Lecture 7

Constraints and Connections

Overview

- Introduction
- Surface-Based Coupling Constraints
- Connector Elements
- Surface-Based Ties
- Mesh-Independent Point Fasteners
- Mesh-Independent Surface Connections
- Tips for Diagnosing Constraint and Connection Errors

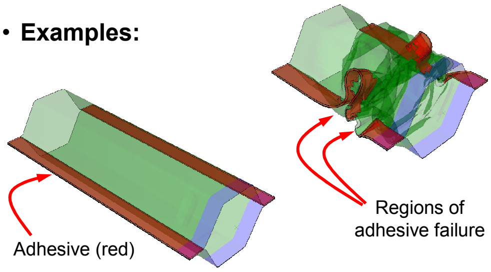
Introduction

Introduction

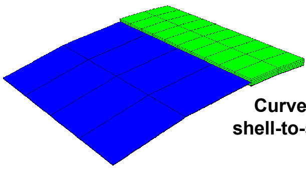
- **Constraints vs. connections**
  - **Constraints** partially or fully eliminate degrees of freedom of a group of nodes and couple their motion to the motion of a master node (or nodes).
  - Examples of constraints include:
    - Rigid Bodies
    - Coupling Constraints
    - Shell-to-Solid Coupling
    - Surface-Based Ties
  - **Connections** model actual connections between parts, such as: ball joints, springs, dampers, bushings, links, hinges, spot welds, rivets, adhesives, bonds, etc.
  - Examples of connections include:
    - Connector Elements
    - Mesh-Independent Point Fasteners
    - Mesh-Independent Surface Connections

Introduction

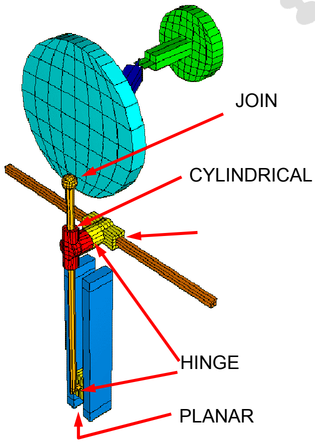
- **Examples:**



Rail crush with failing adhesive layer



Curved plate with shell-to-solid coupling

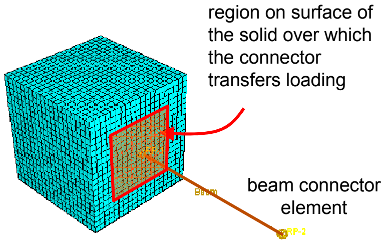


multibody mechanism with connector elements

Surface-Based Coupling Constraints

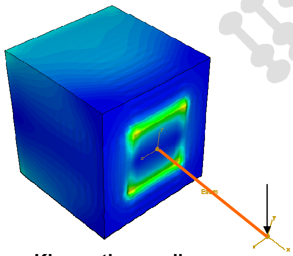
Surface-Based Coupling Constraints

- **Kinematic and distributing couplings**
  - Coupling interactions provide a constraint between a reference node and the nodes on a surface (the coupling nodes).
  - The coupling constraint is useful when a group of coupling nodes is constrained to the rigid body motion of a single node.
  - Typical applications:
    - To apply loads or boundary conditions to a model
    - To model end conditions
    - To model interactions with other constraints, such as connector elements



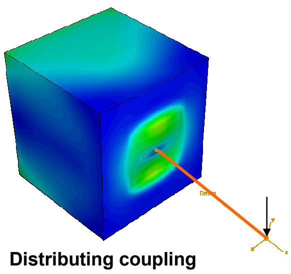
Surface-Based Coupling Constraints

- **Kinematic coupling**
  - Rigid constraints between the master nodes and the coupling nodes
  - Provides a solution for lack of rotational stiffness at nodes connected to solid elements



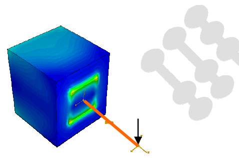
Kinematic coupling

- **Distributing coupling**
  - The constraint is enforced in an average sense
  - Coupling node weight factors provide control of the load transmission.

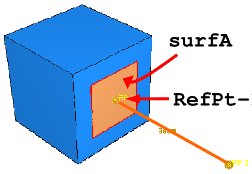


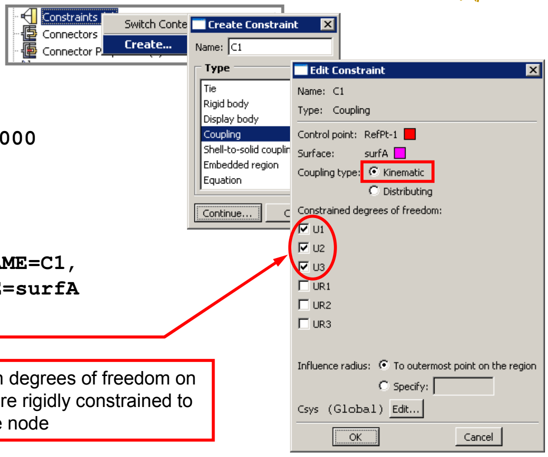
Distributing coupling

Surface-Based Coupling Constraints



- **Kinematic coupling definition**

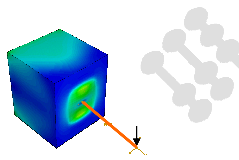




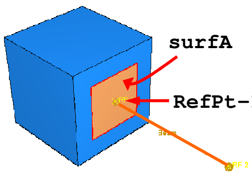

```
*COUPLING, CONSTRAINT NAME=C1,
  REF NODE=1000, SURFACE=surfA
*KINEMATIC
 1, 3
```

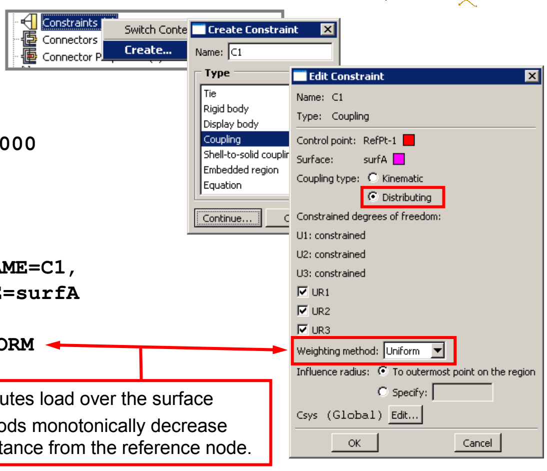
specify which degrees of freedom on the surface are rigidly constrained to the reference node

Surface-Based Coupling Constraints



- **Distributing coupling definition**



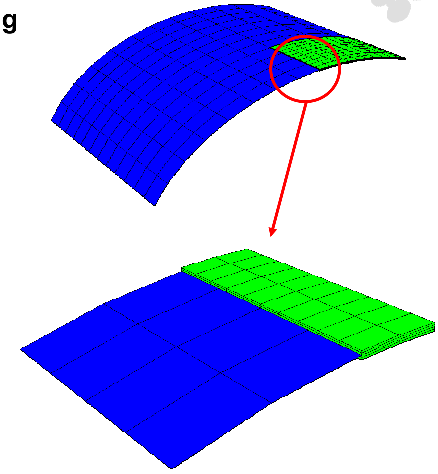



```
*COUPLING, CONSTRAINT NAME=C1,
  REF NODE=1000, SURFACE=surfA
*DISTRIBUTING,
   WEIGHTING METHOD=UNIFORM
 1, 6
```

Uniformly distributes load over the surface
Other weighting methods monotonically decrease loading with radial distance from the reference node.

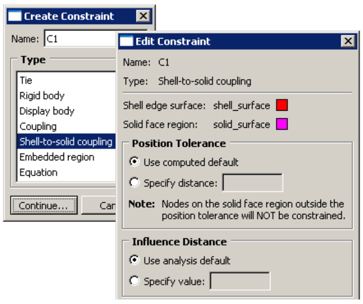
Surface-Based Coupling Constraints

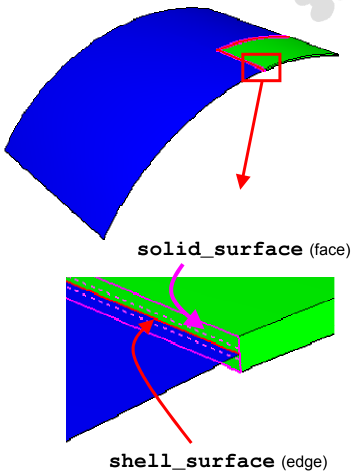
- **Surface-based shell-to-solid coupling**
  - Allows for a transition from shell element modeling to solid element modeling
  - Useful when local modeling requires 3D solid elements but other parts of the structure can be modeled as shells
  - Couples the motion of a "line" of nodes along the edge of a shell model to the motion of a set of nodes on a solid surface
    - Uses a set of internally defined distributing coupling constraints



Surface-Based Coupling Constraints

- **Defining Surface-based shell-to-solid coupling**






```
*SHELL TO SOLID COUPLING, CONSTRAINT NAME=C1
shell_surface, solid_surface
```

The shell surface must be **edge based**

```
*SURFACE, TYPE=ELEMENT, NAME=shell_surface
shell_surface_E1, E1
```

an edge identifier

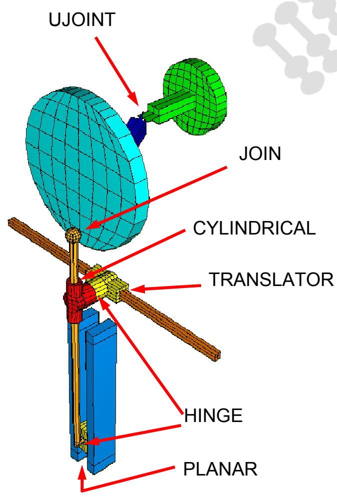
ABAQUS

Connector Elements

Connector Elements

Video Clip

- **Introduction**
  - Connector elements model discrete (point-to-point) physical connections between deformable or rigid bodies.
  - Connectors impose kinematic constraints. For example:
    - hinges
    - constant velocity joints
    - pin-in-slot constraints
  - This section provides a basic introduction to connector elements.
    - Connector elements are discussed in detail in the *Flexible Multibody Systems with ABAQUS* lecture notes.



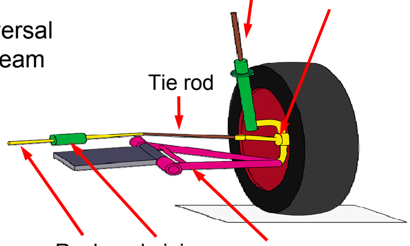
Connector elements in a multibody mechanism

 ABAQUS

Connector Elements

– Connectors may include (nonlinear) force-versus-displacement (or velocity) behavior in their unconstrained relative motion components.
  - Example: axial behavior of shock absorbing struts in an automotive suspension systems.

– ABAQUS has an extensive library of:
  - Connection types
    – For example: axial, hinge, weld, universal joints, constant velocity joints, link, beam connectors, etc.
  - Kinetic behaviors
    – Uncoupled or coupled response
    – Elasticity and damping
    – Plasticity and damage
    – Friction
    – Stops, locks, failure



Typical connections in automotive suspension

Connector Elements

Assembled	Basic translational	Basic rotational
BEAM	LINK	ALIGN
WELD	JOIN	REVOLUTE
HINGE	SLOT	UNIVERSAL
UJOINT	SLIDE-PLANE	CARDAN
CVJOINT	CARTESIAN	EULER
TRANSLATOR	RADIAL-THRUST	CONSTANT VELOCITY
CYLINDRICAL		ROTATION
PLANAR	AXIAL	FLEXION-TORSION
BUSHING	PROJECTION CARTESIAN	PROJECTION FLEXION-TORSION

Connector Elements

- **Example: Truck door hinges – keyword interface**

  1. Define connector elements

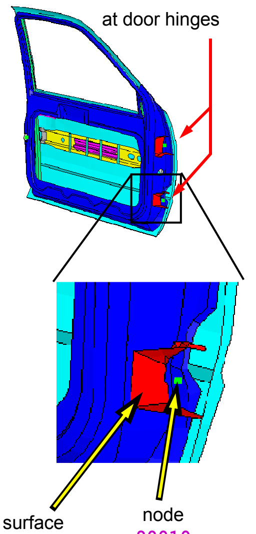
```
*ELEMENT, TYPE=CONN3D2, ELSET=CONN_DOOR_HINGE
620601, 90009, 90010
620602, 90011, 90012
```

2 nodes per element

– In this example, each connector joins two nodes that are reference nodes for distributing coupling constraints.

- One distributes the hinge load to the door (shown) and the other distributes the hinge load to the rest of the truck body (not shown)

```
*COUPLING, REF NODE=90010, SURFACE=DOOR-HINGE-1,
  CONSTRAINT NAME=DOOR-HINGE-1
*DISTRIBUTING
 1,6
```



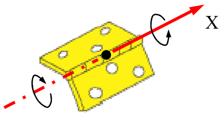
 ABAQUS

Connector Elements

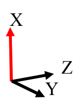
- **Example (cont'd): Truck door hinges – keyword interface**

  2. Define connector orientation

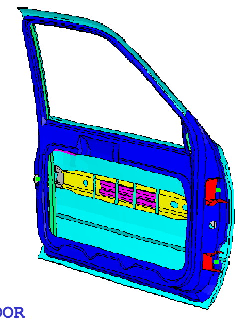
  - Orientations are used to define local directions for connection types that use local directions.
    – Orientation directions rotate with the rotation of the nodes of the element.
  - Hinge connectors require an orientation which will be associated with the first connector node.
    – The hinge axis is aligned with the orientation X-direction.




```
*ORIENTATION,NAME=ORI_CONN_DOOR
0.,0.,1., 1.,0.,0.
3,0
```



ORI_CONN_DOOR



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Connector Elements

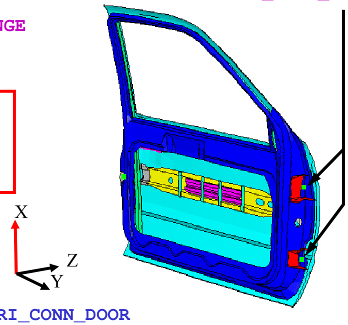
- **Example (cont'd): Truck door hinges – keyword interface**

  3. Define connector section

```
*ORIENTATION,NAME=ORI_CONN_DOOR
 0.,0.,1., 1.,0.,0.
 3,0
*ELEMENT, TYPE=CONN3D2, ELSET=CONN_DOOR_HINGE
 620601,9000009,9000010
 620602,9000011,9000012
*CONNECTOR SECTION, ELSET=CONN_DOOR_HINGE
HINGE
ORI_CONN_DOOR
```

Assembled connection type;
one can also use basic connection types:
JOIN, REVOLUTE

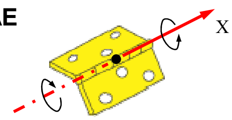
Connector elements
CONN_DOOR_HINGE



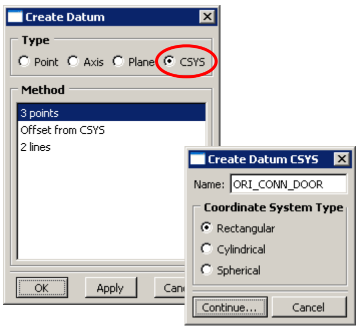
ORI_CONN_DOOR

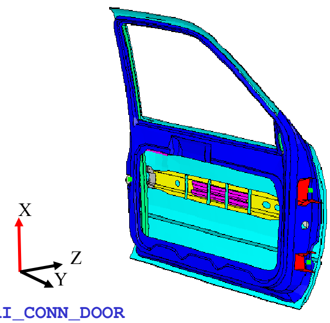
Connector Elements

- **Example (cont'd): Truck door hinges – ABAQUS/CAE**



  1. Define connector orientation
     - In ABAQUS/CAE orientations are defined using datum coordinate systems.



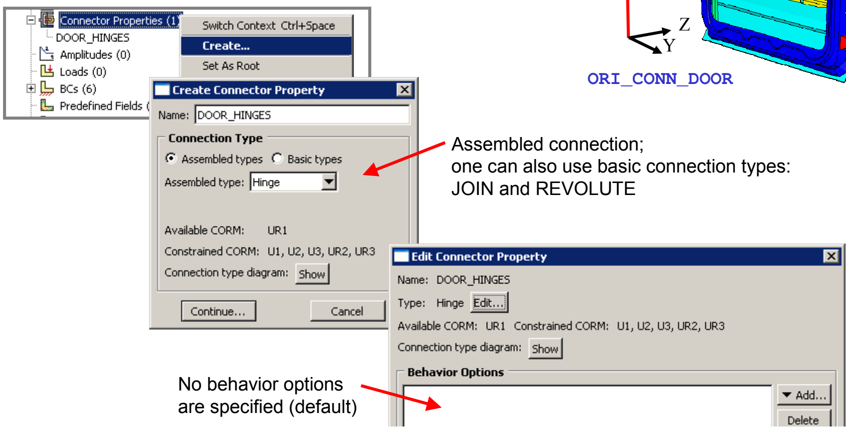


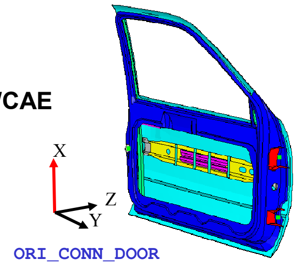
ORI_CONN_DOOR

Connector Elements

- **Example (cont'd): Truck door hinges – ABAQUS/CAE**

2 Define connector property





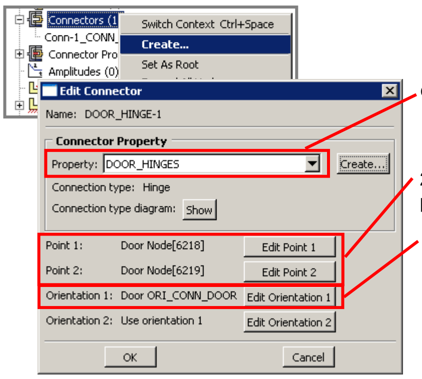
Assembled connection;
one can also use basic connection types:
JOIN and REVOLUTE

No behavior options
are specified (default)

Connector Elements

- **Example (cont'd): Truck door hinges – ABAQUS/CAE**

3 Define connector

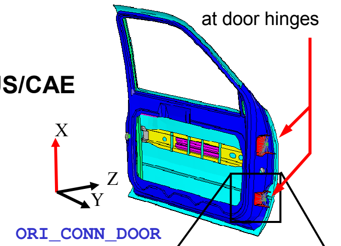


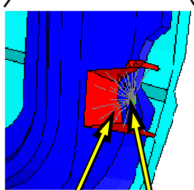
connector property
reference

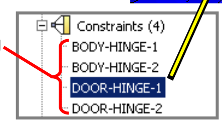
2 nodes/points
per connector

orientation
reference

HINGE connectors
at door hinges





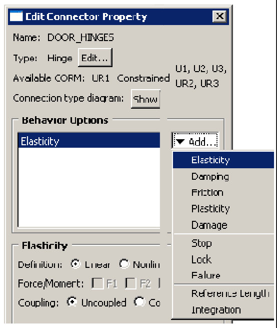


Distributing coupling
constraints connect
connector nodes to
truck door and body

Door
Node[6218]

Connector Elements

- **Connector behavior**
  - Kinetic behavior can be specified only for available components of relative motion
    - Both uncoupled and coupled behavior can be defined
  - A wide variety of behaviors are possible:
    - spring-like elastic behavior (*CONNECTOR ELASTICITY)
    - rigid-like elastic behavior (*CONNECTOR ELASTICITY, RIGID)
    - dashpot-like (damping) behavior (*CONNECTOR DAMPING)
    - friction (*CONNECTOR FRICTION)
    - plasticity (*CONNECTOR PLASTICITY)
    - damage (*CONNECTOR DAMAGE)
    - stops (*CONNECTOR STOP)
    - locks (*CONNECTOR LOCK)
    - failure (*CONNECTOR FAILURE)



 ABAQUS

Connector Elements

- **Example: Truck door hinges with rotational springs – keyword interface**

Connector definition and kinematics

```
*ORIENTATION,NAME=ORI_CONN_DOOR
0.,0.,1., 1.,0.,0.
3,0

*ELEMENT, TYPE=CONN3D2, ELSET=CONN_DOOR_HINGE
620601,9000009,9000010
620602,9000011,9000012

*CONNECTOR SECTION, ELSET=CONN_DOOR_HINGE,
 BEHAVIOR=CONN_DOOR_HINGES_BEH
HINGE
ORI_CONN_DOOR
```

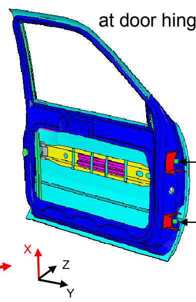
Connector behavior

```
*CONNECTOR BEHAVIOR, NAME=CONN_DOOR_HINGES_BEH

*CONNECTOR ELASTICITY,COMPONENT=4

10.0,
```

spring stiffness

rotation about local X direction

HINGE connectors at door hinges

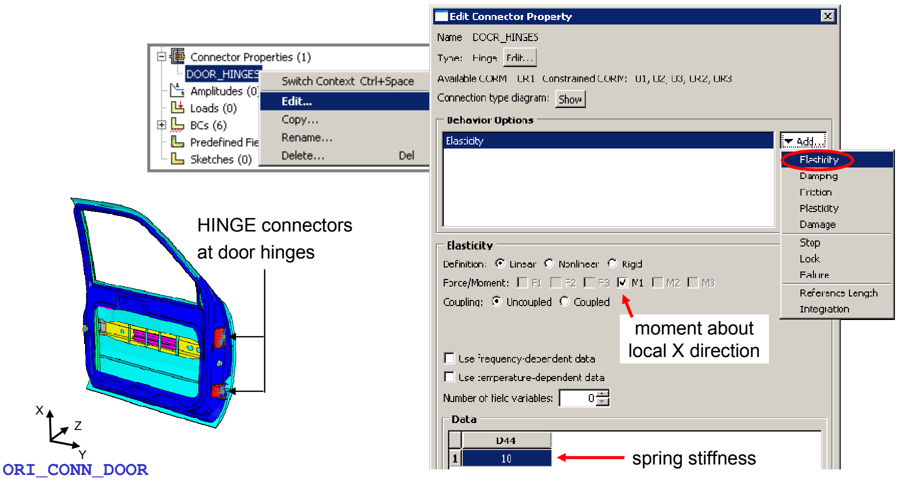


ORI_CONN_DOOR

 ABAQUS

Connector Elements

- **Example: Truck door hinges with rotational springs – ABAQUS/CAE**

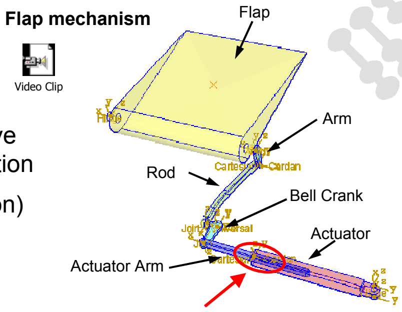


Connector Elements

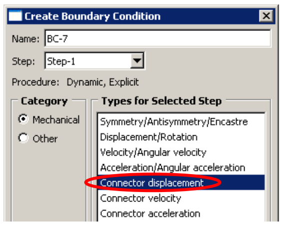
- **Connector actuation**
  - Connector actuation can be used to drive any available component of relative motion
    - by a prescribed displacement (rotation) or
    - by a specified force (moment).
  - It can also be used to fix available components of relative motion.
  - The prescribed relative motions and loads are in the local directions associated with the connector.

```
*CONNECTOR MOTION, AMPLITUDE=AMP-2
TRANSLATOR, 1, 1.0
```

Flap mechanism



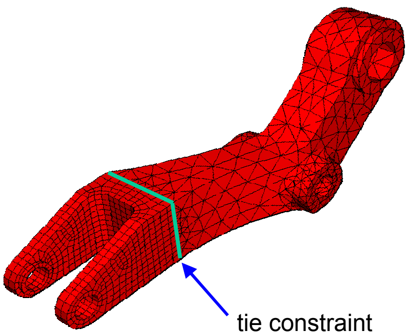
TRANSLATOR connector between Actuator and Actuator Arm



Surface-Based Ties

Surface-Based Ties

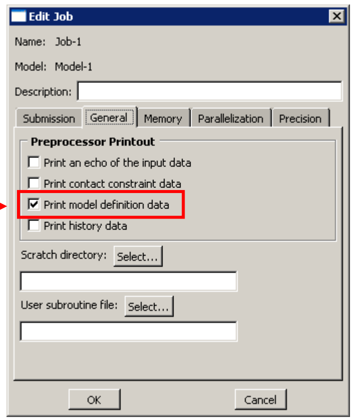
- **In ABAQUS fully constrained contact behavior is defined using tie constraints.**
  - A tie constraint provides a simple way to bond surfaces together permanently.
    - Easy mesh transitioning.
  - Surface-based constraint using a master-slave formulation.
  - The constraint prevents slave nodes from separating or sliding relative to the master surface.



Surface-Based Ties

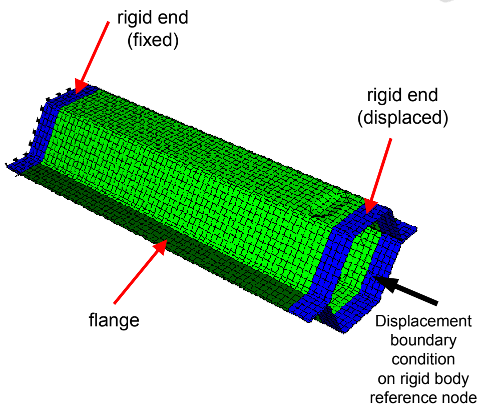
- Slave nodes that contact the master surface at the start of the simulation will be tied to it.
  - Slave nodes not initially tied will remain unconstrained throughout the analysis.
    - They will never “see” the master surface and will be able to penetrate it.
  - A table is printed in the data (`.dat`) file listing each slave node and the master surface nodes to which it will be tied if the preprocessor printout of the model data is requested:

```
*PREPRINT, MODEL=YES
```



Surface-Based Ties

- **Example: Crushing of a rail**
  - The dynamic collapse of a rail is modeled.
  - The ends of the rail are rigid bodies.
    - One end is fully constrained.
    - The other end is loaded with a prescribed displacement.
  - In this section, the flanges are attached using a tie constraint.
    - Different connections types will be used to connect the two halves of the rail later in this lecture.

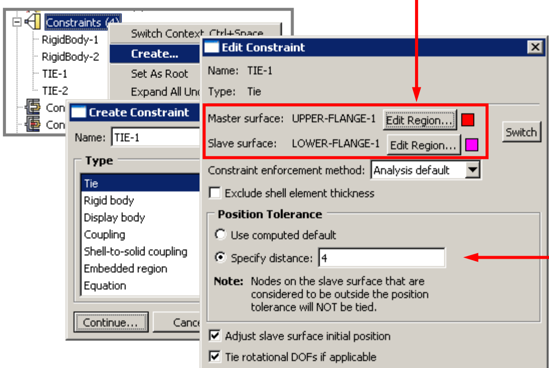


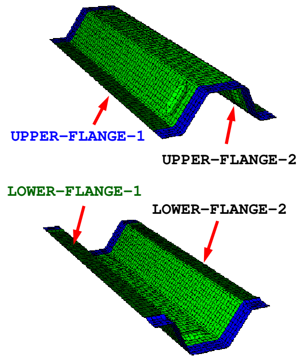
Undeformed rail

Surface-Based Ties

- **Example: Rail crush with tie constraints**

```
*TIE, NAME=TIE, POSITION TOLERANCE=4.0
LOWER-FLANGE-1, UPPER-FLANGE-1
LOWER-FLANGE-2, UPPER-FLANGE-2
```

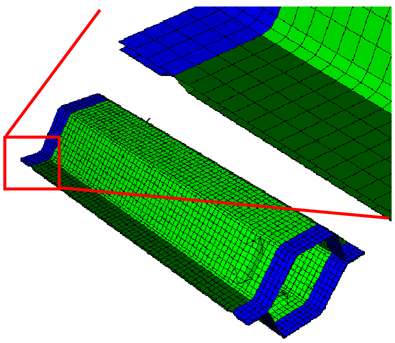




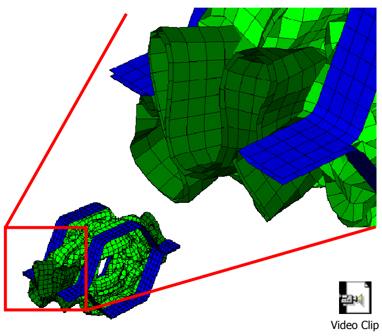
exploded view of rail assembly surfaces are labeled

Surface-Based Ties

- **Example (cont'd): Rail crush with tie constraints**
  - Flange surfaces remain tied throughout the analysis.
    - By default, slave nodes are adjusted to the master surface at the start of the analysis with shell thicknesses accounted for.



undeformed rail assembly

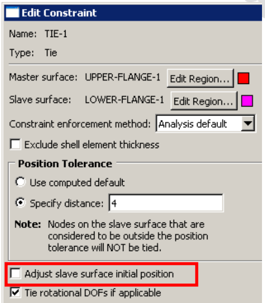


crushed rail assembly

Surface-Based Ties

– The repositioning of slave nodes in the tolerance region onto the master surface is strain-free.
  - In general automatic adjustments are recommended, especially if neither surface has rotations.
    – In this case a constant offset vector is used, which is not appropriate for noncoincident tied surfaces that undergo rigid body rotations.
  - Adjustments can be deactivated

```
*TIE, NAME=TIE, ADJUST=NO
```



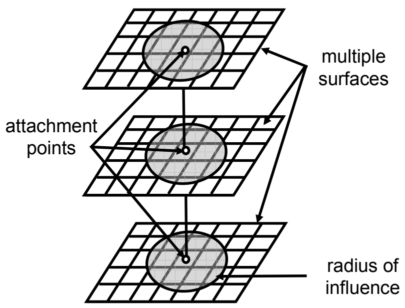
– Avoid applying boundary conditions to the slave nodes of a tie constraint;
  - doing so will overconstrain the model at those nodes.
  - The constraints will be enforced in an average sense using a penalty method, and the analysis computational cost may increase.

ABAQUS

Mesh-Independent Point Fasteners

Mesh-Independent Point Fasteners

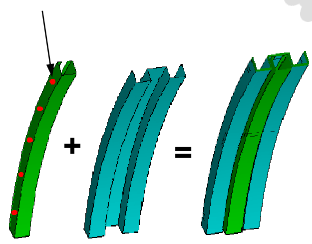
- **Mesh-independent point fasteners allow you to conveniently define point-to-point connections between surfaces.**
  - Fasteners can model spot welds, rivets, screws, bolts, or other types of fastening mechanisms.
  - They can be located anywhere between surfaces.
    - They need not be defined at nodal locations.
  - They can connect multiple layers;
    - i.e., the number of connected surfaces is not restricted.
  - The fastener acts over a specified radius of influence.



Mesh-Independent Point Fasteners

- The fastener capability combines either:
  - connector elements or
  - beam multi-point constraints

  with distributing coupling constraints to define a connection.
- Translation and rotation of the attachment points are related to the translation of nodes on the shell surface.
  - Twist is conveyed by the fastener independently of the shell element drill stiffness.



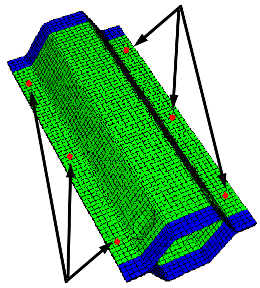
assembly with spot welds

- Fasteners can model either rigid, elastic, or inelastic connections with failure by using the generality of connector behavior definitions.
- Fasteners are not currently supported by ABAQUS/CAE

Mesh-Independent Point Fasteners

- **Example: Rail crush with rigid fasteners**
  - The dynamic rail collapse is analyzed again.
    - Flanges now are connected using six rigid fasteners modeled with connector elements.
  - Procedure to define the fasteners:

1. Define a connector section referencing an element set name with no user-defined elements.
    - Define connector behavior properties as usual.




```
*CONNECTOR SECTION, ELSET=Fasteners
 BEAM,
```

Beam connector type to define a rigid fastener

empty element set

ABAQUS will automatically generate the connector elements and include them in the set named **Fasteners**

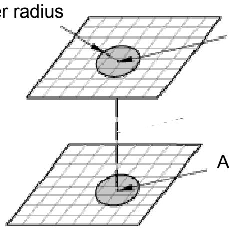
Mesh-Independent Point Fasteners

- **Example (cont'd): Rail crush with rigid fasteners**

2. Define the fastener properties.
    - Fasteners are assumed to have a circular projection onto the connected surfaces.
    - You are required to specify the radius of the fastener.

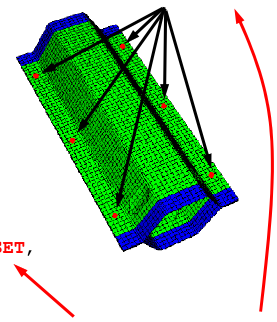
Fastener radius

```
*FASTENER PROPERTY, NAME=FASTENER-RIGID
4.0,
```



Mesh-Independent Point Fasteners

- **Example (cont'd): Rail crush with rigid fasteners**
  3 Define the fasteners.
  - All six fasteners are defined using one *FASTENER option




```
*CONNECTOR SECTION, ELSET=Fasteners
BEAM,

*FASTENER PROPERTY, NAME=FASTENER-RIGID
4.0,

*FASTENER, INTERACTION=F1, ELSET=Fasteners,
PROPERTY=FASTENER-RIGID, REFERENCE NODE SET=FASTENER_NSET,
NUMBER OF LAYERS=1, SEARCH RADIUS=7.0000E+00
```

Same empty element set

One less than the number of surfaces to be joined (2 surfaces – 1 = 1)

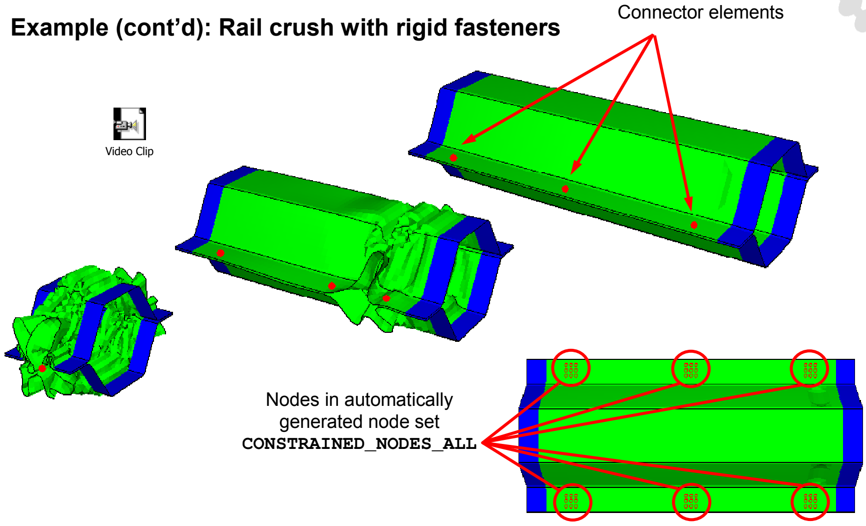
Fasteners will connect only to surfaces that are within this distance of reference nodes (surfaces identified automatically)

Reference nodes used to locate the fasteners

Mesh-Independent Point Fasteners

- **Example (cont'd): Rail crush with rigid fasteners**

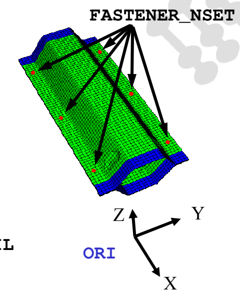
Video Clip



Mesh-Independent Point Fasteners

- **Alternative options for fastener creation**
  - Fastened surfaces can be specified directly using surface names.
    - In some cases the automatic surface identification method is not appropriate.
      - The automatic approach does not distinguish between coincident facets.
      - A number of surfaces may lie within the reference node search radius, but it may not be desirable to connect all of them.
  - Connector elements can be defined directly.
    - This option provides more control over the connector definitions;
      - however, it also requires more user input.
  - Rigid fasteners can be modeled with beam multi-point constraints (MPCs) rather than beam connector elements.
    - Connectors are often recommended because they can be easily modified to model more complex connection behaviors.

Mesh-Independent Point Fasteners



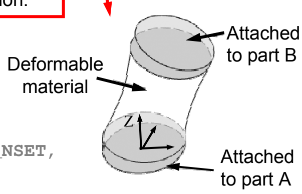
- **Example: Rail crush with deformable fasteners**
  - The rail flanges now are connected using fasteners that allow for plasticity, damage, and failure.

Modifications to the rigid fastener definition are in **black**:

```
*CONNECTOR SECTION, ELSET=Fasteners, BEHAVIOR=CONN_PLAS_FAIL
BUSHING
ORI,

*ORIENTATION, NAME=ORI
1,0,0, 0,0,-1

*FASTENER PROPERTY, NAME=FASTENER-RIGID
4.0,

*FASTENER, INTERACTION=F1, ELSET=Fasteners,
PROPERTY=FASTENER-RIGID, REFERENCE NODE SET=FASTENER_NSET,
NUMBER OF LAYERS=1, SEARCH RADIUS=7.0000E+00
```

BUSHING = PROJECTION CARTESIAN
+ PROJECTION FLEXION-TORSION

It does not impose any constraints on the 6 components of relative motion.



Connection diagram

Mesh-Independent Point Fasteners

- **Example (cont'd): Rail crush with deformable fasteners**
  - The options used to define the connector behavior:

```
*CONNECTOR BEHAVIOR, NAME=CONN_PLAS_FAIL
```

Elastic behavior:
```
*CONNECTOR ELASTICITY
```

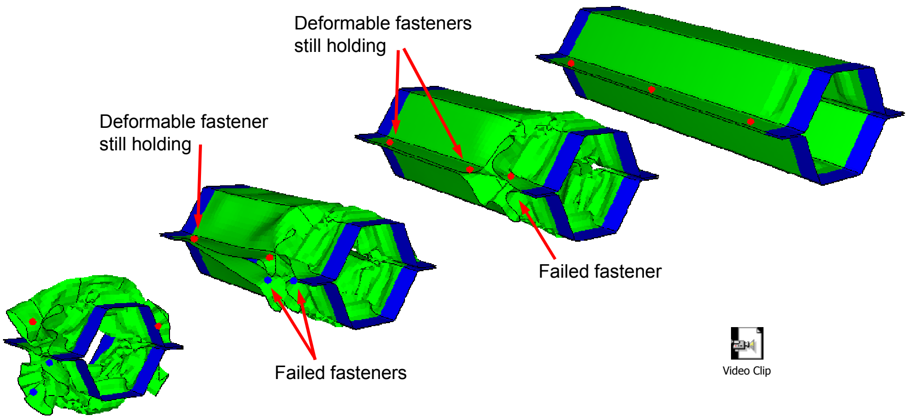
Plastic behavior:
```
*CONNECTOR DERIVED COMPONENT
*CONNECTOR PLASTICITY
*CONNECTOR POTENTIAL
*CONNECTOR HARDENING
```

Damage and failure:
```
*CONNECTOR DAMAGE INITIATION, CRITERION=PLASTIC MOTION
*CONNECTOR DAMAGE EVOLUTION
```

  - Connector damage and failure will be discussed in Lecture 9, *Material Damage and Failure*.
  - For more information on other connector behavior options refer to the *ABAQUS Analysis User's Manual* or the *Flexible Multibody Systems with ABAQUS* lecture notes

Mesh-Independent Point Fasteners

- **Example (cont'd): Rail crush with deformable fasteners**



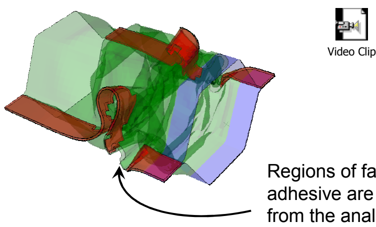
Video Clip

ABAQUS

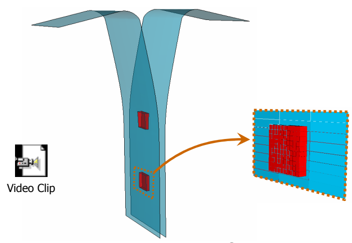
Mesh-Independent Surface Connections

Mesh-Independent Surface Connections

- **Introduction**
  - ABAQUS uses cohesive elements to model the behavior of adhesives or interfaces
  - Cohesive elements model separation between two initially bonded surfaces
  - Specific applications include
    - Progressive failure of adhesives
    - Delamination in composites
    - Detailed spot-weld modeling



Regions of failed adhesive are eliminated from the analysis

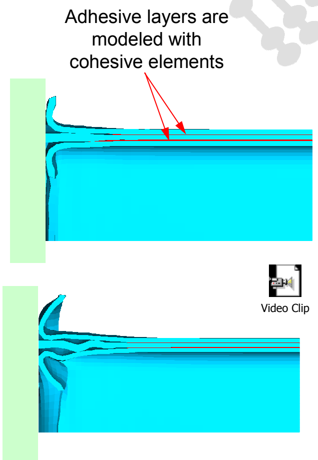


T-peel analysis: Cohesive elements are used for modeling spot-welds

ABAQUS

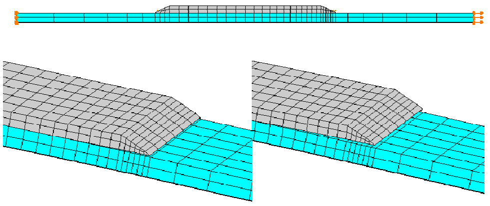
Mesh-Independent Surface Connections

- Complex fracture mechanisms are idealized with a macroscopic "cohesive law," which relates the traction across the interface to the separation
- Particularly attractive when interface strengths are relatively weak compared to the adjoining materials



Video Clip

Composite delamination



Beginning of separation   After separation

Skin/stiffener debonding in a composite structure

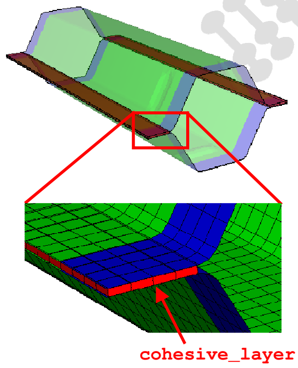
Video Clip

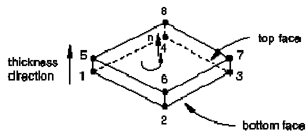
Mesh-Independent Surface Connections

- **Example: Rail crush with adhesive interface**
  - The rail flanges now are connected by an adhesive modeled with cohesive elements.

1. Define cohesive elements.
   - Cohesive element response is unique in the thickness and tangential directions.
   - By default, thickness direction is determined by the nodal connectivity.
     - Similar to continuum shell elements described in Lecture 2, *Elements*.

```
*ELEMENT, TYPE=COH3D8, ELSET=cohesive_layer
273, 1036, 1037, 1042, 1041, 691, 692, 697, 696
274, 1037, 1038, 1043, 1042, 692, 693, 698, 697
:
```

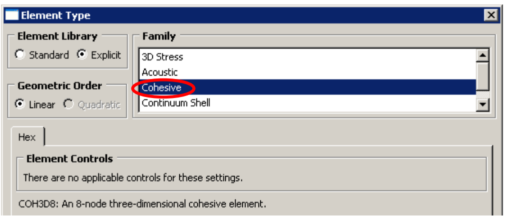


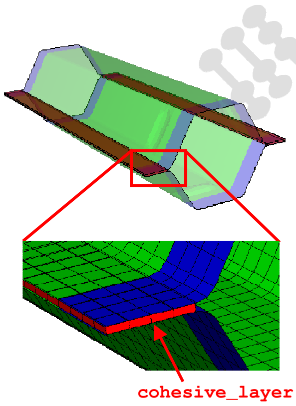


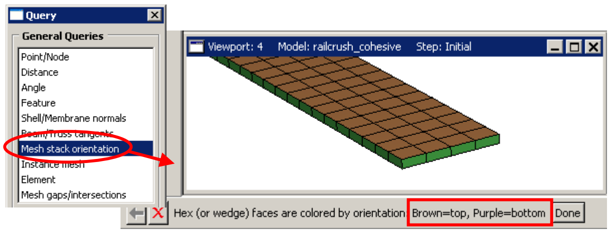
Default thickness direction

Mesh-Independent Surface Connections

- **Example (cont'd): Rail crush with adhesive interface**





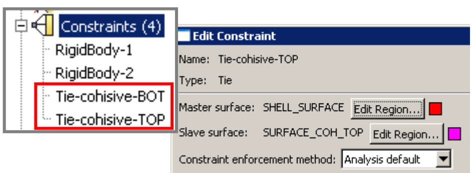


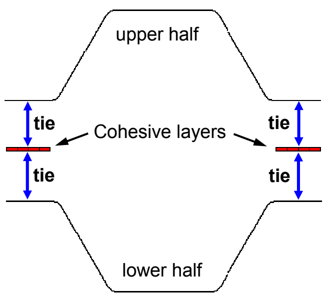
 ABAQUS

Mesh-Independent Surface Connections

- **Example (cont'd): Rail crush with adhesive interface**
  2. Tie the cohesive elements to the flange surfaces.
     - Cohesive elements may connect to other model components through:
       – shared nodes,
       – contact conditions, or
       – tie constrains (used in this example).

```
*TIE, NAME=cohesive_tie, ADJUST=NO
surface_coh_top, shell_surface
surface_coh_bot, shell_surface
```





Exploded view of rail cross-section

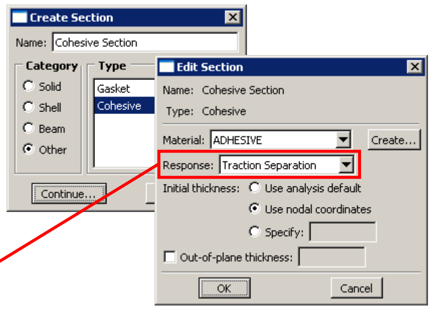
 ABAQUS

Mesh-Independent Surface Connections

- **Example (cont'd): Rail crush with adhesive interface**

  3 Define the cohesive elements section properties.

```
*ELEMENT, TYPE=COH3D8, ELSET=cohesive_layer
 273,1036,1037,1042,1041,691,692,697,696
 :

*COHESIVE SECTION, ELSET=cohesive_layer,
   MATERIAL=adhesive, THICKNESS=GEOMETRY,
   RESPONSE = TRACTION SEPARATION
```



Constitutive model specified directly in terms of **traction versus separation**

Intended for bonded interfaces where the interface thickness is negligibly small

Use the **continuum** response when the adhesive joint connects two bodies has a finite thickness.

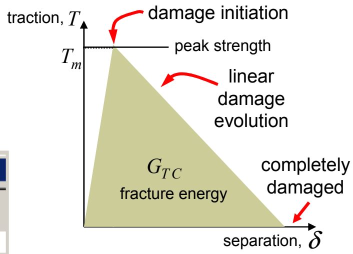
Use the **gasket** response to define a uniaxial stress-based constitutive model

 ABAQUS

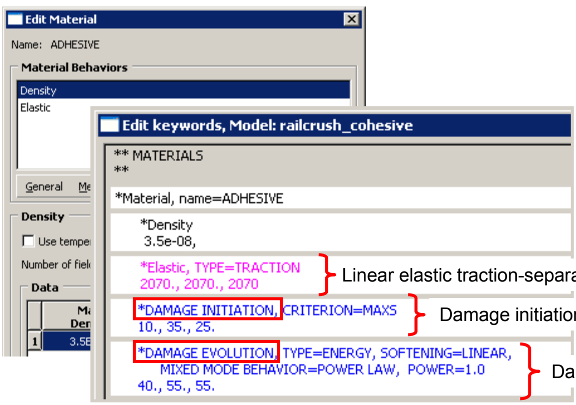
Mesh-Independent Surface Connections

- **Example (cont'd): Rail crush with adhesive interface**

  4 Define the cohesive elements constitutive behavior.



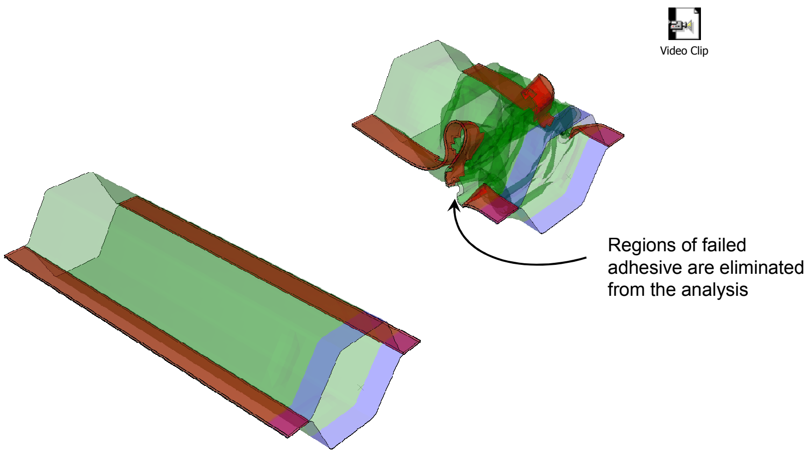
Traction-separation response



 ABAQUS

Mesh-Independent Surface Connections

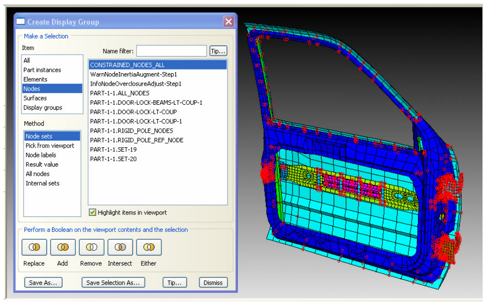
- **Example (cont'd): Rail crush with adhesive interface**



Tips for Diagnosing Constraint and Connection Errors

Tips for Diagnosing Constraint and Connection Errors

- **Viewing constrained nodes**
  - Constrained nodes can be viewed by displaying node set CONSTRAINED_NODES_ALL using display groups.



Constrained nodes displayed in ABAQUS/Viewer

Tips for Diagnosing Constraint and Connection Errors

- **Overconstraints**
  - An overconstraint means applying multiple kinematic constraints to a single degree of freedom.
    - overconstraints are **consistent** if all the constraints are compatible with each other.
      - All consistent constraints are resolved automatically by ABAQUS/Explicit.
    - overconstraints are **inconsistent/conflicting** if the constraints are incompatible with each other.
      - A correct **solution does not exist**.
        - The model is ill-posed.
      - Conflicting constraints may lead to inaccurate solutions or termination of the analysis.