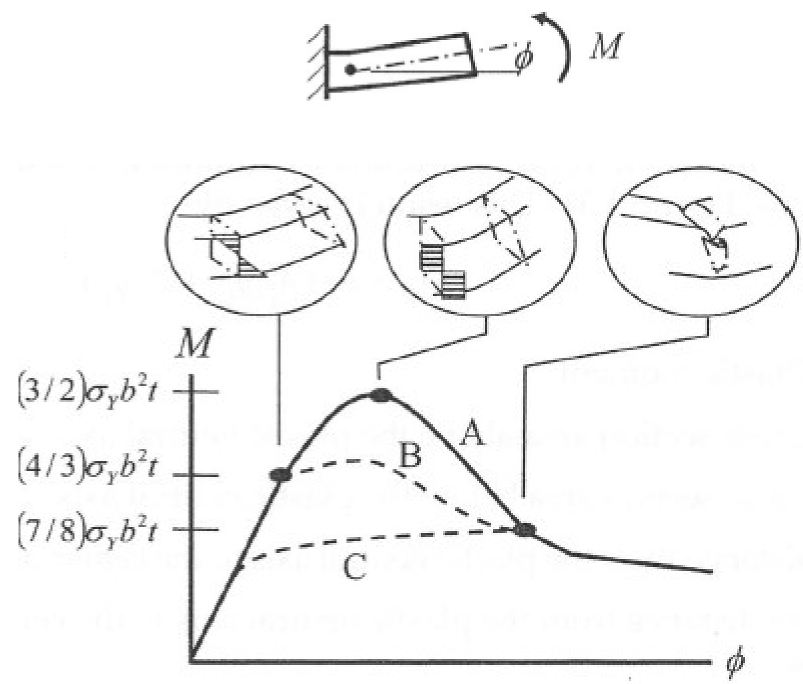
plastic neutral axis? (not necessarily same to the elastic neutral axis)

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

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

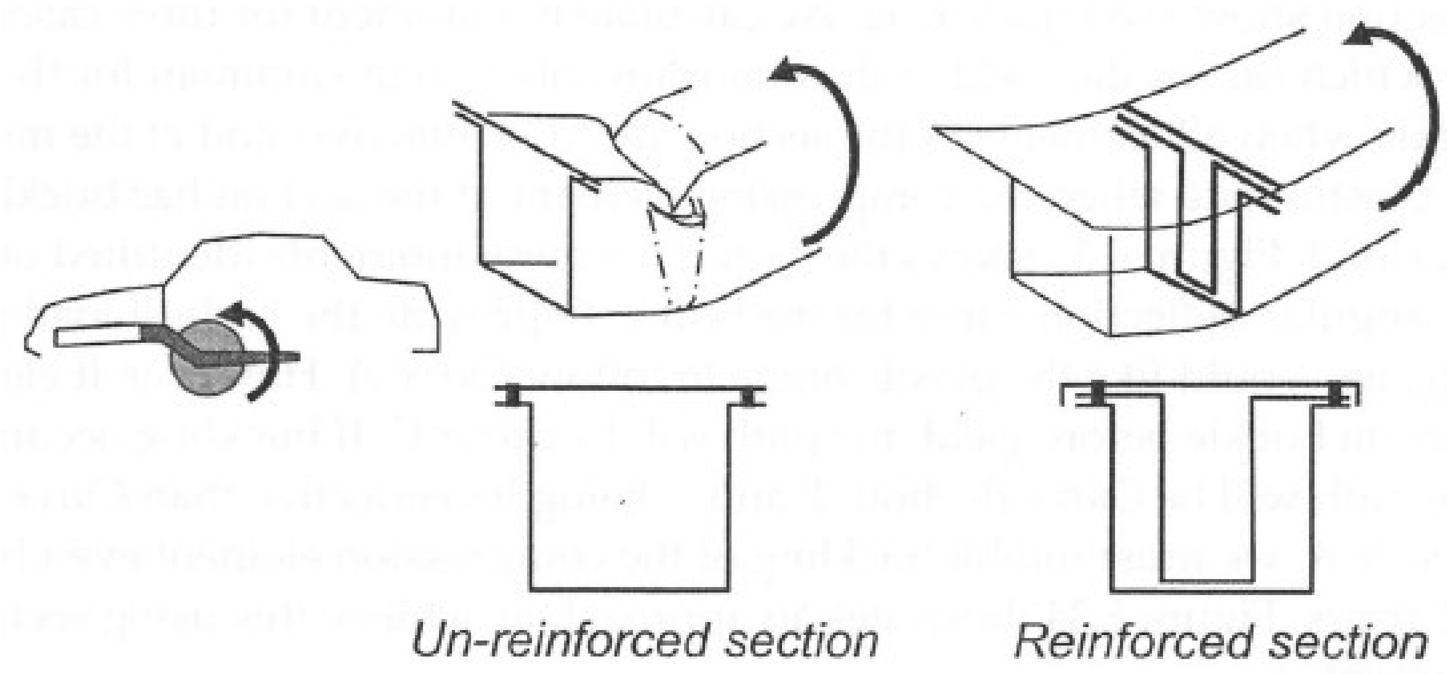
Square Thin-Walled Section





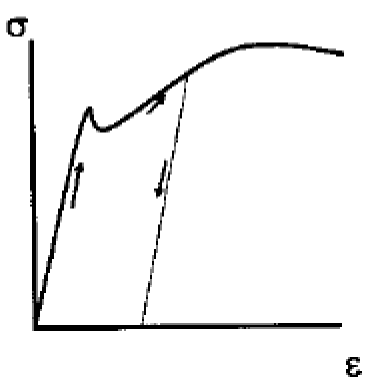
– Curve A: highest load reaction capability (inhibit buckling of the compressed element even beyond the yield)
– Curve B: bucking occurs after yield
– Curve C: bucking occurs before yield

Reinforcement to Increase Mp

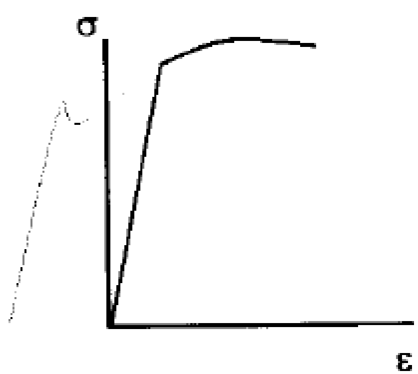


Material Behavior

- 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

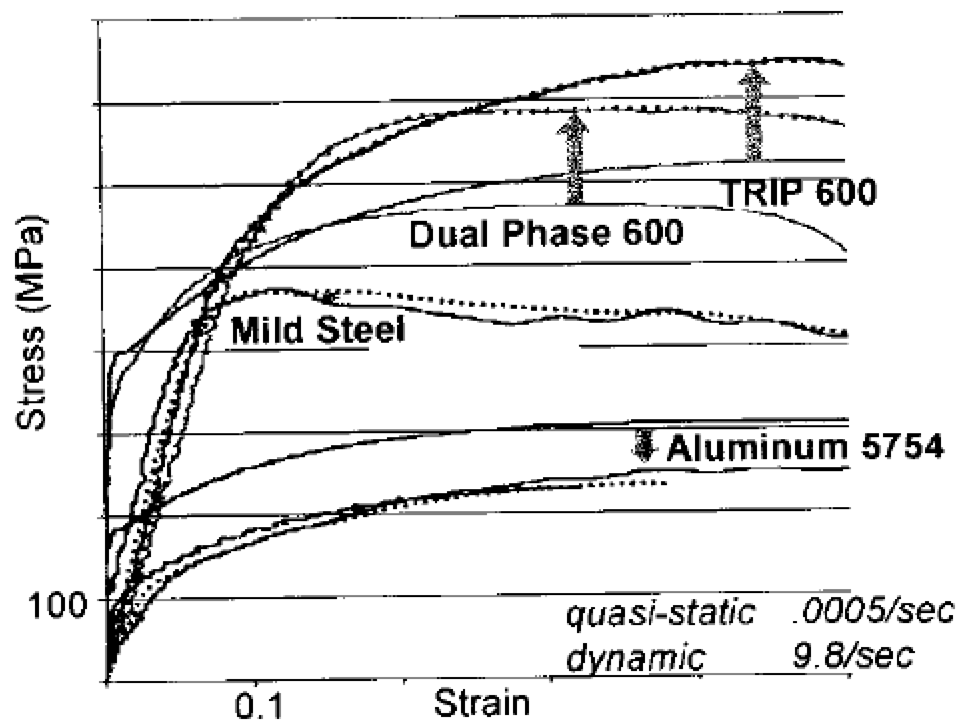


Straining during forming process



Post forming material behavior

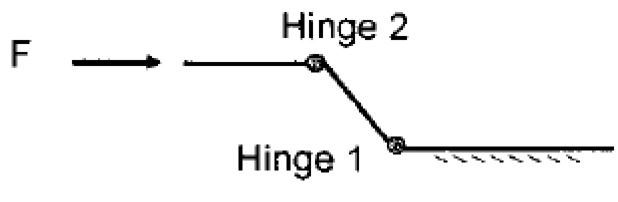
Work hardening



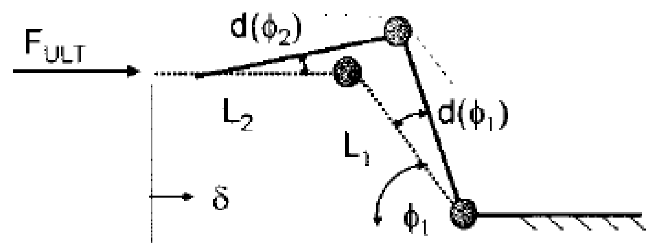
Dynamic Stress-strain Behavior

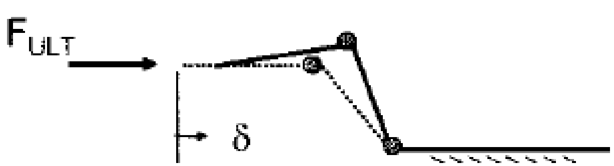
Limit Load Analysis: Midrail

- 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

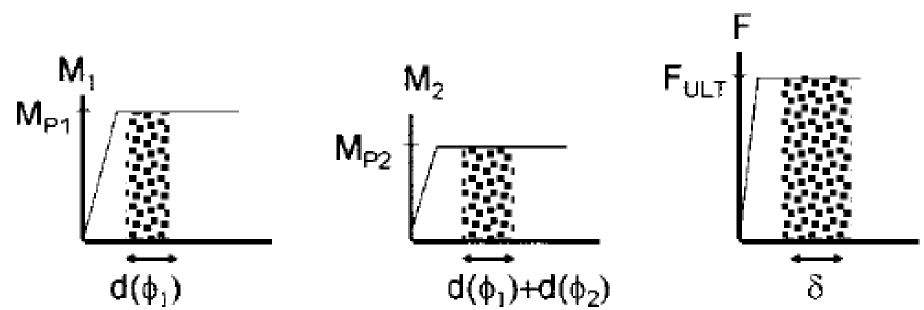


Rigid link / Plastic Hinge Model
(a)





Model with small deflection
(b)



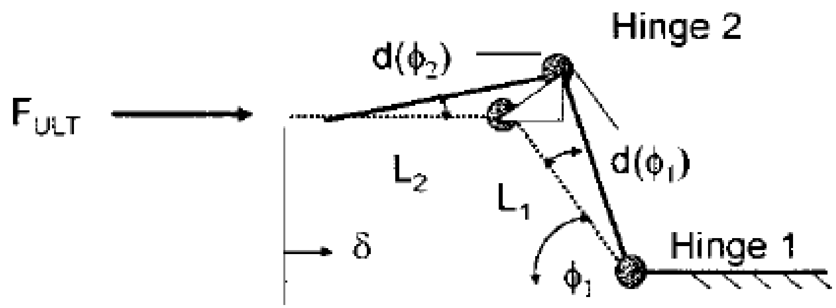
Load Capacity: F_{ULT}?

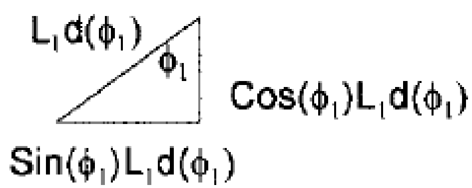
- Geometry of the longitudinal structure
  - L_1, L_2, ϕ_1
- Plastic moment capacity at the hinge joints
  - M_{p1}, M_{p2}

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

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

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





$$\delta = \mathrm{Sin}(\phi_1)L_1 d(\phi_1)$$

$$L_2 d(\phi_2) = \mathrm{Cos}(\phi_1)L_1 d(\phi_1)$$

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

$$d(\phi_2) = \frac{\mathrm{Cos}(\phi_1)\delta}{\mathrm{Sin}(\phi_1)L_2}$$

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

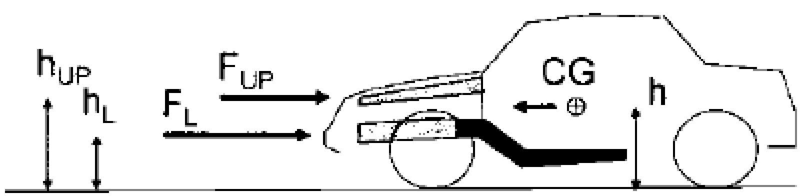
$$\left.\begin{aligned} F_B\left(h-h_L\right) &= I\alpha \\ F_B &= Ma \end{aligned}\right\} \rightarrow \frac{Ma}{I}\left(h-h_L\right)=\alpha$$

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

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

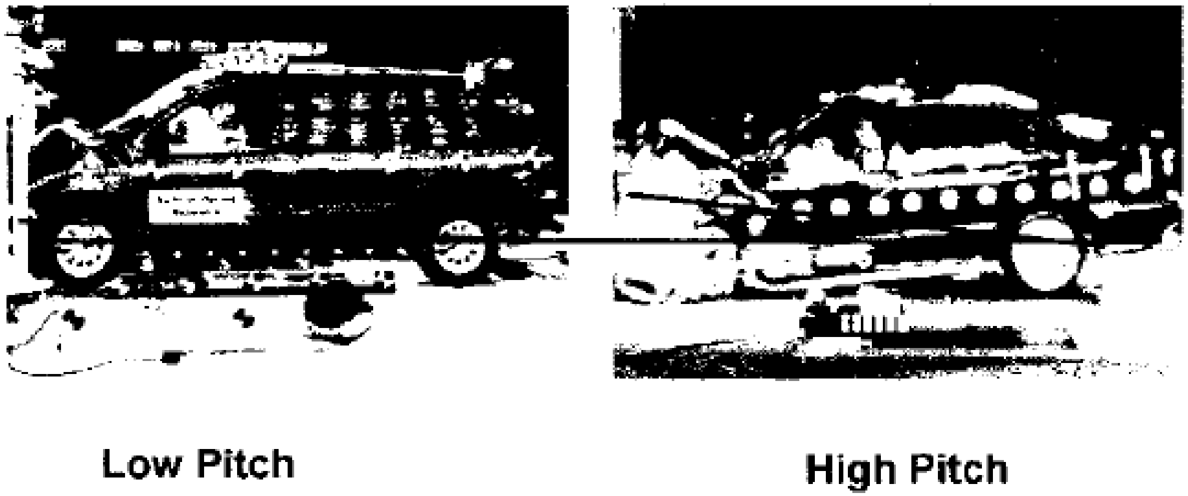
$$\rightarrow \frac{F_{UP}}{F_L}=\frac{h-h_L}{h_{UP}-h}$$

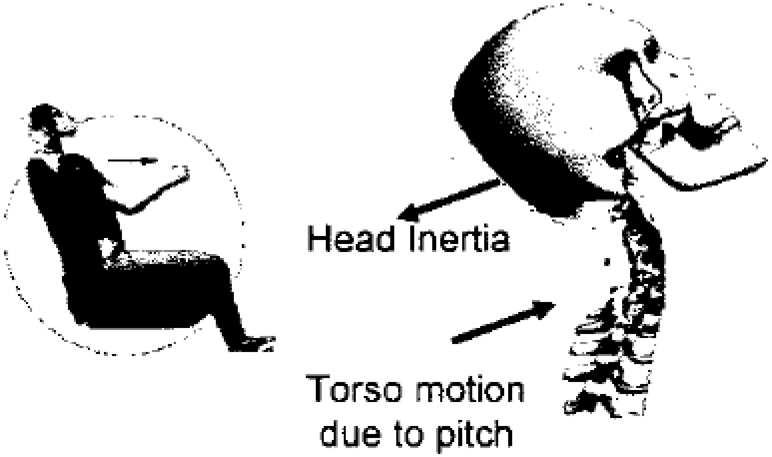
(a) Vehicle pitch without upper load path



(b) Addition of upper load path

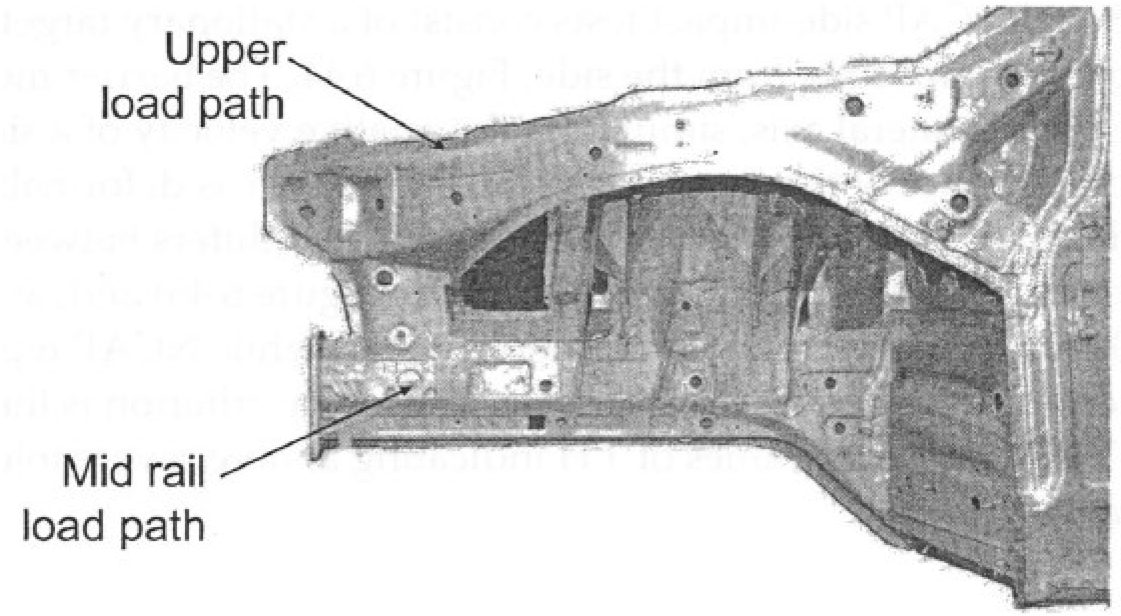
- Vehicle pitch on impact with rigid barrier
- Neck injury related to vehicle pitch





Example of Upper Load Path

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

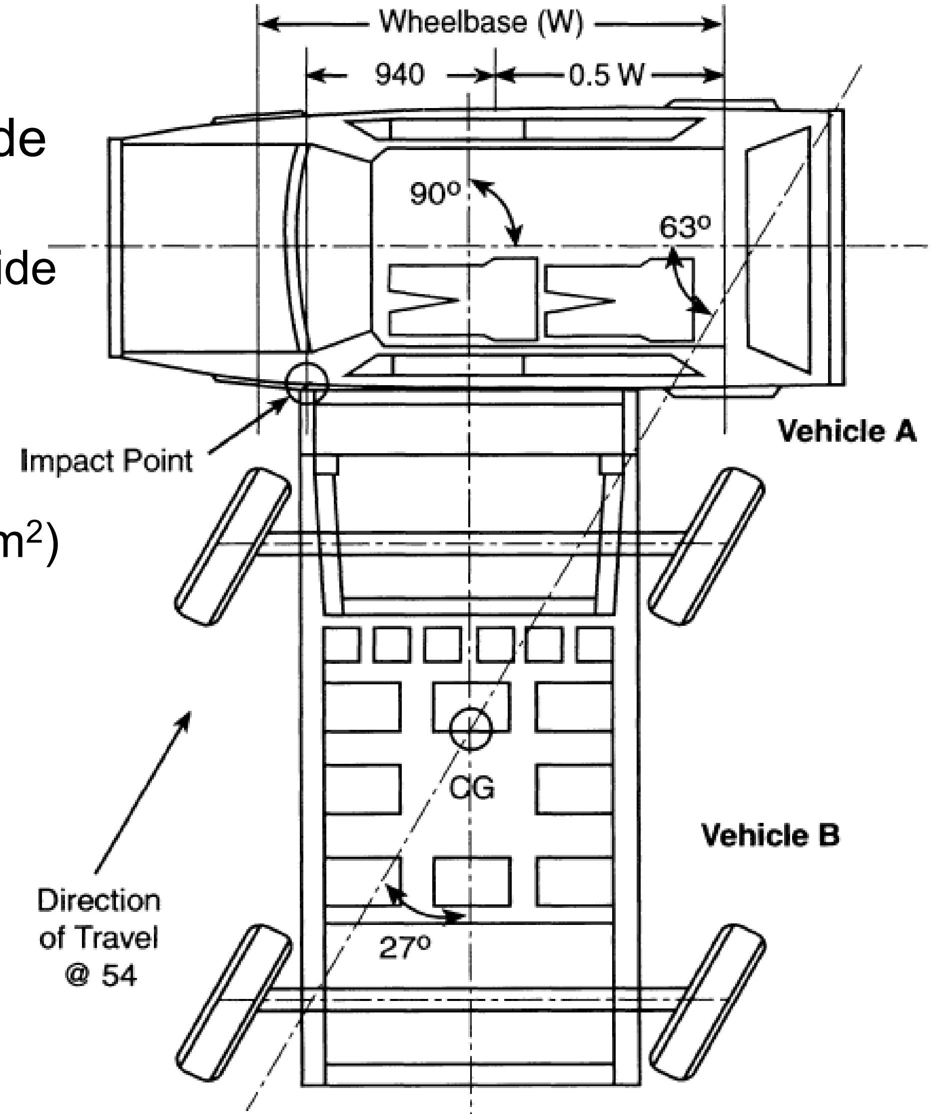


Structure for Front Barrier Impact

- 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

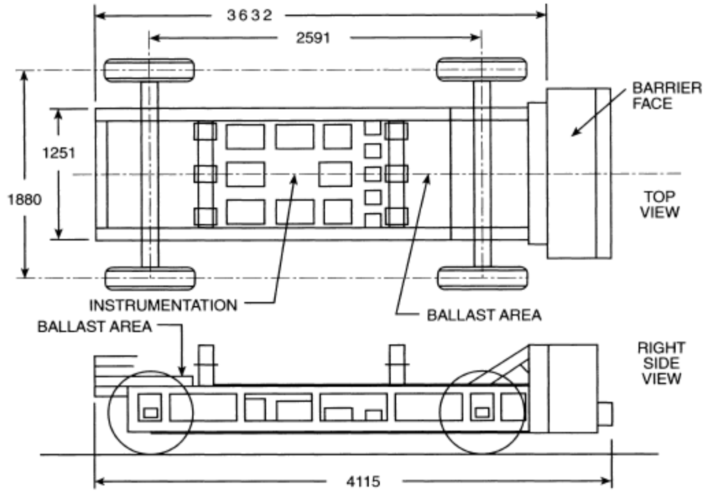
6.3 Side Impact

- 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

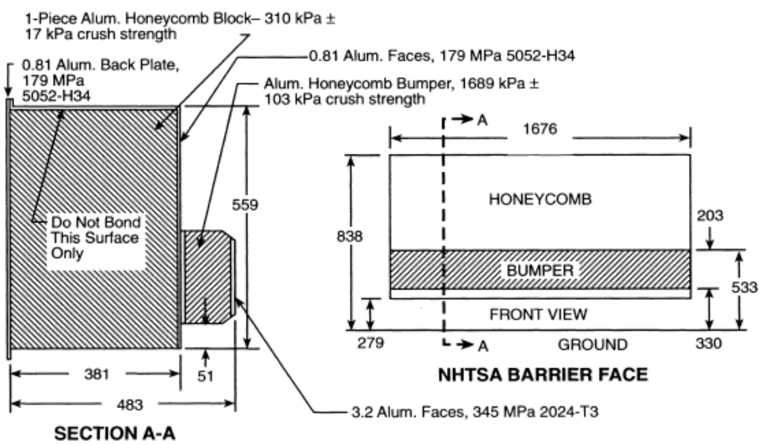


Side Impact

- moving deformable barrier

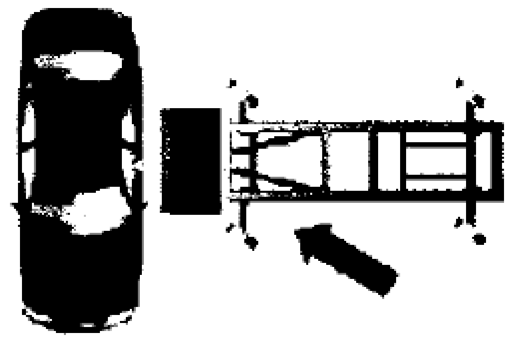


NHTSA VEHICLE SIMULATOR
All dimensions in millimeters (mm)



- NCAP (New Car Assessment Program)

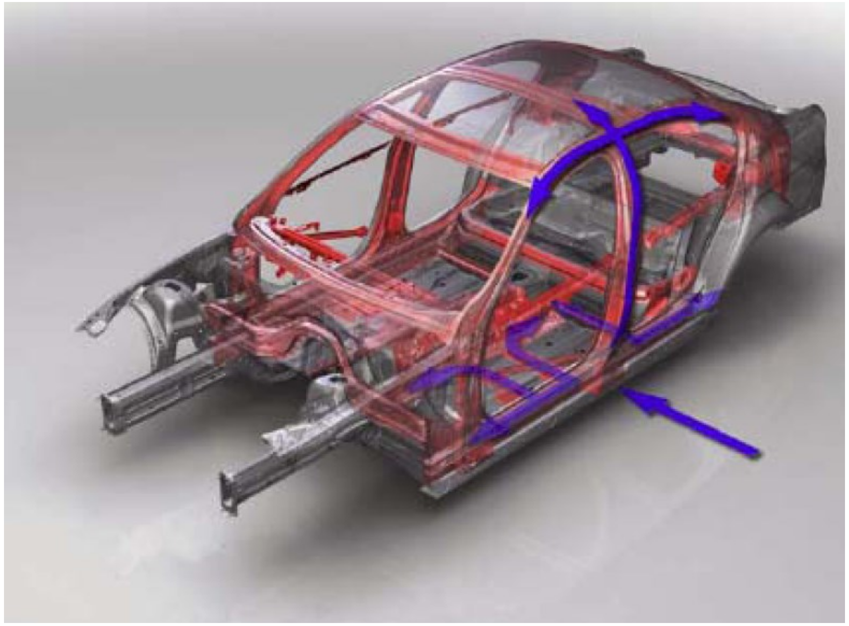
The SINCAP or LINCAP is based on the thoracic trauma index (TTI) using the US-SID dummy. The TTI is defined as the average of the peak accelerations in the rib and lower spine.

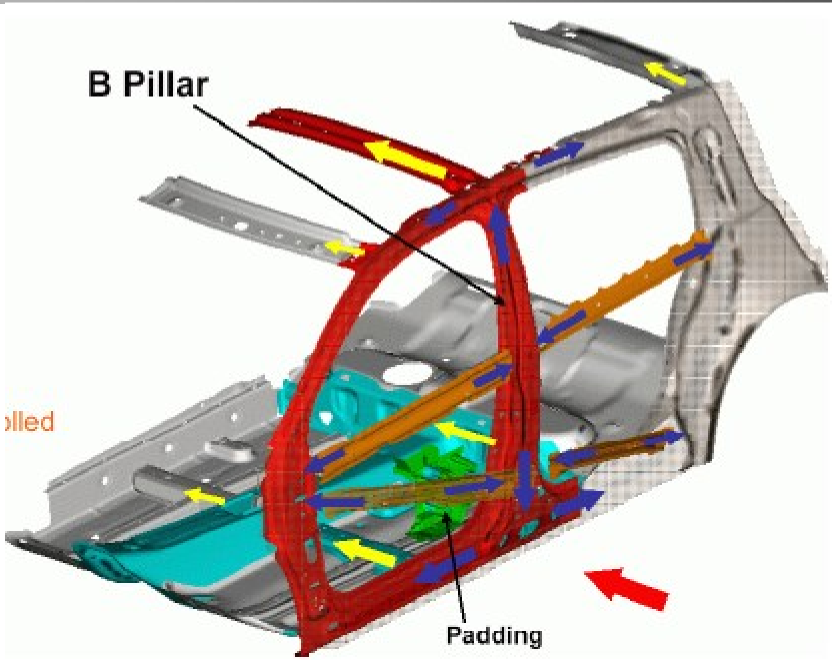


38.5 mph (61.6 km/h) impacted by 1370 kg barrier moving 27° to lateral axis of vehicle

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

Load Path

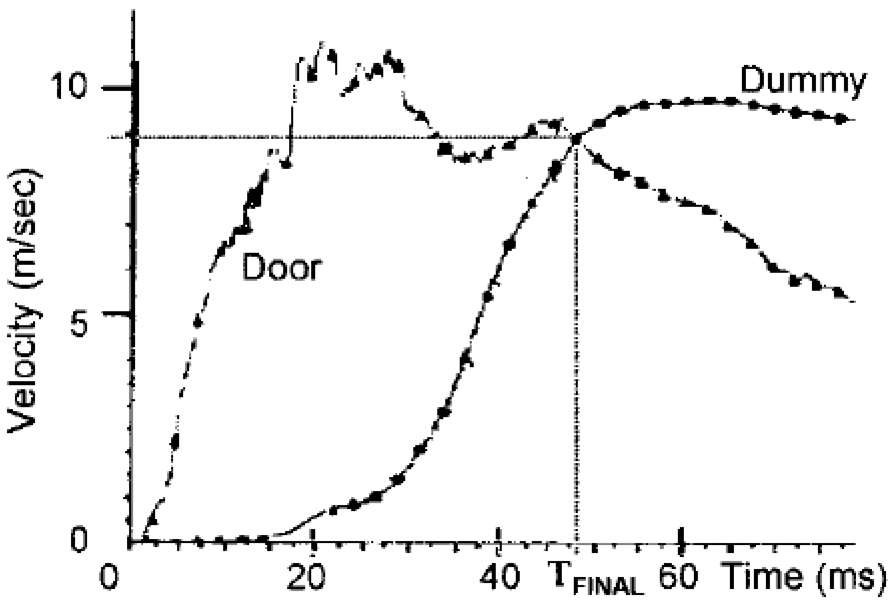


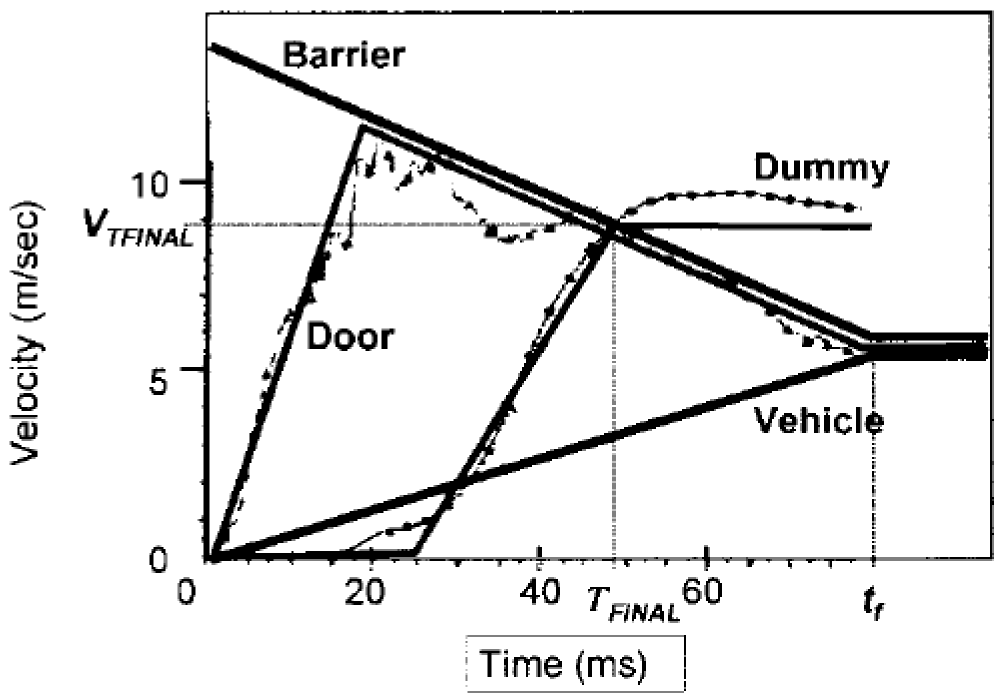


- Structural criteria
  - Load transfer continuity to doors
  - Small relative displacements
  - Small absolute displacements up to t = 40ms for enabling airbag inflation

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



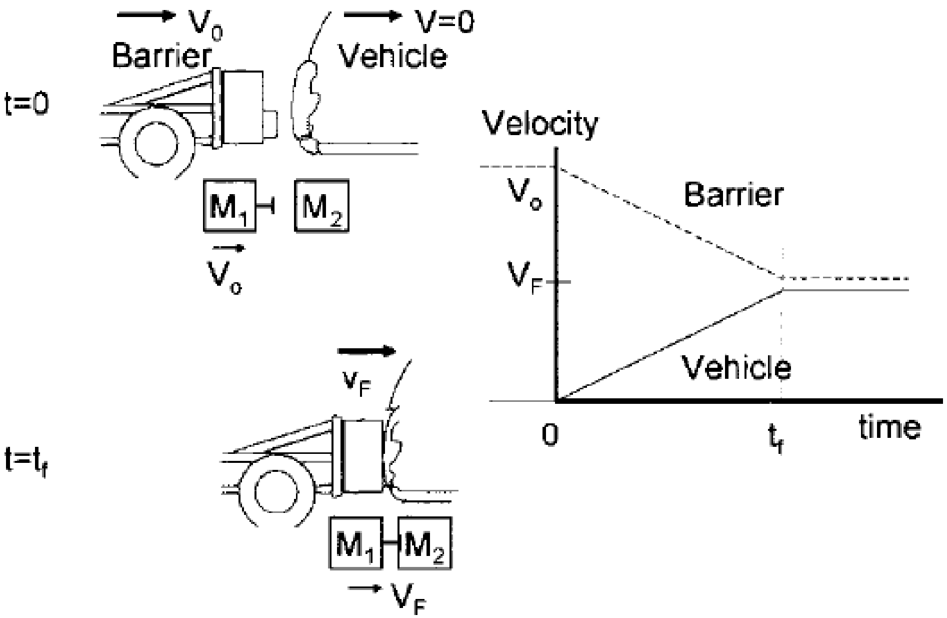


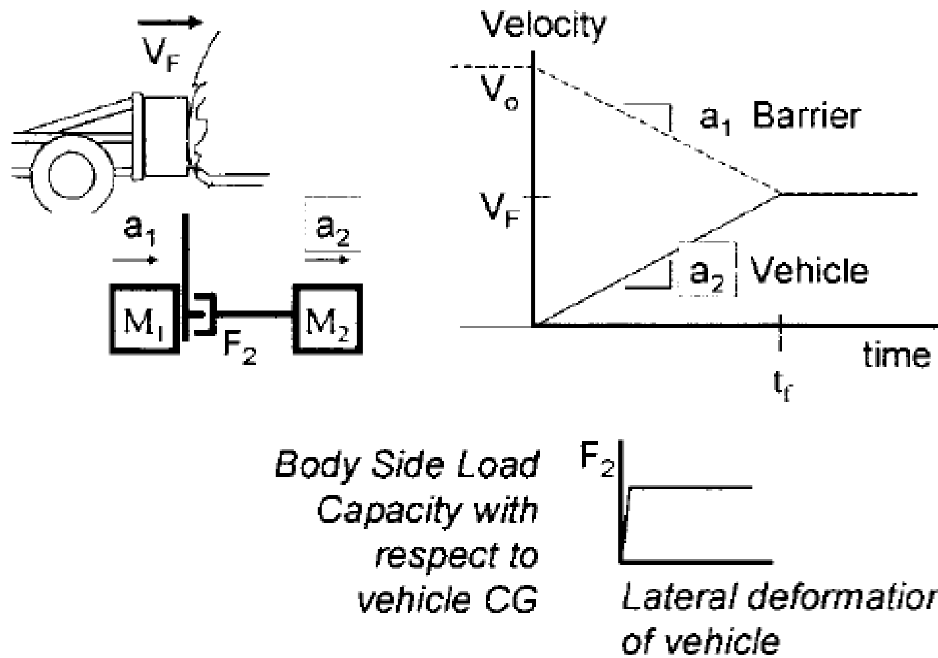
Performance Criterion

- 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





$$M_1V_0 = \left(M_1 + M_2\right)V_F \rightarrow V_F = \frac{M_1}{M_1 + M_2}V_0$$

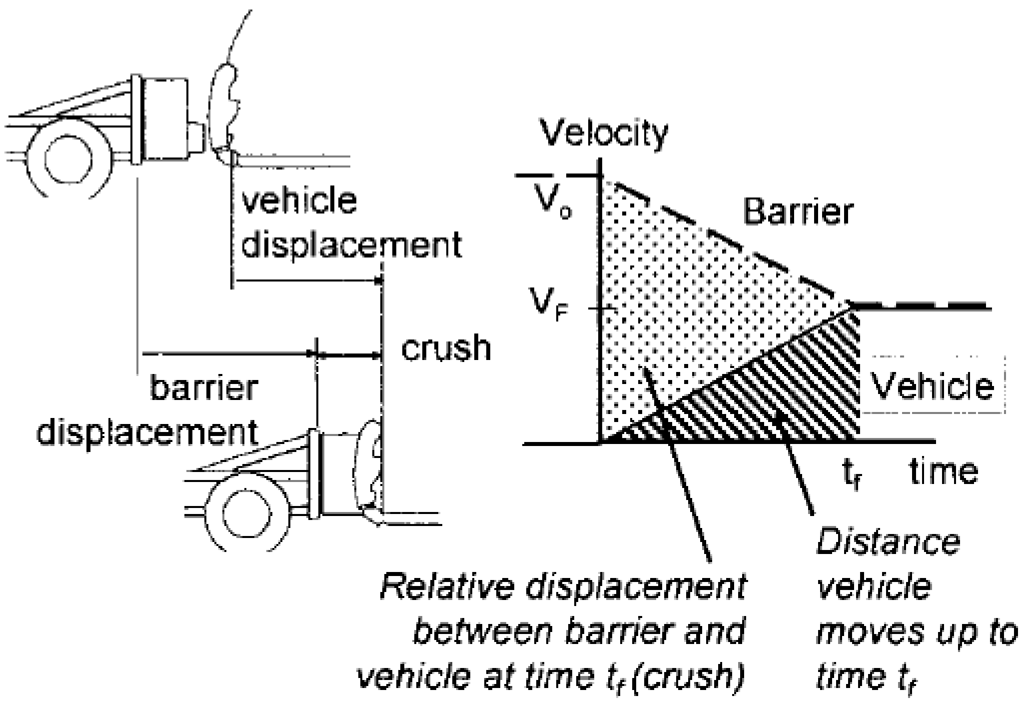
$$\begin{cases} M_1: \text{ barrier mass} \\ M_2: \text{ vehicle mass} \\ V_0: \text{ lateral impact speed } \left(S_{test}\cos\alpha\right) \\ V_F: \text{ final speed of vehicle and barrier} \end{cases}$$

$$-F_2 = M_1a_1 \rightarrow a_1 = -\frac{F_2}{M_1},\ \ F_2 = M_2a_2 \rightarrow a_2 = \frac{F_2}{M_2}$$

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

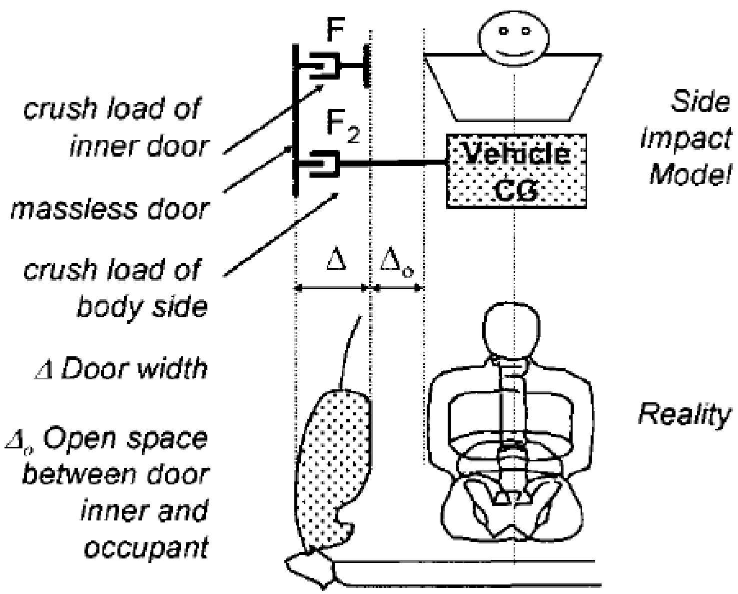
Crush Characteristics

- 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

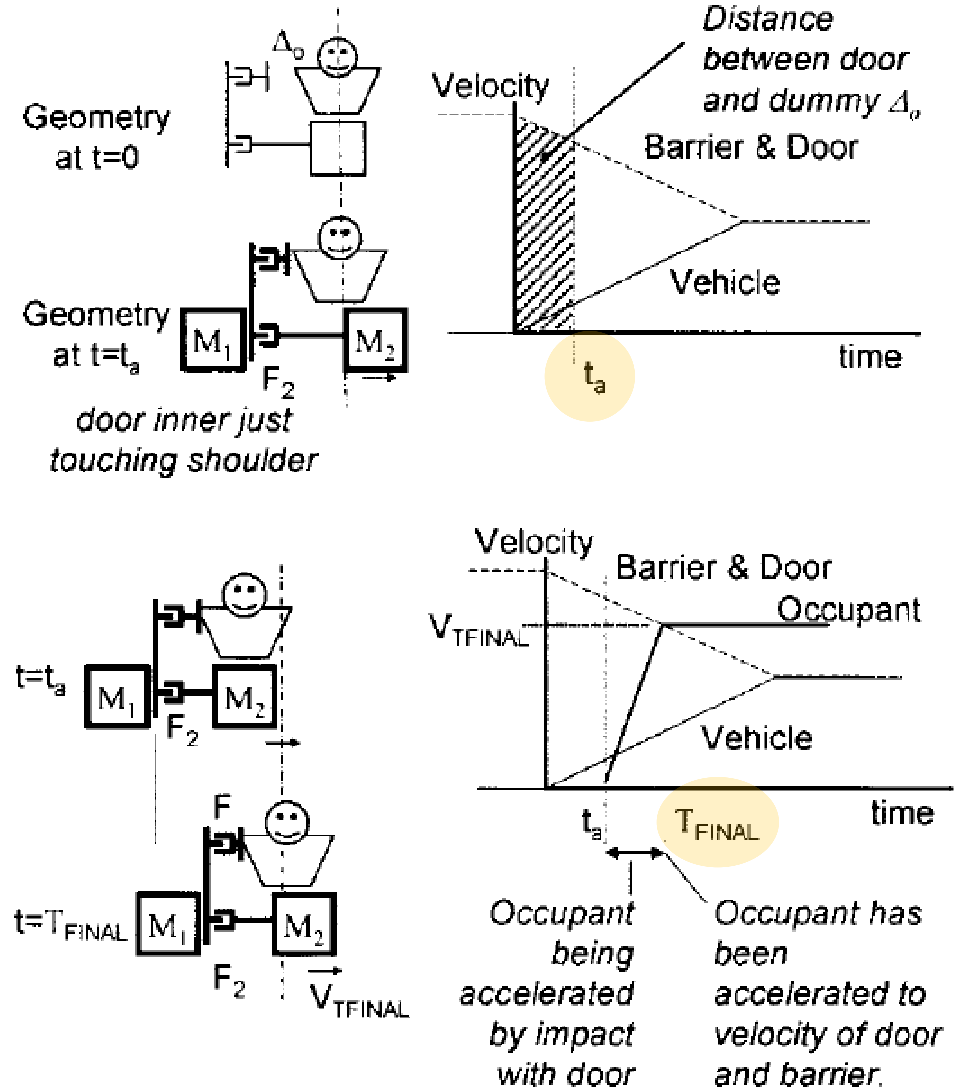


Impact of Vehicle and Barrier (1)

- 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

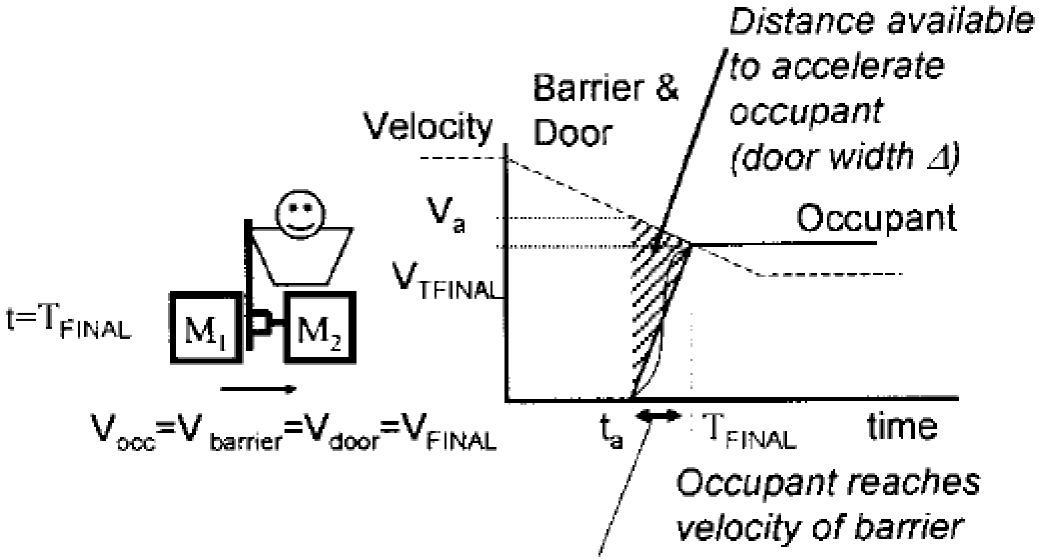
- Objective for kinematic analysis
  - Estimate the change in velocity of the occupant
  - Indicator of injury: V_{TFINAL}

Impact of Vehicle and Barrier (2)



Door Inner Deformation Characteristics

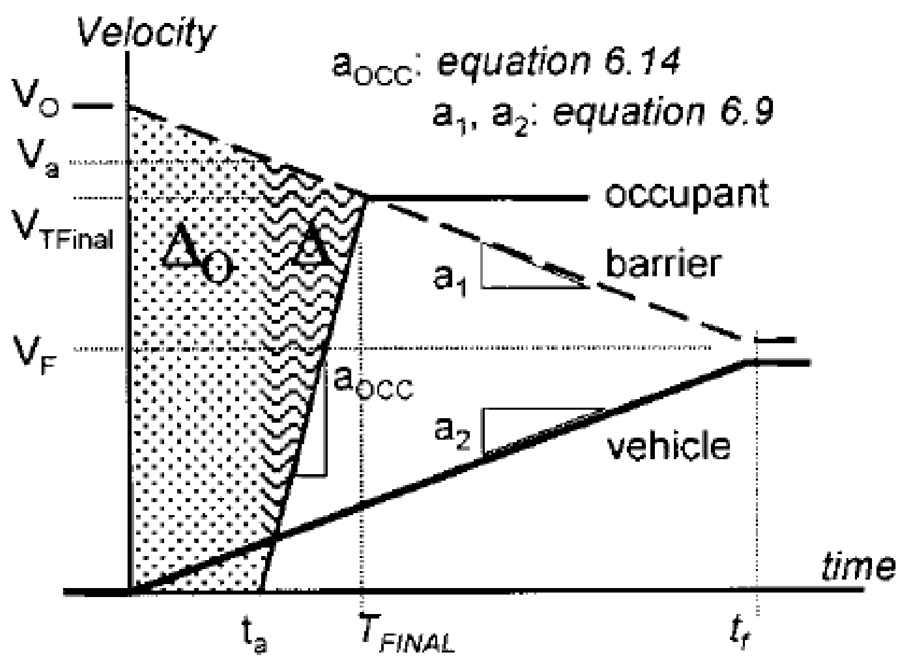
– Assumption: square wave load-deformation crush curve



Door inner deforms as it strikes the occupant.
Note: the minimum peak acceleration is imparted when the acceleration-time is square wave (constant crush force)

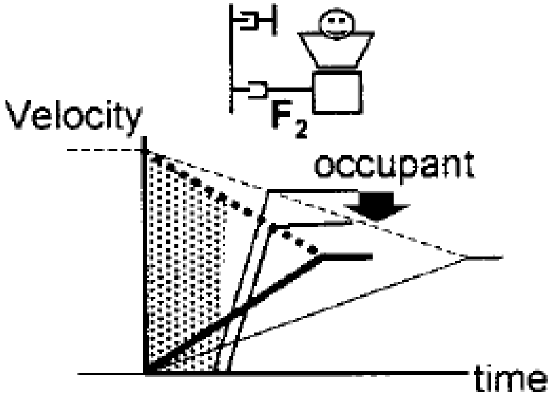
Summary of Kinematic Relationships

– 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



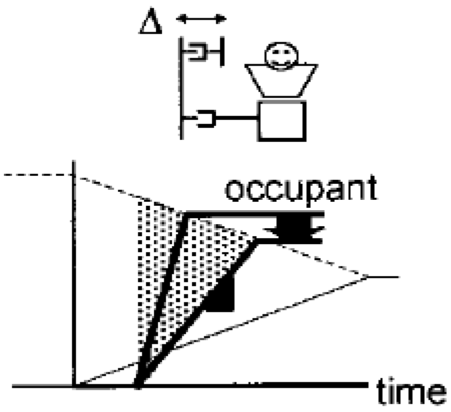
Design Considerations (1)

- 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



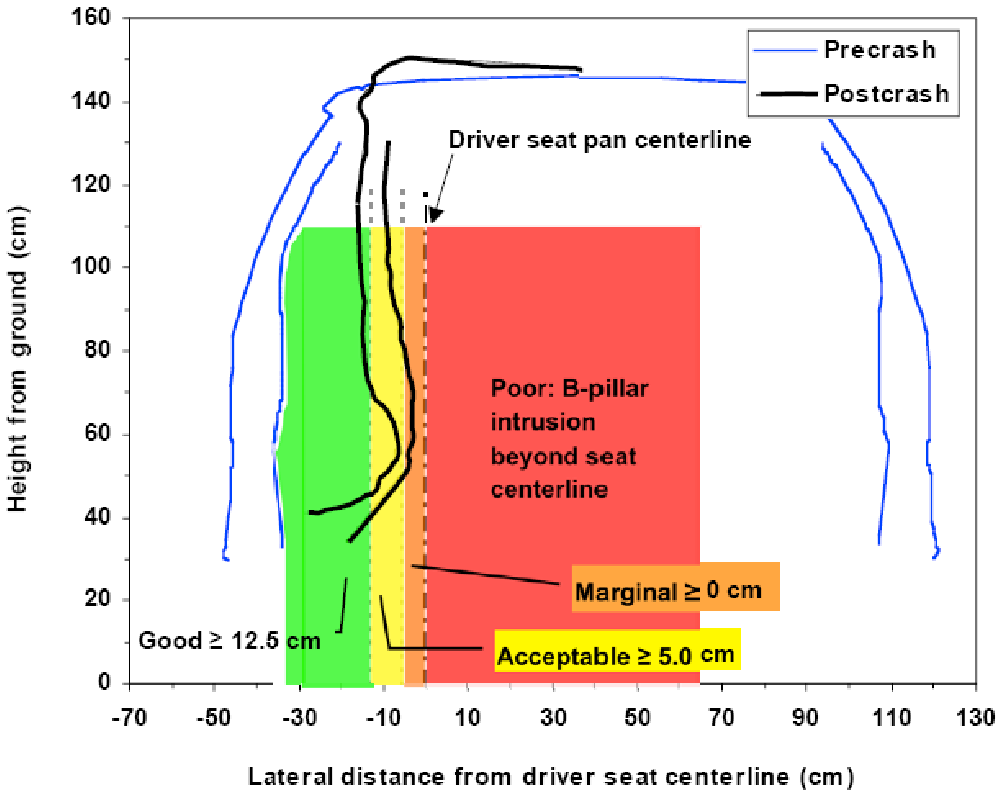
Design Considerations (2)

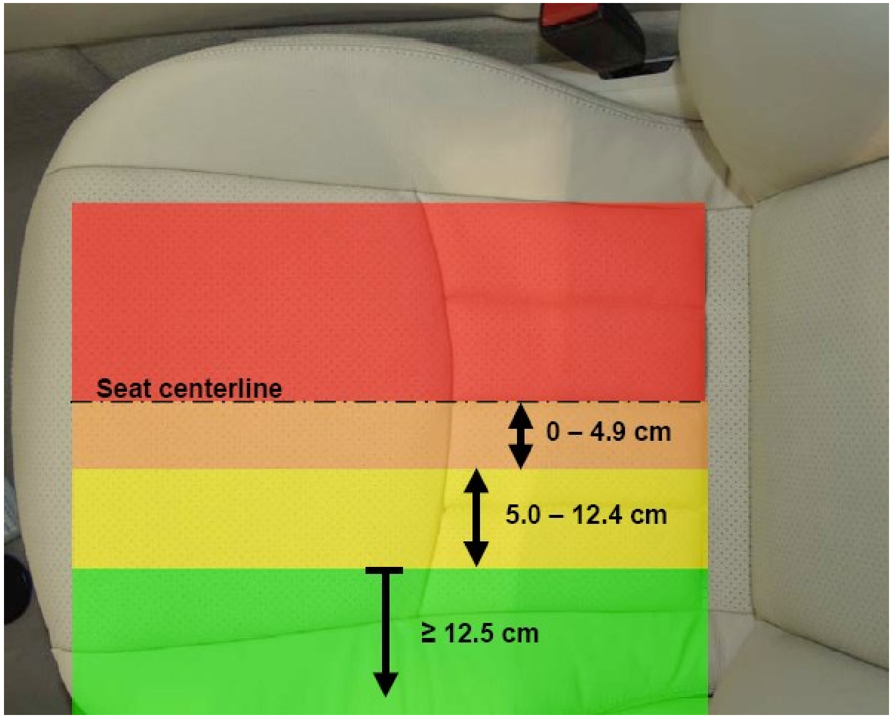
- Clearance between the occupant shoulder and door panel
  - Minimize the impact acceleration of the occupant
  - Increasing this space decreases the average slope of the occupant velocity curve
  - Lower impact force being applied to the occupant
- Door inner crush characteristic: F
  - Minimize the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

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

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

(work of deformation)

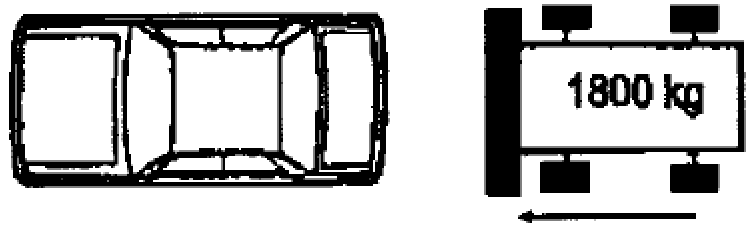
= (change of kinetic energy before and after the impact)

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

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

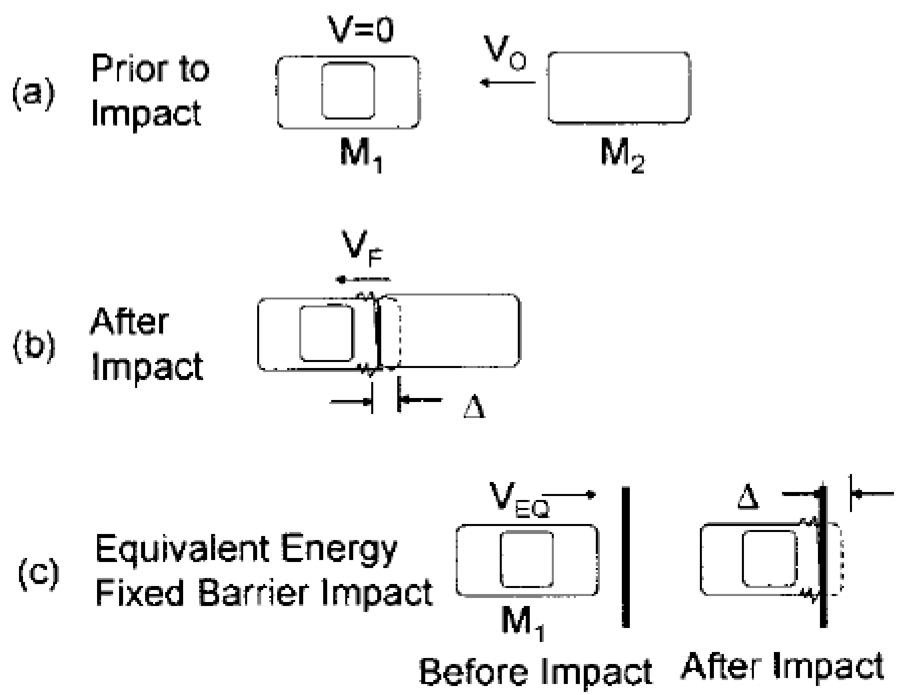
$$\frac{1}{2} M_1 V_{EQ}^2 = F_{AVG}\Delta \rightarrow F_{AVG} = \frac{M_1 V_{EQ}^2}{2\Delta}$$

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



FMVSS 301

30mph Impact by moving barrier
Fuel system integrity

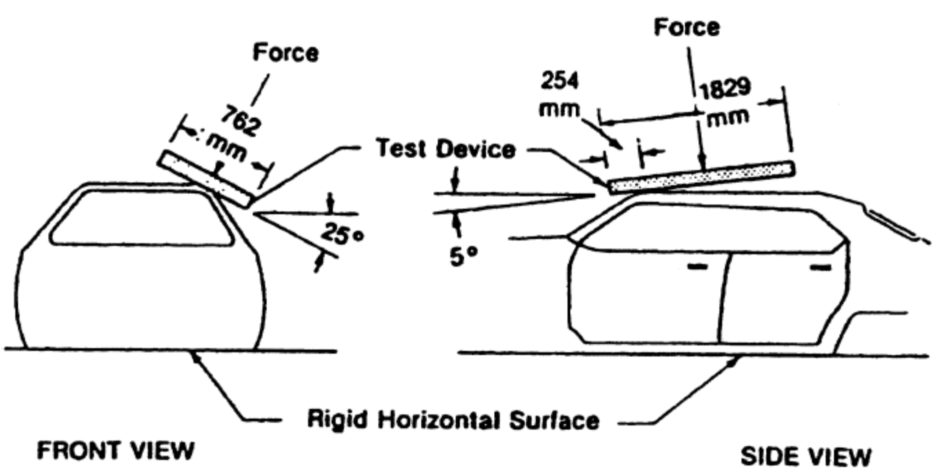


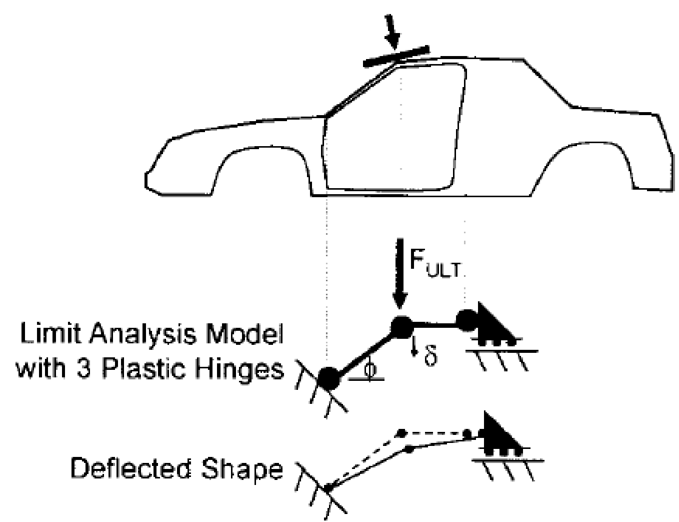
Preliminary Design

- 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

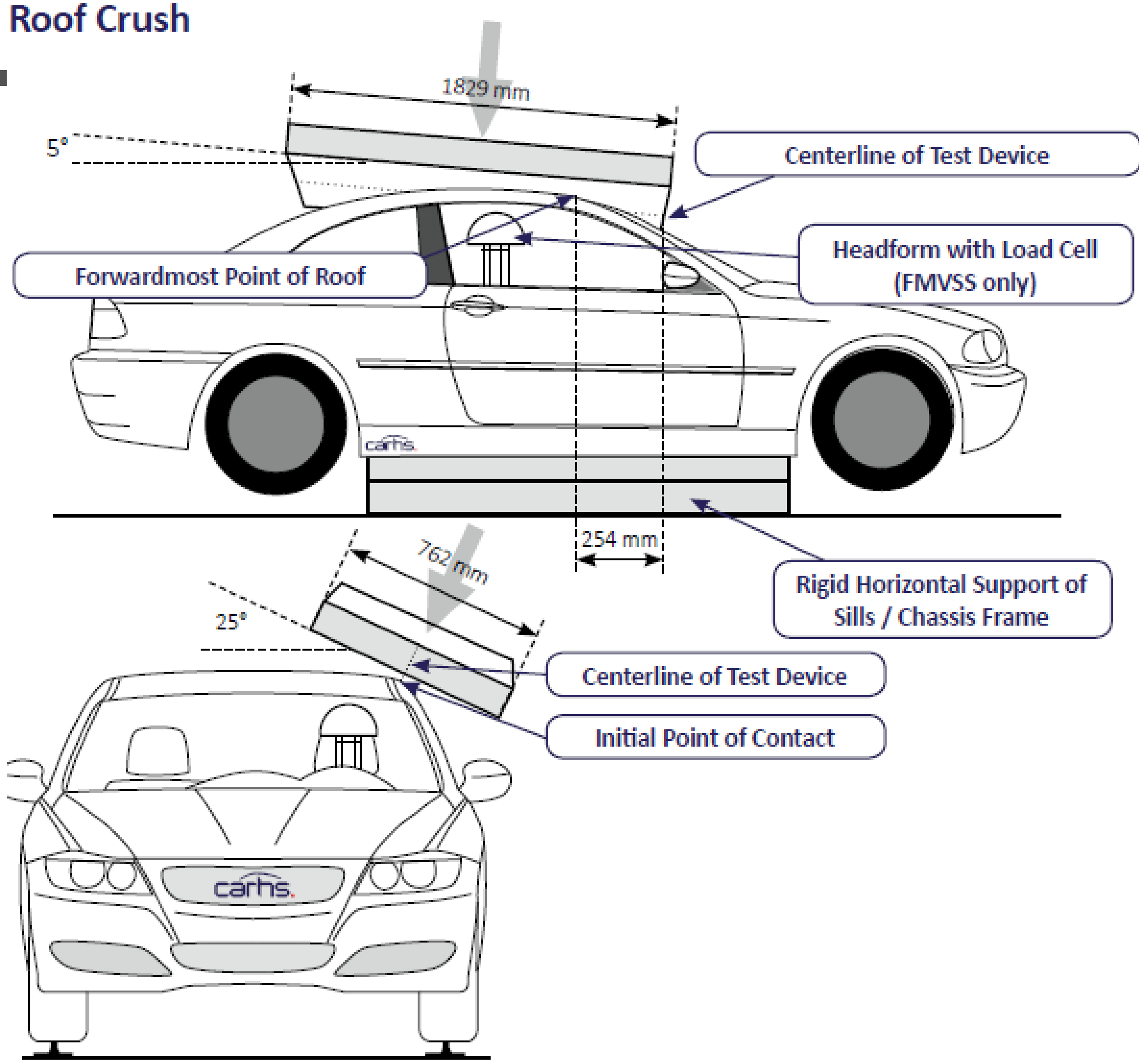
6.5 Roof Crush

- 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 x 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

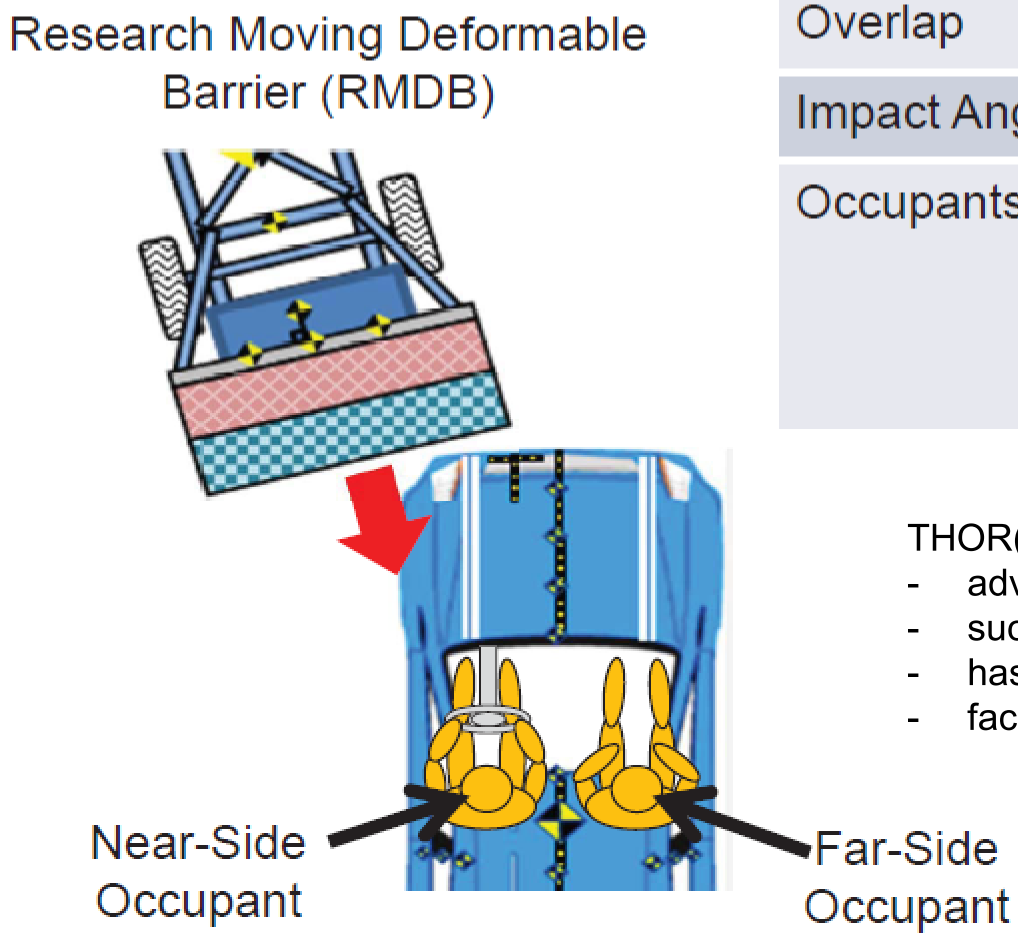
	Weight (kg)	Seating Height (cm)	Instruction for Calibration
Eurosid 1	72.0	90.4	Eurosid 1 Certification Procedure 96/27/EC, UN R95
ES-2	72.0	90.9	FTSS- User Manual / UN R95
ES-2 re	72.4	90.9	CFR 49 Part 572, Subpart U
US-SID	76.7	89.9	CFR 49 Part 572, Subpart F
US-SID/Sid-H3	77.2	89.9	CFR 49 Part 572, 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

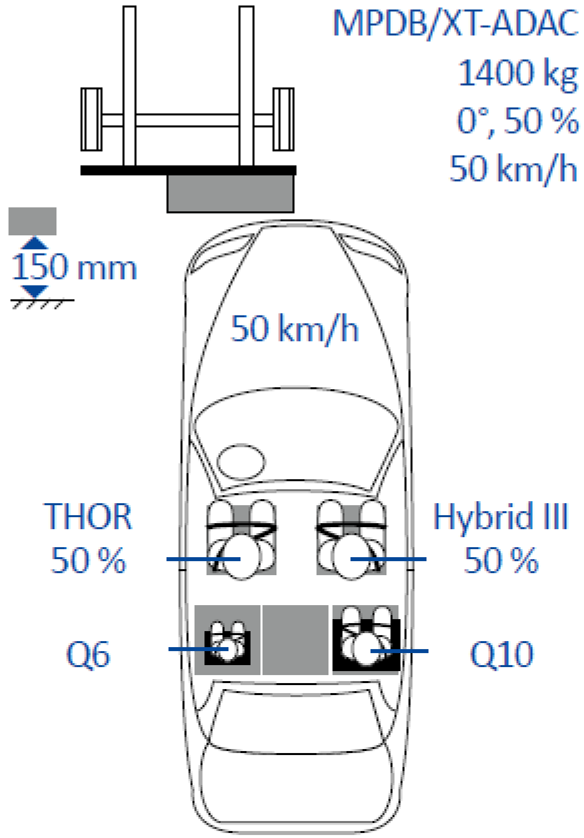
RMDB Speed	56 mph (90 kph)	
Overlap	35 percent	
Impact Angle	15 degrees (PDOF = 345)	
Occupants	Near-side (Driver)	THOR Mod Kit 50^{th} Male
	Far-side (Passenger)	THOR Mod Kit 50^{th} Male



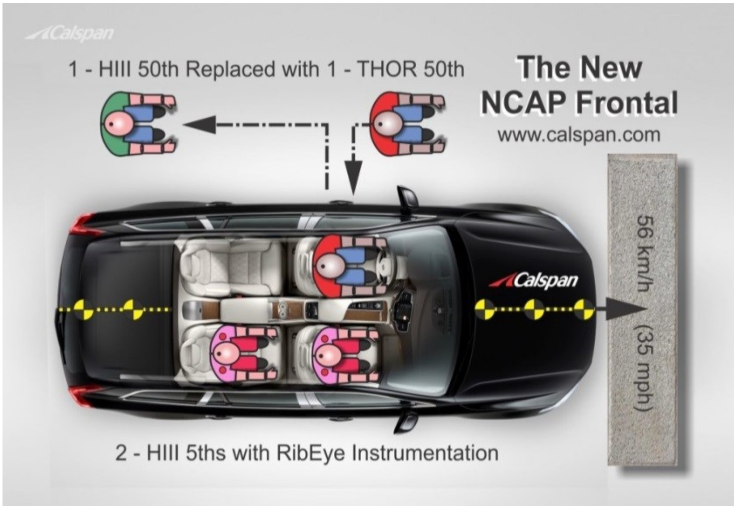
THOR(Test device for Human Occupant Restraint)

- advanced 50th percentile male dummy
- successor of Hybrid III
- has more human-like spine and pelvis
- face contains a number of sensors

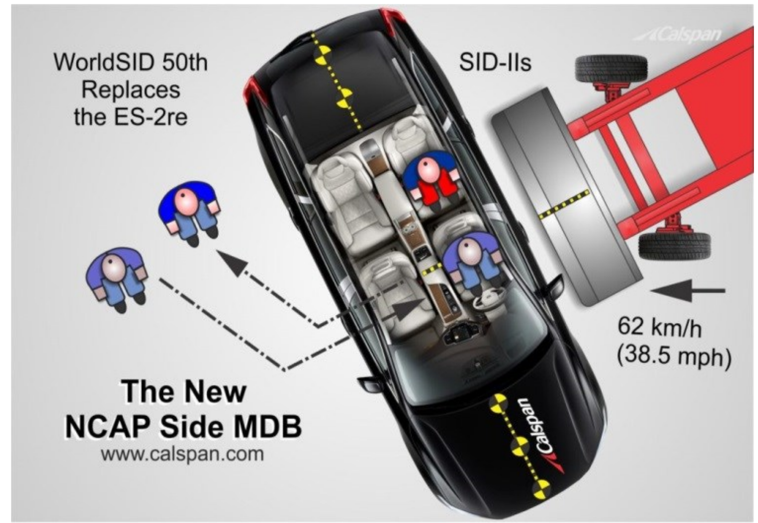
EURO NCAP: MPDB Frontal Impact (2020)



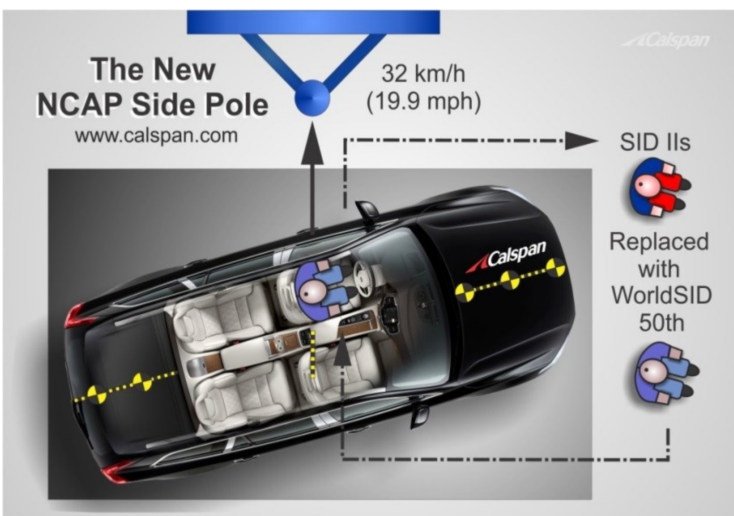
2019 NCAP



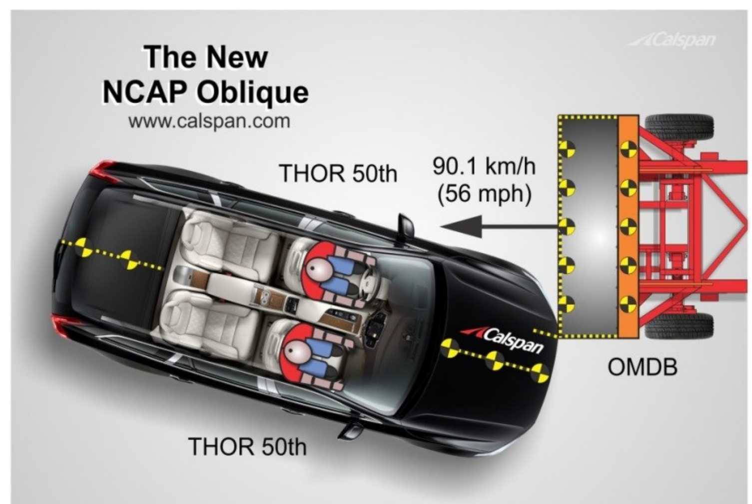
1 - HIII 50th Replaced with 1 - THOR 50th
The New
NCAP Frontal
www.calspan.com
56 km/h (35 mph)
2 - HIII 5ths with RibEye Instrumentation



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



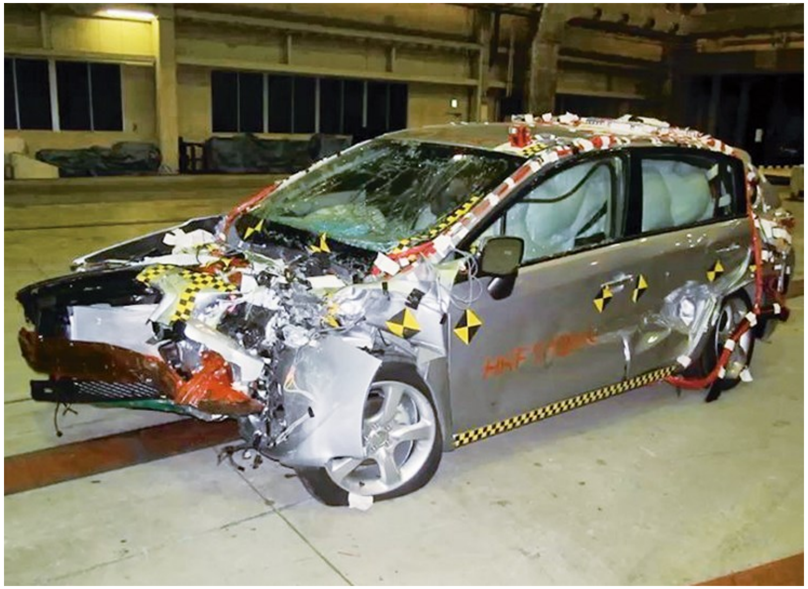
The New
NCAP Side Pole
www.calspan.com
32 km/h
(19.9 mph)
SID IIs
Replaced
with
WorldSID
50th



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

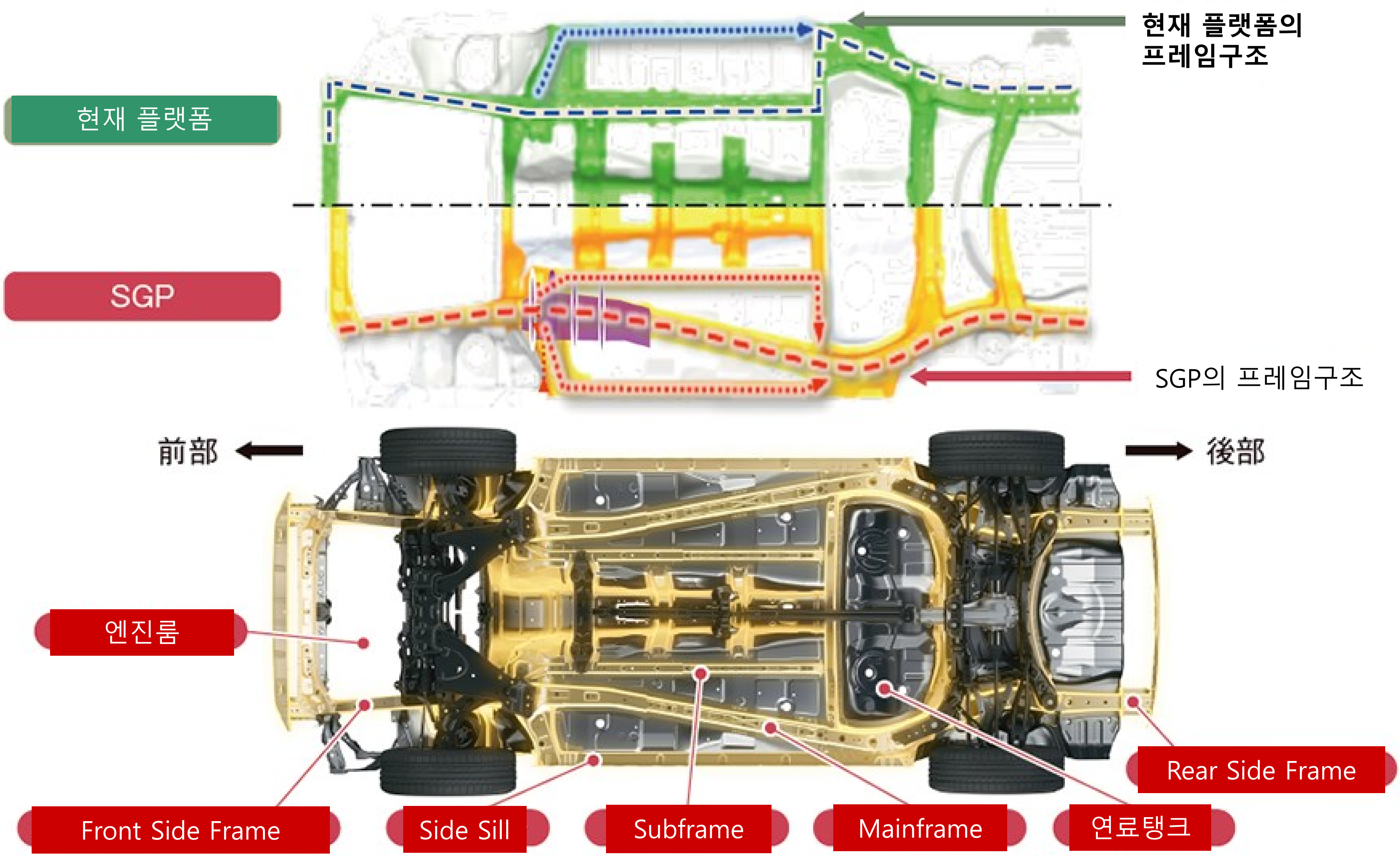


2.5 ton SUV

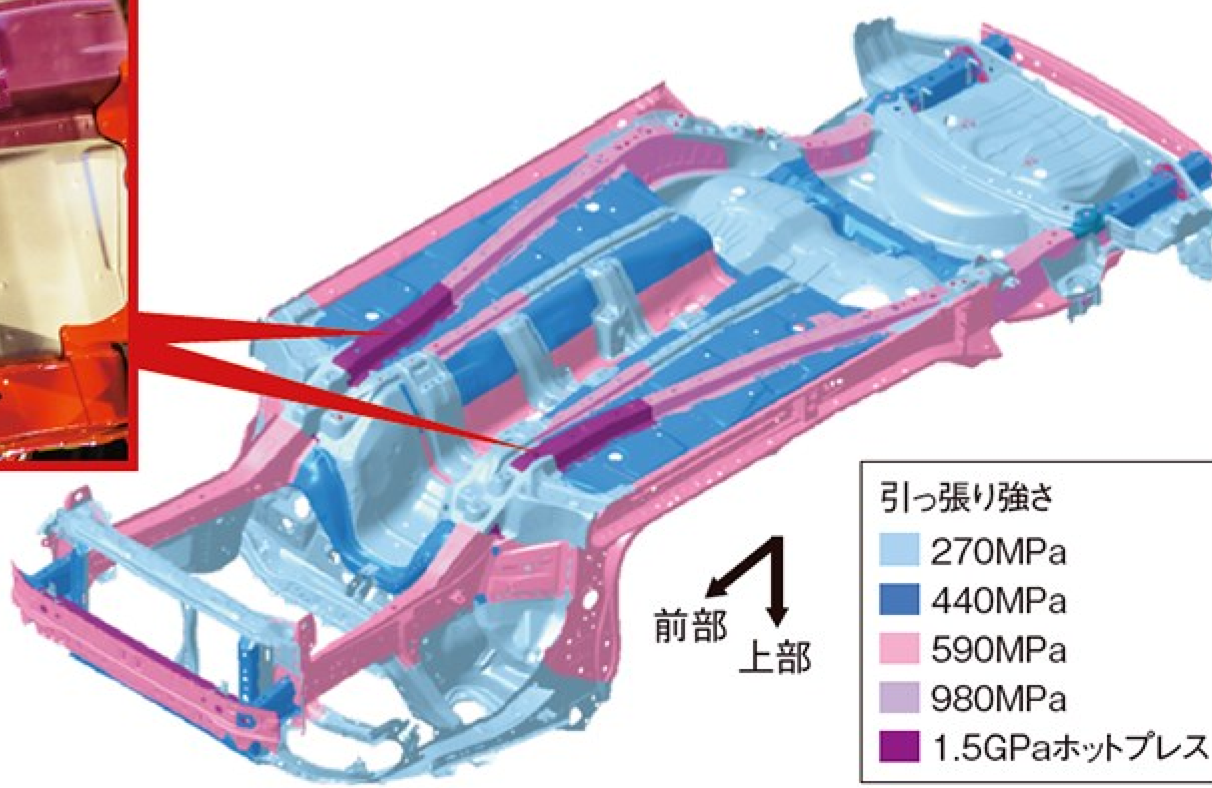
- 프레임구조 개선
- 프런트필러 관절부분의 강도 강화
- 프런트 벌크헤드 주변 결합 강화
  - 엔진룸과 캐빈 사이 격벽
- 플랫폼 전체 강도 강화

Nikkei Automotive 2016년 8월호

충돌 시 하중을 3방향으로 분산

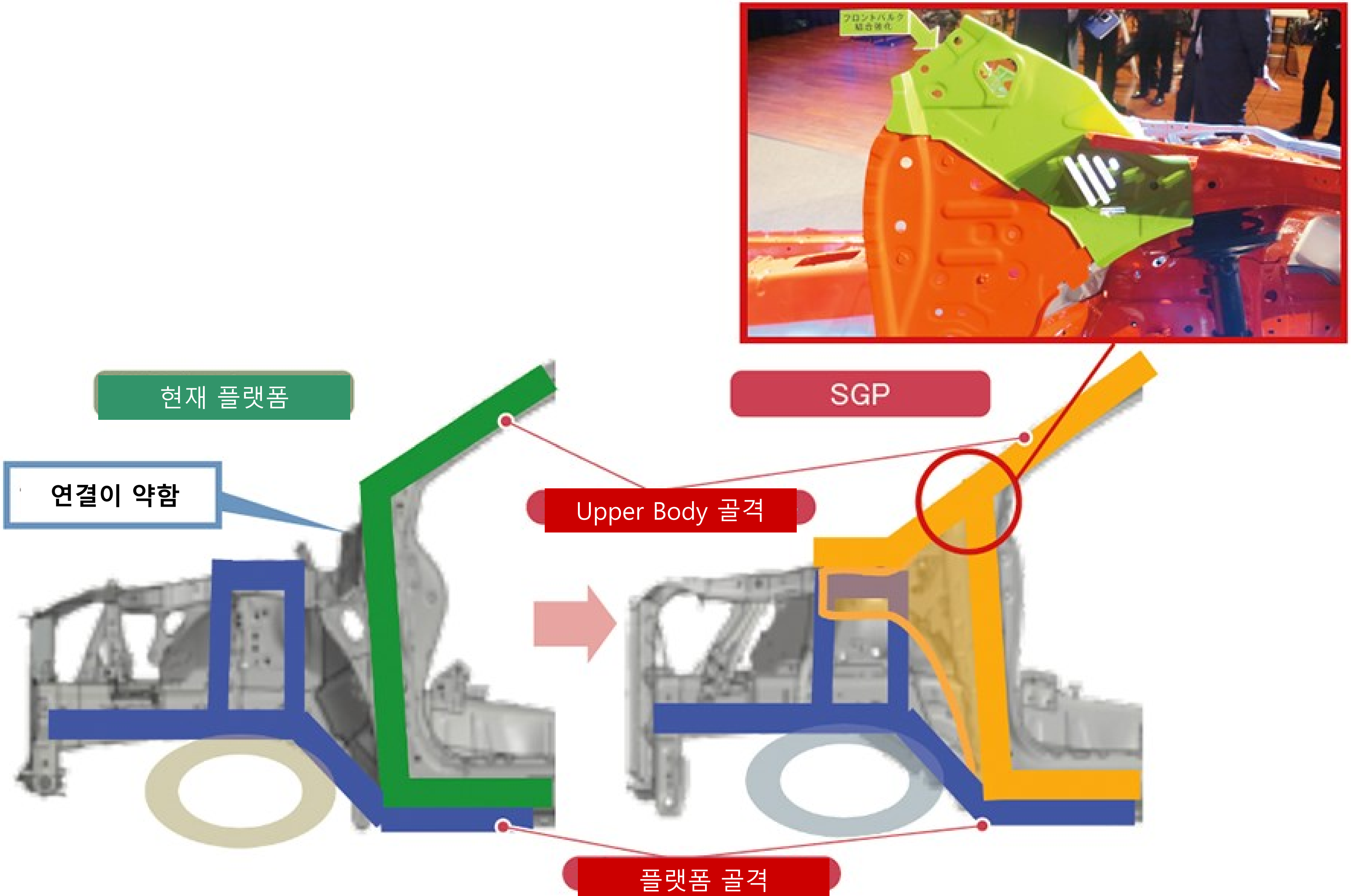


고장력 강판 사용비율 증가

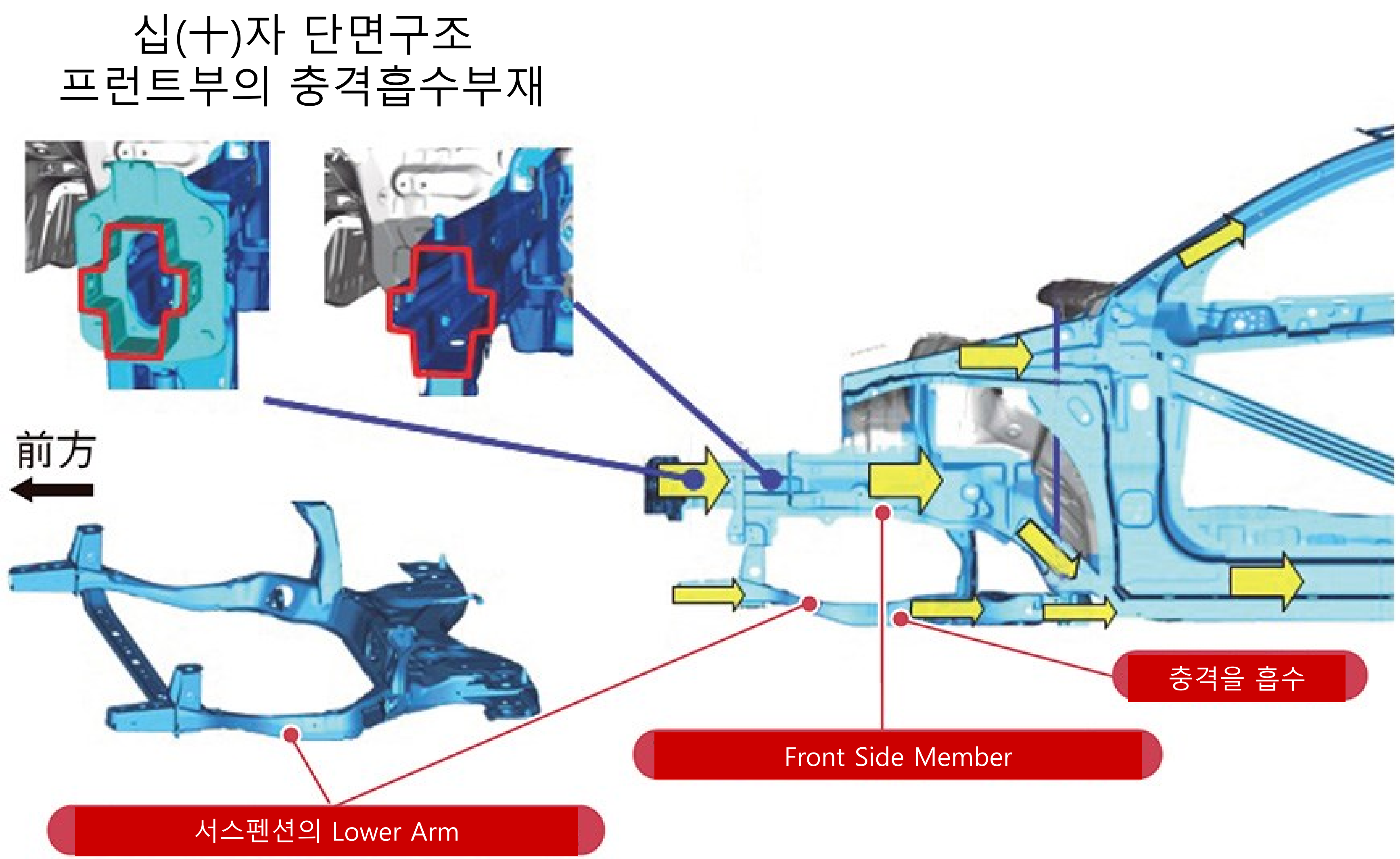


인강강도	이전 플랫폼	SGP
440MPa	11%	15%
590MPa	45%	40%
980MPa		1%
1.5GPa		7%
고장력 강판	56%	63%

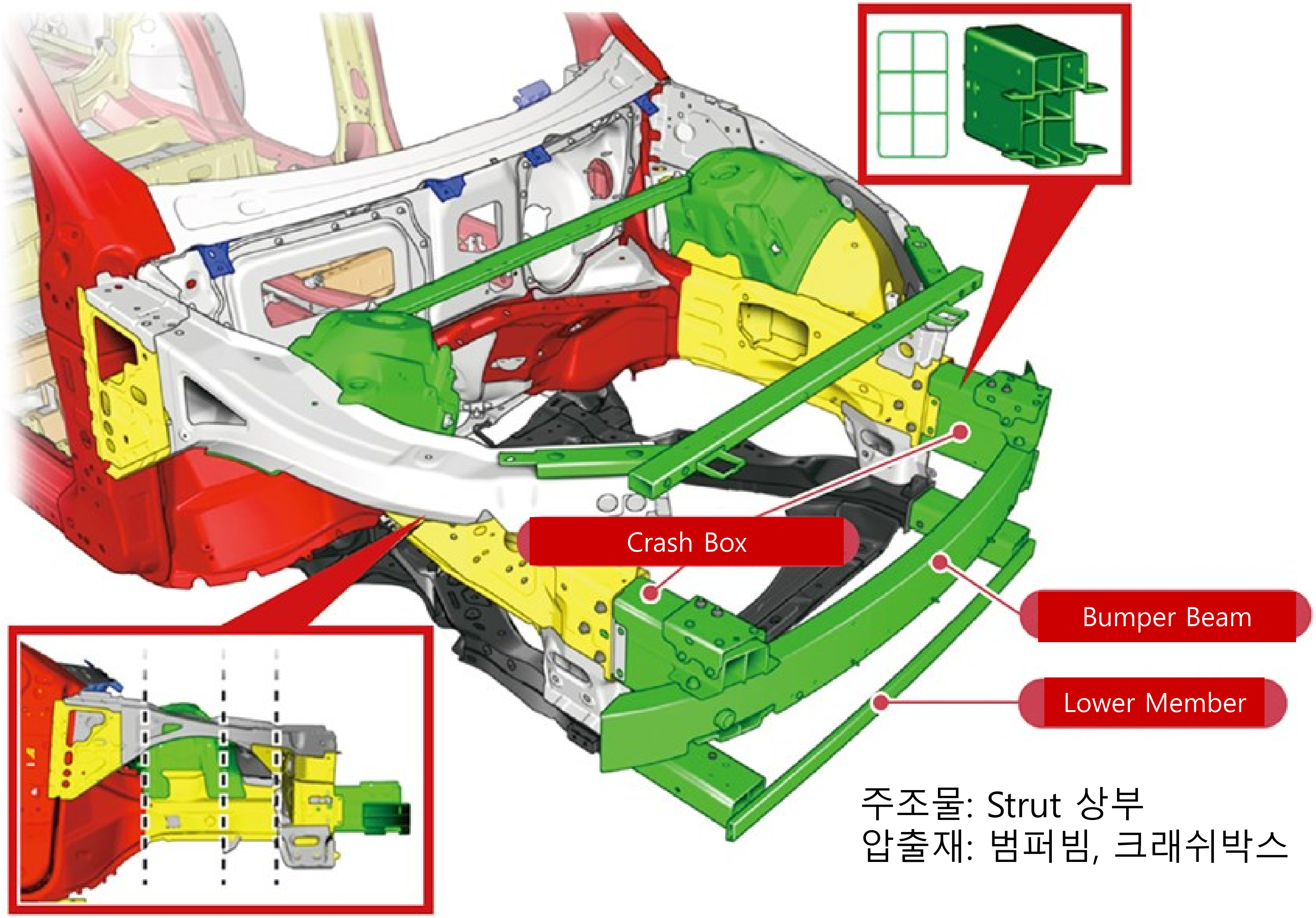
SGP와 Upper Body 골격을 Inner Panel로 결합



Mazda CX-3 에너지 흡수 구조



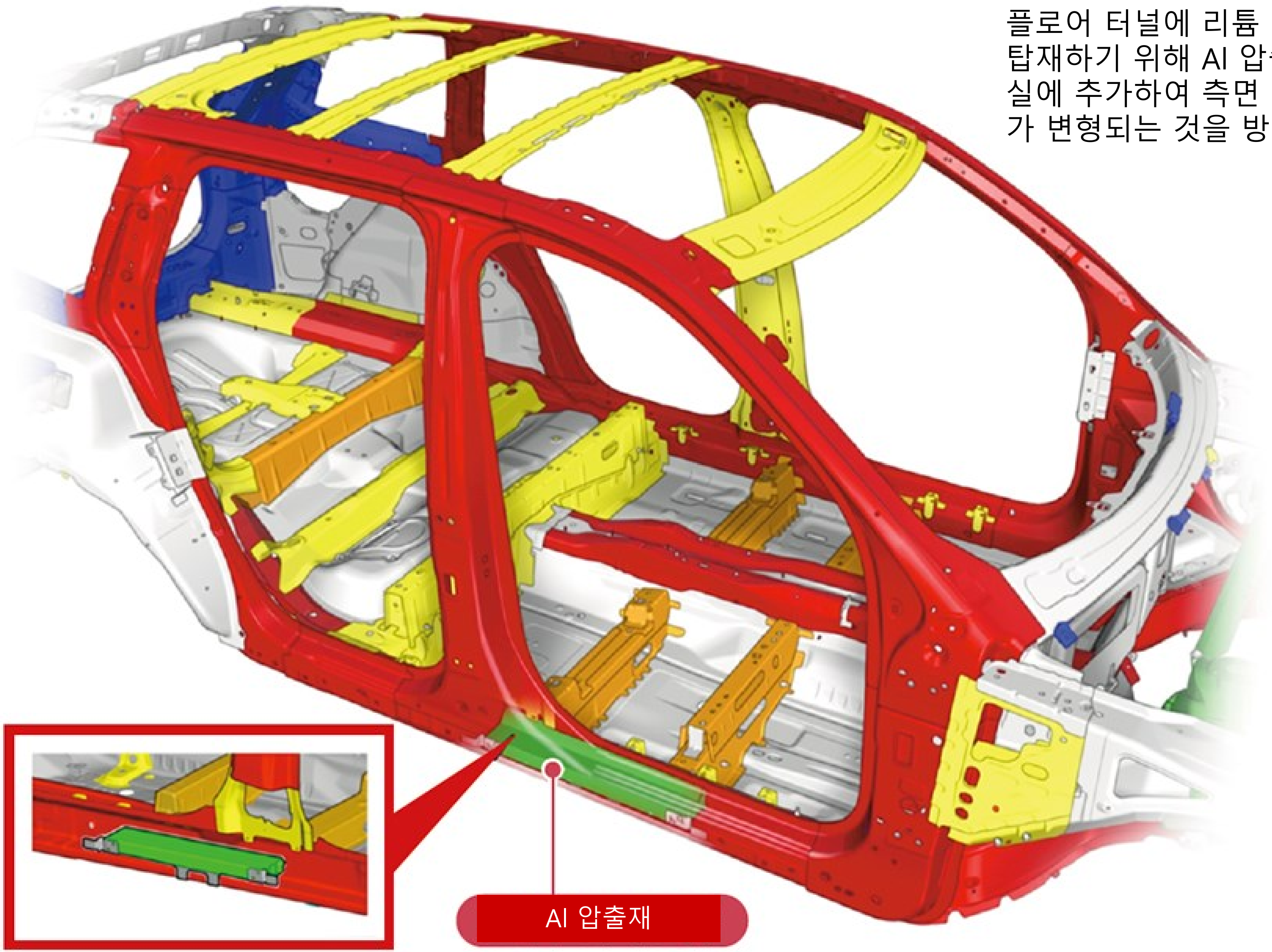
Volvo XC90 (Al합금 사용)



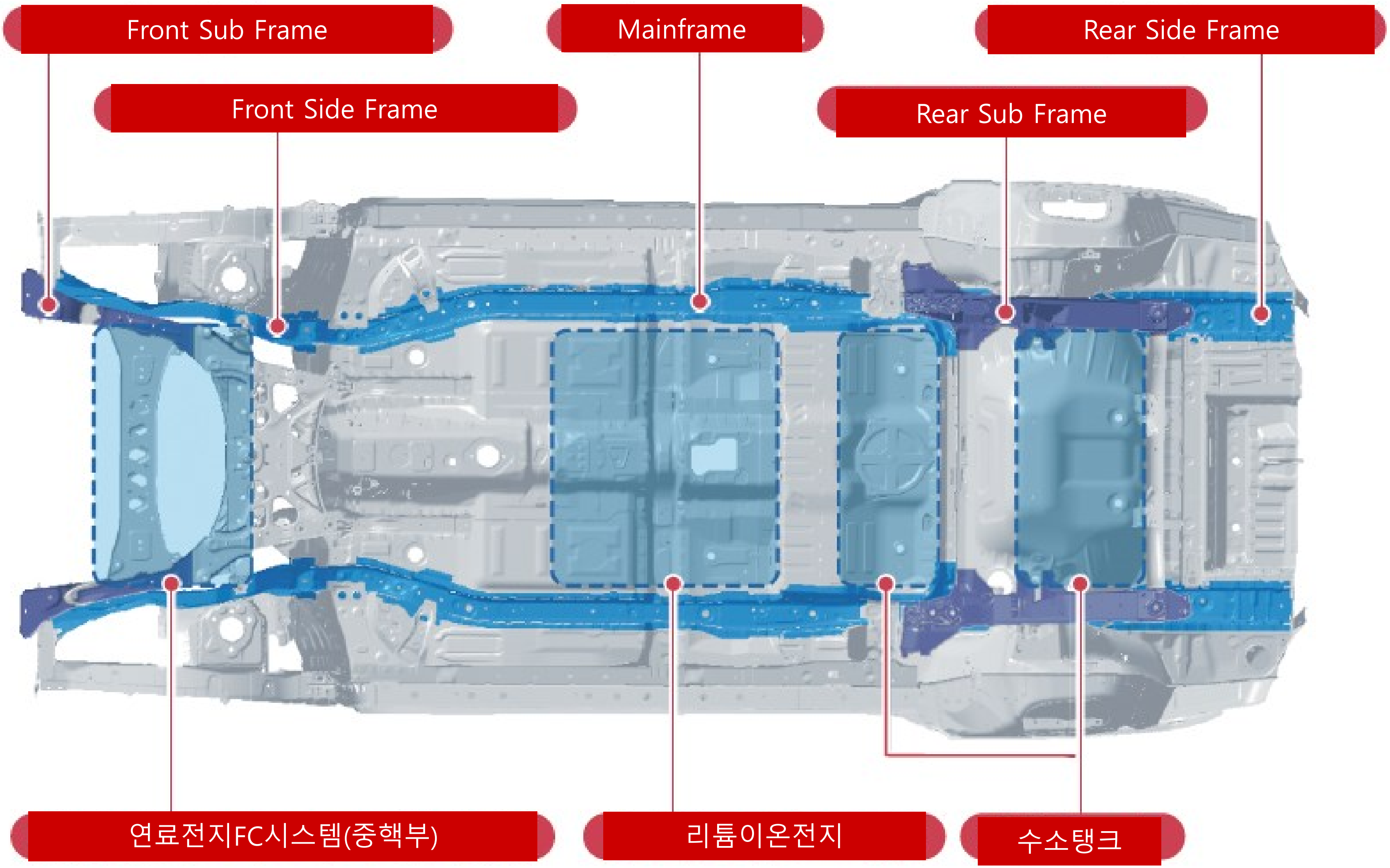
주조물: Strut 상부
압출재: 범퍼빔, 크래쉬박스

Nikkei Automotive 2016년 10월호

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



Honda FCV



Nikkei Automotive 2016년 6월호