San Diego CIREN Center

Rollover crash research:

Anatomy of a Rollover

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Today's Presenters

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Today's Presentation

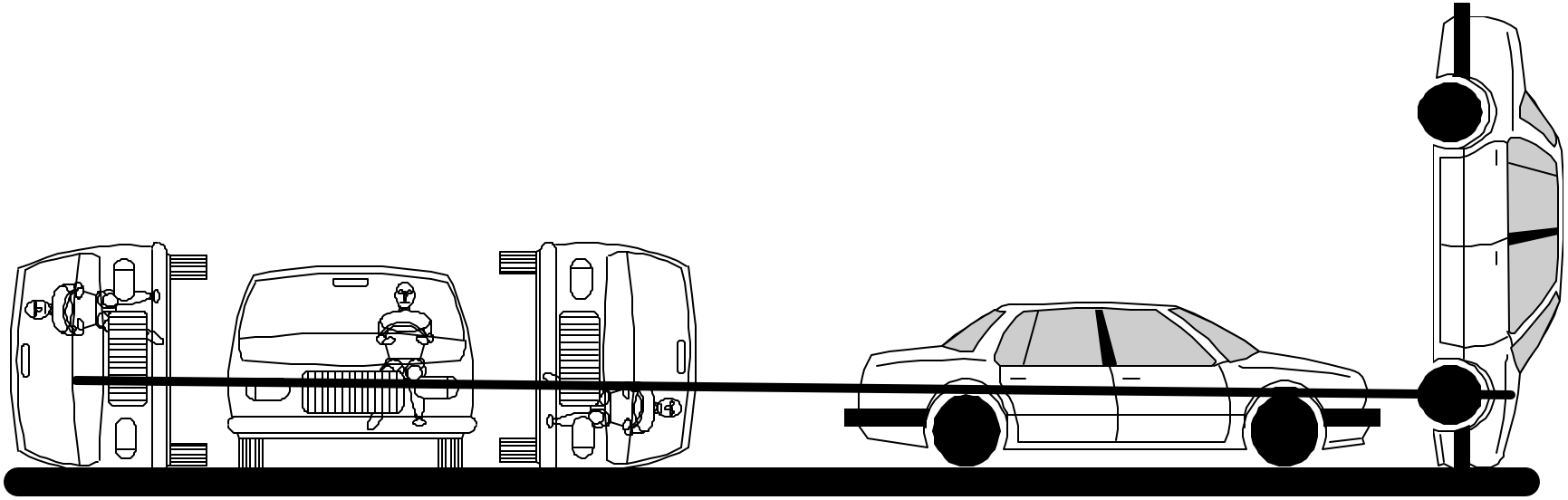
- Rollover Review
- Steering Maneuvers as Causation
- CIREN Rollover Frequency, Injury, & Source
- Roof Crush Dynamics
- San Diego Rollover Analysis

Rollovers

- Almost 215,000 passenger vehicles are in tow-away rollovers every year (CDS, NASS Data)
- Rate of serious injury is 36% higher than in collisions with no rollover
  - These rollover statistics include ejections
- 3-4% of all crashes are rollovers, but 20% of all fatal crashes involve rollovers
- About 2/3 of rollover deaths involve occupant ejection

What IS a “Rollover”?

At least one quarter over-turn (90-degrees) from the horizontal axis



CDS/NASS Rollover Initiation Types

- **Trip-over (lateral slide interuptus) 69.4%**
- **Collision with other vehicle and then rollover 14.5%**
- **Flip-over (up and back down same side) 7.0%**
- **Bounce-over (Rebound off object) 5.7%**
- **Climb-over (climb up and over) 1.1%**
- **Turn-over (lateral slide sway) 1.1%**
- **End-over-end (launch) 1.0%**
- **Fall-over (gravity) 0.9%**
- **Other initiation type 0.3%**

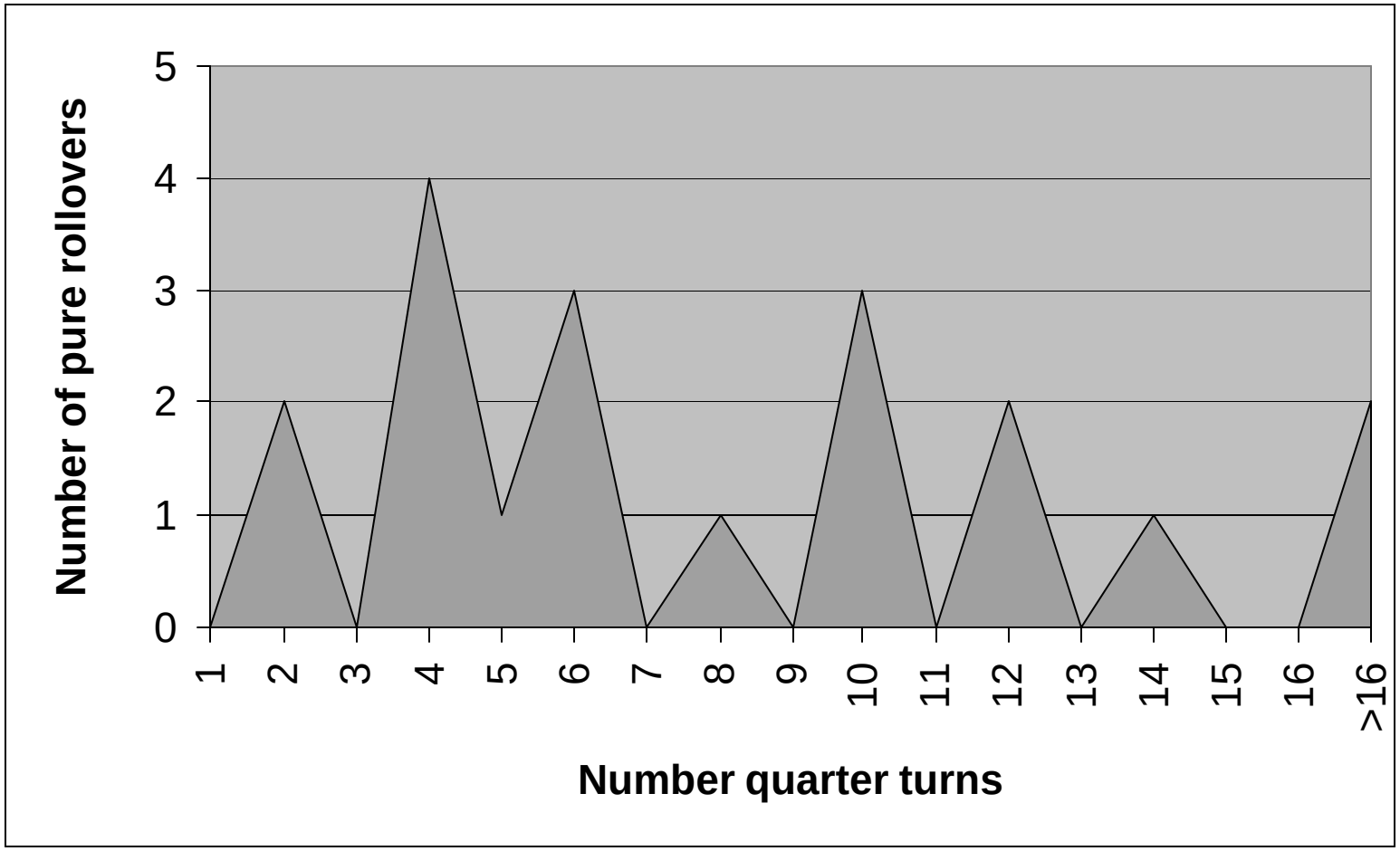
CIREN Statistics Used in this Presentation

- **Include “Pure” rollovers (27)**
  - **rollovers without another significant impact, prior or subsequent to roll**
- **Exclude**
  - **end over end rollovers**

Initiation for CIREN "Pure" Rollover Cases (denominator = 27)

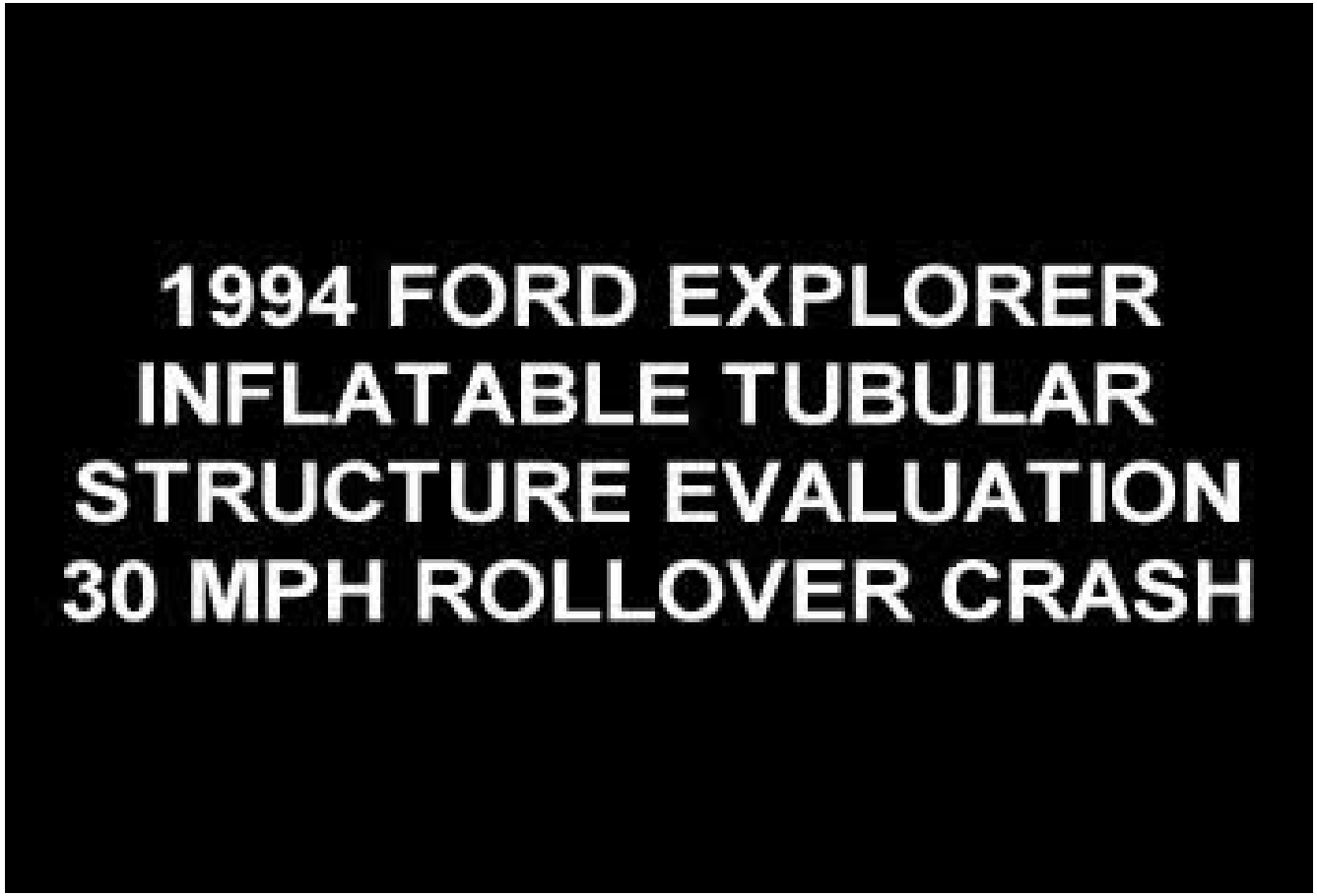
- 24 coded as trip-over (89%)
- 1 fall-over
- 1 flip-over
- 1 undetermined

Number of quarter turns for pure rollovers, CIREN



Rollover Tests
vs.
Real World Crashes

Sled & Test **(11 Quarter-turns)**



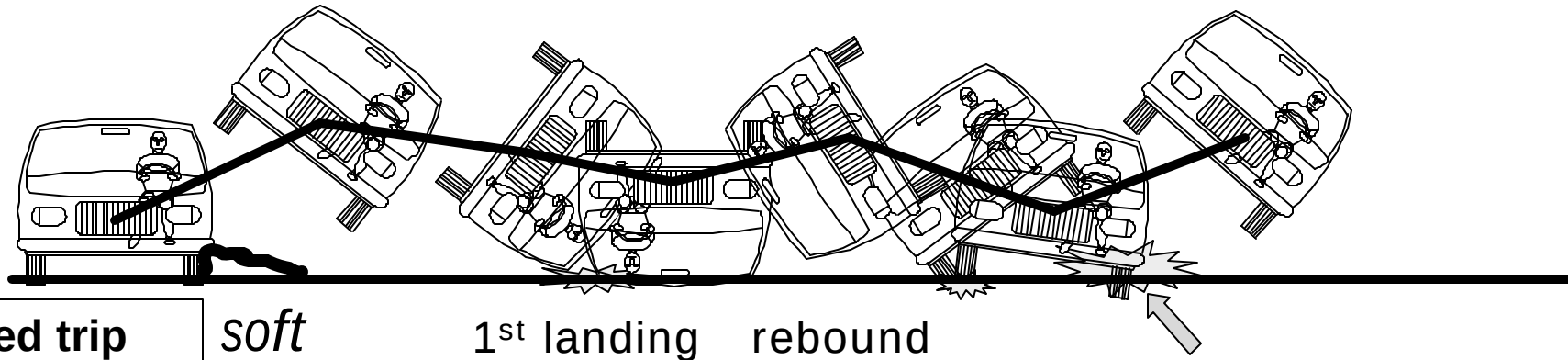
Same side roof rail landing

Rollover tests – tipping down a slope or launching from a tilted platform

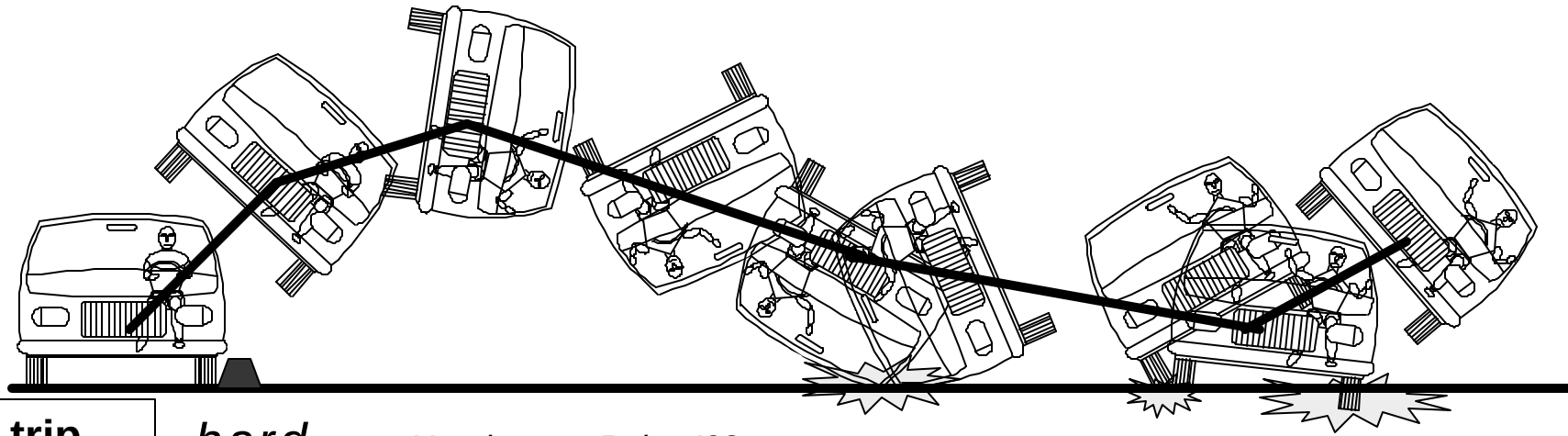
Sawtooth motion of vehicle CG in ‘lateral’ roll

- In most cases, the rebound speed reaches that of the impact speed.

- The largest change in vertical velocity occurs when the underside of the vehicle is in contact with the ground, at the start and at the end of a full roll.



Prolonged trip *soft* 1st landing rebound largest change



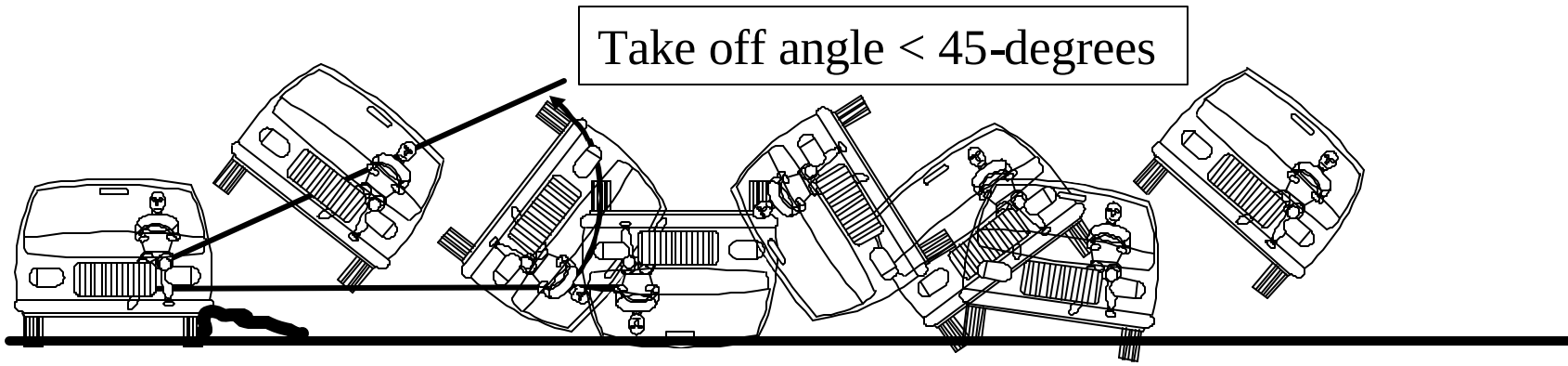
Abrupt trip *hard*

Henderson, Paine ’98

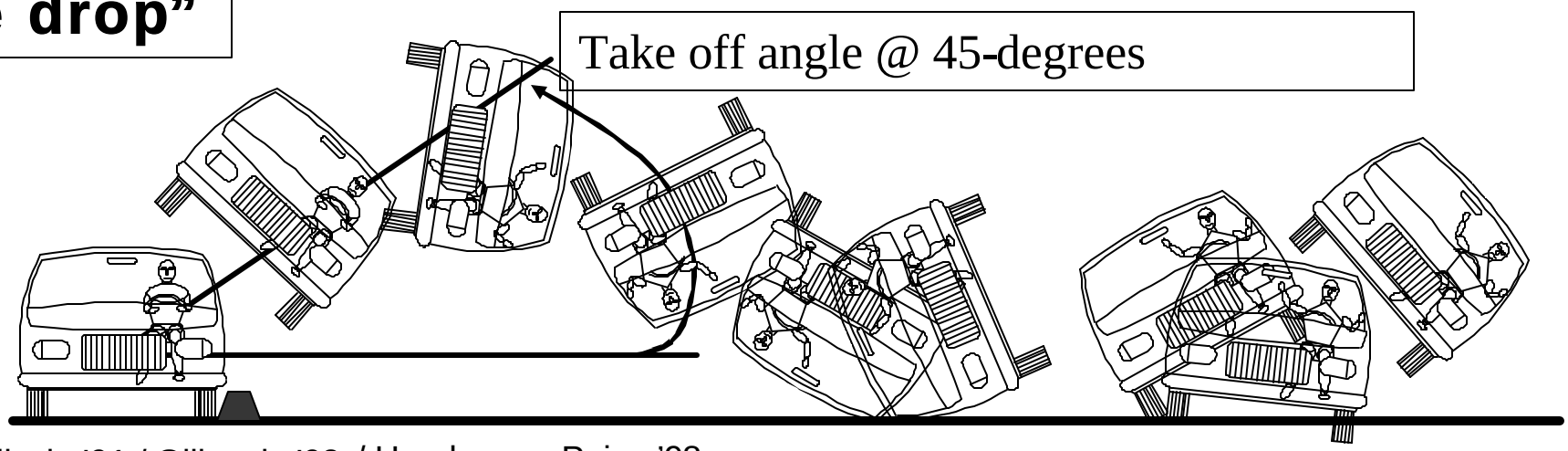
Post trip, typical horizontal velocity = 11m/s (40kmph) @ trip (pass. car)

The "skipping stone"

Average roll rates:
Single roll = 2.3 sec's, double roll = 1.5 per rev.
Multiple (3+) = 1.1 per rev.
Average for 1 or more = 1.7 sec's



"The drop"



Diggs&Klisch, '91 / Gillespie,'92 / Henderson, Paine '98

Pre-Crash: Over-correction steering

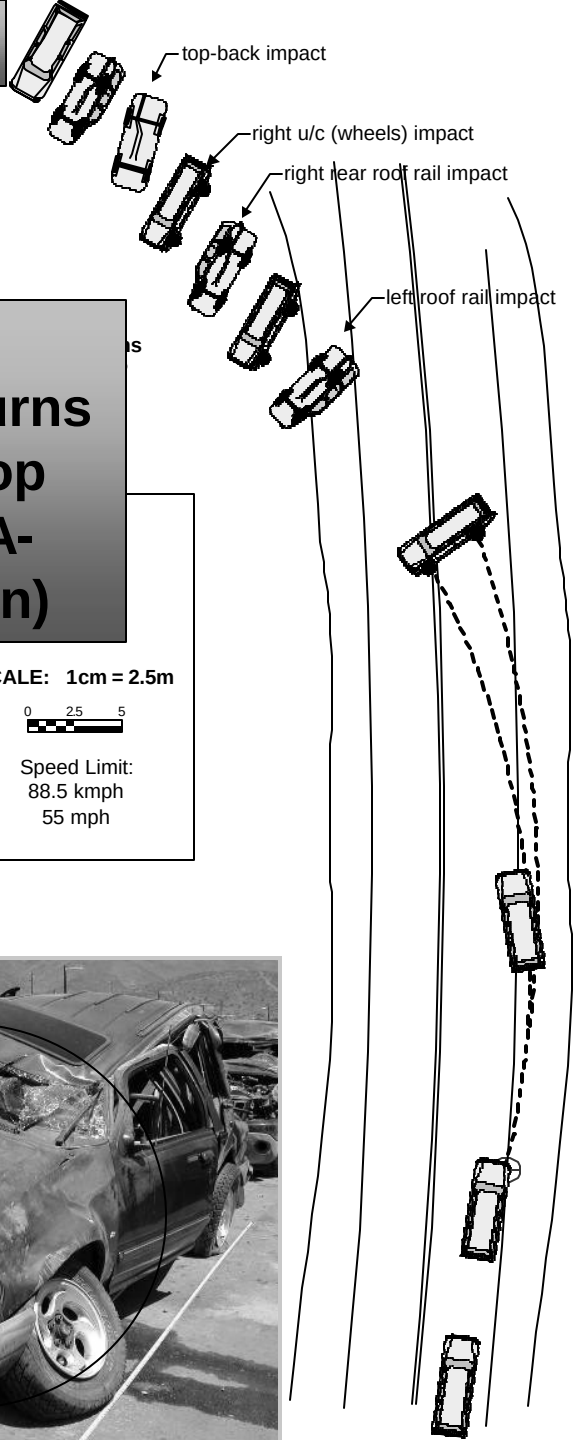
- 9 out of 27 “pure” CIREN R/O’s were a result of over-correction steering

- Most common reason is a single over-steering correction

- 2nd most common is double over-correction steering (i.e., re-turn to roadway, exit opposite side, lane..etc).

- Over-correction yaw off of the roadway is achieved much easier than on the roadway due to the coefficient of friction

Single Overcorrection steering



Trip Right
12 quarter-turns
1st landing top left front (+ A-pillar junction)

SCALE: 1cm = 2.5m

0 25 5

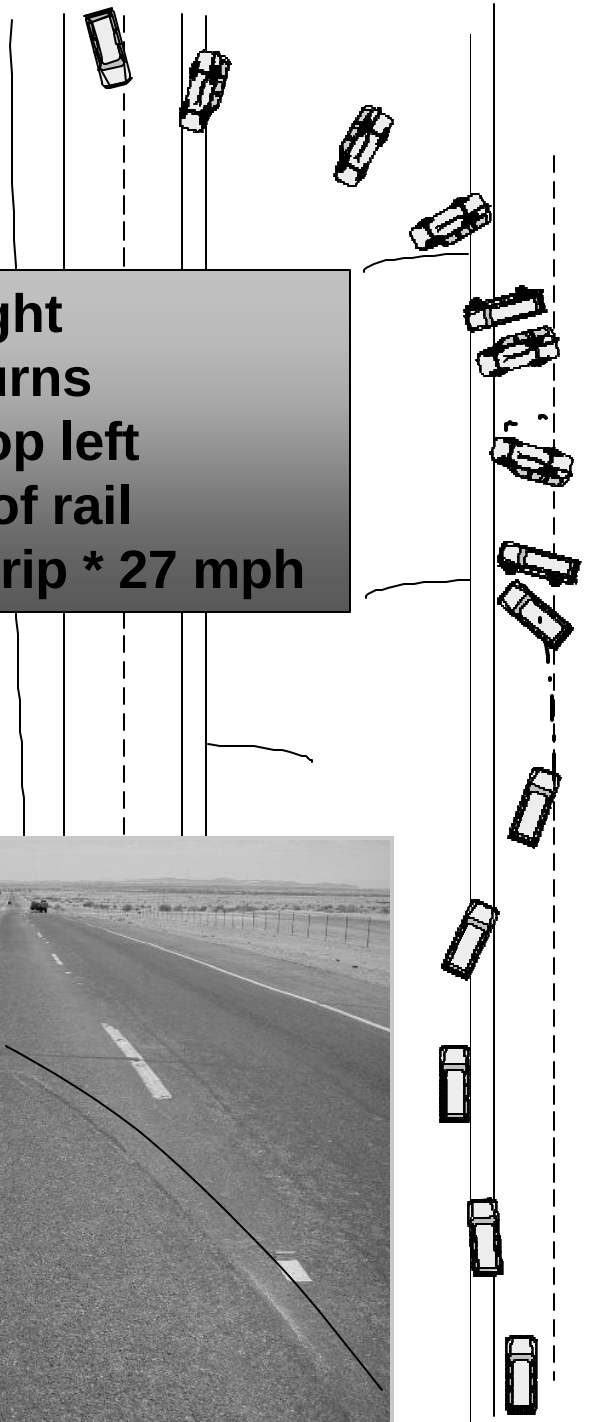
Speed Limit:
88.5 kmph
55 mph

35 cm M/C… 1st landing @ left A, W/S header

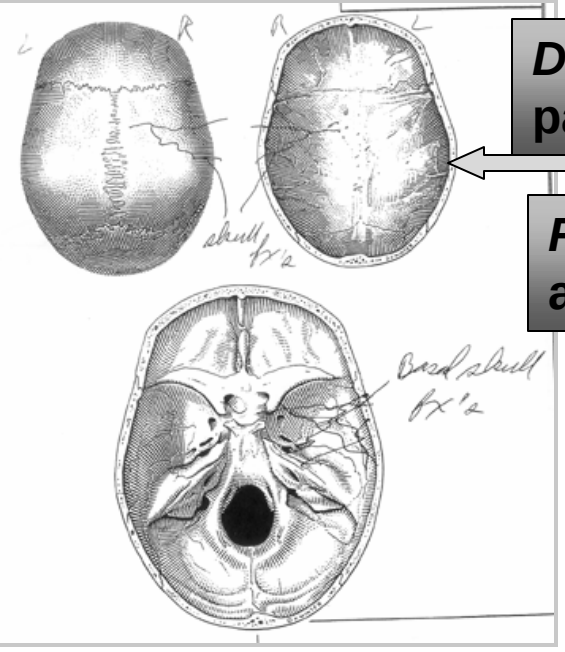
Right rib fractures 7-11 with small nneumothorax

Double overcorrection steering

Trip-over, right
16 quarter-turns
1st landing top left
A-pillar & roof rail
Velocity @ Trip * 27 mph



Max. greenhouse crush 35cms laterally



Driver **- Open right parietal skull fracture**

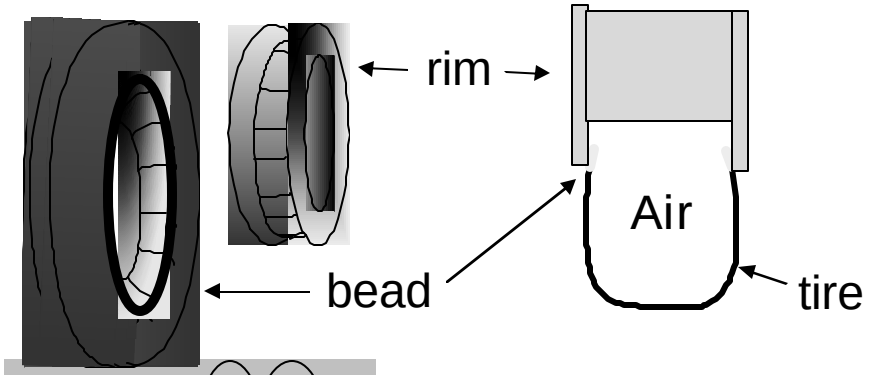
RF passenger **- Right frontotemporal EDH and temporal skull fracture**

De-Beading

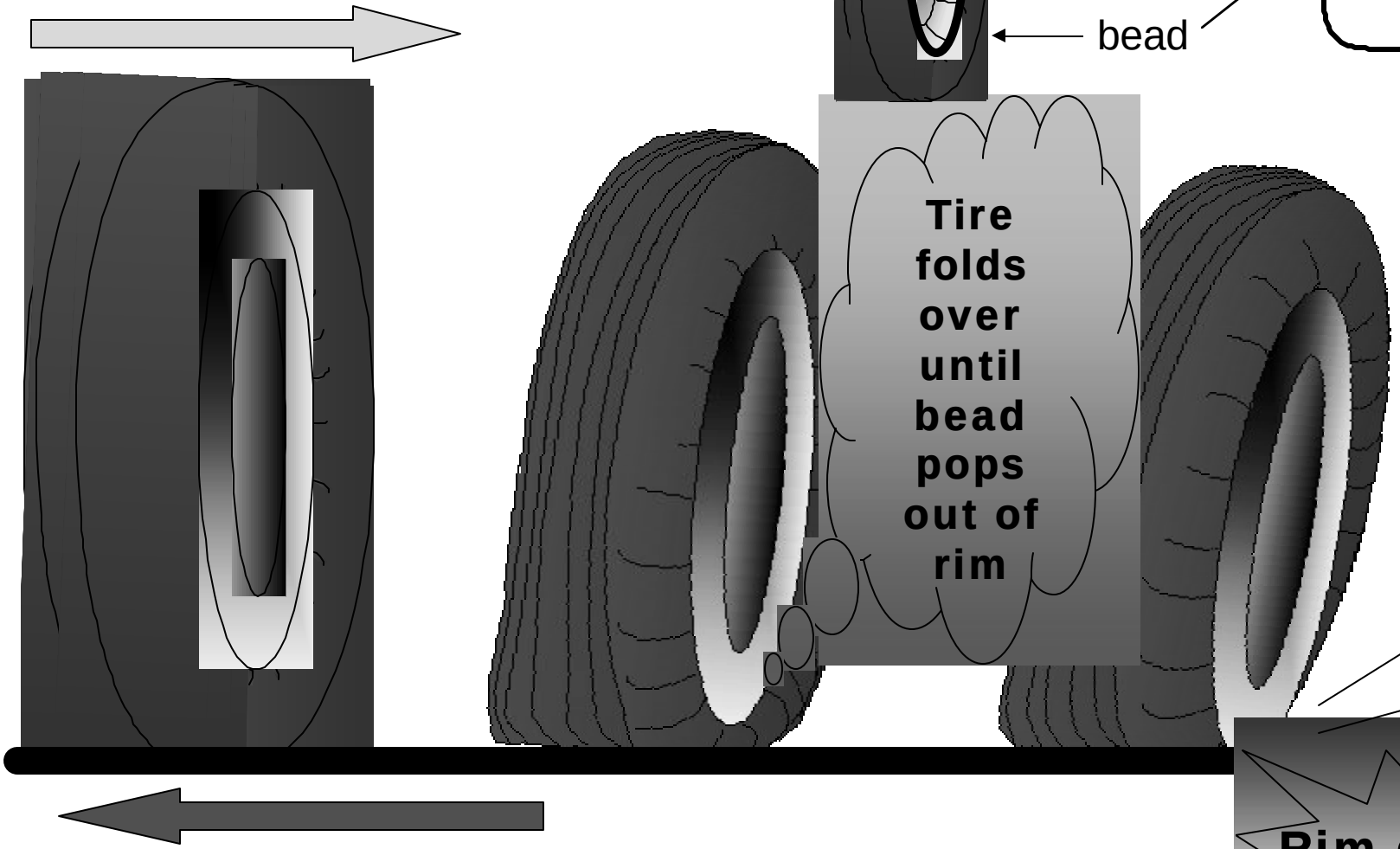
Of the 24 Trip-overs:

- 18 suspected of tire de-beading as a factor
- 7 not suspected as a factor
- 2 unknown

‘Bead’; Steel cord molded into lip(s) of tire fits into rim, makes seal when inflated



Direction of lateral slide



Resistance due to friction

‘De-beading’

Rim gouges surface

Over-steering Questions

- Will Electronic Stability Control Systems help mitigate rollovers due to over-steering?

  (none of the these CIREN R/O's had ESC)

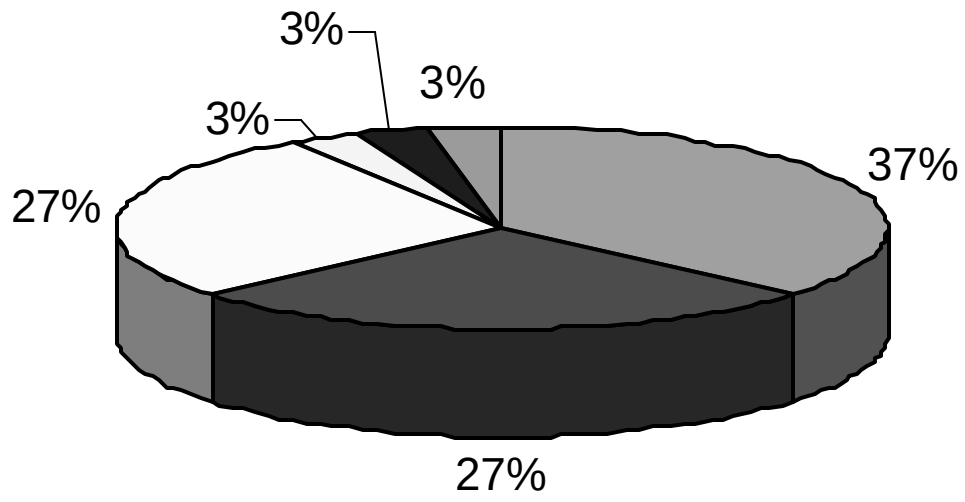
- Can de-beading be mitigated with better wheel design?

- Will Public Education help?

Real World Experiences Using CIREN Cases

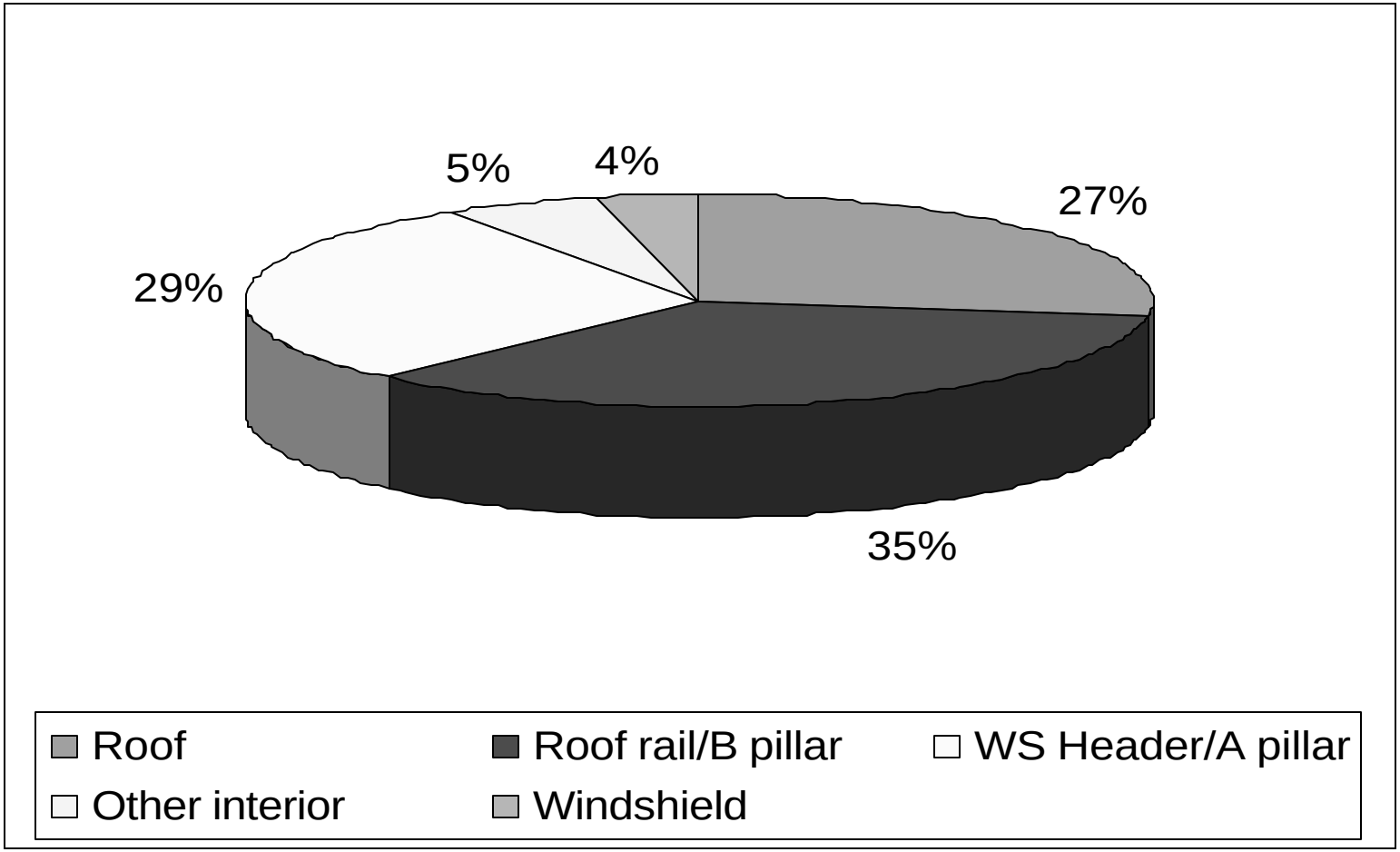
- CIREN Injuries, Sources, Intrusions in “Pure” Rollover Cases

Injured Body Region for Pure Rollovers, CIREN

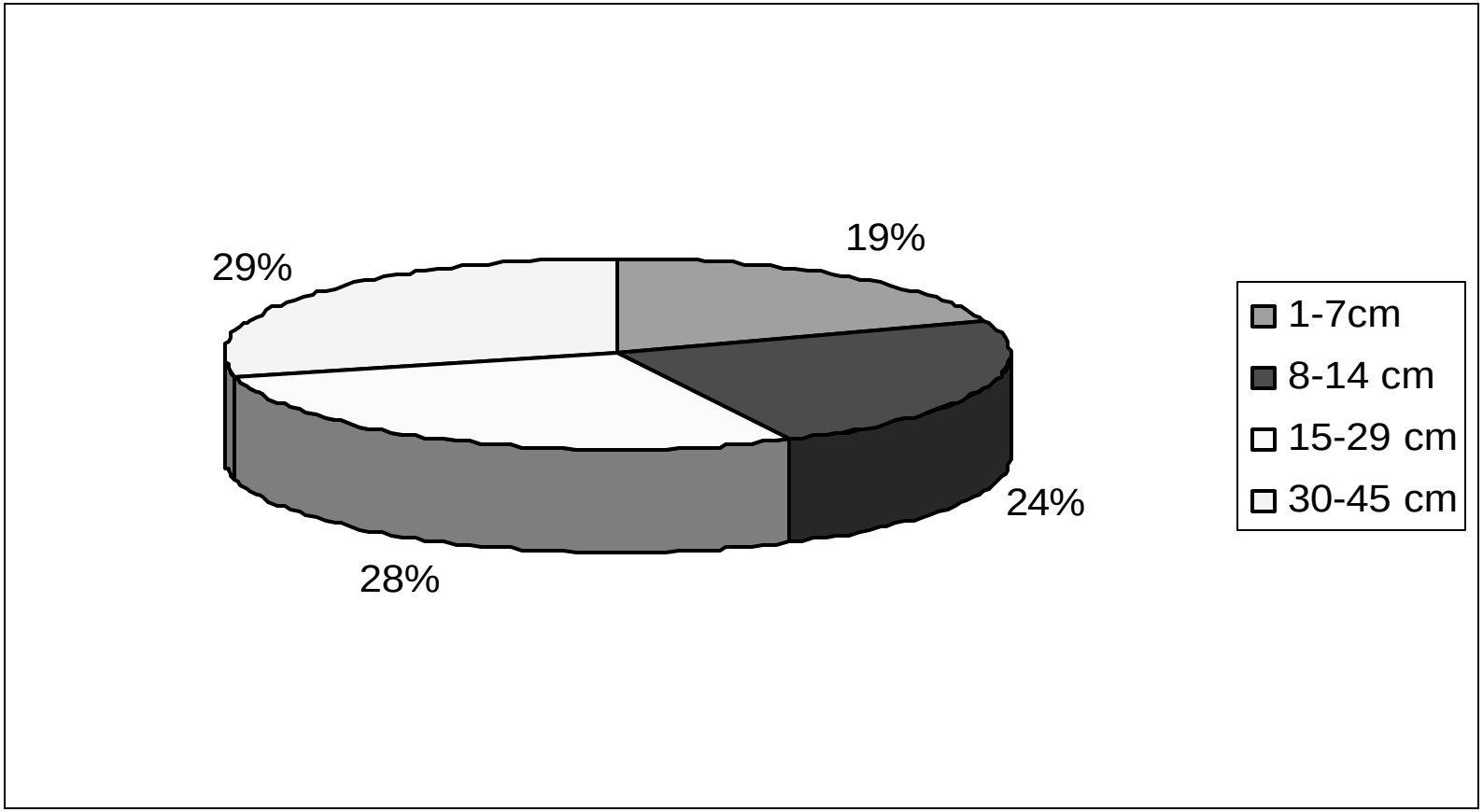


No face or lower extremity injury >AIS 2

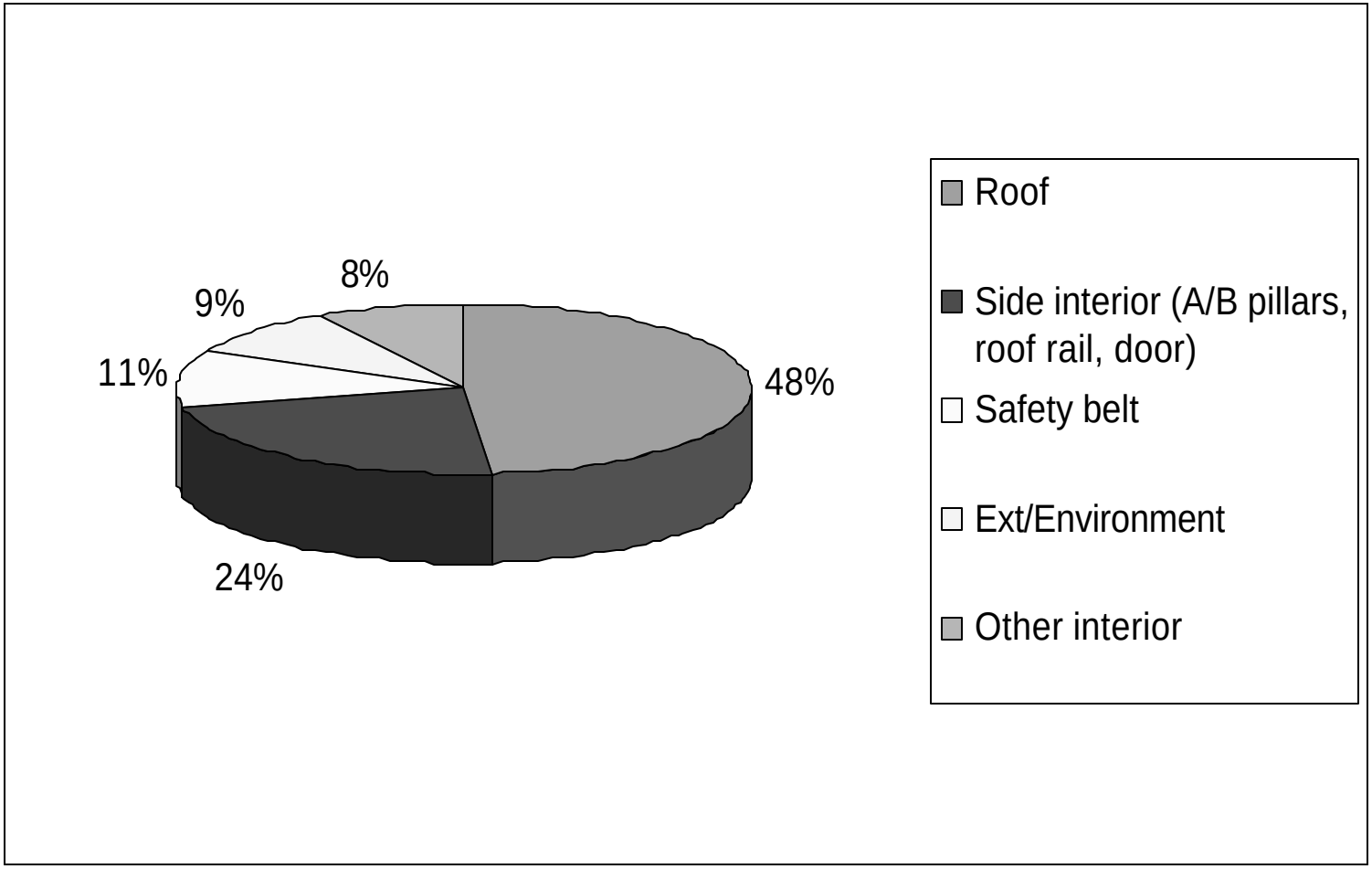
Intruding Components for Pure Rollovers, CIREN



Magnitude of Intrusion for Pure Rollovers, CIREN



Injury Sources for Pure Rollovers, CIREN



Kinematics

Left lateral roll – sled test

What about Roof Crush??

- Two Schools of Thought
  - Roof crush directly related to injuries (FMVSS 216 should be strengthened)
  - Roof crush is not causally linked to injuries – rather it is dependent on kinematics

NO SIGNIFICANT HEAD INJURY: Left rib fractures 7 -10 @ costotransverse junction, Splenic laceration, Grade 3

- Driver - 24 y/o male
- Lap & shoulder belt
  - (no pre-10, not integrated)
- Left Trip-over
- 10 ¼-turn
- 1999 Ford Ranger XLT
- 40 cm M/C @ left roof
- 2 greenhouse impacts

NO SIGNIFICANT HEAD INJURY: Left forehead abrasions
Left proximal humerus fracture

- RF passenger, 25 yo female
- Lap/shoulder belt used
  - (no pretensioner, not integrated)
- Right Roll
- 8 quarter-turn fall-over
- 1999 Chevrolet S-10 pick-up
- 50 cm max crush
- 2 greenhouse impacts

Roof Crush + Rollover Dynamics

- **Lateral (predominately) overturning**

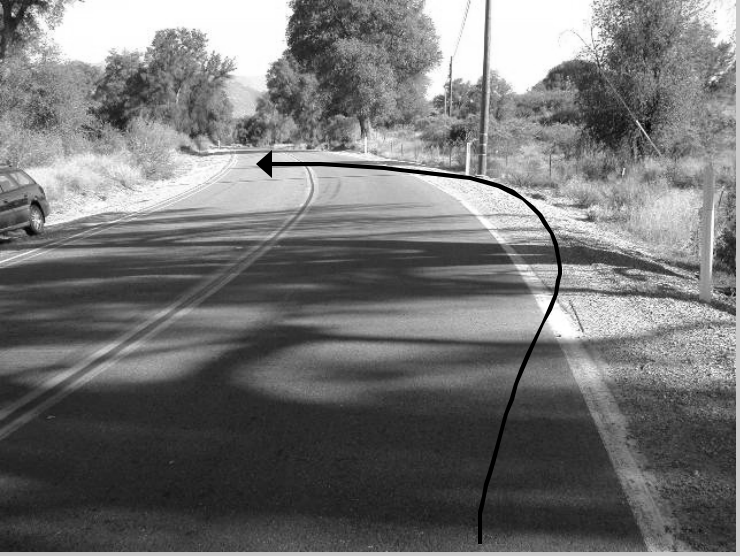
  (roof rail to roof rail, roof crush less likely)

- **‘Corkscrew’ overturning**

  (with a forward momentum, roof crush more pervasive due to A-pillar involvement)

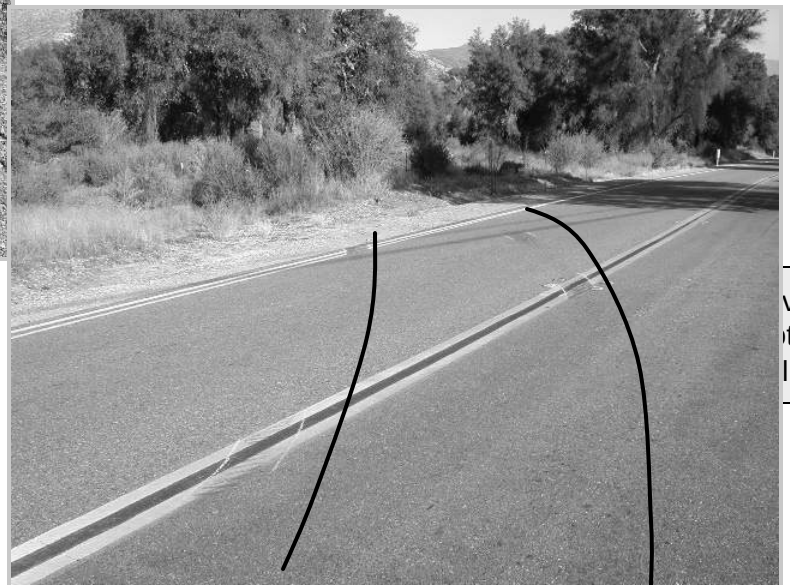
- **Launch/Vault**

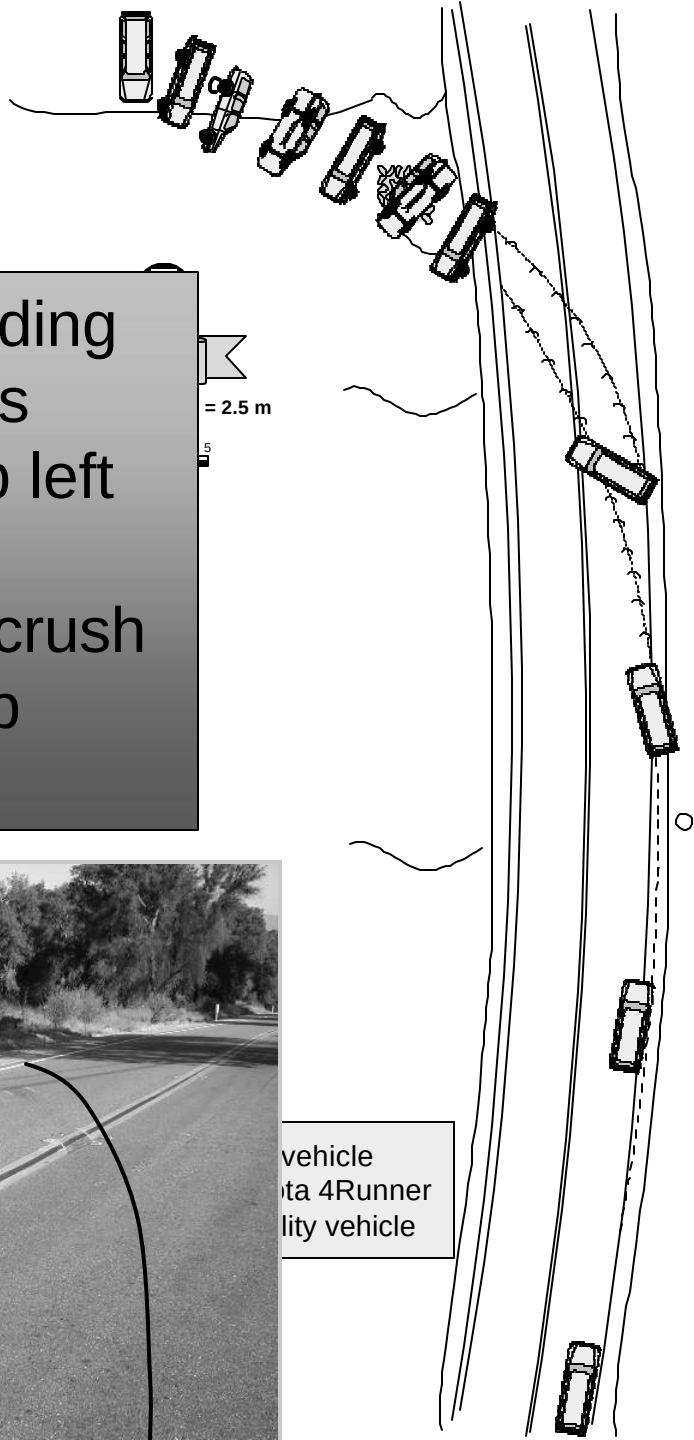
  (freefall, roof strength critical)



Trip-over **(lateral)**

Right side leading
8 quarter-turns
1st landing top left roof rail
12 cms max. crush
Velocity @ trip 21mph



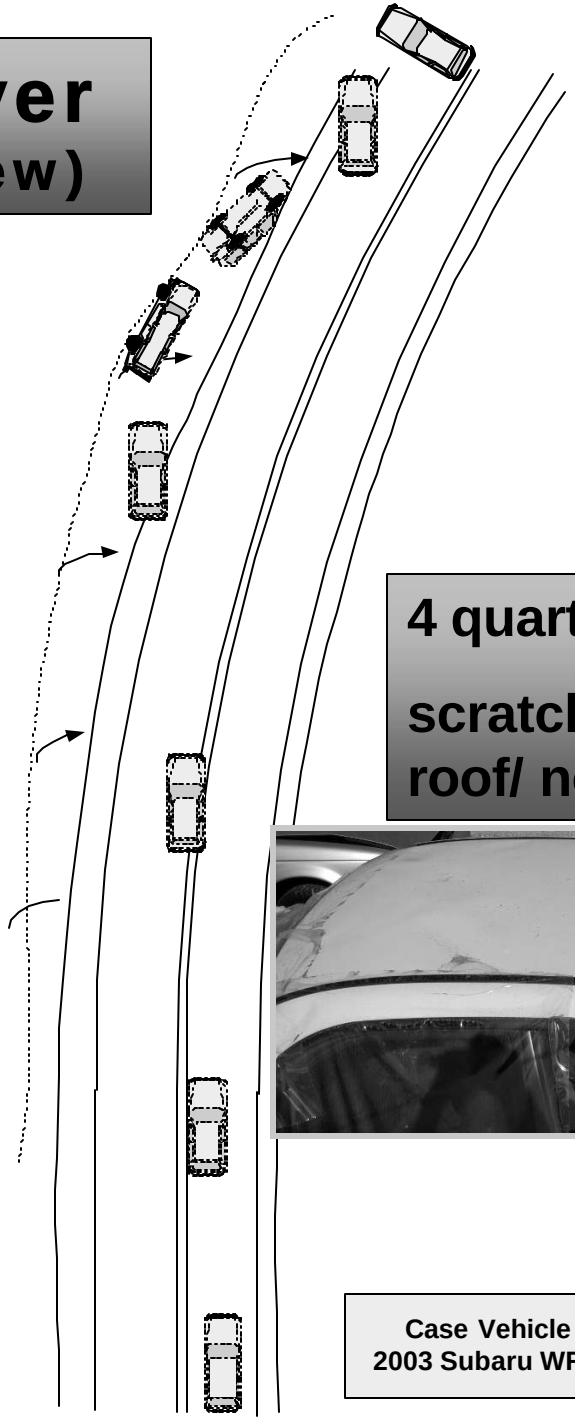


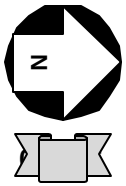
vehicle
ta 4Runner
lity vehicle

Acute, non-displaced fracture of the left superior articular facet of C7

1999 Toyota 4Runner

Flip-over
(corkscrew)





SCALE: 1 cm = 2.5 m

0 2.5 5

4 quarter-turns

scratching to roof/ no crush

Case Vehicle
2003 Subaru WRX

2003 Subaru Impreza WRX

Fall-over (launch/vault)

2 quarter-turns
M/C 55cms
Top-BL

Epidural Hematoma
Cervical & thoracic fx's
Facial Fx's
Thoracic Fx's

Note "Side-sway" 'A' folded mid pillar, 'B' folded @ beltline

Current San Diego Rollover Research

Rollover crashes: Predicting serious injury based on occupant, vehicle, and crash characteristics

In press: Accident Analysis and Prevention

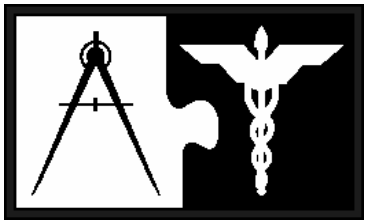
Rollover research methods

- Pure rollover crashes in CIREN and CDS, NASS were identified
  - No significant impacts before or after rollover
  - Complete ejections excluded
  - End-over-end rollovers excluded

- Compared 27 seriously injured (MAIS 3-5) CIREN occupants to 606 CDS, NASS less seriously injured occupants (MAIS 0-2)

- Occupant, vehicle, and rollover characteristics associated with serious injury were evaluated

Demographic characteristics of seriously injured CIREN occupants (MAIS 3-5) and less seriously injured CDS, NASS (MAIS 0-2)



- Age
  - 20-49 years: 70% for seriously injured CIREN occupants and 57% for less seriously injured CDS, NASS occupants
- 56% male seriously injured CIREN occupants and 59% male less seriously injured CDS, NASS occupants
- Mean occupant height: 168.1 cm for seriously injured CIREN occupants and 172.2 cm for less seriously injured CDS, NASS occupants
- 74% of seriously injured CIREN occupants were driving compared to 71% of less seriously injured CDS, NASS occupants
- 46% of seriously injured CIREN occupants were in vehicles with other occupants compared to 59% of less seriously injured CDS, NASS occupants

Vehicle characteristics comparing seriously injured CIREN occupants (MAIS 3-5) and less seriously injured CDS, NASS occupants (MAIS 0-2)

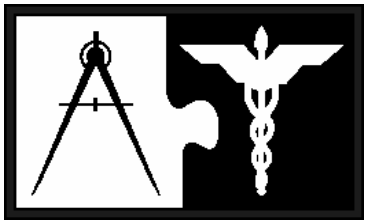
- Vehicle curb weight
  - Medium (1,134 - 1,542 kg): 46% for seriously injured CIREN occupants and 51% for less seriously injured CDS, NASS occupants

- All seriously injured CIREN occupants were in vehicles meeting current roof crush standard compared to 88% of less seriously injured CDS, NASS occupant vehicles

- Vehicle plane with greatest deformation
  - Top: 77% for seriously injured CIREN occupants and 81% for less seriously injured CDS, NASS occupants

- Vehicle body type
  - Passenger automobiles: 39% for seriously injured CIREN occupants and 45% for less seriously injured CDS, NASS occupants

Rollover crash characteristics of seriously injured CIREN occupants (MAIS 3-5) and less seriously injured CDS, NASS occupants (MAIS 0-2)



- Initiation type
  - Trip overs: 70% for seriously injured CIREN occupants and 74% for less seriously injured CDS, NASS occupants
- Rollover location
  - Roadside or median accounted for 62% for seriously injured CIREN occupants and 71% for less seriously injured CDS, NASS occupants
- Far side rollovers
  - 59% for seriously injured CIREN occupants and 52% for less seriously injured CDS, NASS occupants
- Roof vs. wheel landing
  - Roof: 48% for seriously injured CIREN occupants and 47% for less seriously injured CDS, NASS occupants
  - Wheels: 41% for seriously injured CIREN occupants and 32% for less seriously injured CDS, NASS occupants

Injury sources and intrusion comparing seriously injured CIREN cases (MAIS 3-5) and CDS, NASS less seriously injured occupants (MAIS 0-2)

- Roof was 3 times more likely to be injury source for seriously injured CIREN occupants compared to less seriously injured CDS, NASS occupants

- Side interior (A, B pillars, armrest, interior door, hardware) was almost 5 times more likely to be injury source for seriously injured CIREN occupants compared to less seriously injured CDS, NASS occupants

- Seriously injured CIREN occupants were 4 times more likely to have intrusion at their seat position compared to less seriously injured CDS, NASS occupants

- Seriously injured CIREN occupants were twice more likely to have roof rail/B pillar intrusion compared to less seriously injured CDS, NASS occupants

Additional Research Required

- What are the roles of Electronic Stability Control Systems and Vehicle Ride Height ?
- What is the role of belts in relation to occupant kinematics and rollover dynamics?
- Can de-beading be mitigated with better wheel design?
- Analysis of rollovers, though not an initial CIREN target, will allow CIREN teams to better understand complex crash dynamics and ultimately vehicle safety improvement