Damage Profile Measuring Procedures

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Premise

- Recall,
  - Work is defined as a product of Force times Displacement.
  - Work is equal to a change in Kinetic Energy, per the Work-Energy Theorem.
- Thus, if the amount of work performed in damaging the vehicle can be determined, the equivalent amount of kinetic energy expended will also be known.

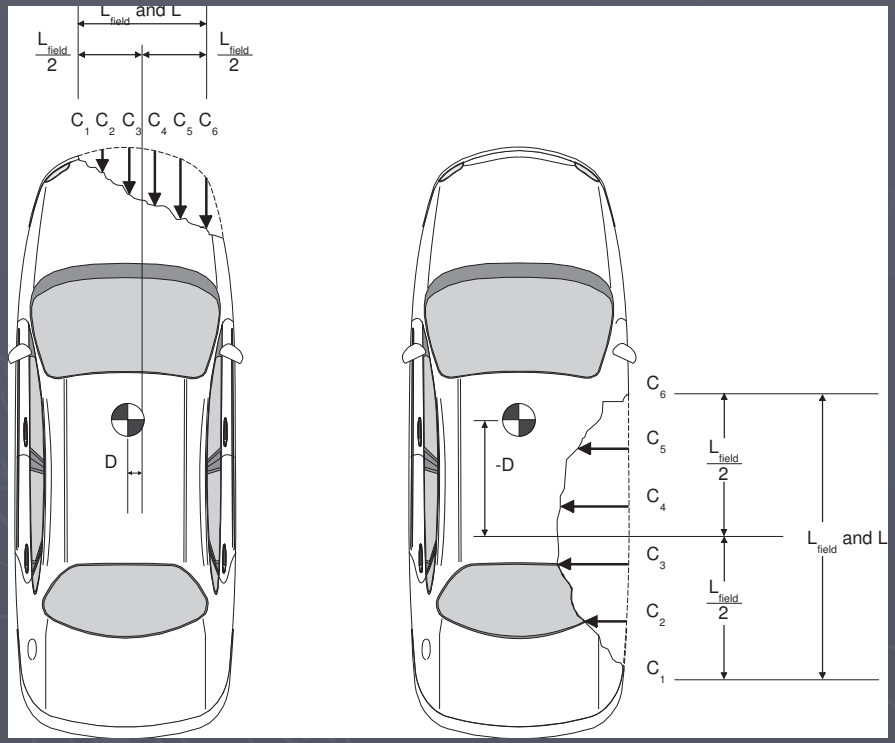
What to do

- Use energy equations to calculate the amount of damage energy.
- From this calculated Ke, the ΔV and/or the EBS the vehicle experienced during the crushing can be calculated.

How to do it

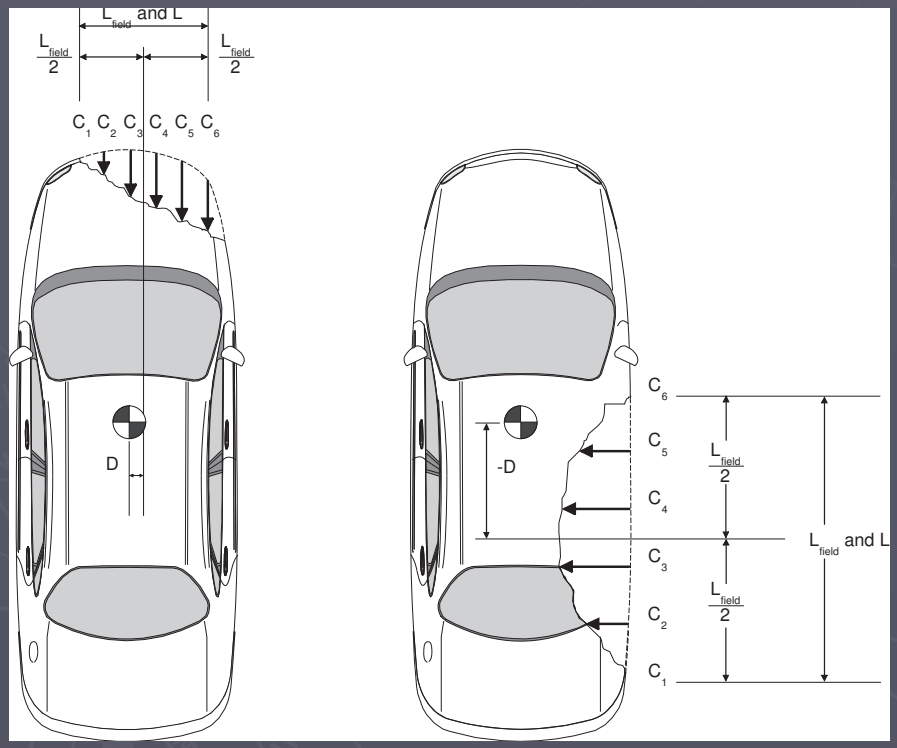
- Determine how much the vehicle was displaced from its original profile.
- Take measurements of the damage area.
  - Commonly referred to as "taking crush measurements."
  - Measuring techniques commonly used are largely based on measuring protocol outlined in Tumbas and Smith's "Measuring Protocol for Quantifying Vehicle Damage from an Energy Point of View" (SAE 880072).
  - Energy equations use these measurements to calculate the square inch area of the damage and subsequently the amount of kinetic energy it took to create the crush.

Terminology, Definitions and Procedures



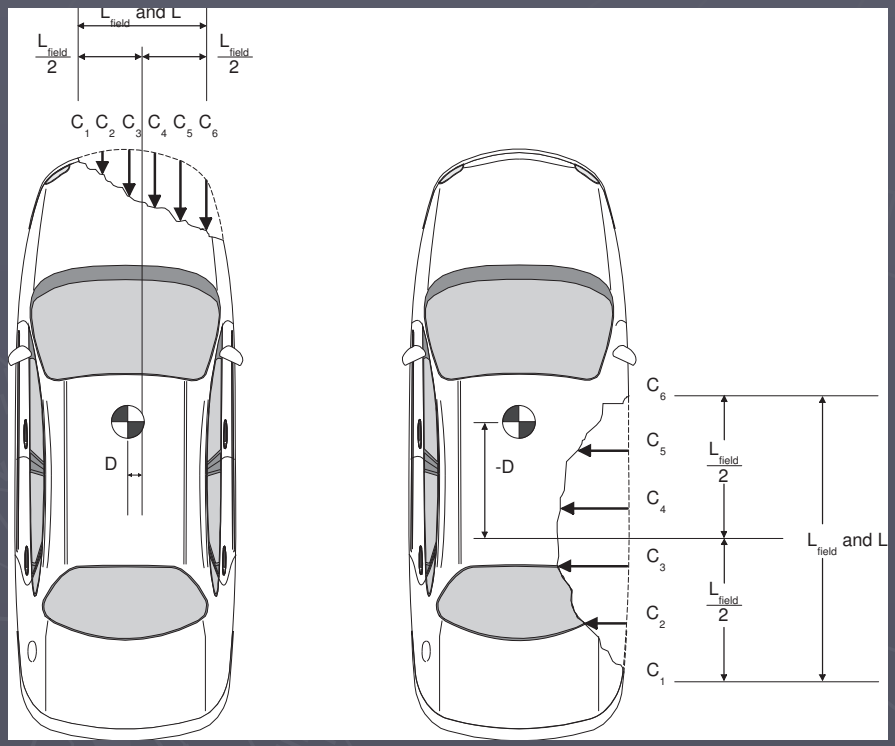
- General Overview
  - Crush measurements, called "C", are taken horizontally
    - at the level of the bumper for end damage
    - at the level of maximum deformation for side impacts
  - C's are perpendicular to the plane of the damaged side.
  - Two, four or six C measurements are taken.
  - C measurements are numbered 1-2, 4, or 6, e.g. C_1, C_2, C_3, etc.

Terminology, Definitions and Procedures (cont.)



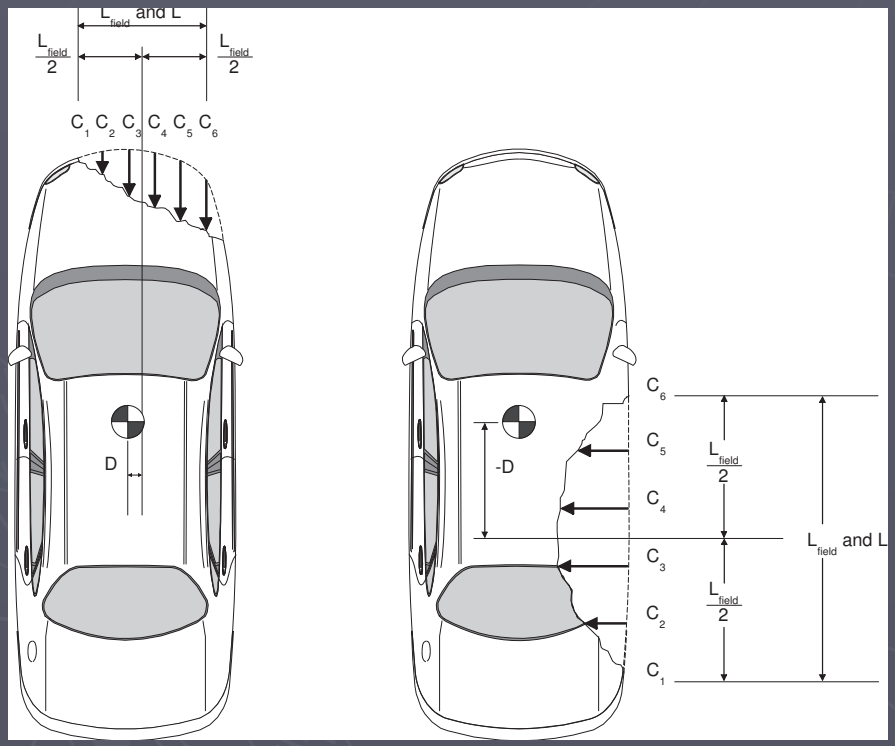
- General Overview (cont.)
  - The measurements are numbered rear-to-front for side impacts and left-to-right for end impacts (which makes them proceed in a positive direction of the vehicle coordinate system).
  - Measurements are equally spaced across the damage width.

Terminology, Definitions and Procedures (cont.)



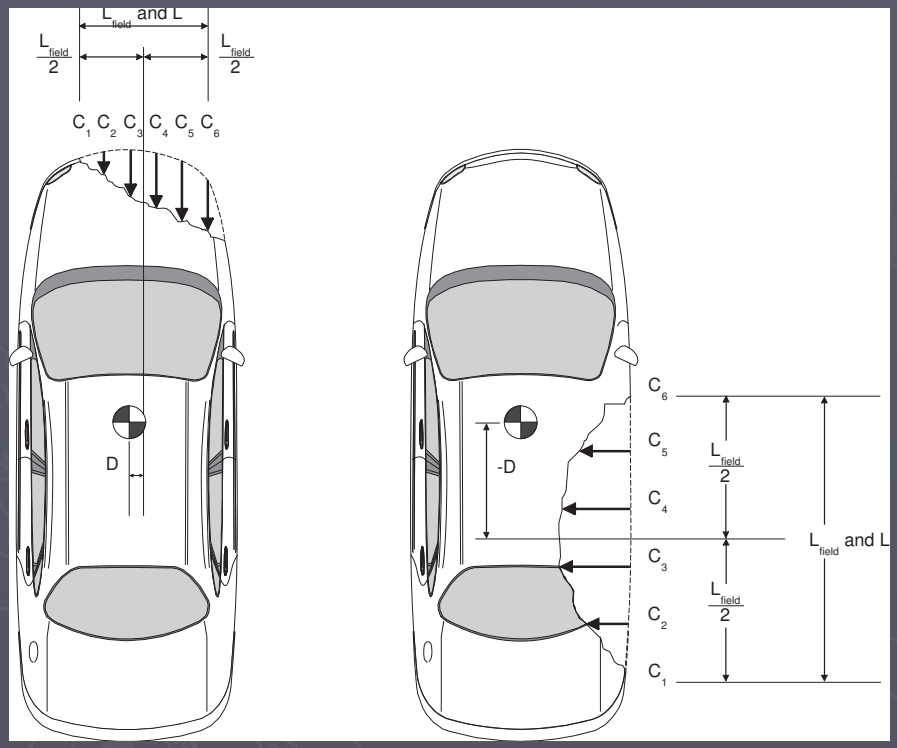
- Damage Width
  - Damage width includes direct and contiguous induced damage.
  - Two variables associated with damage width:
    - *L*, sometimes called CRASH damage width
    - L_{field}, called field damage width.
  - The equidistant spacing between C measurements is determined by dividing the field damage width by one less than the number of C measurements desired.

Terminology, Definitions and Procedures (cont.)



- Damage Width (cont.)
  - The *L* damage width is needed by the energy equations and CRASH computer programs.
  - There are instances where $L = L_{field}$.
  - There are instances where *L* = undamaged end width of the vehicle (in end impacts).

Terminology, Definitions and Procedures (cont.)

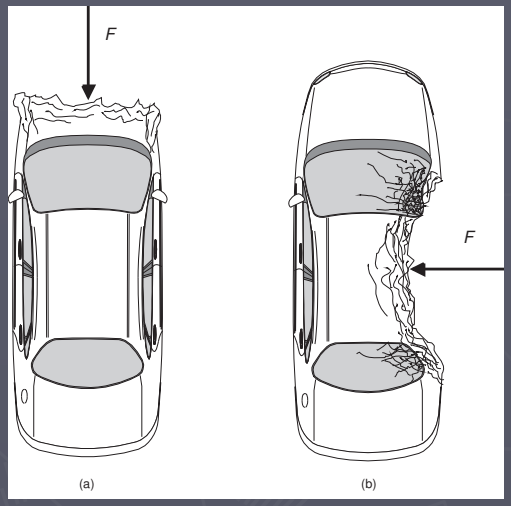


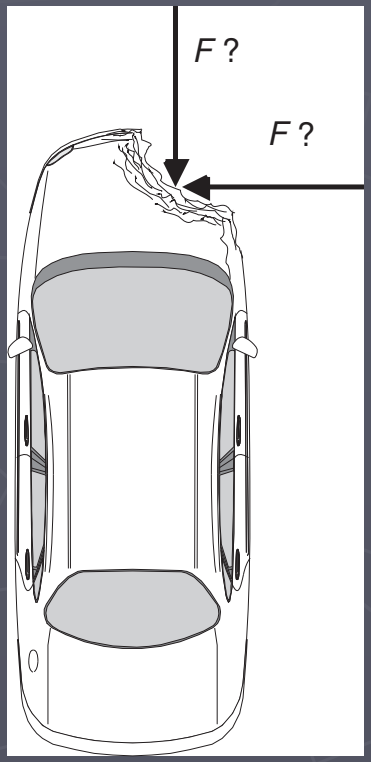
- Damage Offset
  - Side-to-side distance, *D*, the center of *L* or L_{field} is from the center of mass.
  - Used to position the damage profile on an undamaged outline of the vehicle.
  - Used to determine the location of the centroid of the damage area with respect to the local vehicle axis.
  - Care must be taken when determining *D* if the vertical profile is not uniform.

Terminology, Definitions and Procedures (cont.)

- Override – Underride
  - The amount of crush depends on the stiffness of the vehicle.
  - Stiffer, less crush; softer, more crush.
  - "A" and "B" stiffness coefficients for any particular vehicle determined by numerous crash tests into a flat, non-movable barrier.
  - Results in a fairly uniform vertical crush profile.
  - Real life crashes generally do not have a uniform vertical crush profile.
  - Care must be taken in measuring C's if the vertical profile is not uniform.

Identifying the Plane of Damage





- Must identify the plane (i.e. side of the vehicle) to which the damage occurred.
- DUH!
- Not always obvious.
- Which plane in third picture?
- Determines which stiffness coefficients to use.

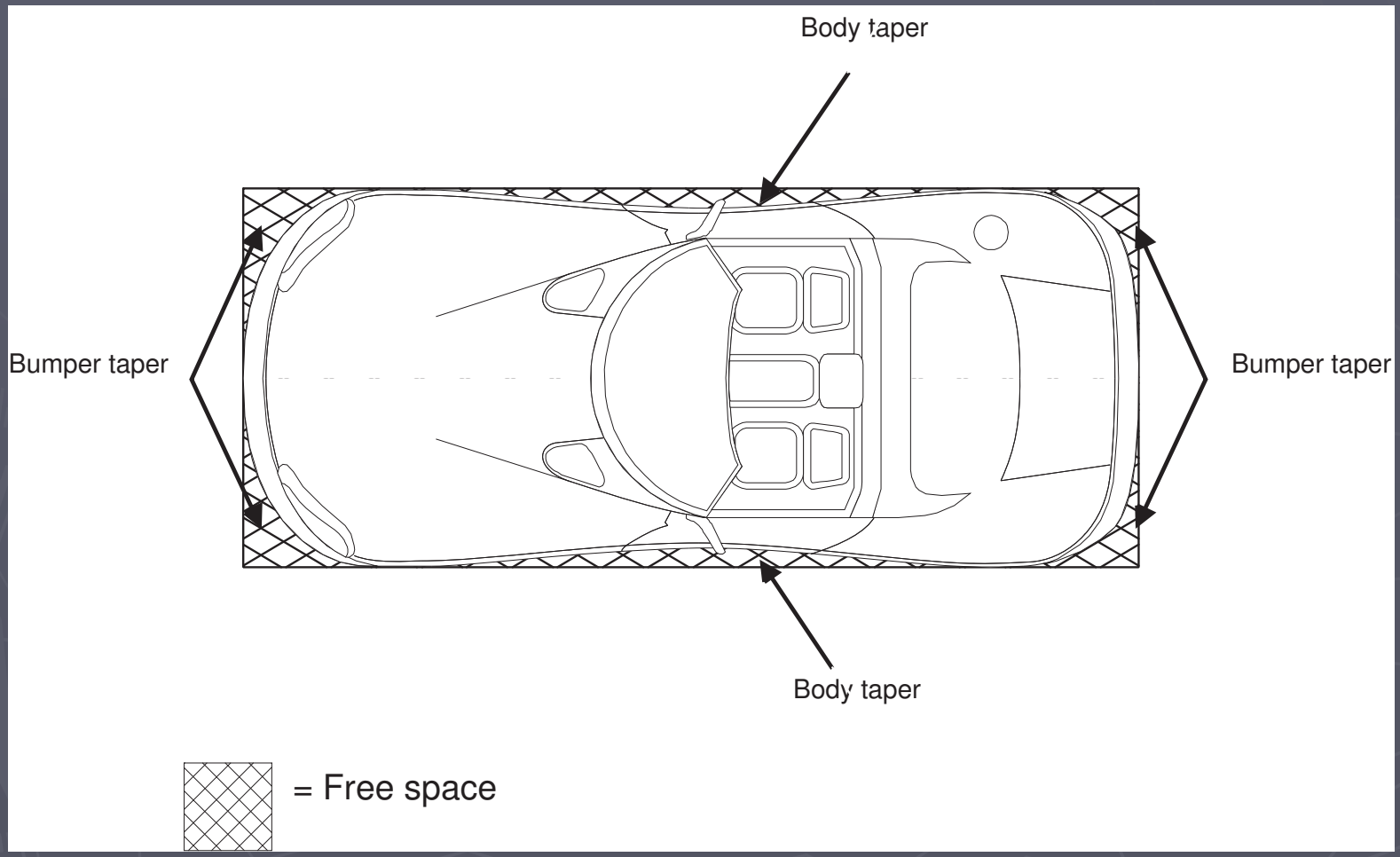
Free Space

- Body line free space & bumper free space.
- Body line free space
  - Vehicles are not flat sided rectangles.
  - Vehicles have curves, rounded bodies, rolling panels, etc.
  - Goal is to calculate energy expended to damage vehicle.
  - No energy is expended through space.
  - Space exists between flat side and curvy body (taper).
  - If a flat side was used as the undamaged profile the C measurements taken would be too long and result in an overestimation of the energy expended in crushing the side.
  - In turn, an overestimation of ΔV and/or EBS results.
  - Free space must be excluded in crush measurements.

Free Space (cont.)

- Bumper free space
  - Bumpers have free space also.
  - Taper
    - Bumper is curved where the corners sweep away from a flat profile.
  - Plastic bumper covers.
    - Space exists between the cover and the metal bumper behind.
    - Energy absorbing foam between the cover and the metal bumper behind.
  - Free space must be excluded.

Free Space (cont.)



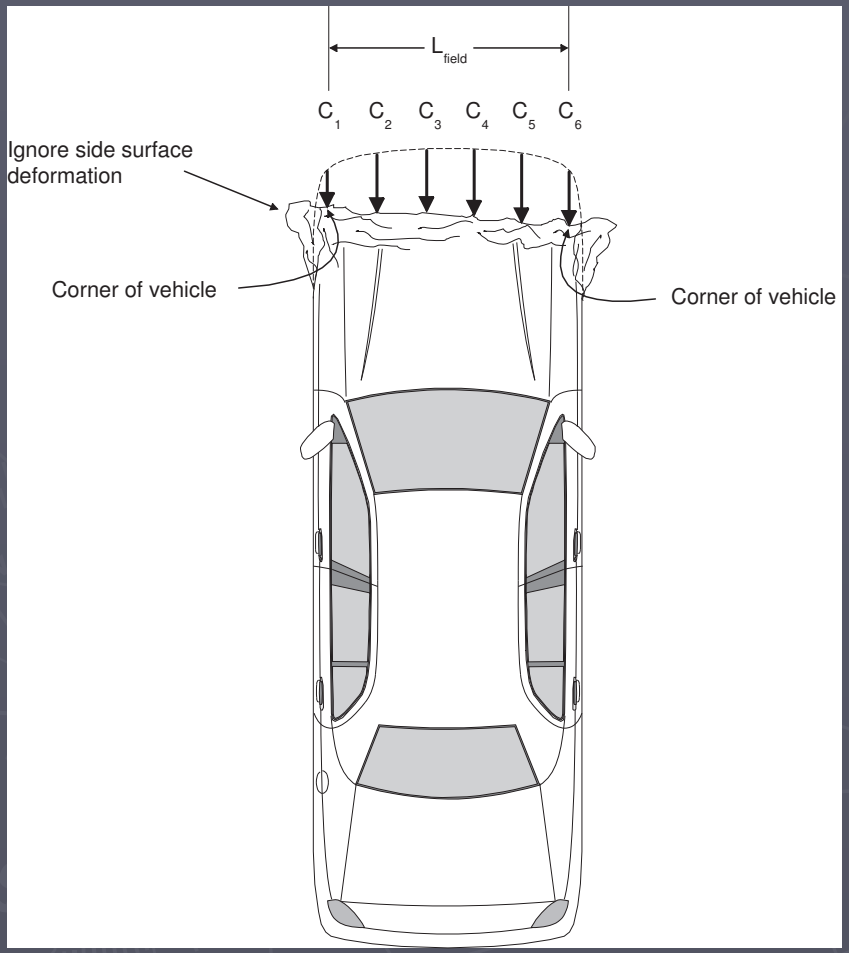
Free Space (cont.)

- Plastic bumper cover

Free Space (cont.)

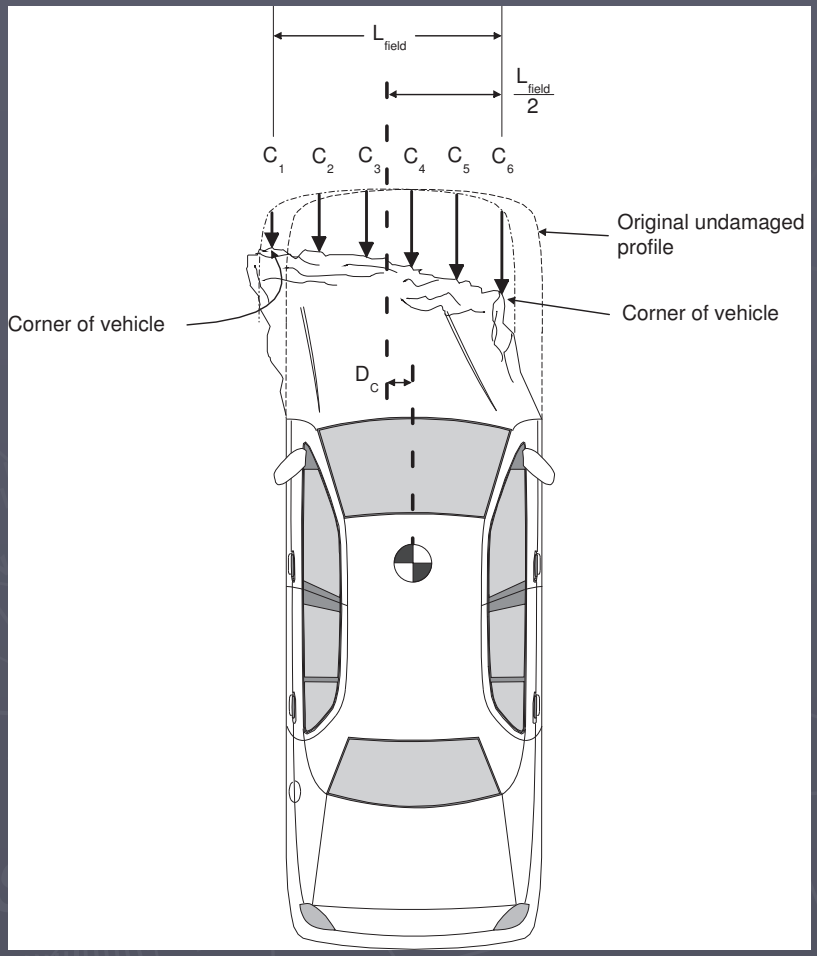
Measuring End Damage

End Damage With No Shifting – Direct Damage Across Entire Width



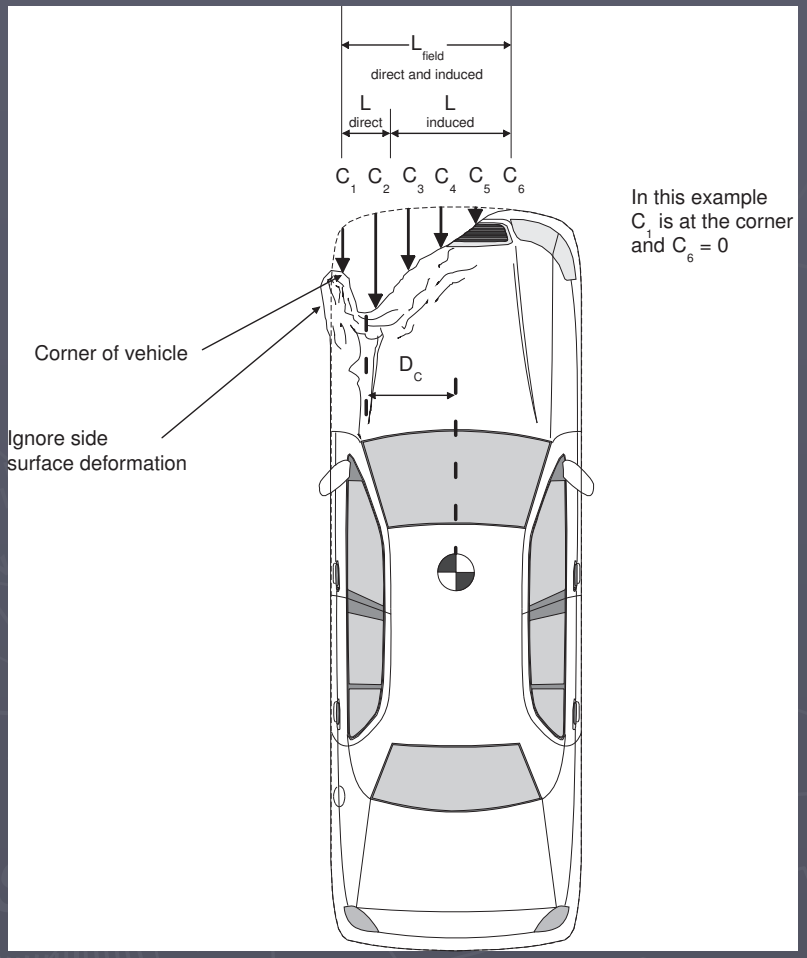
- Direct damage across entire width
- May have some side ballooning (ignore it).
- Locate damaged corners.
- Distance between damaged corners is L_{field}.
- Divide L_{field} by 5 if taking 6 C's.
- C_1 and C_6 are at the left and right corners, respectively.
- For calculation purposes, L equals the original undamaged width.
- Damage offset, $D = 0$.

End Damage With Shifting – Direct Damage Across Entire Width



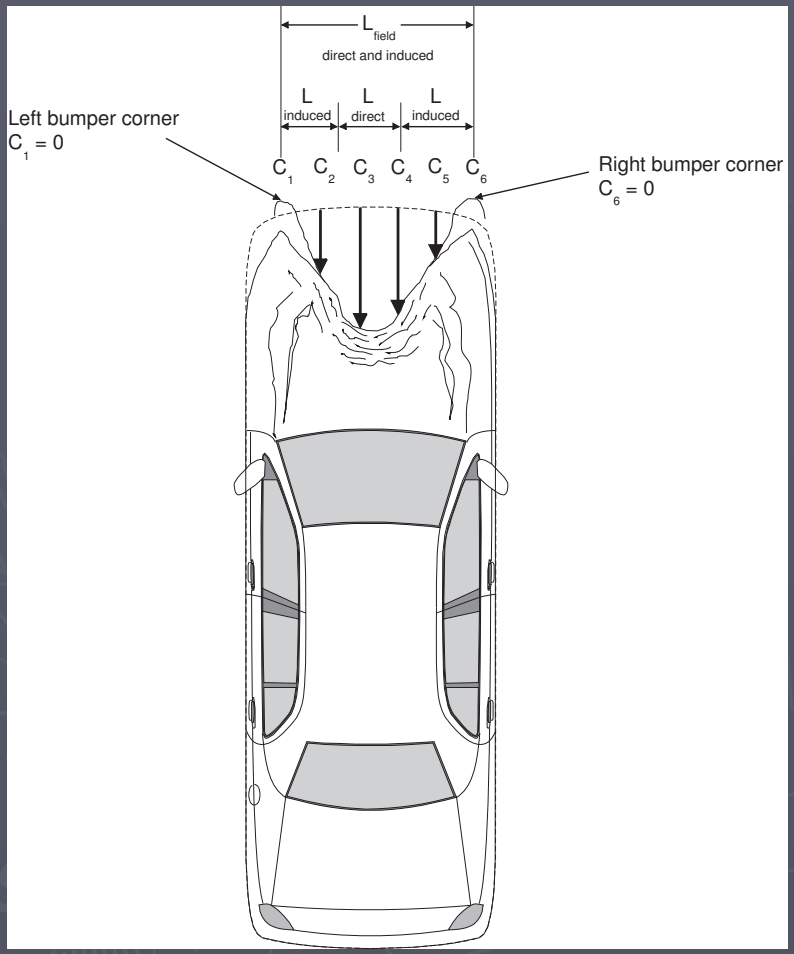
- Direct damage across entire width
- Locate damaged corners.
- Distance between damaged corners is L_{field}.
- Divide L_{field} by 5 if taking 6 C's.
- C_1 and C_6 are at the left and right corners, respectively.
- For calculation purposes, *L* equals the original undamaged width.
- Damage offset, *D* will be the distance between the center of L_{field} and the centerline of the vehicle.

End Damage With No Shifting – Direct and Induced Damage Does Not Extend Across Entire Width – Corner Involved



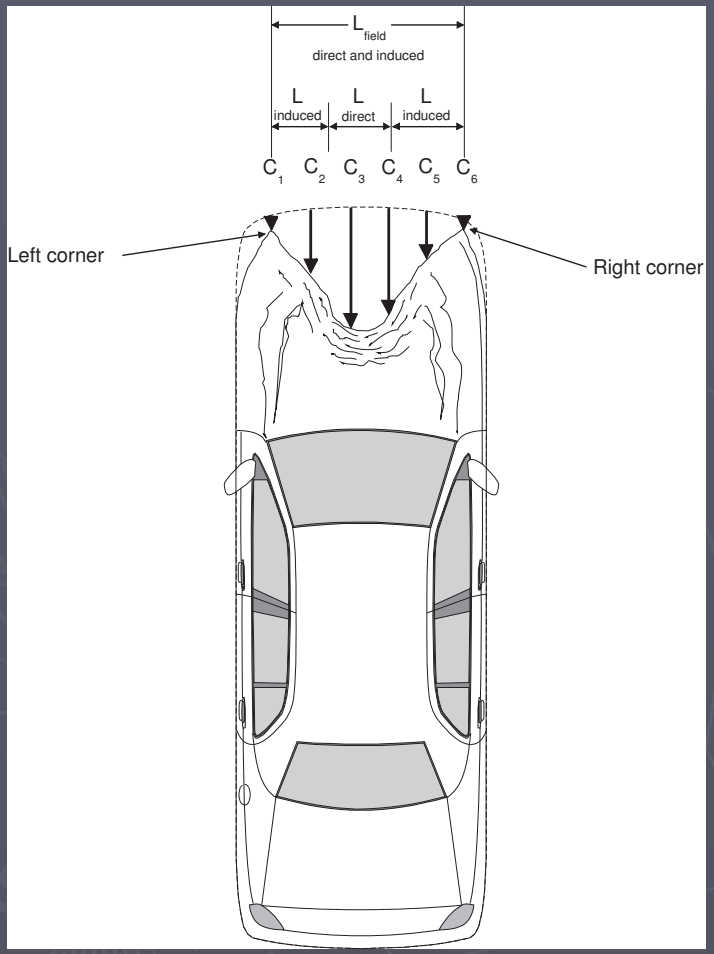
- Direct damage across entire width
- May have some side ballooning (ignore it).
- Locate the damaged corner.
- Distance between damaged corner and end of the deformation is L_{field}.
- Divide L_{field} by 5 if taking 6 C's.
- C_1 or C_6 is at the damaged corner.
- For calculation purposes, $L = L_{field}$.
- Damage offset, D_c is the distance from the centerline of the vehicle to the center of the direct (contact) damage, not the center of L_{field} .

End Damage – Narrow Object, Central Impact With Inward Crush and Bumper Protrusion



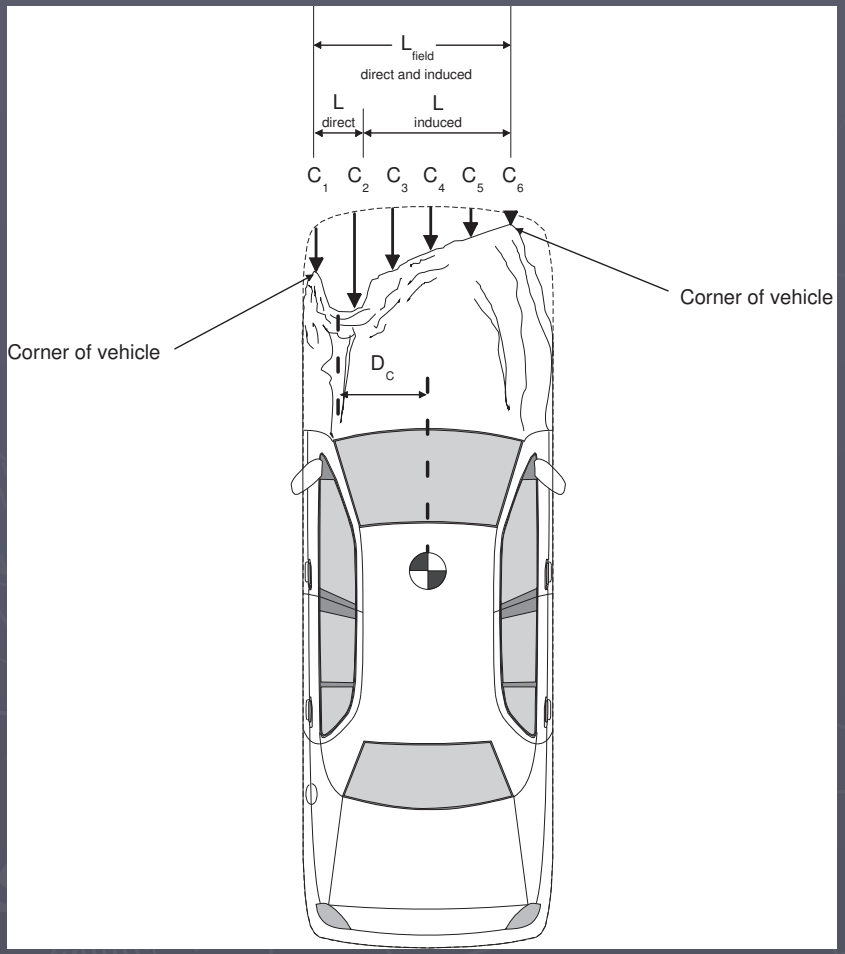
- Impact caused corners to pull inward.
- Bumpers ends sprung forward of the undamaged body line.
- Direct and induced damage across the width of the vehicle.
- Locate damaged bumper corners.
- Distance between damaged bumper corners is L_{field}.
- Divide L_{field} by 5 if taking 6 C's.
- C_1 and C_6 are at the left and right bumper corners, respectively and are equal to 0.
- For calculation purposes, L equals the original undamaged width.
- Damage offset, $D \approx 0$.
- Maximum crush depth should be located and measured if it doesn't coincide with a crush measurement.

End Damage – Narrow Object, Central Impact With Inward Crush



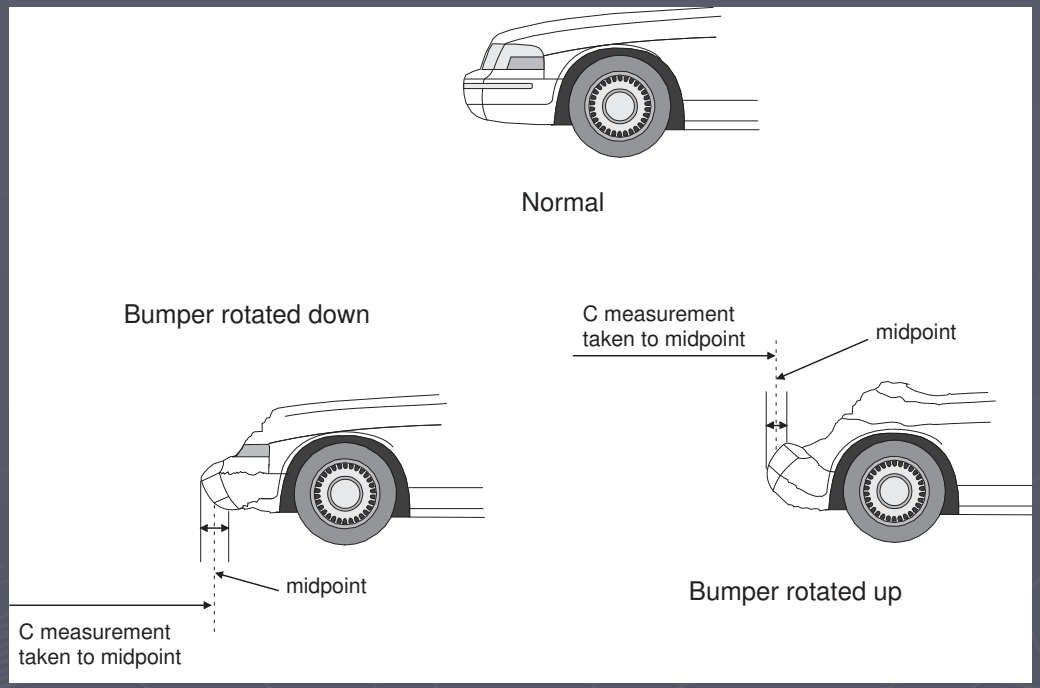
- Impact caused corners to pull inward.
- Direct and induced damage across the width of the vehicle.
- Locate damaged corners.
- Distance between damaged corners is L_{field}.
- Divide L_{field} by 5 if taking 6 C's.
- C_1 and C_6 are at the left and right corners, respectively.
- For calculation purposes, L equals the original undamaged width.
- Damage offset, $D \approx 0$.
- Maximum crush depth should be located and measured if it doesn't coincide with a crush measurement.

End Damage – Narrow Object, Non-Central Impact With Inward Crush



- Impact caused corners to pull inward.
- Direct and induced damage across the width of the vehicle.
- Locate damaged corners.
- Distance between damages corners is L_{field}.
- Divide L_{field} by 5 if taking 6 C's.
- C_1 and C_6 are at the left and right corners, respectively.
- For calculation purposes, L equals the original undamaged width.
- Damage offset, D_c is the distance from the centerline of the vehicle to the center of the direct (contact) damage, not the center of L_{field}.
- Maximum crush depth should be located and measured if it doesn't coincide with a crush measurement.

Bumper Rotation



- Impact has rotated bumper either up or down or twisted it.
- All C measurements should be measured to the midpoint of the original face of the bumper.

End Damage – Underride and Override Situations

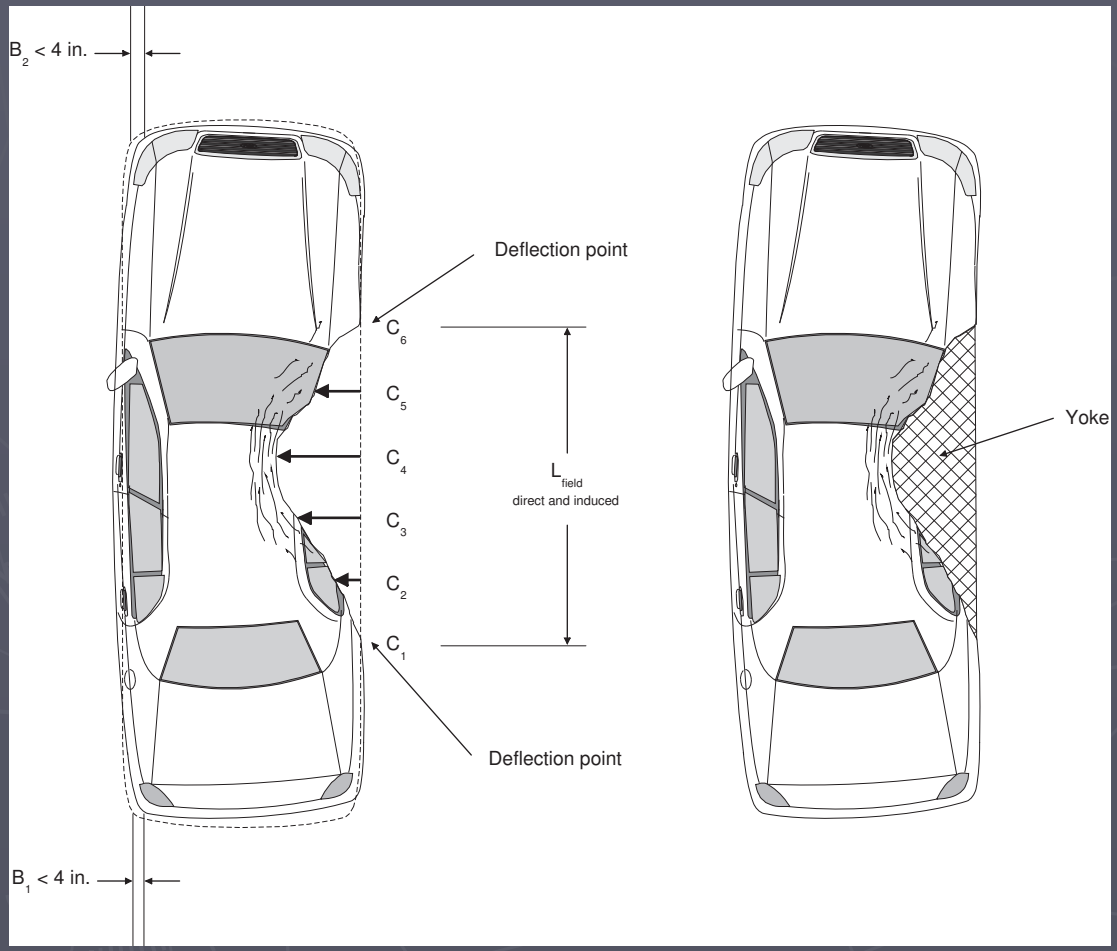
- End damage where body above bumper is not crushed to the same depth as the bumper.
- Underride
  - Situation where crush above the bumper is greater than the crush at the bumper.
  - If the crush above the bumper is greater than or equal to 5 inches more than the crush at the bumper, at the same C station, average the two measurements.
  - If the crush above the bumper is less than 5 inches, use the bumper crush measurement.
  - Crush analysis is neither applicable nor valid in severe cases of underride; e.g. running under the side of a semitrailer where only the "greenhouse" is sheared back, or where no bumper contact was made, with all the damage occurring above the bumper.

End Damage – Underride and Override Situations (cont.)

- Override
  - Situation where crush at the bumper is greater than the crush above the bumper.
  - Measure at the bumper level.

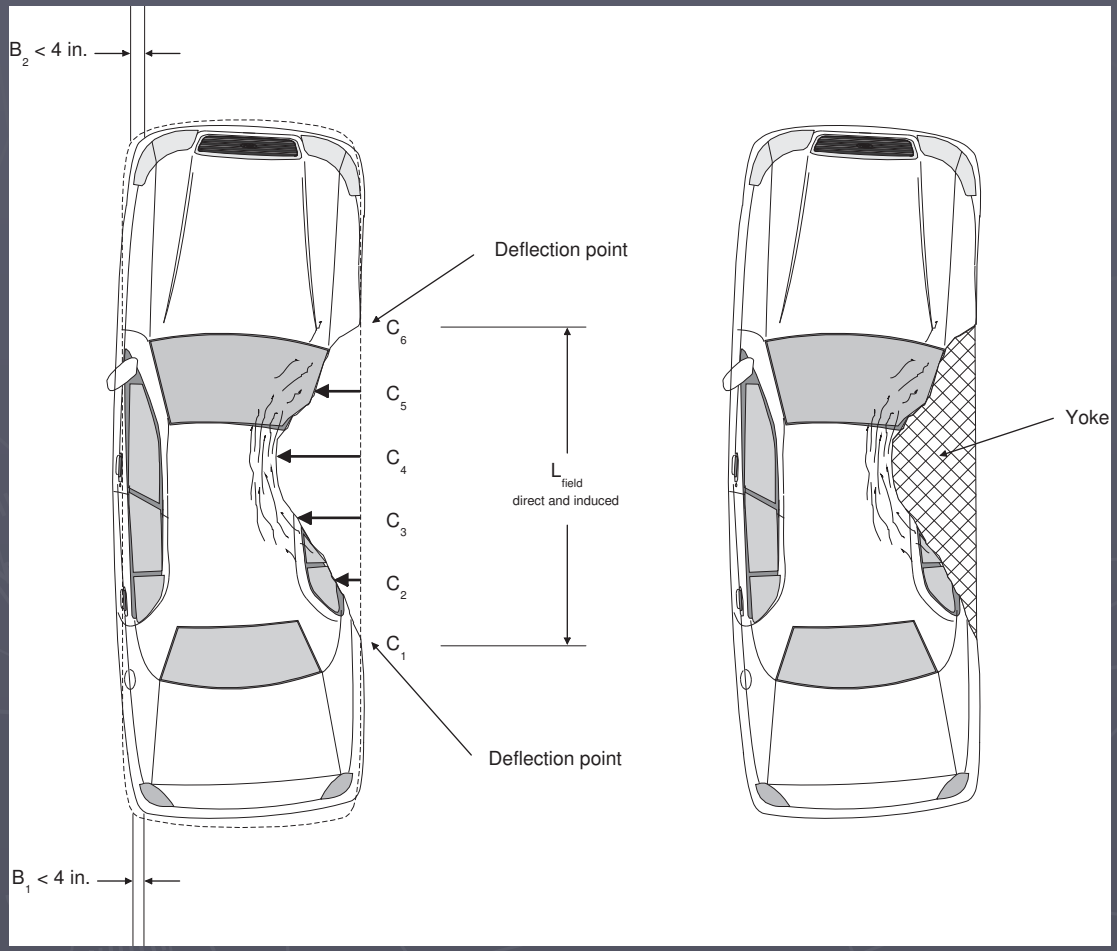
Measuring Side Damage

Side Impact – No Bowing



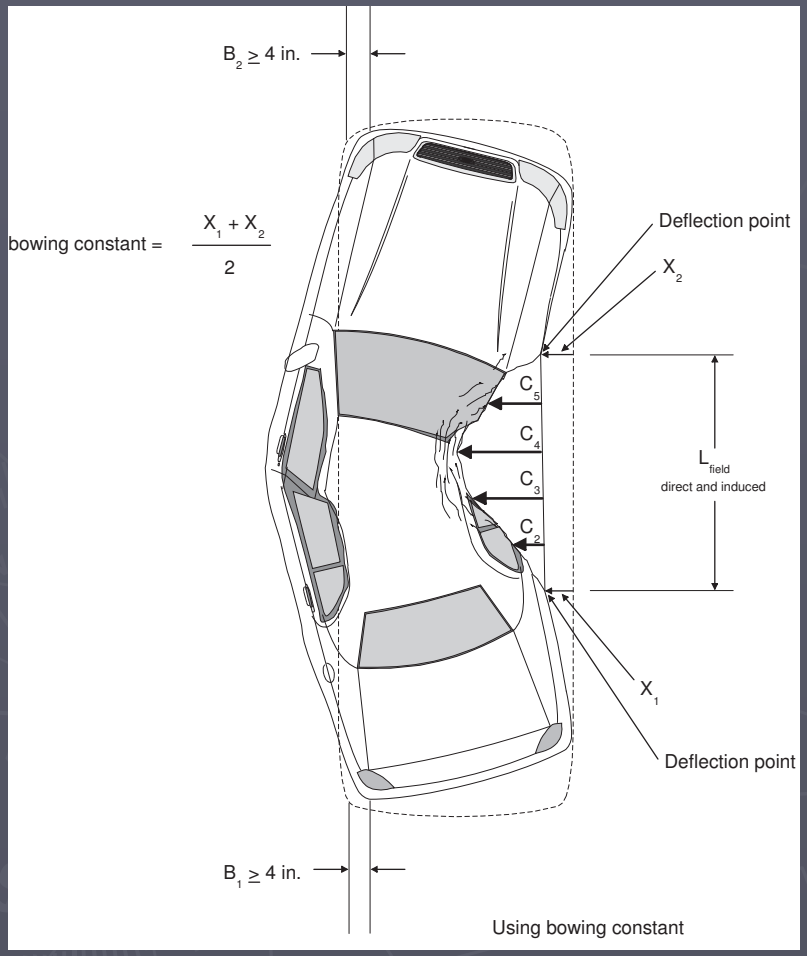
- Impact to side with direct damage between the wheels.
- Vehicle not bowed.
- Determine if bowed by:
  - Measuring distance between displaced corners and their original positions, called B_2 and B_1.
  - If both are less than 4 inches each, then vehicle is not bowed.
- The area of the damage is called the *yoke*.
- The points where the damage areas begin are called deflection points.

Side Impact – No Bowing (cont.)



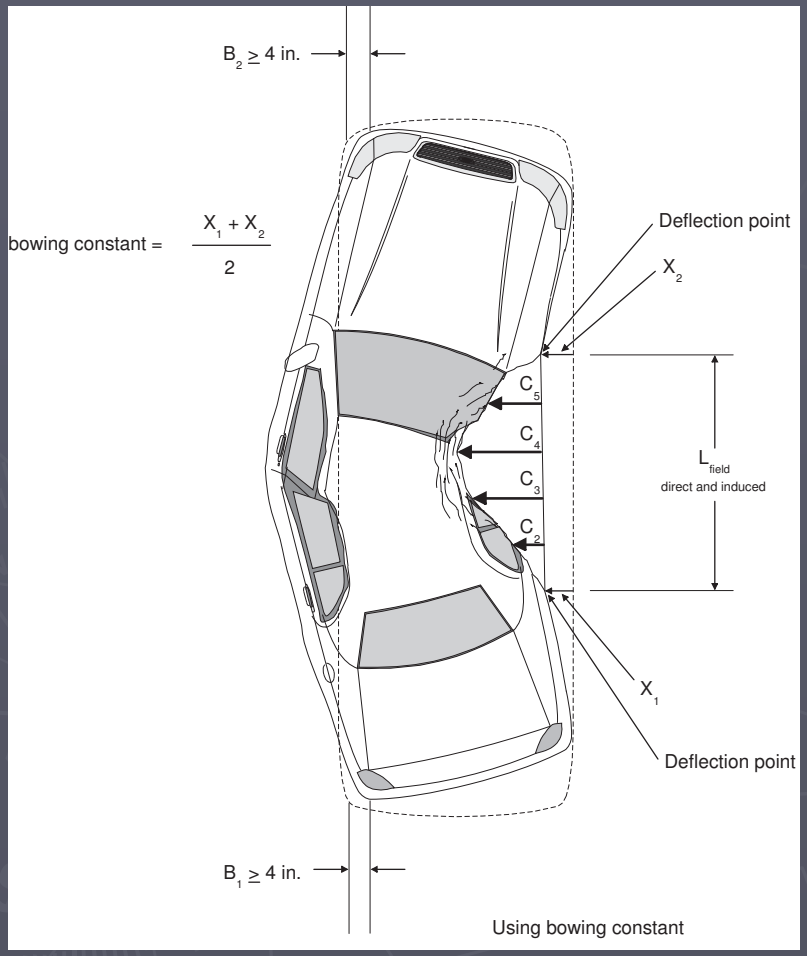
- Distance between the deflection points is L_{field}.
- Divide L_{field} by 5 if taking 6 C's.
- Establish a baseline between deflection points from which the C measurements will be taken.
- C_1 and C_6 are at the rear and front deflection points, respectively, and are equal to 0.
- For calculation purposes, $L = L_{field}$.

Side Impact – With Bowing, Using a Bowing Constant



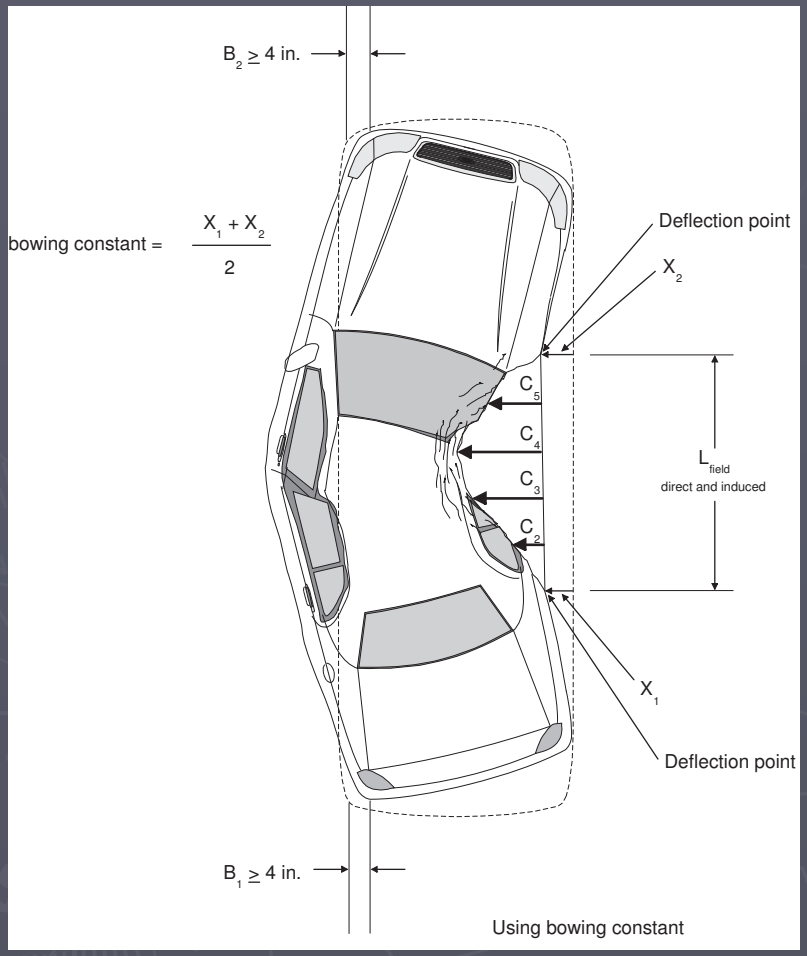
- Impact to side with direct damage between the wheels.
- Vehicle is bowed.
- Determine if bowed by:
  - Measuring distance between displaced corners and their original positions, called B_2 and B_1.
  - If either are greater than or equal to 4 inches, then vehicle is bowed.
- The area of the damage is called the *yoke*.
- The points where the damage areas begin are called deflection points.

Side Impact – With Bowing, Using a Bowing Constant (cont.)



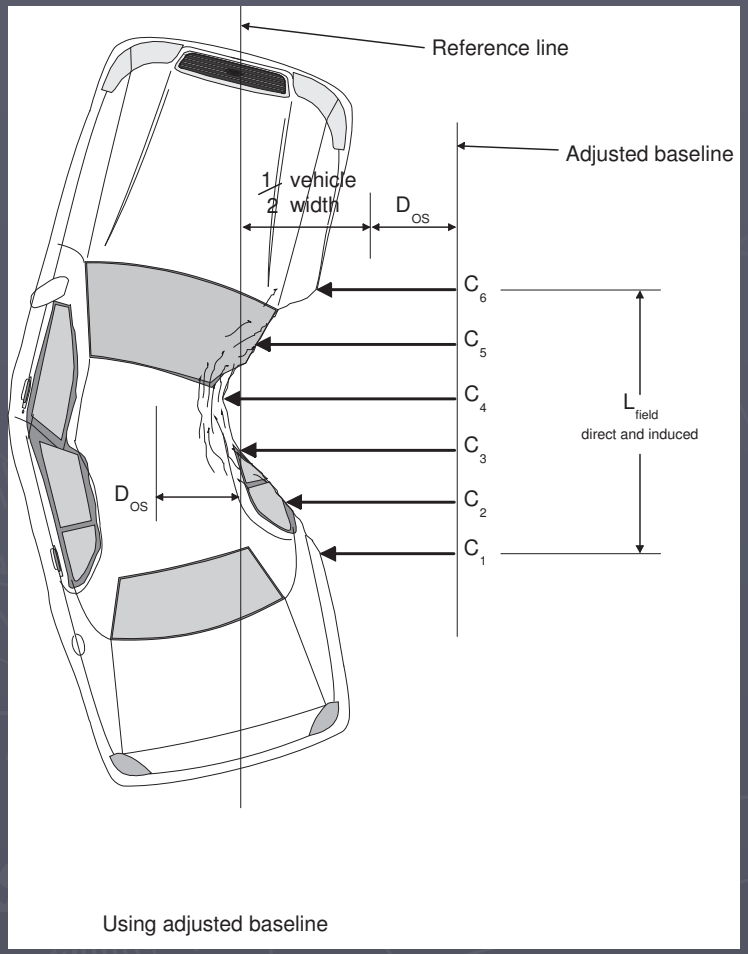
- Distance between the deflection points is L_{field}.
- Divide L_{field} by 5 if taking 6 C's.
- Establish a baseline between deflection points from which the C measurements will be taken.
- C_1 and C_6 are at the rear and front deflection points, respectively, and are equal to 0 for now.
- The bowing of the vehicle has to be taken into account.

Side Impact – With Bowing, Using a Bowing Constant (cont.)



- Establish a reference line between the front and rear corners of the vehicle on the damaged side.
- Measure perpendicular from the reference line to the baseline at C_1 and C_6. These are X_1 and X_2 respectively.
- Average X_1 and X_2. This is the *bowing constant*.
- Add the bowing constant to **all** C measurements
- For calculation purposes, $L = L_{field}$.

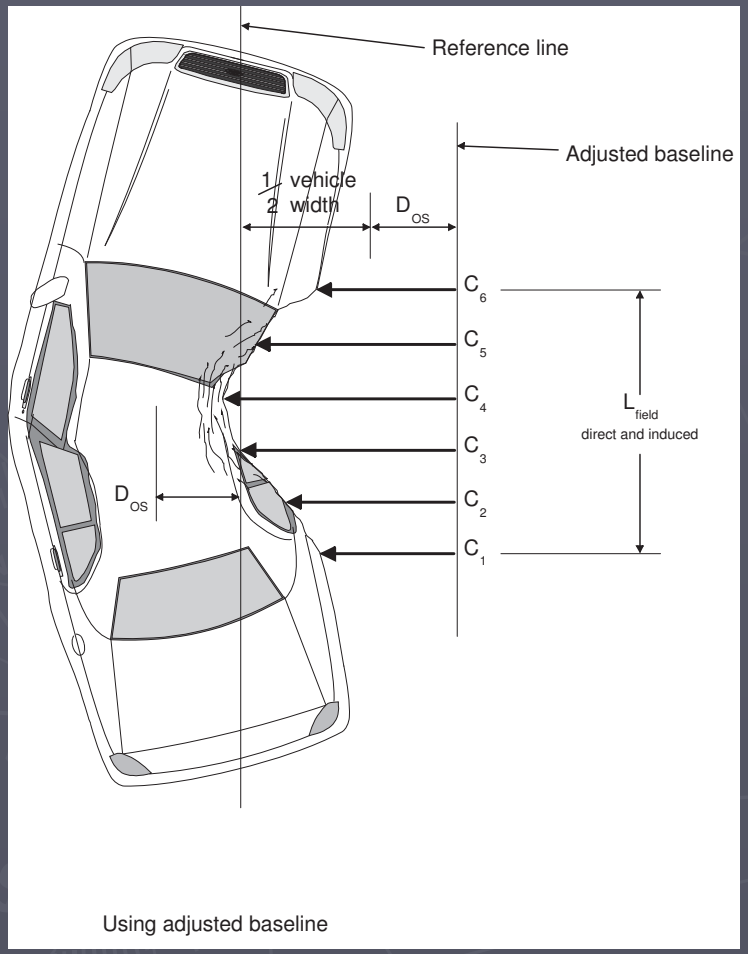
Side Impact – With Bowing, Using An Adjusted Baseline



Using adjusted baseline

- An alternative way to using a bowing constant.
- Developed because is difficult to tell if the corner displacement is greater or less than 4 inches.
- Works regardless if vehicle if bowed or not.

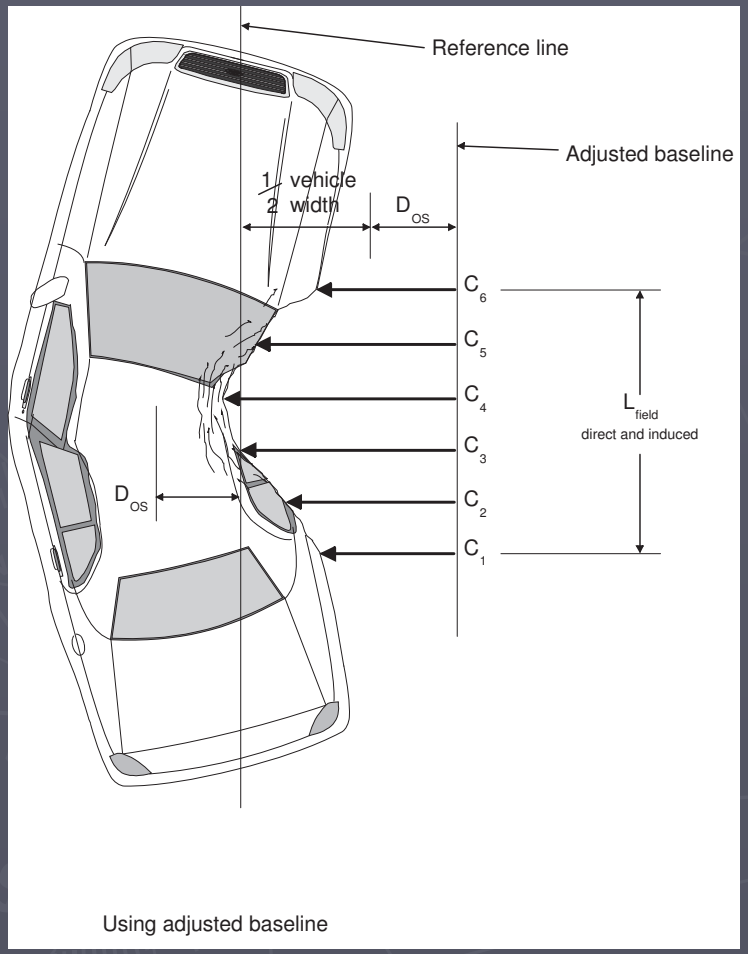
Side Impact – With Bowing, Using An Adjusted Baseline (cont.)



Using adjusted baseline

- Establish a reference line between the centers of the end planes.
- Use the middle of the bumpers if not damaged. If damaged, use the center of the structure above the bumper, if not damaged.
- Determine the distance the now displaced original centerline of the vehicle is from the reference line. Call this offset D_{OS}.

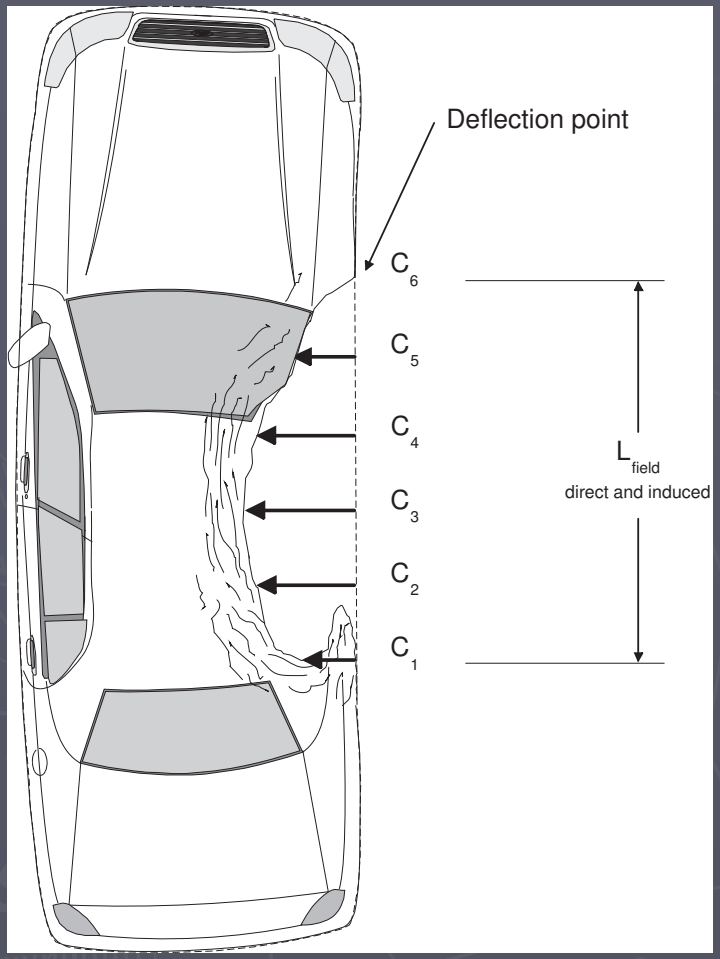
Side Impact – With Bowing, Using An Adjusted Baseline (cont.)



Using adjusted baseline

- Establish an adjusted baseline.
- The adjusted baseline is parallel to reference line, on the damaged side a distance away from the reference line equal to ½ the width of the vehicle plus D_{OS}.
- Take C measurements from the adjusted baseline.

Side Impact – With Pocketing Damage



- Impact to side which resulted in pocketing damage.
- Distance between the deflection points to the point of greatest pocketing is L_{field}.
- The point of greatest pocketing may not be the point of maximum depth of crush.
- Divide L_{field} by 5 if taking 6 C's.
- Establish a baseline between deflection point and the point of greatest pocketing from which the C measurements will be taken.
- C_1 or C_6 is at the deflection point, the other is at the point of greatest pocketing; C_6 and C_1 respectively, in this example. $C_6 = 0$ in this example.
- For calculation purposes, $L = L_{field}$.

Side Impact – Variation in Crush Depth

- Side impacts generally result in varying crush depths.
- Measuring procedures used depend on structural integrity.
- Question to ask is "Was there hinge, door latch or pillar failure."

Side Impact – Variation in Crush Depth (cont.)

- No hinge, door latch or pillar failure
  - Measure maximum crush.
  - Doesn't have to be in a horizontal plane.
  - Tumbas says can measure horizontally in a 4 inch wide band. (SAE 880072)
- Hinge, door latch or pillar failure
  - If the difference between the maximum crush and the door sill, at any C station, is greater than or equal to 5 inches, average the two measurements.
  - If it is not, use the maximum crush measurement at that station.