Contact Analysis using MSC Nastran and Patran

NAS133 Course Notes

March 2014

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SECTION 1

CONCEPTS OF CONTACT IN LINEAR MSC NASTRAN

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OVERVIEW

- When to consider contact
- Types of contact – ‘Linear’ vs ‘Nonlinear’
- License issues with contact
- Contact Bodies/Types
- Contact Pairs/Tables
- Solution Requirements

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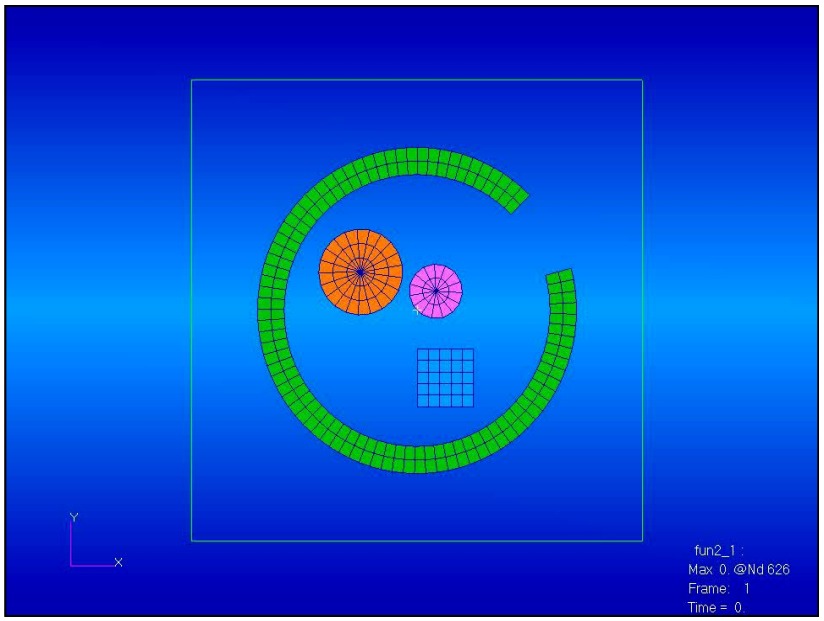
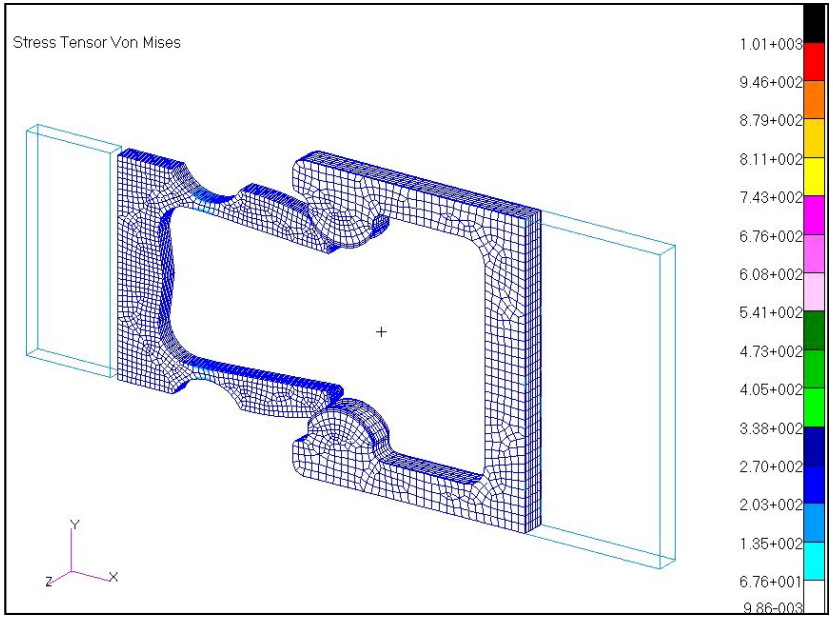
WHEN TO CONSIDER CONTACT

- **Intermittent interaction between unique components**





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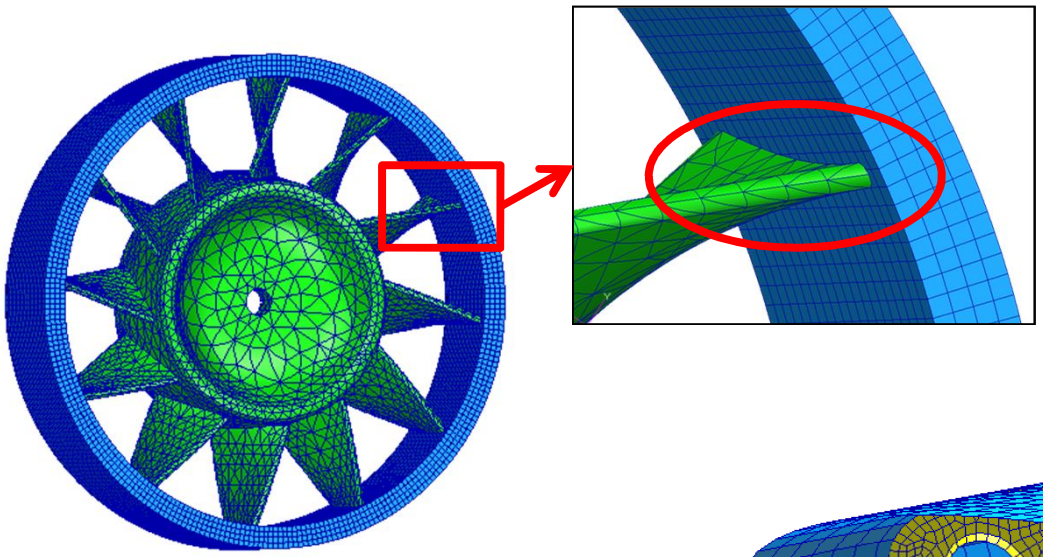
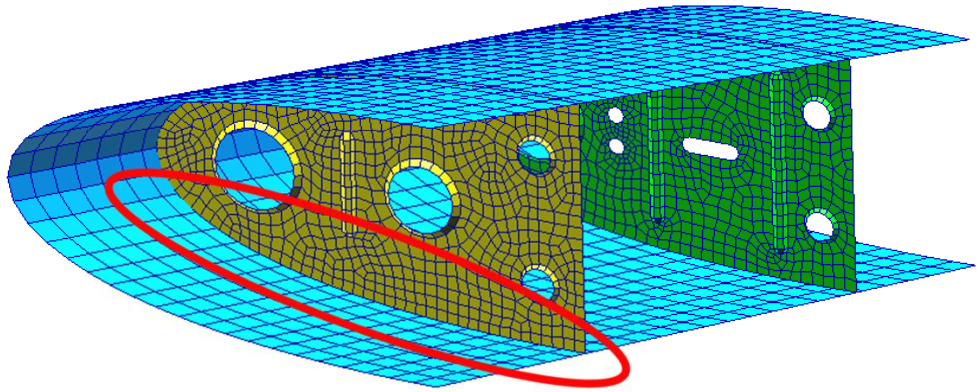
WHEN TO CONSIDER CONTACT

- **Connections between dissimilar meshes**



Solid Face-to-Face



Shell Edge-to-Face

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TYPES OF CONTACT

- **Linear**
  - Small deflection theory
  - Sliding neglected
  - All aspects of the simulation are ‘linear’ with the exception structural contact
  - Glued

- **Nonlinear**
  - Large deformation
    - Allows sliding between element edges/faces
  - No other limitations

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LICENSING OF CONTACT CAPABILITIES IN MSC NASTRAN

- **Linear**
  - Included in ‘basic’ MSC Nastran
    - Can be seen in license file as:
      - “FEATURE NA_Linear_Contact”
- **Nonlinear**
  - Requires SOL400 capability
    - Can be seen in license file as:
      - “FEATURE NA_Nonlinear”
      - “FEATURE NA_Implicit_Nonlinear”
      - “FEATURE NA_Adv_Nonlinear”

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CONTACT BODIES

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CONTACT BODIES

- **Contact evaluation requires the creation of 'Contact Bodies'**
- **Contact Bodies are groups of elements or geometries that are to be evaluated for contact with other Contact Bodies**
- **There are 2 types of Contact Bodies:**
  - Deformable
  - Rigid
- **Contact can occur between Deformable-Deformable or Deformable-Rigid**

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DEFORMABLE BODIES

- **A deformable body is a collection of finite elements**
- **A deformable body must contain elements of the same class:**
  - linear plates/shells, CQUAD4/CTRIA3
  - quadratic plates/shells, CQUAD8/CTRIA6
  - linear solid, CHEXA/CPENTA/CTETRA
  - quadratic solid, CHEXA/CPENTA/CTETRA

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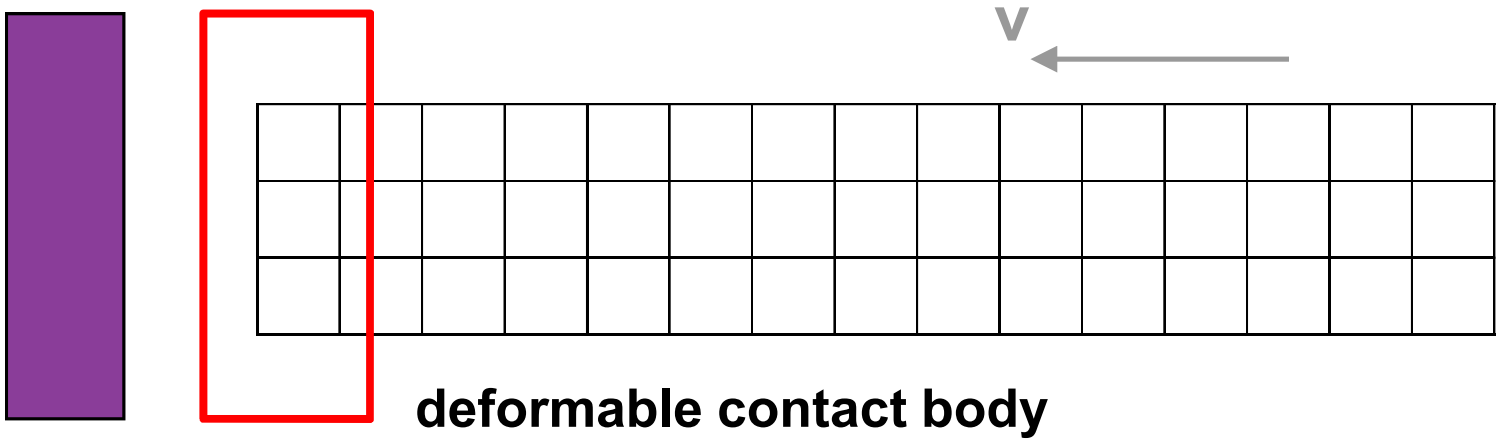
DEFORMABLE BODIES

- Each deformable body consists of one or more finite elements
- Nodes or elements must belong to NO MORE than one deformable body
- A deformable body does not need to completely correspond with a physical body:



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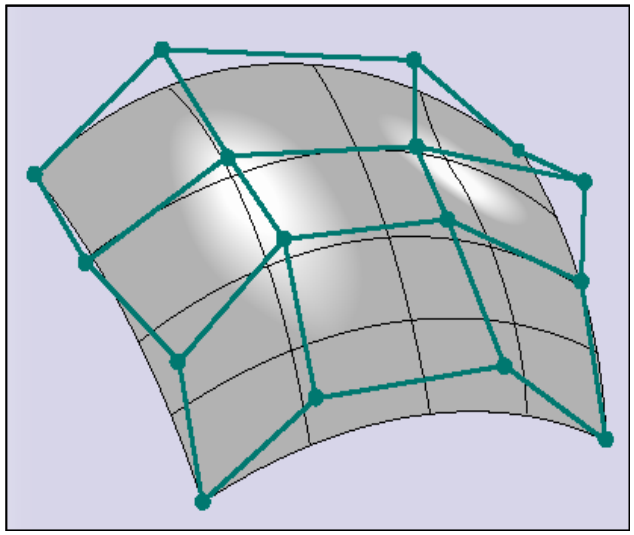
RIGID BODIES

- **Rigid Bodies can be modeled as**
  - PATCH3D (4 point patches)
  - BEZIER
  - NURBS2D
  - NURBS



- **It is recommended to use Bezier or NURBs:**
  - Continuity of the normal vector along the surface
  - A mathematical description
  - Robustness of the Contact Algorithm

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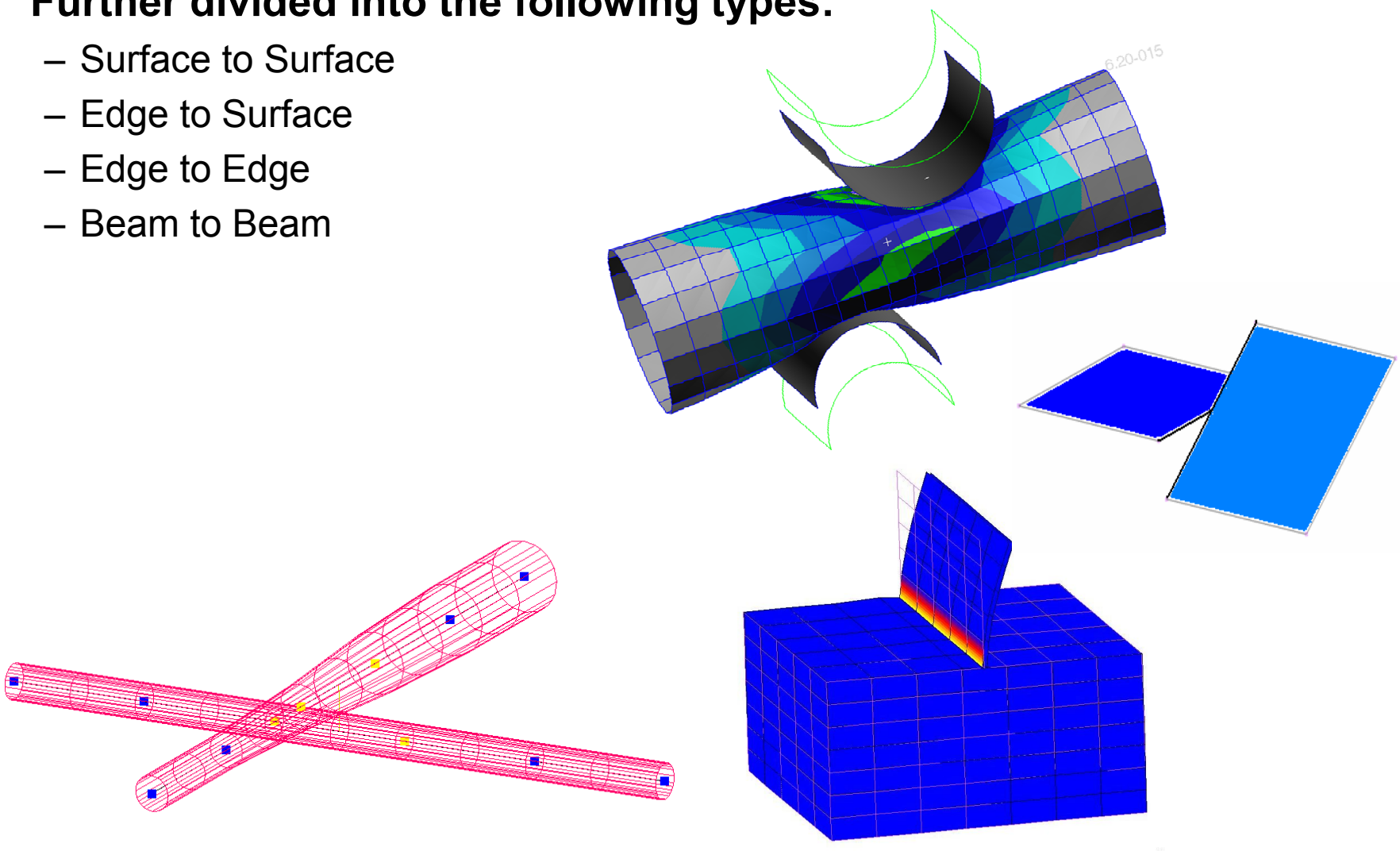
DEFORMABLE-DEFORMABLE CONTACT

- **Further divided into the following types:**
  - Surface to Surface
  - Edge to Surface
  - Edge to Edge
  - Beam to Beam



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CONTACT PAIRS/TABLES

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CONTACT PAIRS/TABLES

- **Patran/MSC Nastran allows 2 methods to define which contact bodies are to be considered for contact with which other bodies**
  - 'Contact Table'
    - As the name implies, this method allows the user to populate a 'table' which defines which bodies contact which other bodies
    - Easy to use
    - Only practical for relatively small (typically<10) numbers of contact bodies
  - 'Contact Pair'
    - Explicit definition of which bodies are to touch which other bodies
    - Allows ease of use when many (>10) contact bodies exist
- **Further, each method, allows for specification of the contact type as**
  - Touching – allows intermittent contact
  - Glued – enforces a permanent connection between contact bodies
- **Both methods define the same characteristics/properties, the choice of which method is be used comes down to which is 'easier', typically determined by the number of contact bodies**

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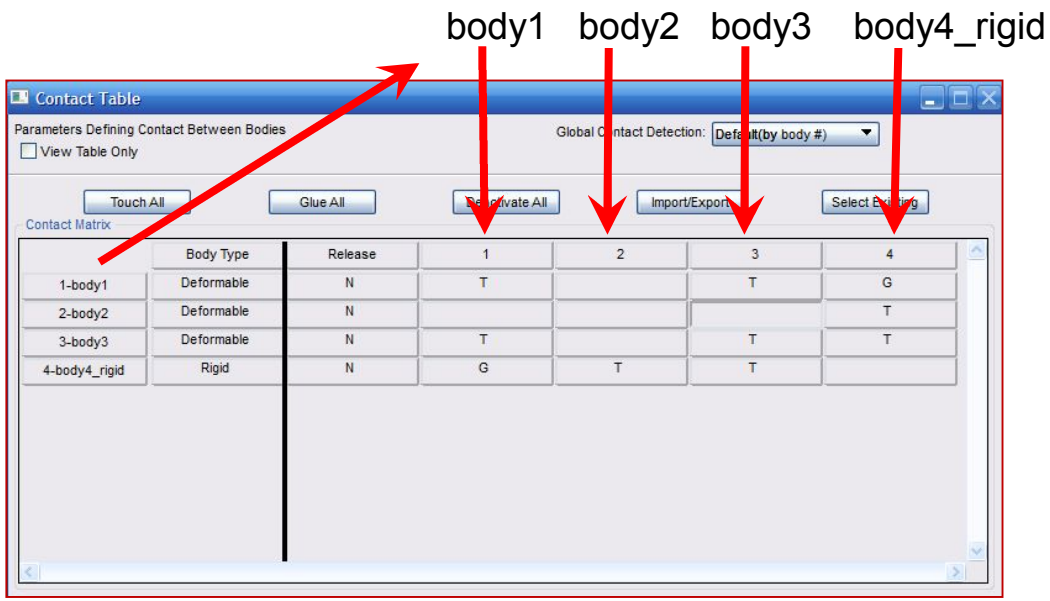
CONTACT TABLES

- **Best described using example:**



- **In this example:**
  - 'body1' is only allowed to 'touch' itself and 'body3'
  - 'body1' is 'glued' to 'body4_rigid'
  - 'body2' is only allowed to' touch' 'body4_rigid'
  - 'body3' is only allowed to 'touch' itself and 'body4_rigid'

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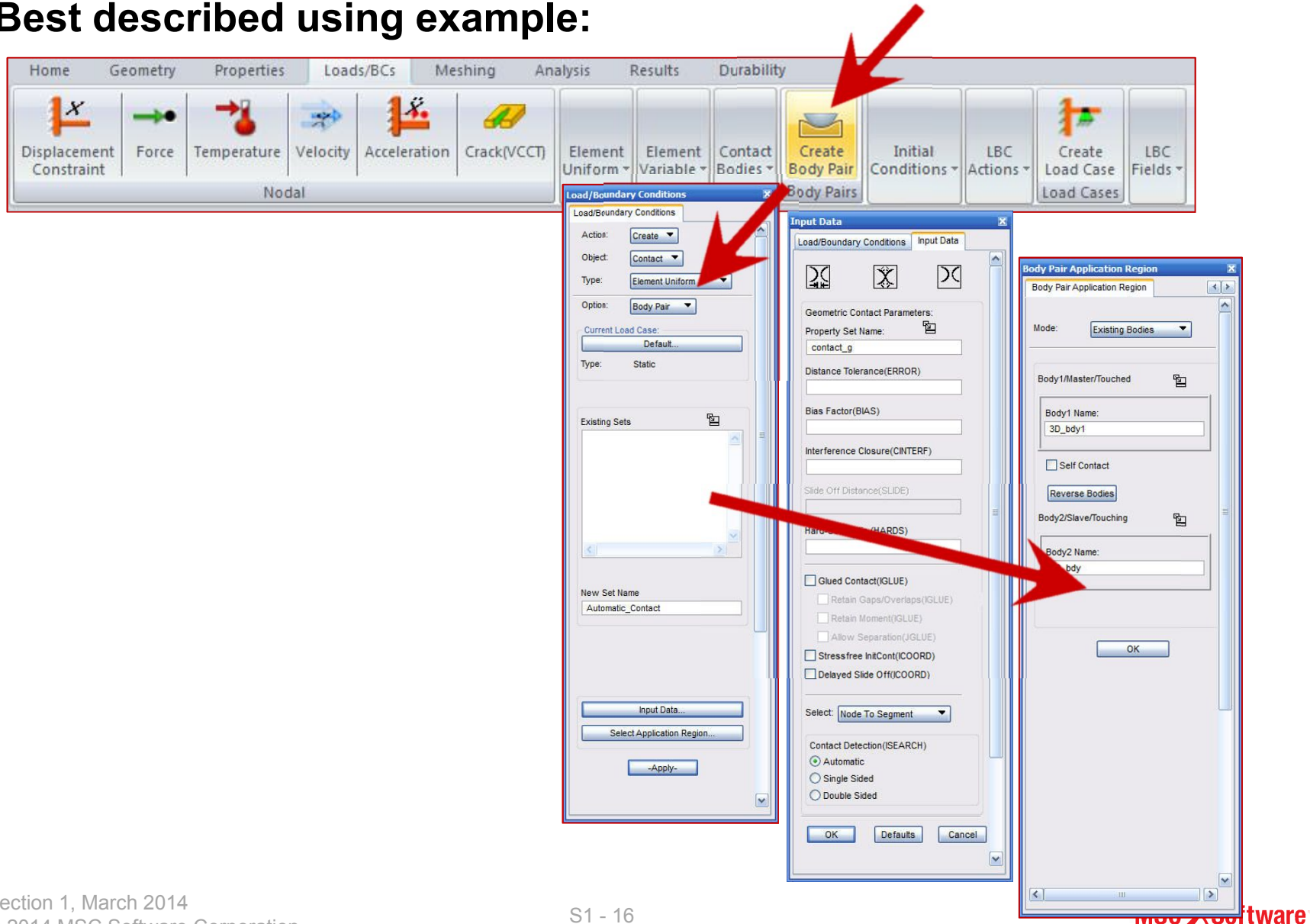
CONTACT PAIR

- **Best described using example:**



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SOLUTION REQUIREMENTS FOR CONTACT IN LINEAR ANALYSIS

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LINEAR ANALYSIS CONSEQUENCES

- **Solving a Linear System of Equations**

$$K \cdot u = P$$

- **In Linear Analysis it follows that:**
  - Direction of loads are independent of deformation
  - Displacements are directly proportional to the loads
  - Results for different loads can be superimposed

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FEM QUANTITIES IN LINEAR ANALYSIS

- **Kinematics**

$$u_e = T_{eg} \cdot u_g$$

u_e	T_{eg}	u_g
Element Displacement Vector	Displacement Transformation Matrix	Global Displacement Vector

---

- **Compatibility**

$$\varepsilon = B \cdot u_e$$

ε	B	u_e
Element Strains	Strain Displacement Matrix	Element Displacement Vector

---

- **Constitutive Law**

$$\sigma = D \cdot \varepsilon$$

σ	D	ε
Element Stresses	Stress-Strain Relationship	Element Strains

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FEM QUANTITIES IN LINEAR ANALYSIS

- **Equilibrium**

$$P = \sum T^{T}_{eg} \cdot F_e$$

P		$\sum T^{T}_{eg}$		F_e
External Load Vector	=	Force Transformation Matrix	·	Element Forces

---

- **Constraints**

$$u_g = \alpha$$

- **The transformation matrices do not change**
- **Force is directly proportional to the displacement**
- **The Constraints (SPC, MPC) do not change**

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NONLINEAR ANALYSIS

- **In Nonlinear Analysis, upon deformation the following changes are allowed:**
  - $T_{(disp)}$ geometric nonlinear
  - $T_{(force)}$ follower forces
  - B large strain
  - D material nonlinear
  - $T_{(disp)} <> T_{(force)}$ buckling
  - α constraints, contact

- **It follows that the system of equations gets nonlinear, the load sequence is unique and the results must not be superimposed – EVEN FOR LINEAR CONTACT ANALYSIS**

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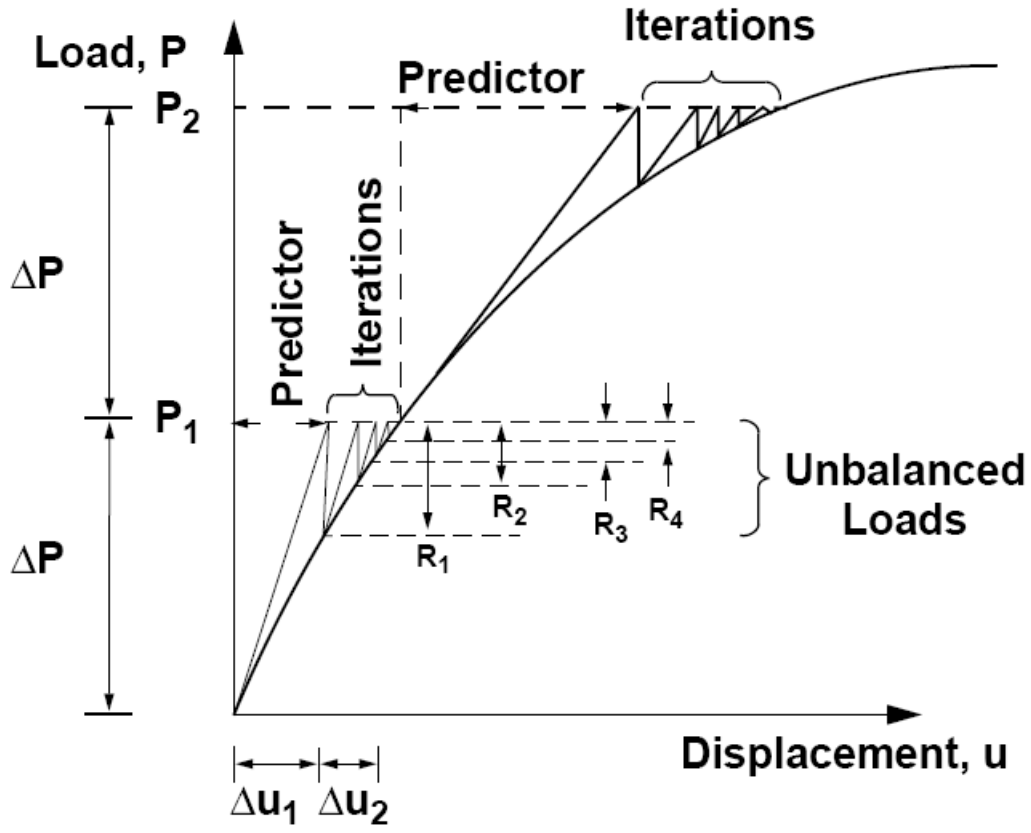
NONLINEAR ANALYSIS

- **Since the system of equations has become nonlinear an iteration strategy is needed**



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CONTACT IN LINEAR ANALYSIS

- **Even though we use the term ‘Linear Contact’ the simulations are actually nonlinear in nature due to the potential for intermittent contact**
- **As such, iterative solution techniques are required**
- **Superposition is no longer valid**
- **Solutions are load sequence dependent**

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LINEAR CONTACT SUMMARY

- Basic definition of Contact is through the use of Contact Bodies
- Contact bodies can be Deformable or Rigid
- Contact can be Touching or Glued
- Nonlinear and iterative solution techniques are required

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DOCUMENTATION

- **MSC Nastran Demonstration Problems (more than 50 examples for the use of SOL 400)**
- **MSC Nastran Quick Reference Guide**
- **MSC Nastran Release Guides**
- **Marc Users Manuals**
  - Volume A – Theory and User Information
  - Volume B – Element Library
  - Volume E – Demonstration Problems

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REVIEW QUESTIONS

1. **Why does SOL101 with contact require a nonlinear analysis?**

2. **How do I know if I need to use contact?**

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SECTION 2

CONTACT BODY DEFINITION

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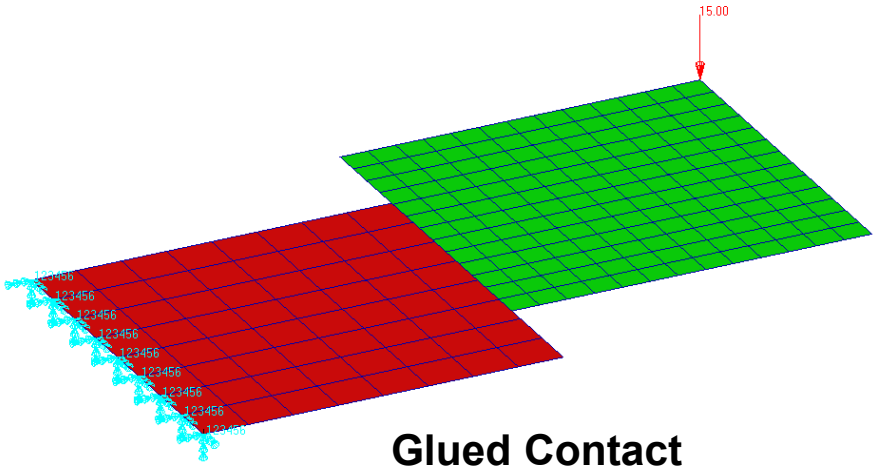
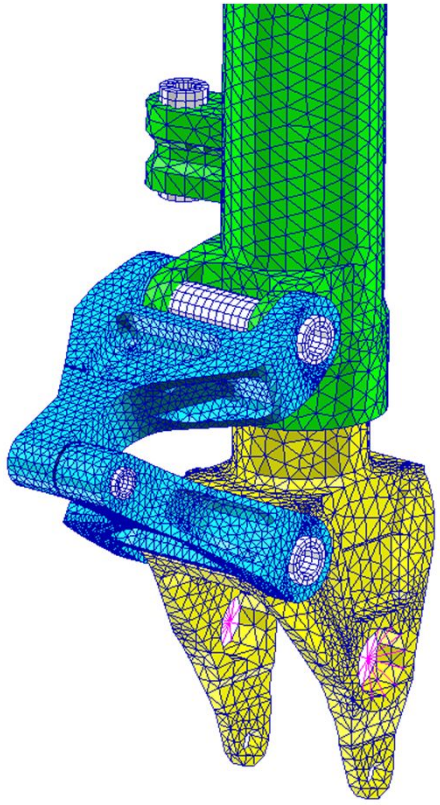
WHAT IS CONTACT ANALYSIS?

- **Contact analysis is the analysis of contact bodies (deformable or rigid) interacting with each other**
- **Contact can be deformable-deformable or rigid-deformable**
- **Contact analysis types**
  - Touching Contact
  - Glued Contact



Glued Contact



Touching Contact

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CONTACT IN OTHER SOLUTION SEQUENCES

- SOL 400 has general 2D and 3D contact capability
- SOL 101 has only 3D Contact capability
- The contact in SOL 101 is linear in the sense that materials and geometry stay linear
- Higher order elements are supported

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CONTACT IN SOL 400 and SOL 101

- **Two versions of contact are available**
  - Node to Segment
  - Segment to Segment
- **Two Friction Models are supported**
  - Bilinear Coulomb Friction
  - Bilinear Shear Friction
- **Glued Contact can be permanent or general, controlled via NLGLUE on BCPARA**
  - NLGLUE=0, permanent
  - NLGLUE=1, general

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CONTACT IN OTHER SOLUTION SEQUENCES

- **In other solution sequences only permanent glued contact is available. This is true for SOLs 103, 105, 107, 108, 109, 110, 111, 112 and 200.**
  - Permanent Glued Contact is a special case of glued contact
  - Primarily used to join 2 dissimilar meshes
  - Contact must initially be true (bodies should be in contact initially)
  - When edges or grids are to be glued, gluing can also be done for the rotational DOFs (Moment Carrying Glue)
  - Permanent contact constraint MPC equations are used. No nonlinear increments or iterations involved

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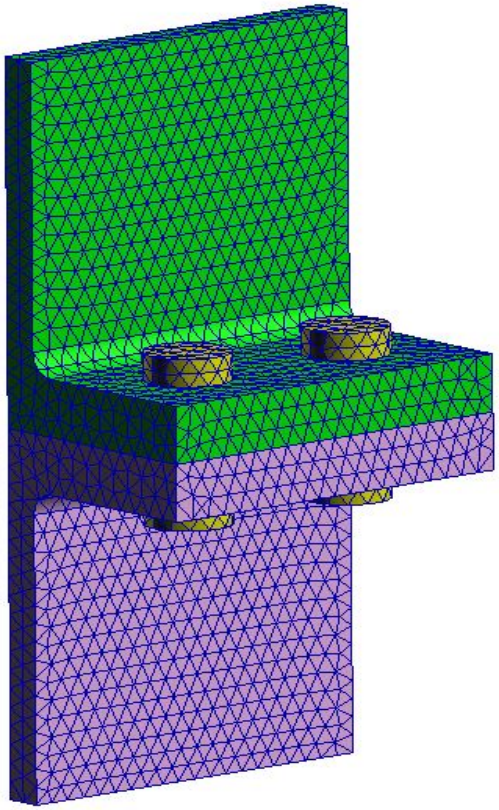
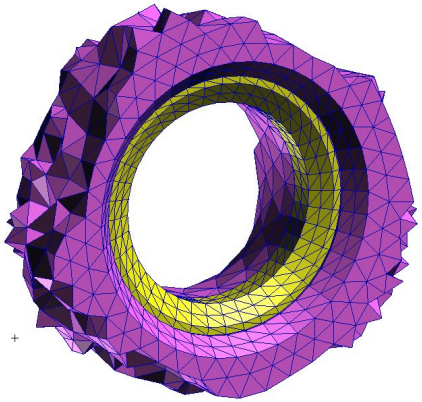
CONTACT ANALYSIS EXAMPLES

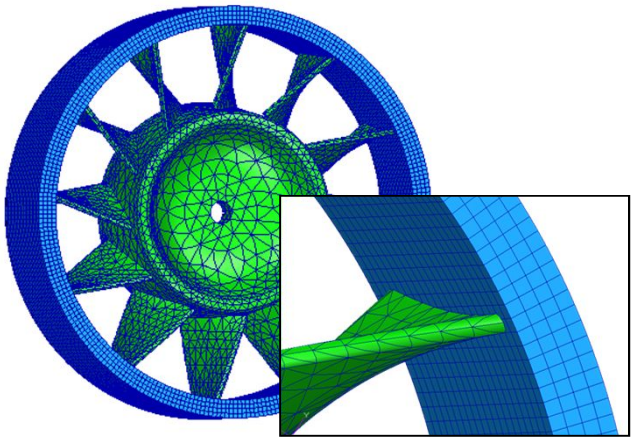
- **Solid-to-solid contact examples**



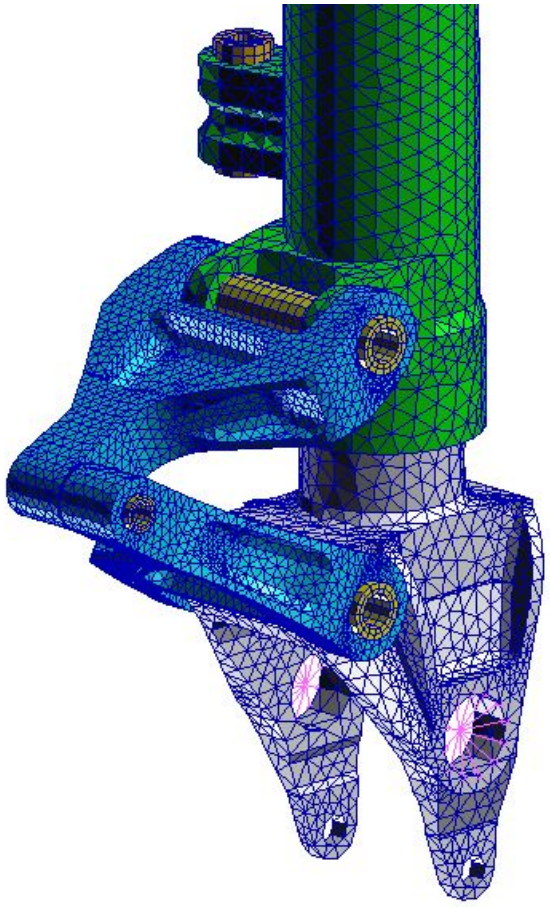
Preloaded Bolted Joint



Interference Fit



Glued Assembly



Lug-Clevis-Pin

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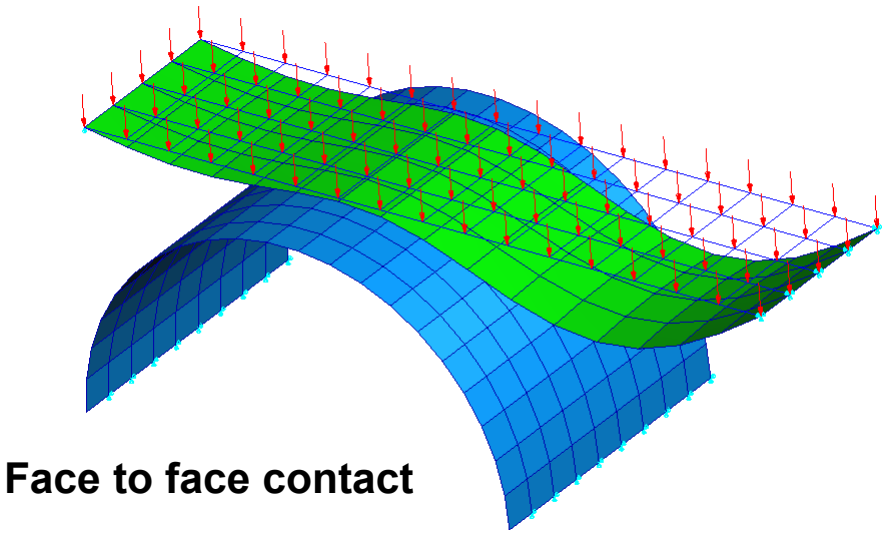
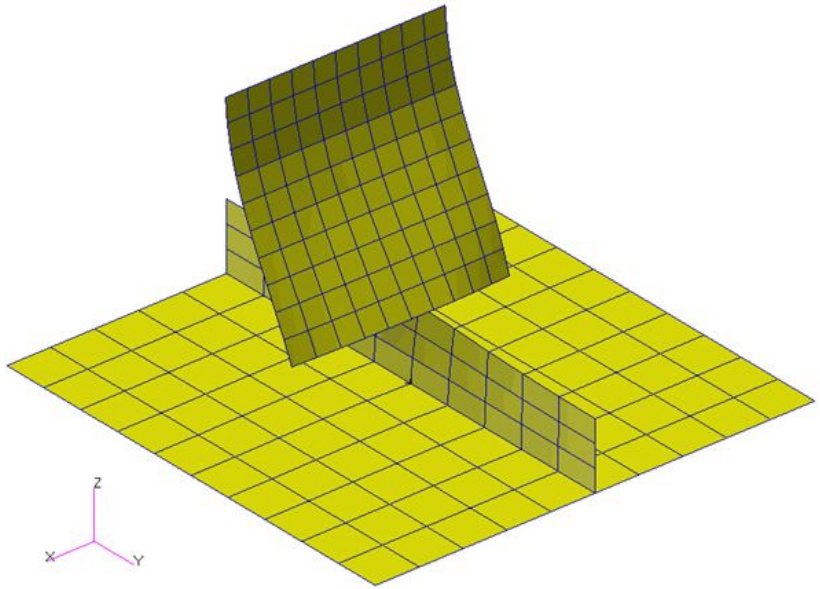
CONTACT ANALYSIS EXAMPLES

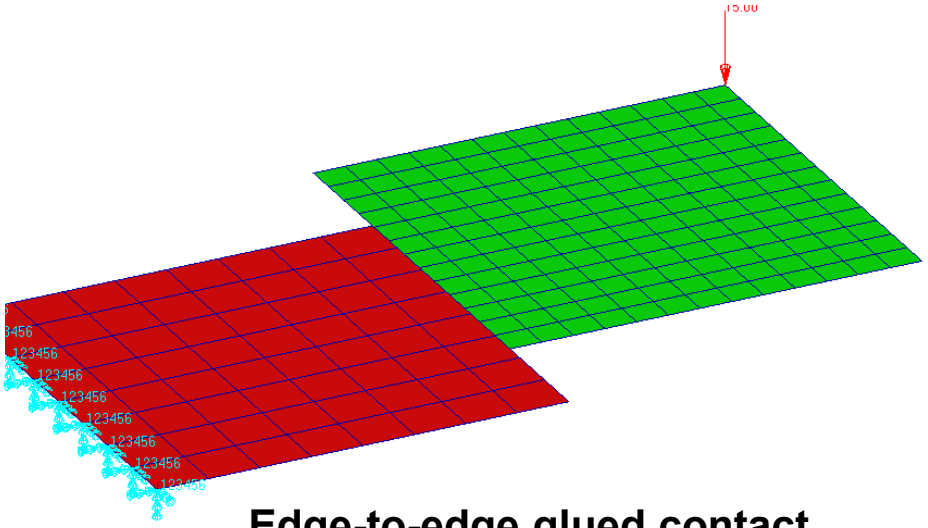
- **Shell-to-shell contact examples**



Face to face contact



Edge-to-edge contact



Edge-to-edge glued contact

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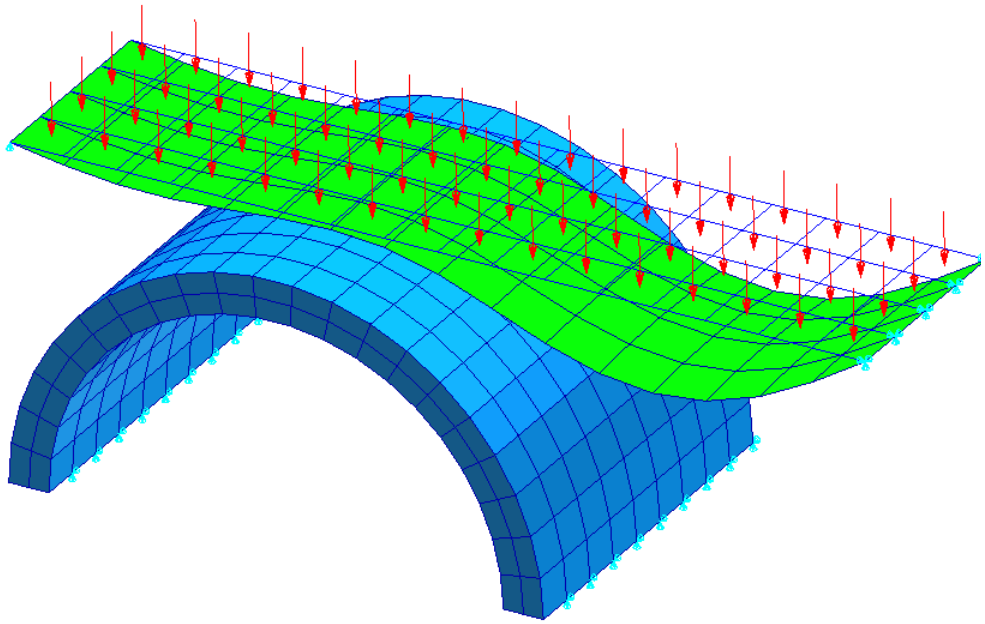
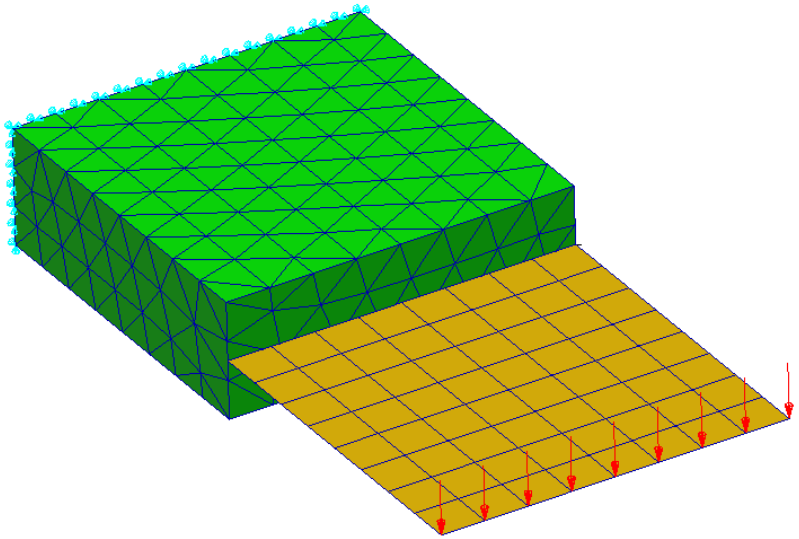
CONTACT ANALYSIS EXAMPLES

- **Shell-to-solid contact examples**



Face-to-face contact



Edge-to-face glued contact

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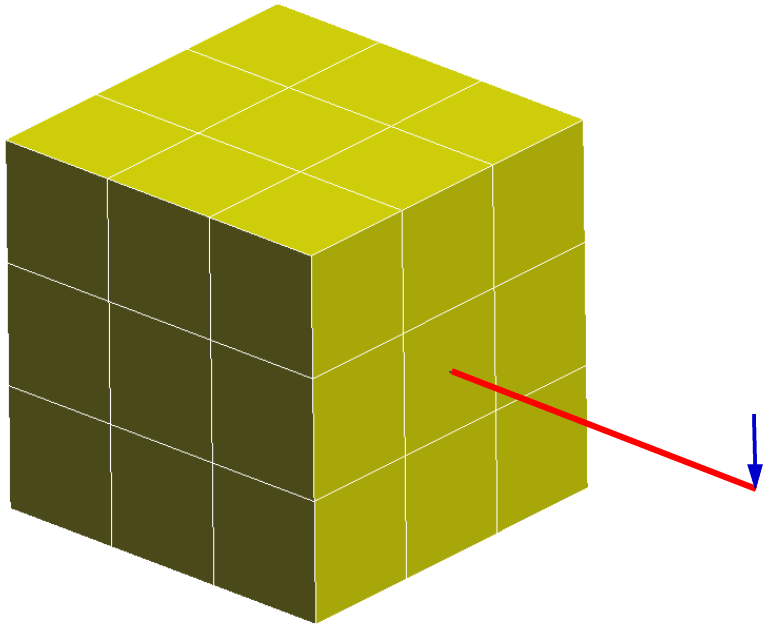
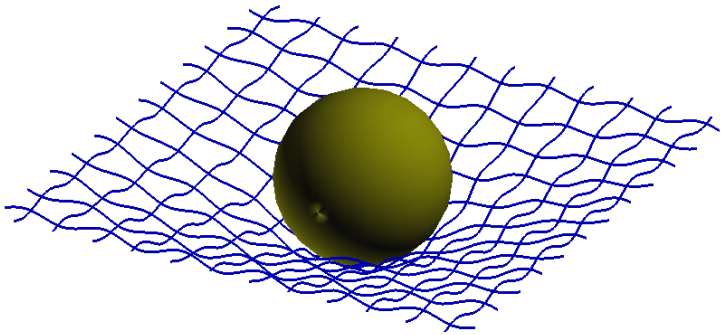
CONTACT ANALYSIS EXAMPLES

- **Beam contact examples**



Beam-to-solid glued contact



Beam-to-beam contact

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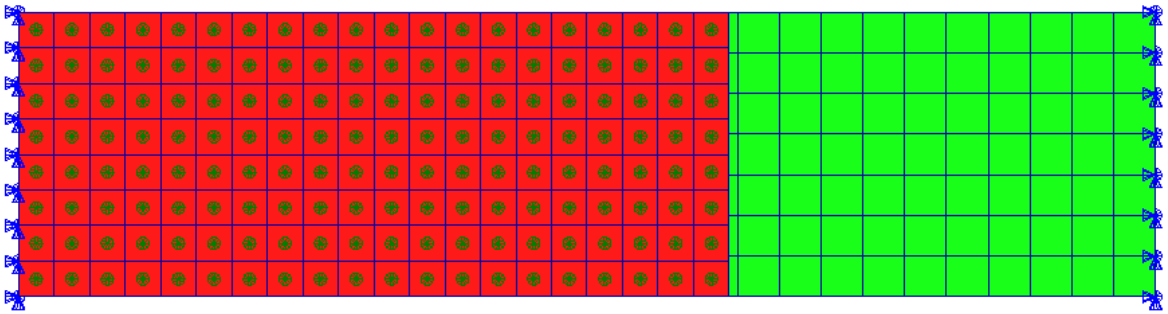
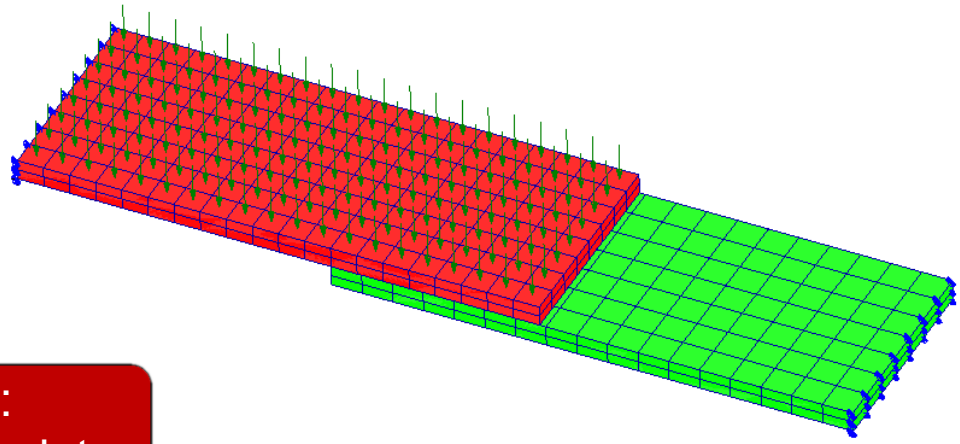
CASE STUDY

- **Two parts with different mesh densities**





Play Case study video:
NAS133_S2_cs_two_solid_plate

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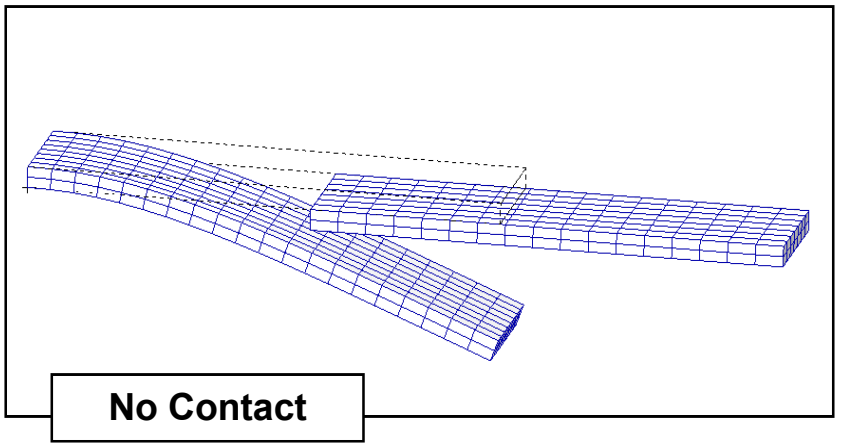
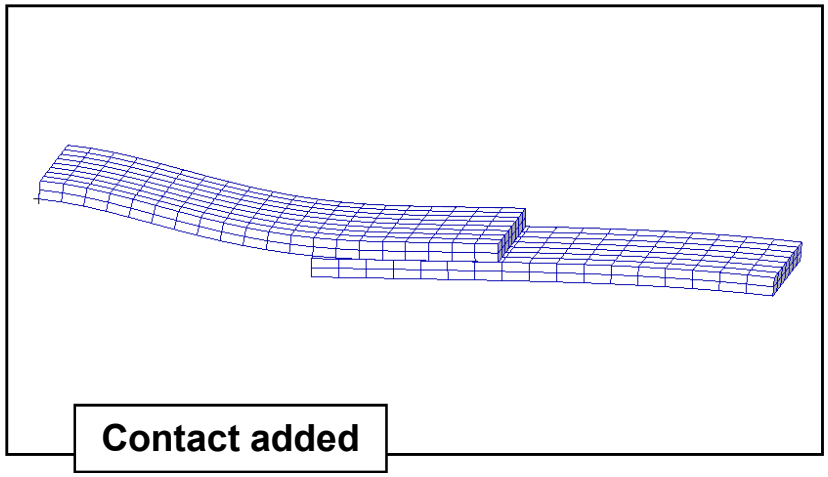
CASE STUDY

- **Initial Pass: No Contact definition**
  - Parts don't see each other
  - Parts pass through each other



- **Second Pass: Add Contact Body definition**
  - Parts now contact each other



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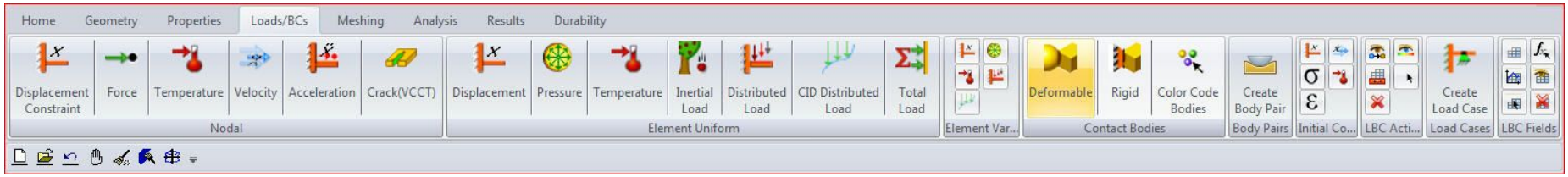
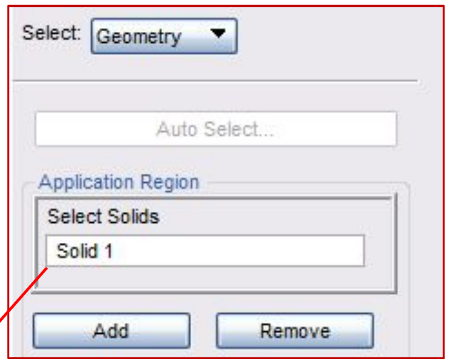
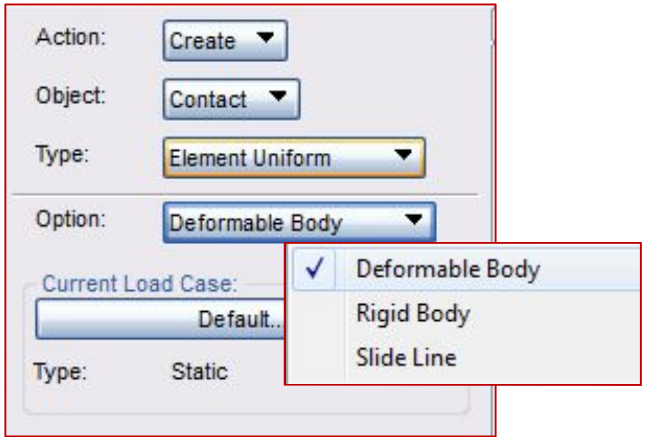
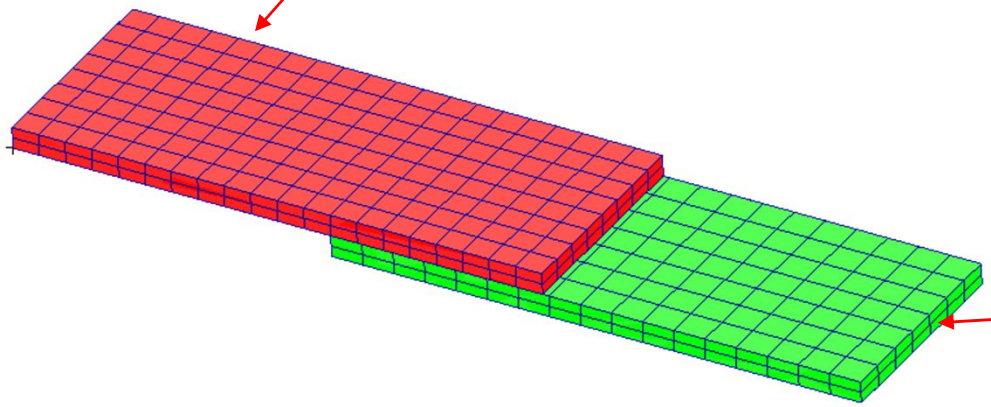
CASE STUDY

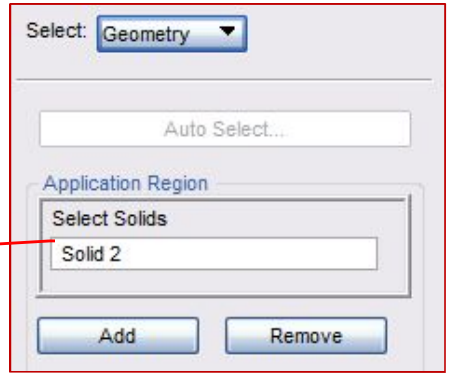


- **Easy contact body setup:**









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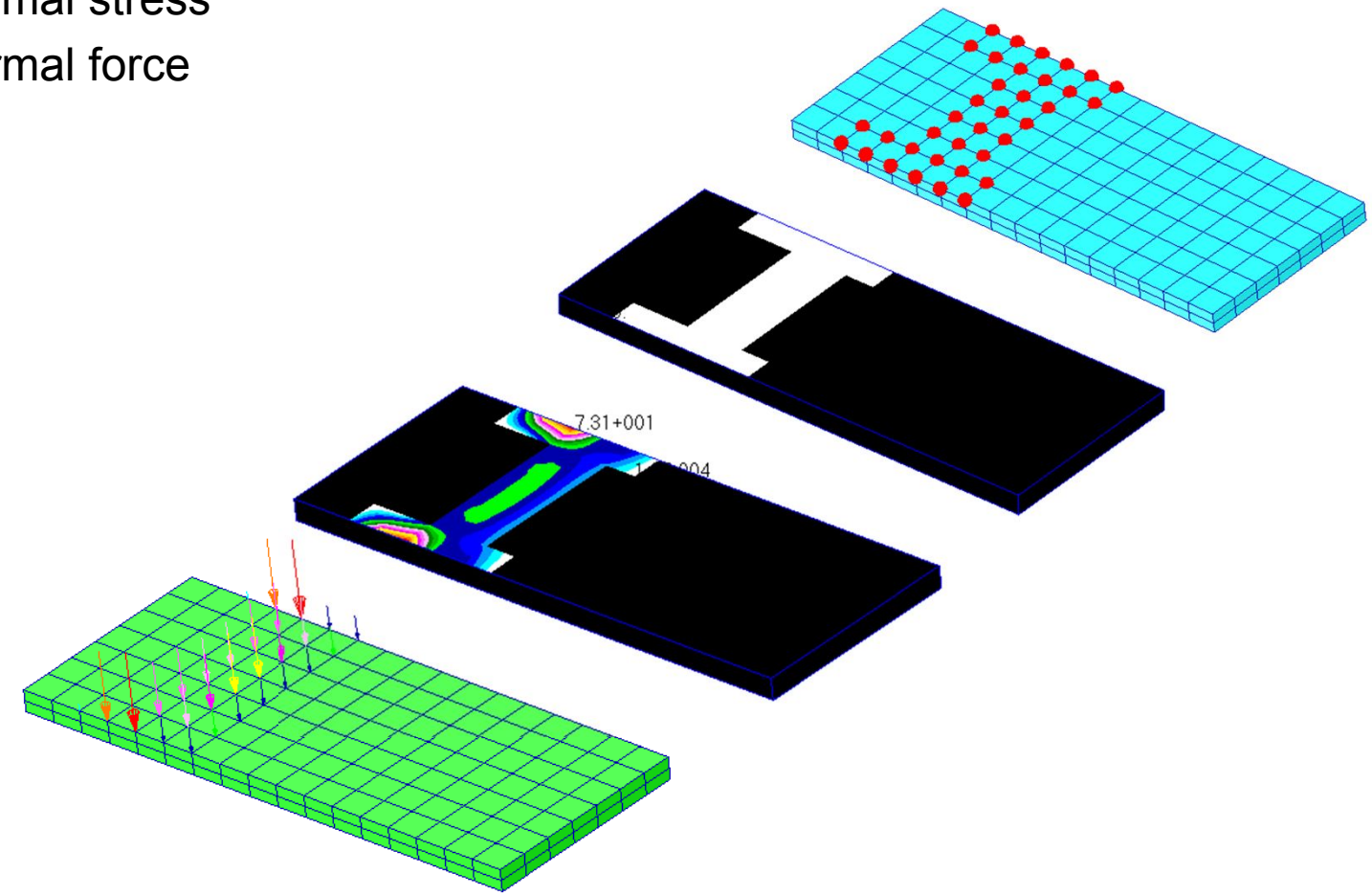
CASE STUDY

- **Comprehensive contact results plots:**
  - Contact status
  - Contact normal stress
  - Contact normal force



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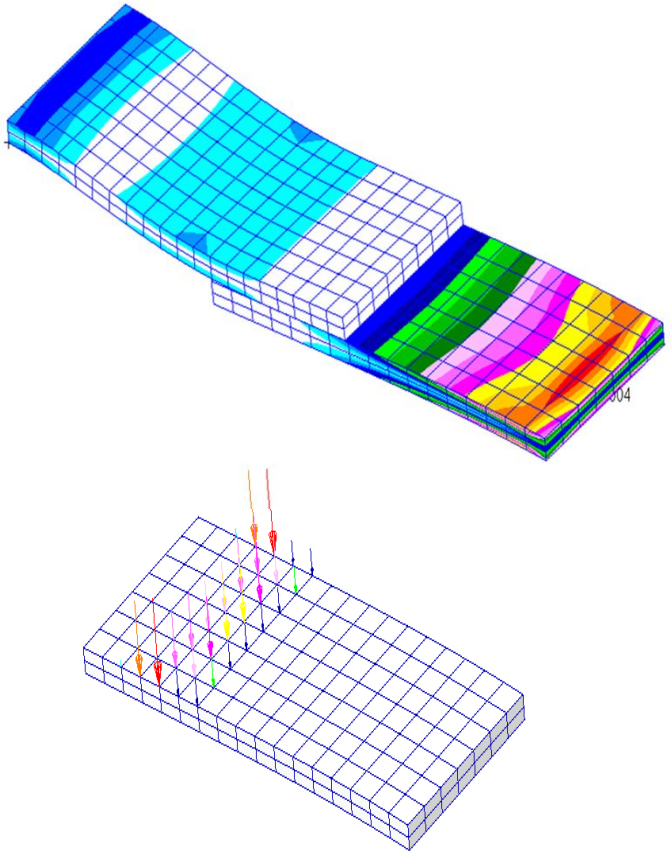
CASE STUDY

- **Summary of Case Study**
  - Studied contact between two parts with dissimilar meshes
  - Demonstrated easy contact setup
  - Solved the problem in Linear Static SOL 101
  - Plotted contact normal stress and force to gain insight into load path and contact status



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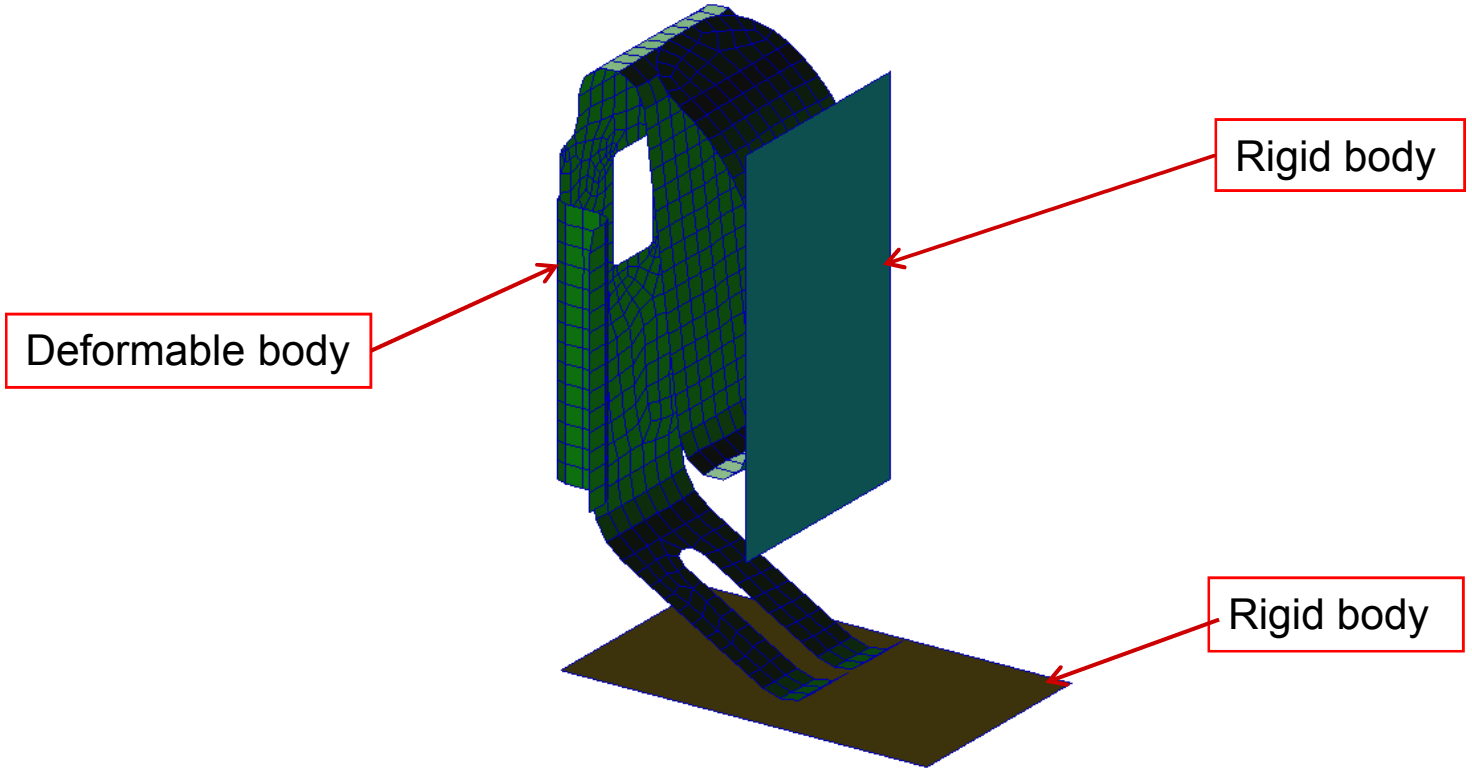
CONTACT BODY TYPES

- **Contact bodies can be deformable or rigid**
- **A deformable body is defined by element IDs or element properties**
- **A rigid body is defined by geometry (curves and surfaces) or 4-node patches**



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DEFINITION OF DEFORMABLE BODIES

- **A deformable body is a collection of finite elements**
- **A deformable body must contain elements of the same class:**
  - Linear shell — CTRIA3/CQUAD4
  - Quadratic shell — CTRIA6/CQUAD8
  - Linear solid — CHEXA/CPENTA/CTETRA
  - Quadratic solid — CHEXA/CPENTA/CTETRA
  - Beams — CBAR/CBEAM/CROD
- **Quadratic contact is supported and is automatically activated when contact body contains higher order elements**

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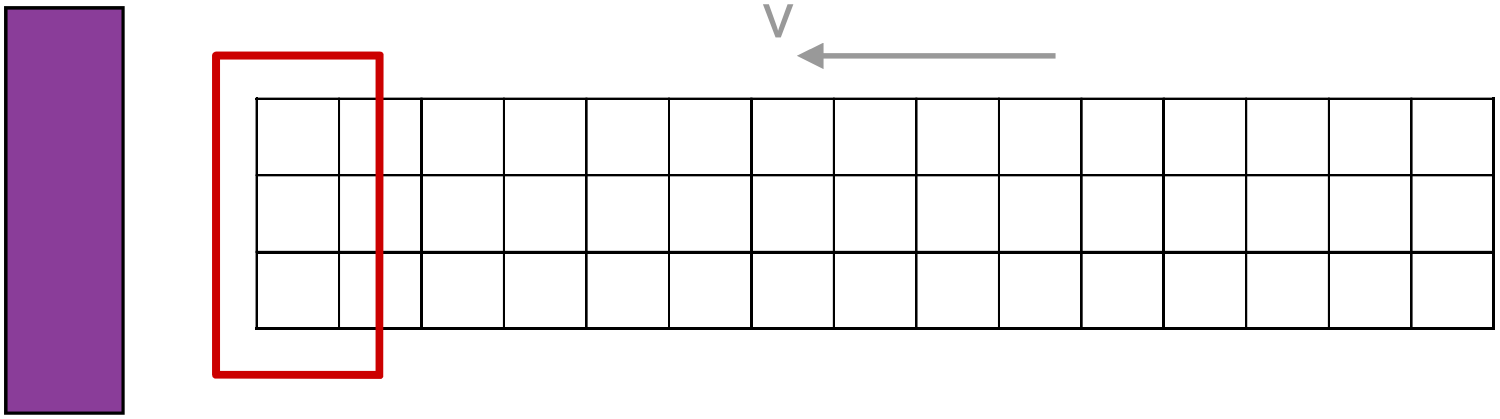
DEFINITION OF DEFORMABLE BODIES

- Each deformable body consists of one or more finite elements
- Nodes or elements must belong to no more than one deformable body
- A deformable body does not need to completely correspond with a physical body:



deformable contact body

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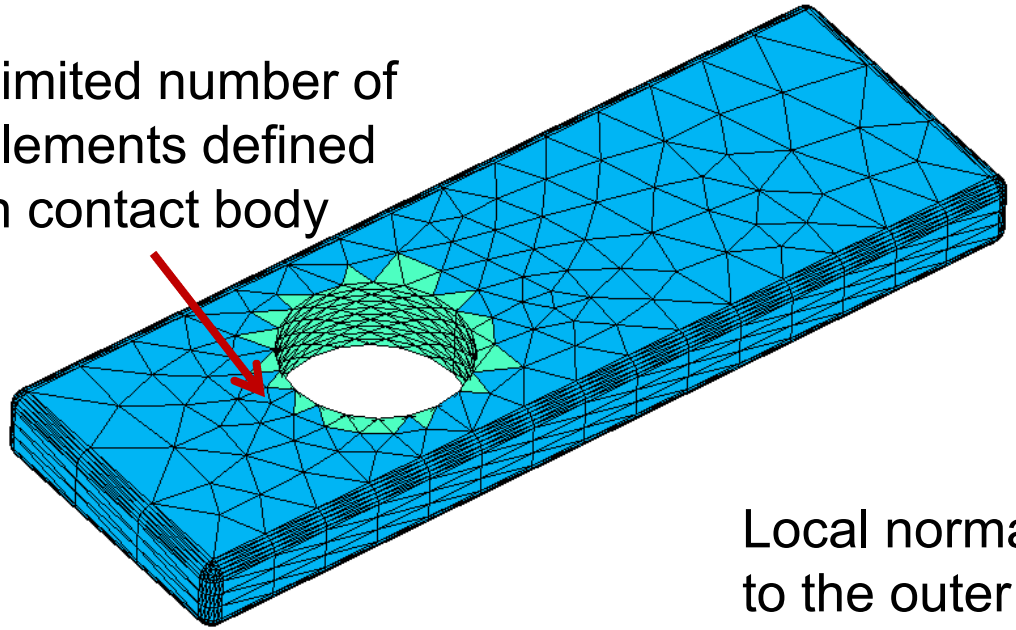
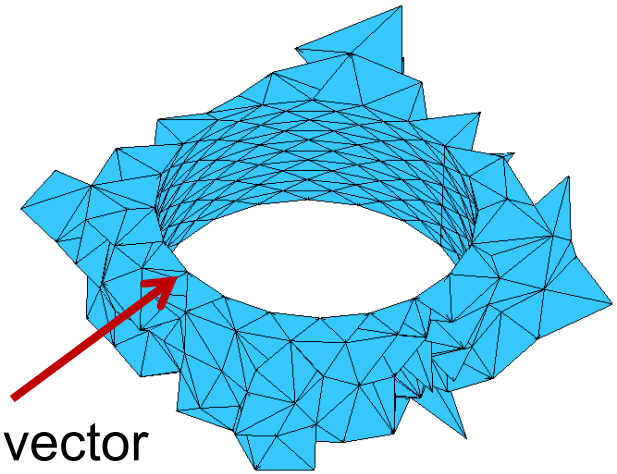
DEFINITION OF DEFORMABLE BODIES

- **On the other hand be careful with a subset of elements**
  - When using tet elements discontinuous element normals cause numerical problems. Hence the use of a subset of tet elements should be avoided:

Limited number of elements defined in contact body





Local normal vector to the outer boundary may be completely wrong

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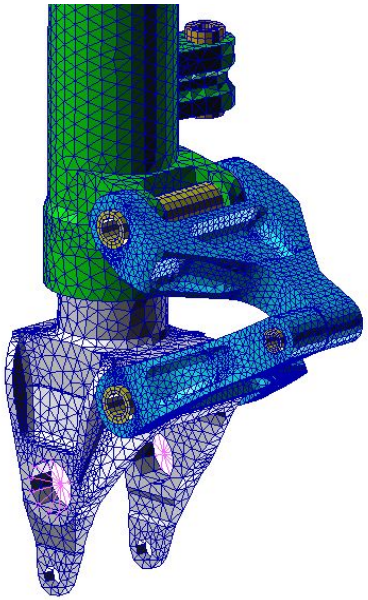
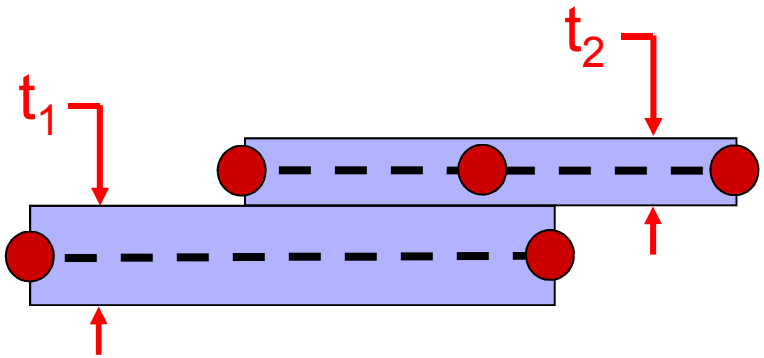
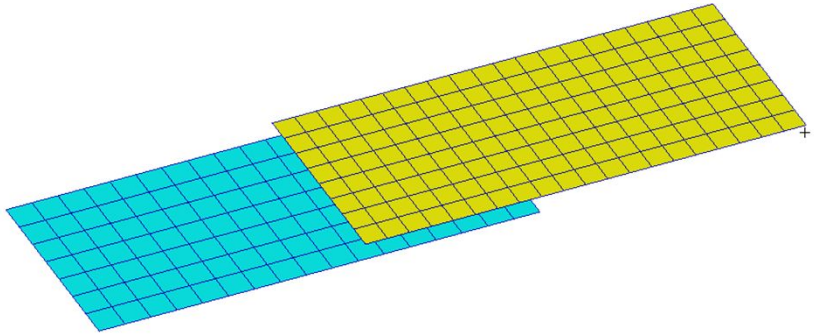
DEFINITION OF DEFORMABLE BODIES

- All deformable bodies can come in contact with each other, including self-contact
- MSC Nastran automatically figures out the free faces as potential contact surfaces
- MSC Nastran also automatically accounts for shell thicknesses







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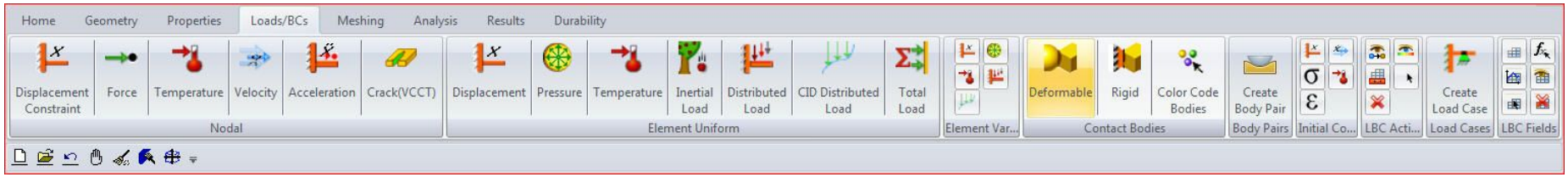
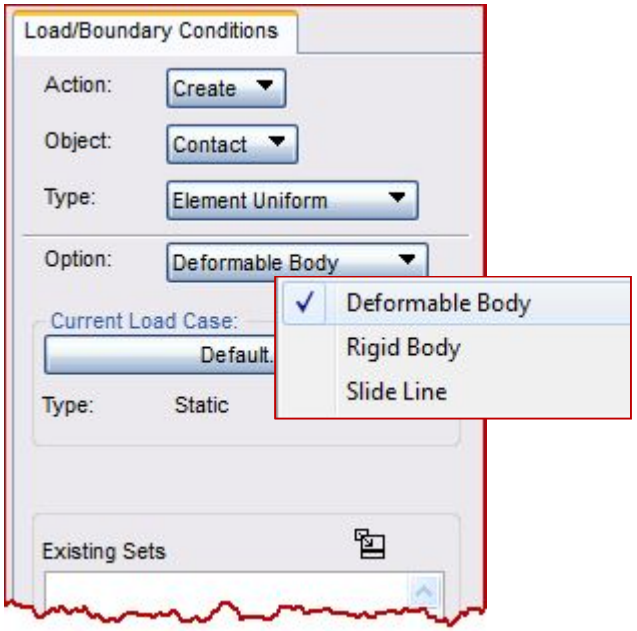
CREATING A DEFORMABLE BODY



- **Under the Patran Loads/BCs tab:**
  - Click Deformable
  - Enter New Set Name
  - Pick Target Element Type



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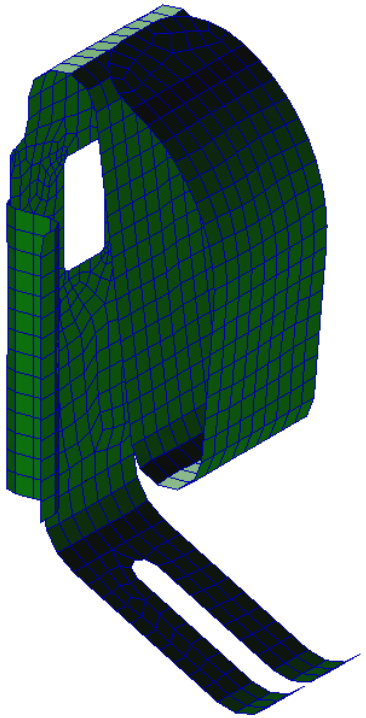
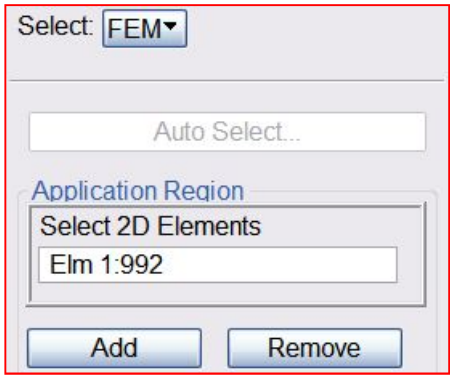
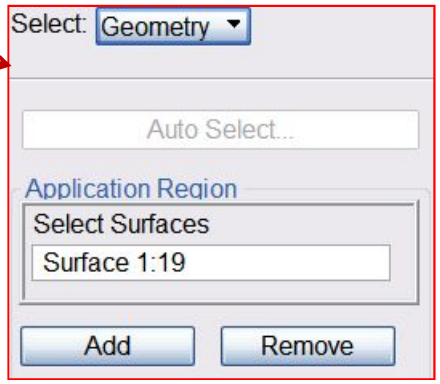
CREATING A DEFORMABLE BODY

- **On Select Application Region form: Select elements**
  - Directly
  - Based on geometry (if elements are associated with geometry) or
  - Based on associated property

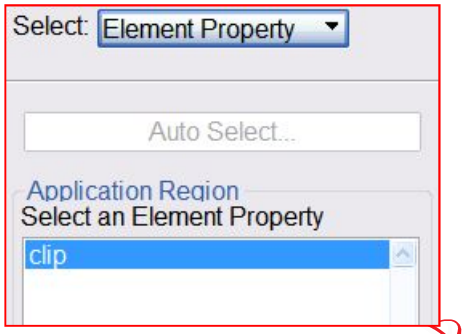




or



or



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CREATING A DEFORMABLE BODY

- **Contact Body MSC Nastran entries:**
- **BCBODY – Flexible or Rigid Contact Body**

BCBODY	BID	DIM	BEHAV	BSID	ISTYP	FRIC	IDSPL	CONTROL	
	NLOAD	ANGVEL	DCOS1	DCOS2	DCOS3	VELRB1	VELRB2	VELRB3	
	"ADVANCE"	SANGLE	COPTB						
	"RIGID"	CGID	NENT	--- Rigid Body Name ---					
	"GROW"	GE1	GE2	GE3	TAB-GE1	TAB-GE2	TAB-GE3		

BSURF	ID	ELID1	ELID2	ELID3	ELID4	ELID5	ELID6	ELID7	

- **BSURF – Defines a contact body by Element IDs**

  (Referenced by BSID in BCBODY)

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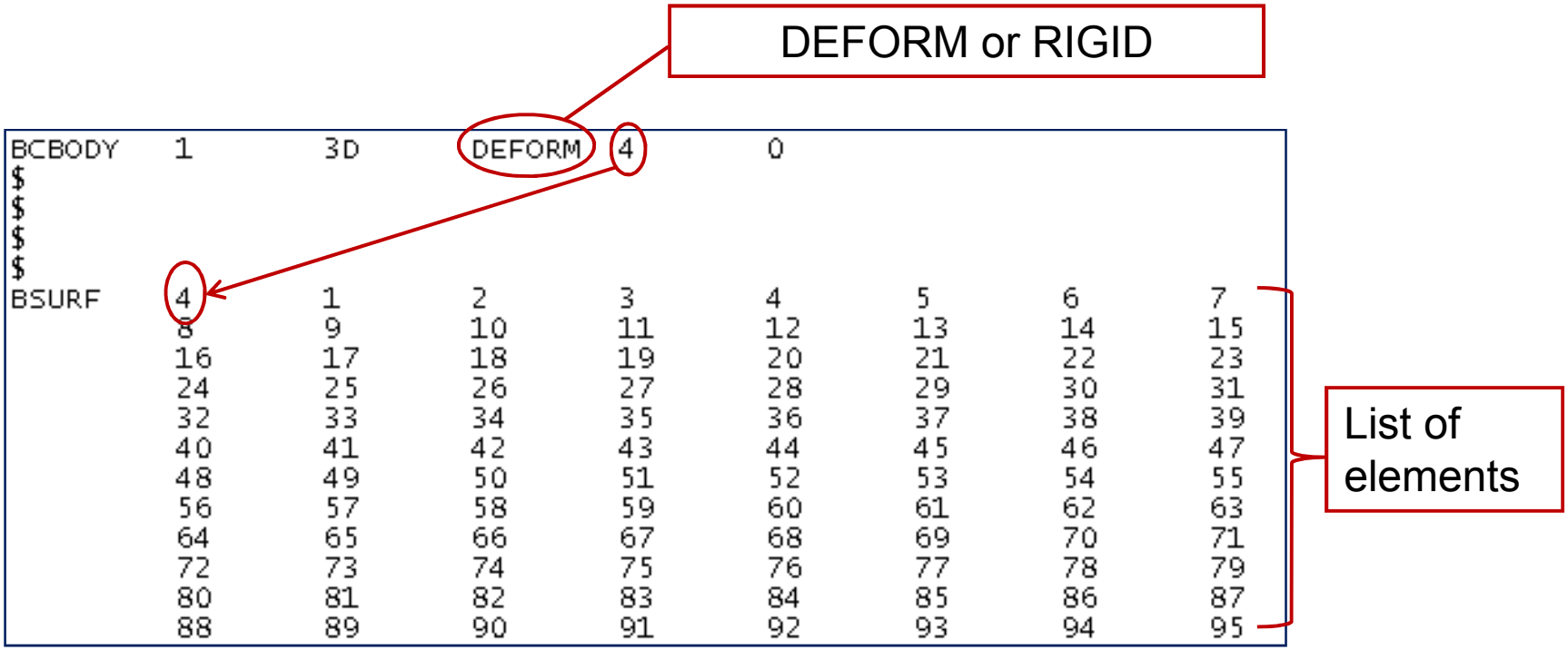
CREATING A DEFORMABLE BODY

- **Sample MSC Nastran input file:**




```
BCBODY   1        3D       DEFORM   4        0
$
$
$
$
BSURF    4        1        2        3        4        5        6        7
         8        9        10       11       12       13       14       15
         16       17       18       19       20       21       22       23
         24       25       26       27       28       29       30       31
         32       33       34       35       36       37       38       39
         40       41       42       43       44       45       46       47
         48       49       50       51       52       53       54       55
         56       57       58       59       60       61       62       63
         64       65       66       67       68       69       70       71
         72       73       74       75       76       77       78       79
         80       81       82       83       84       85       86       87
         88       89       90       91       92       93       94       95
```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CREATING A DEFORMABLE BODY

- **Property-based MSC Nastran entry:**
  - BCPROP: Defines a contact body to Element Property (Referenced by BSID in BCBODY)

1	2	3	4	5	6	7	8	9	10
BCPROP	ID	IP1	IP2	IP3	IP4	IP5	IP6	IP7	
	IP8	IP9	etc.						

Example:

BCPROP	1	101	201	301					

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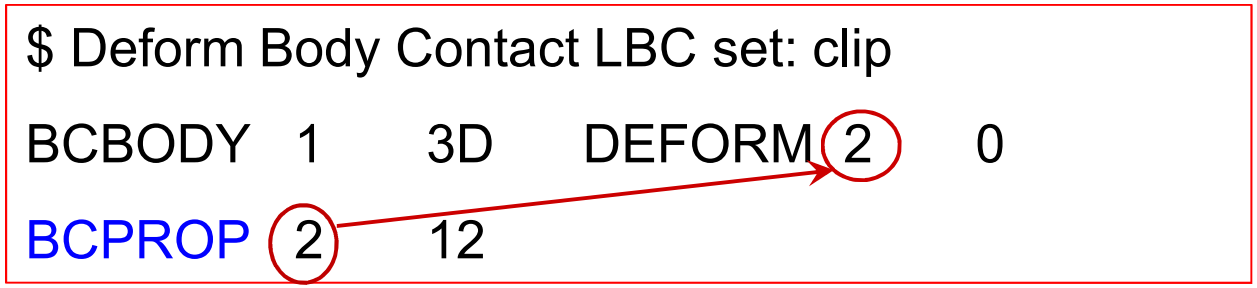
CREATING A DEFORMABLE BODY

- **Sample MSC Nastran input file:**

```
$ Deform Body Contact LBC set: clip
BCBODY   1       3D      DEFORM  2       0
BCPROP   2       12
```



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DEFINITION OF RIGID BODIES

- **Rigid Bodies can be modeled with geometry or finite elements**
  - Curves for 2D contact (NURBS2D)
    - Allows for 3 DOF – UX, UY, and ROTZ
  - Surfaces for 3D contact (NURBS)
    - Allows for 6 DOF – UX, UY, UZ, ROTX, ROTY, and ROTZ
  - 2D elements (PATCH3D), 4-node patches only, triangular patches are not supported
- **It is recommended to use geometry:**
  - Continuity of the normal vector along the surface
  - A mathematical description
  - Robustness of the contact algorithm

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DEFINITION OF RIGID BODIES

- **Rigid bodies can be stationary (default) or moved in space**
- **There are three different methods of controlling rigid body movements. The input is done via CONTROL on the BCBODY entry**
  - 0, velocity controlled
  - -1, position controlled
  - Positive Integer, load controlled

1	2	3	4	5	6	7	8	9	10
BCBODY	BID	DIM	BEHAV	BSID	ISTYP	FRIC	IDSPL	CONTROL	
	NLOAD	ANGVEL	DCOS1	DCOS2	DCOS3	VELRB1	VELRB2	VELRB3	
	"ADVANCE"	SANGLE	COPTB		MIDNOD				
	"RIGID"	CGID	NENT	--- Rigid Body Name ---					

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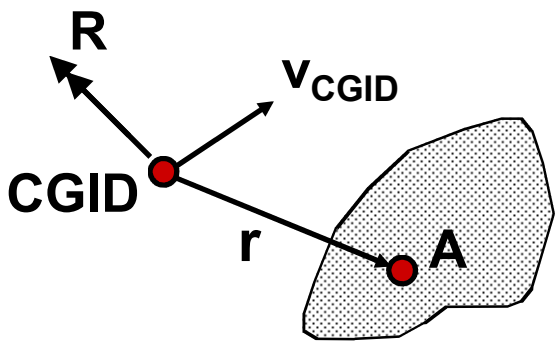
DEFINITION OF RIGID BODIES

- **For velocity control, on the BCBODY entry define:**
  - CONTROL=0
  - ANGVEL, angular velocity w about the local axis R through the center of rotation CGID, in radians/time
  - DCOSi, direction cosines of local axis R
  - VELRBi, translational velocity vCGID of the center of rotation CGID in direction i
- **The velocity of point A of the rigid body then reads:**

$$v_A = v_{CGID} + \omega R \times r$$



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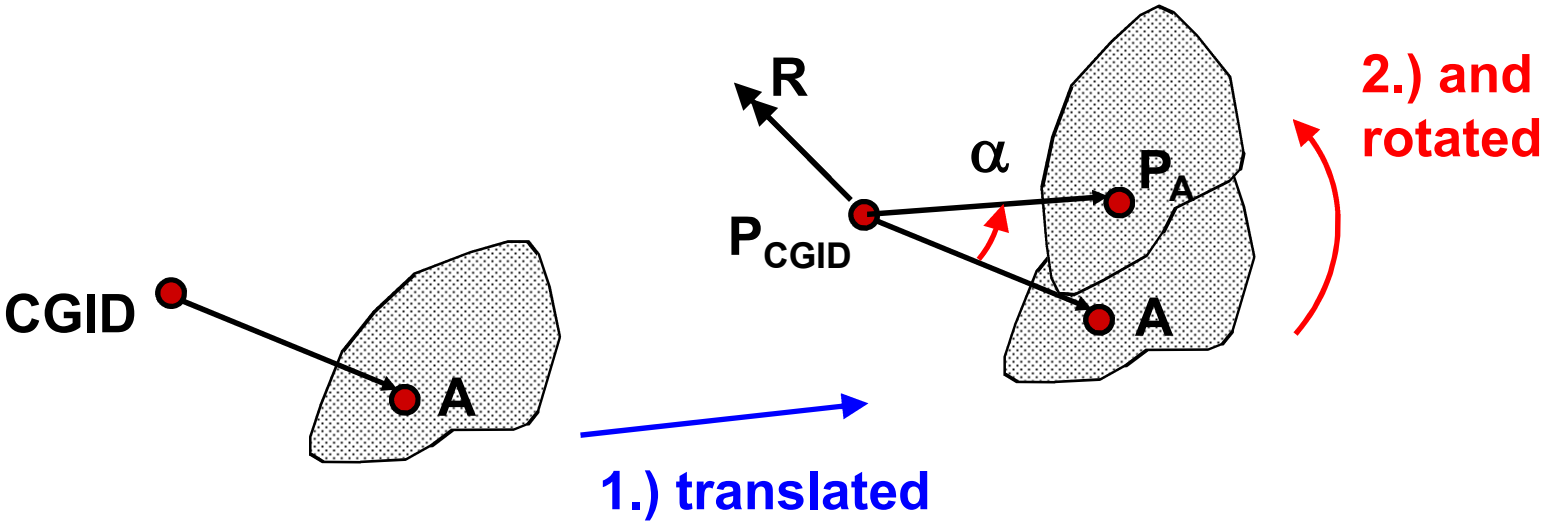
DEFINITION OF RIGID BODIES

- **For position control, on the BCBODY entry define:**
  - CONTROL= -1
  - ANGVEL, angular position a about the local axis R through the center of rotation, in radians
  - DCOSi, direction cosines of local axis R
  - VELRBi, target position PCGID of the center of rotation in direction i



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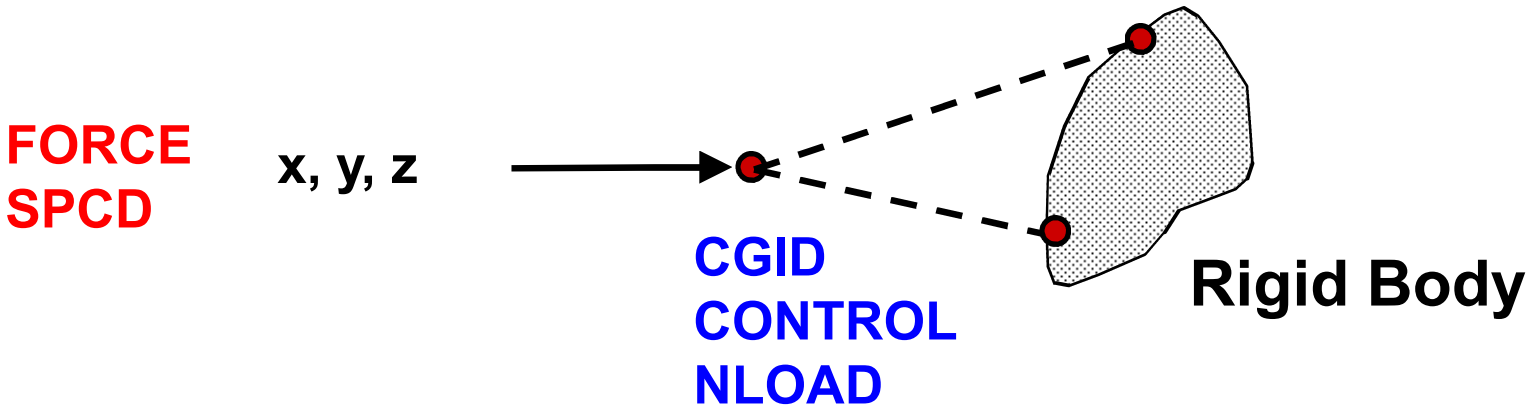
DEFINITION OF RIGID BODIES

- **For load control, on BCBODY card define:**
  - CONTROL = ID of the grid point to which translational loads or SPCDs are applied and at which the translations of CGID are reported
  - NLOAD = ID of the grid point to which the rotational loads or SPCDs are applied and at which the rotations of CGID are reported



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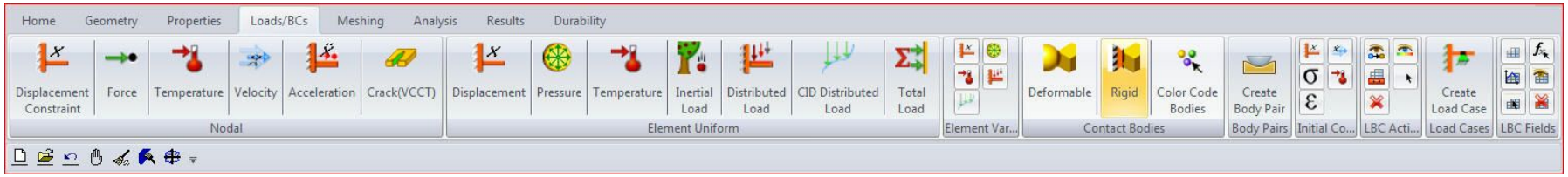
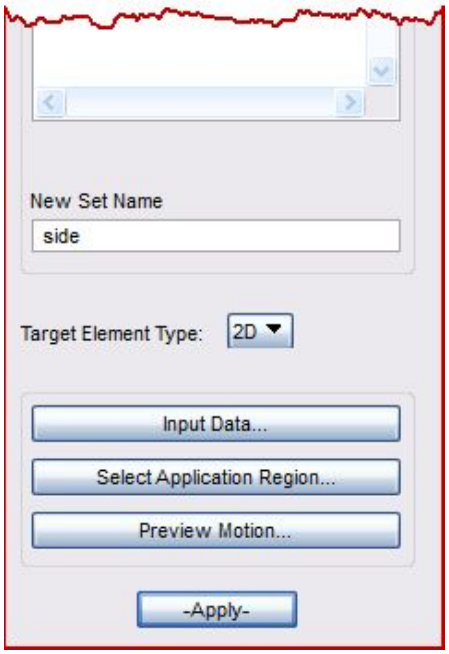
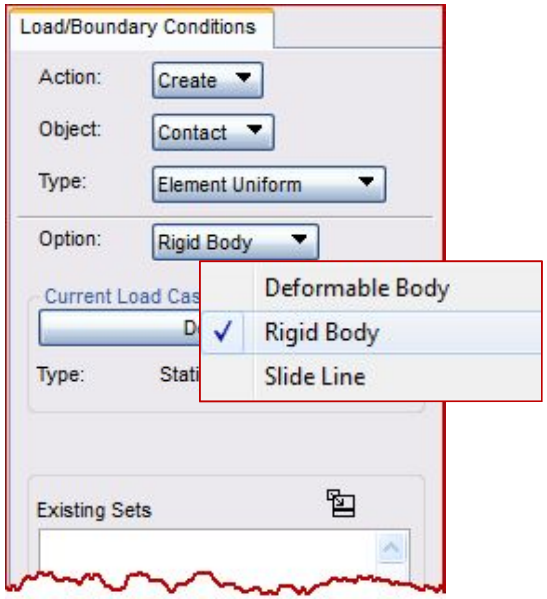
CREATING A RIGID BODY



- **Under the Patran Loads/BCs tab:**
  - Click Rigid
  - Enter New Set Name
  - Pick Target Element Type





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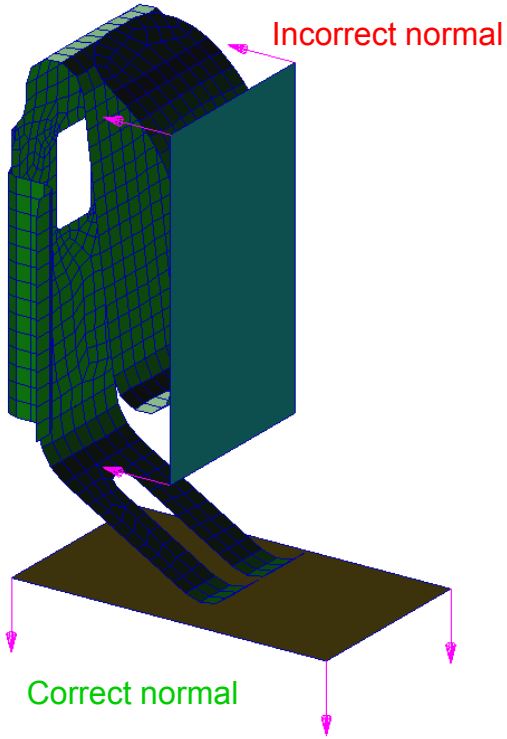
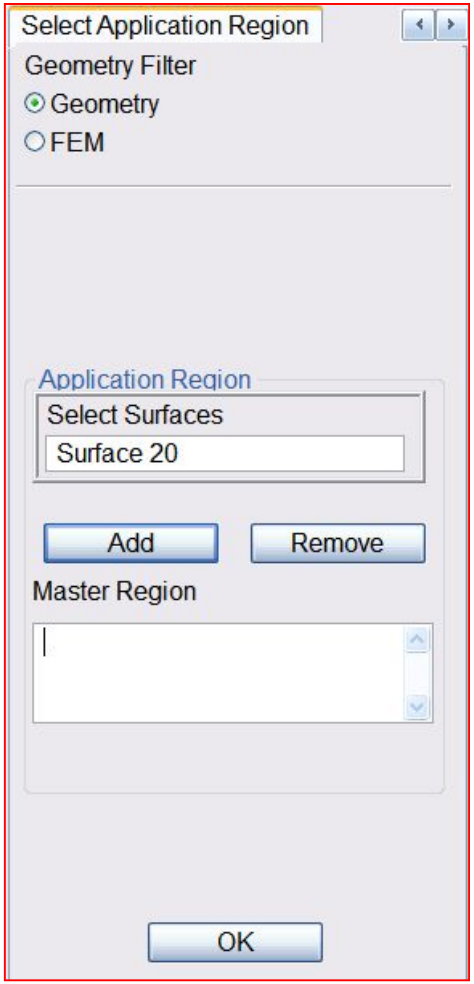
CREATING A RIGID BODY

- **On Select Application Region form:**
  - Select Geometry directly (to create NURBs) or
  - Based on FEM (to create PATCH3D)

The rigid body normal should point away from the deformable body to be contacted.





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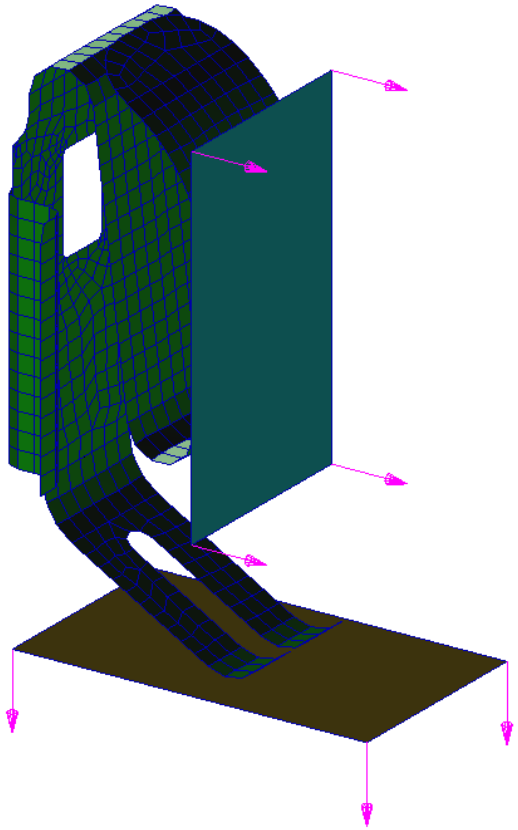
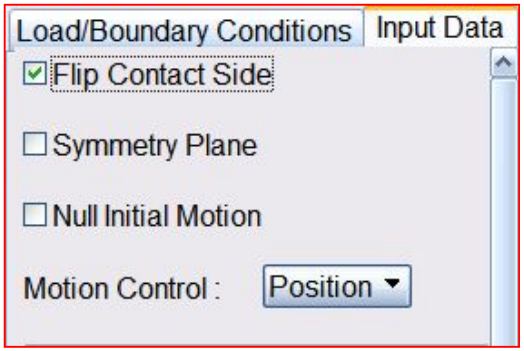
CREATING A RIGID BODY

- **To change rigid body normal, check Flip Contact Side on Input Data form.**





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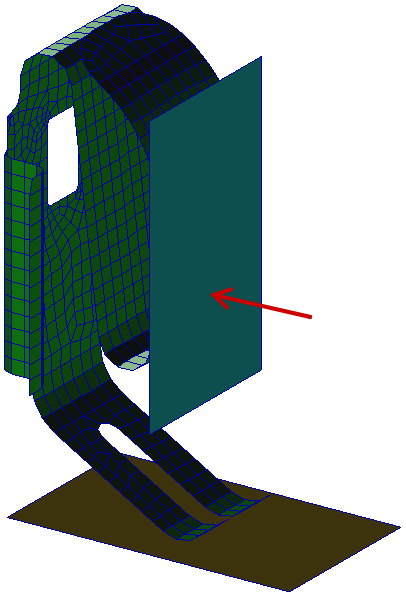
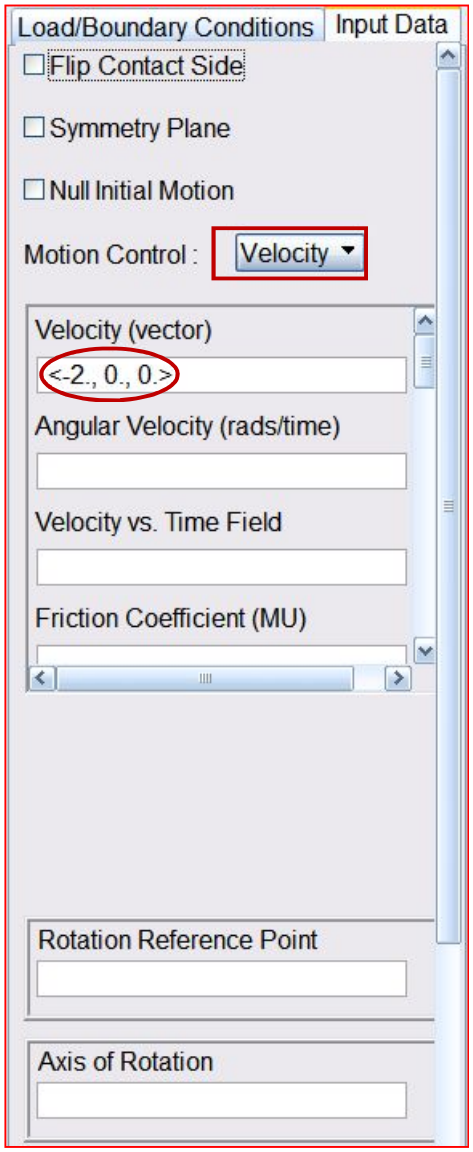
CREATING A RIGID BODY

- **Setup velocity controlled rigid body motion**
  - Select Velocity motion control on Input Data form
  - Specify rigid body translational velocity vector
  - If the rigid body rotates about a local axis, then specify
    - Angular velocity
    - Rotation reference point (center of rotation)
    - Axis of rotation





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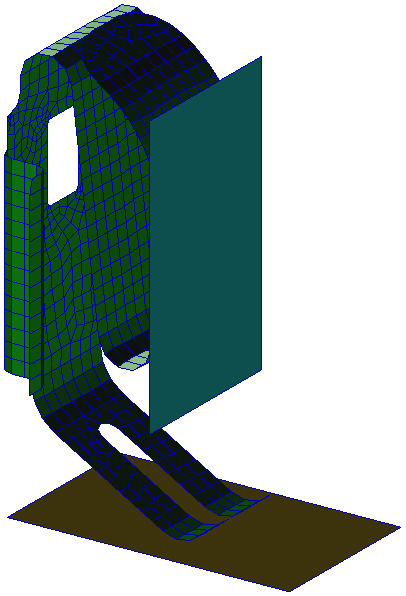
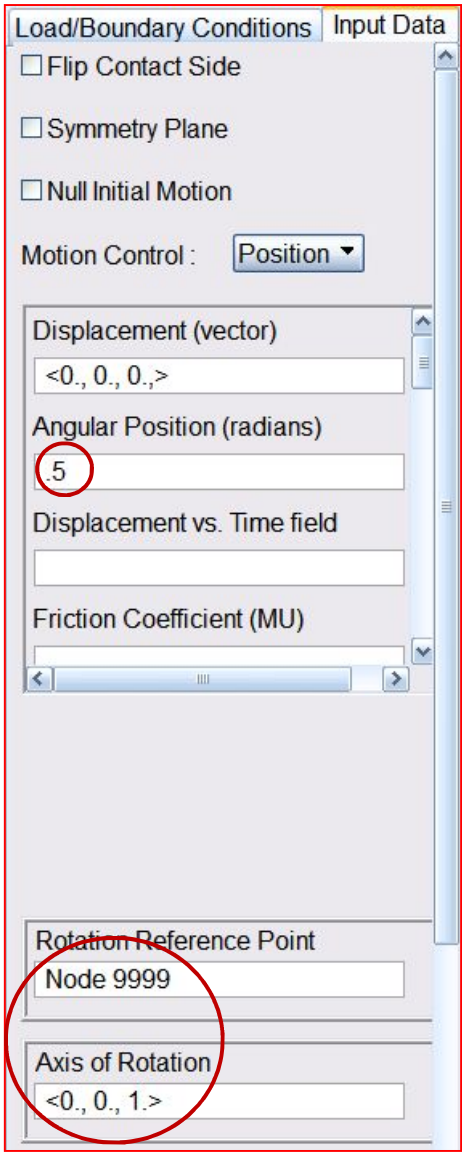
CREATING A RIGID BODY

- **Setup position controlled rigid body motion**
  - Select Position motion control on Input Data form
  - Specify rigid body translational displacement vector
  - If the rigid body rotates about a local axis, then specify
    - Angular position
    - Rotation reference point (center of rotation)
    - Axis of rotation





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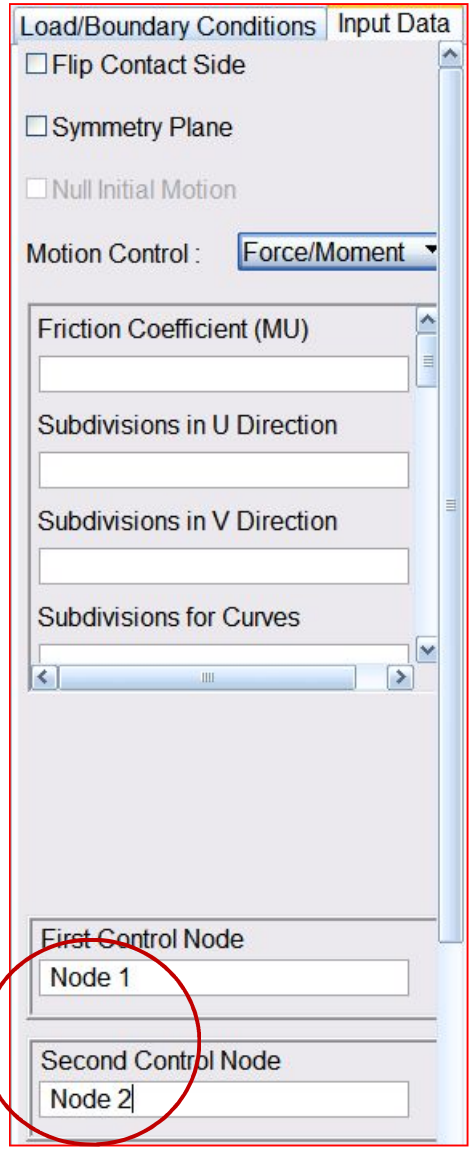
CREATING A RIGID BODY

- **Setup load controlled rigid body motion**
  - Select Force/Moment motion control on Input Data form
  - Specify first control node (center of rotation), this node represents translational DOFs of the rigid body
  - Specify second control node (location is irrelevant), this node represents rotational DOFs of the rigid body
  - Apply force or translational displacement to the first control node
  - Apply moment or rotational displacement to the second control node
  - If no load or SPCD applied to the control nodes, the rigid body is free to move



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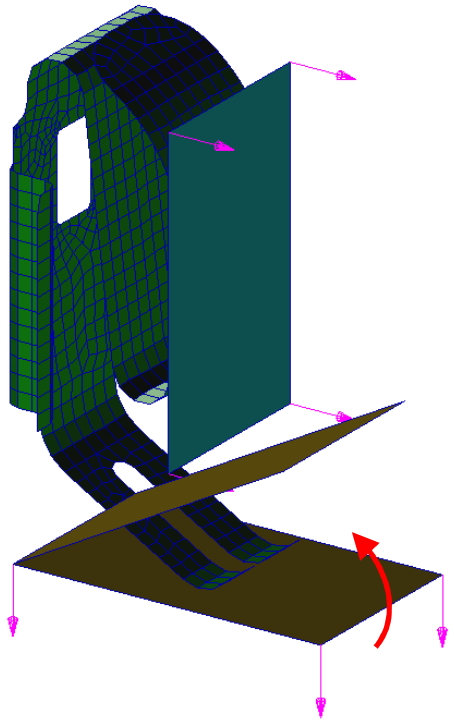
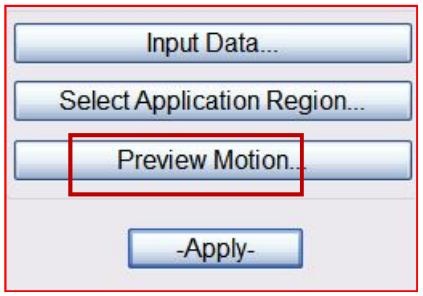
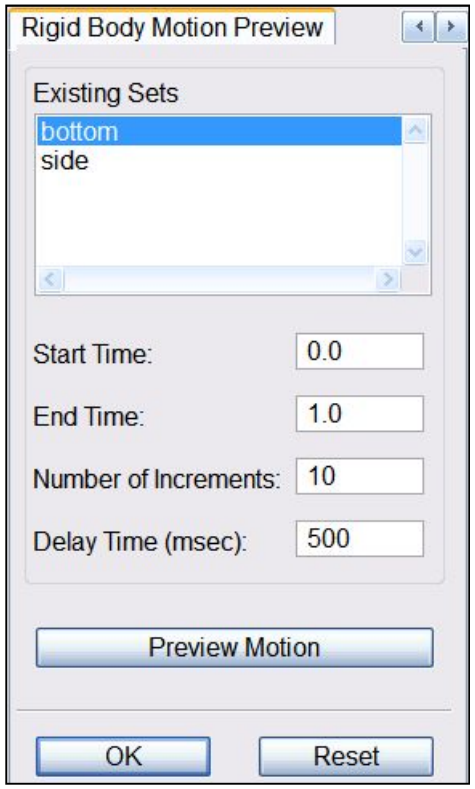
CREATING A RIGID BODY

- **Preview rigid body motion**
  - Available only for velocity and position control
  - On Preview Motion form
    - Select a rigid body from existing sets
    - Click Preview Motion







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CREATING A RIGID BODY

- **Sample MSC Nastran input file:**

Don’t try this at home!!!!

```
$ Rigid Body Contact LBC set: side
BCBODY  3       3D      RIGID           0               1       0
        0       0.      0.      0.      0.      -2.     0.      0.
        RIGID   0       1       SIDE
        NURBS   -2      2       2       2       50      50      4
                5.1016  5.3644-8-2.9    5.1016  9.9     -2.9
                5.1016  5.3644-82.9     5.1016  9.9     2.9
```


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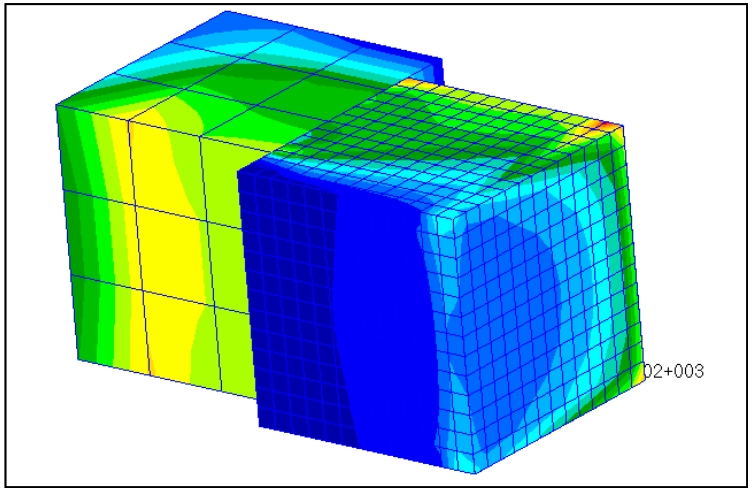
WORKSHOP 1 – SOLID TO SOLID CONTACT

- **Perform a start to finish solid to solid contact analysis with MSC Nastran**
- **Gain familiarity with the Patran contact analysis GUI**



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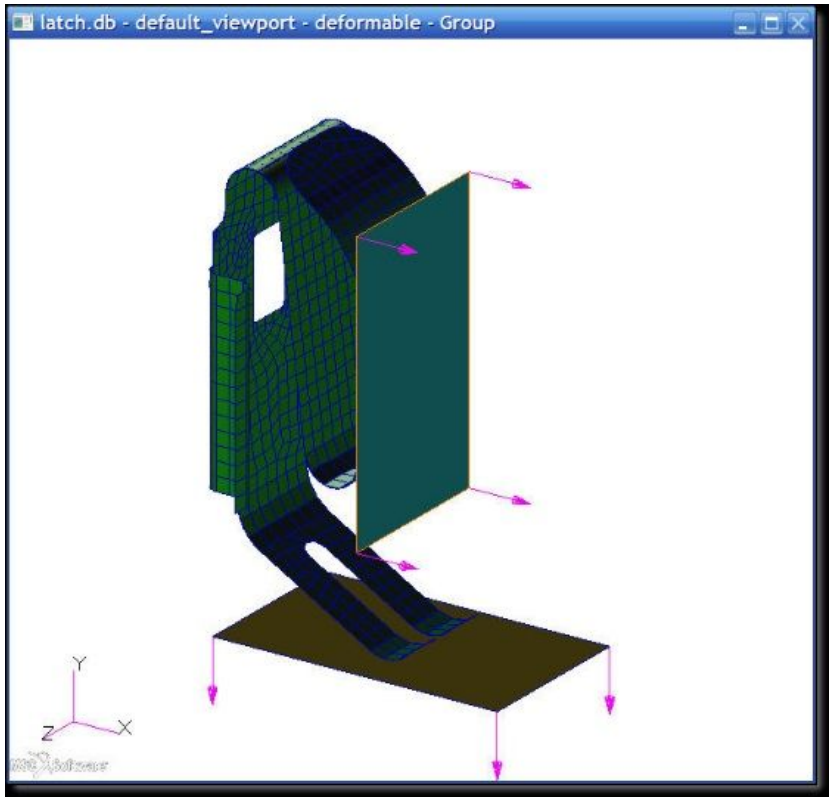
WORKSHOP 1A – DEFORMABLE TO RIGID CONTACT

- **Perform a start to finish contact analysis with MSC Nastran that uses both deformable and rigid contact bodies**
- **Gain experience in the definition of the motion of rigid contact bodies**
- **Gain familiarity with the Patran contact analysis GUI**



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REVIEW QUESTIONS

1. **What visual indicators does Patran use to show rigid body orientation? In which direction should those indicators be pointing for a rigid body to make contact with a deformable body?**

2. **How many degrees of freedom are there for a 1D rigid body? What are they?**

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REVIEW QUESTIONS

3. How many degrees of freedom are there for a 2D rigid body and what are they?

4. How can a rigid body be controlled?

5. What field in the BCBODY entry is used to define the method of control of a rigid body?

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SECTION 3

CONTACT DETECTION

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NODE TO SEGMENT CONTACT

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NODE TO SEGMENT CONTACT

- This type of contact had been developed and tested for many years and is a proven technique.
- However it has some drawbacks. Segment to Segment contact was recently developed to overcome these drawbacks (discussed later).
- For Node to Segment contact a node can come into contact with a segment.
- For Segment to Segment contact a segment can contact another segment (discussed later).

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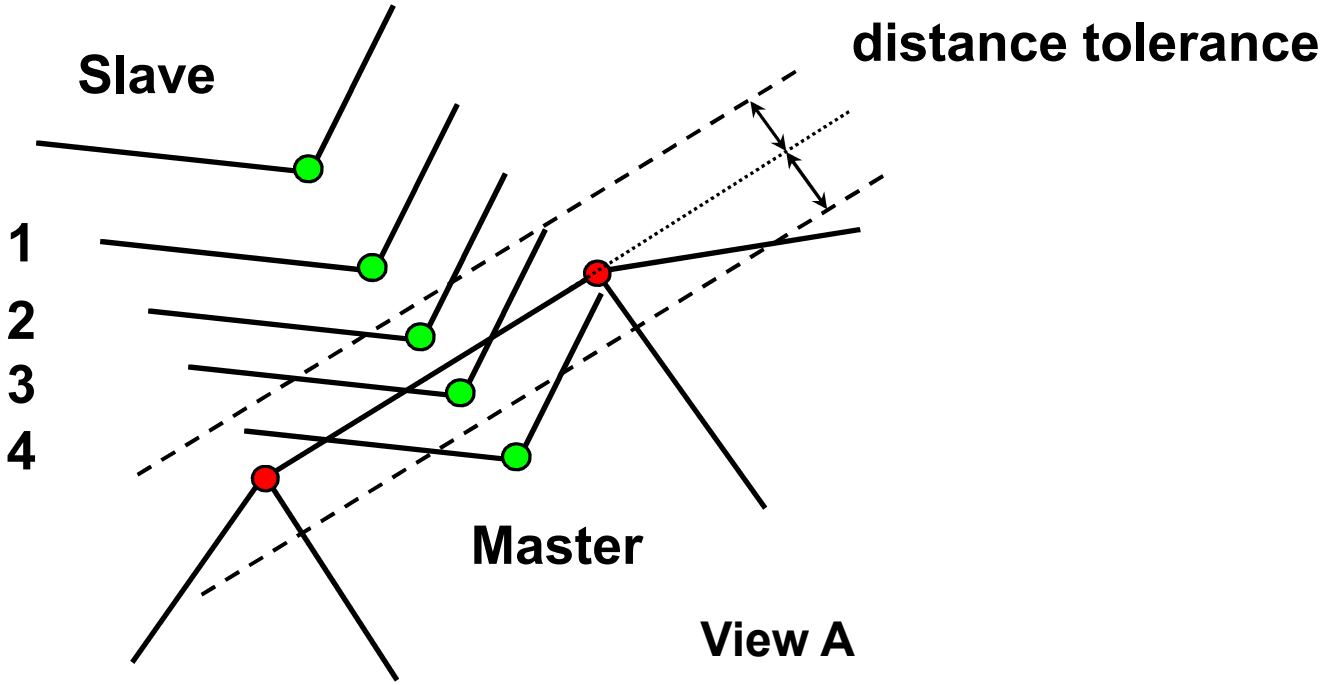
POSSIBLE CONTACT SCENARIOS



1) Node outside element patch, outside distance tolerance
2) Node outside element patch, inside distance tolerance
3) Node inside element patch, inside distance tolerance
4) Node inside element patch, outside distance tolerance

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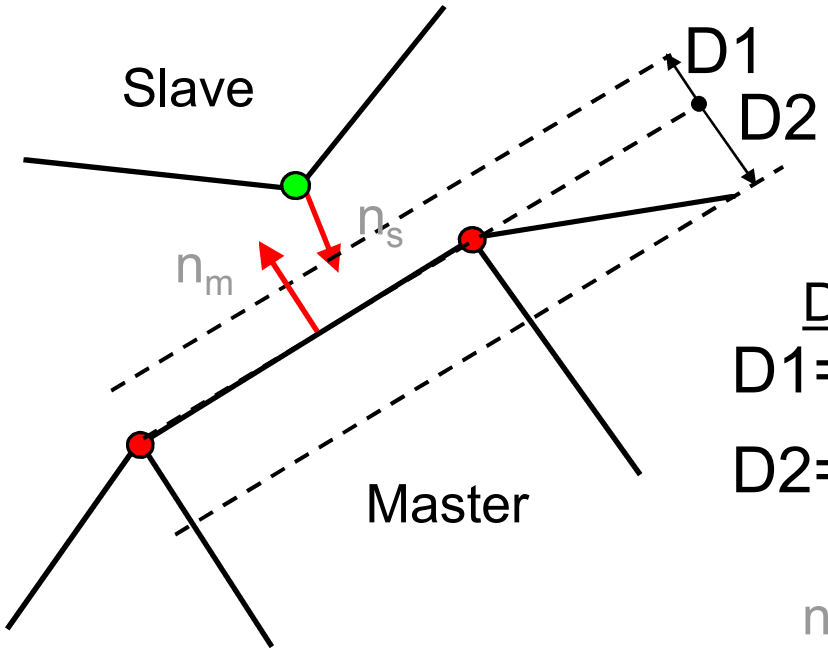
CONTACT DETECTION – SCENARIO 1

- **Slave grid <u>outside</u> master and <u>outside</u> D1**
  - bodies are not in contact
  - nothing has to be done, most simple case



<u>Distance Tolerances</u>

D1=(1 – BIAS)xERROR

D2=(1 + BIAS)xERROR

n – contact normals

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DISTANCE TOLERANCES

- **Input on BCPARA,0 or BCONPRG (discussed later)**

BCPARA	0	ERROR	0.25	BIAS	0.9	ERRBAS	1	

- **By default, ERROR is evaluated from:**
  - 1/20 x “smallest element edge“ for continuum elements
  - ¼ x “smallest thickness“ for beam and shell elements
  - Measured globally or pair wise (ERRBAS=0/1)
- **BIAS**
  - The range is between 0.0 and 1.0
  - Default value is 0.9
  - For glued contact it will be 0.0

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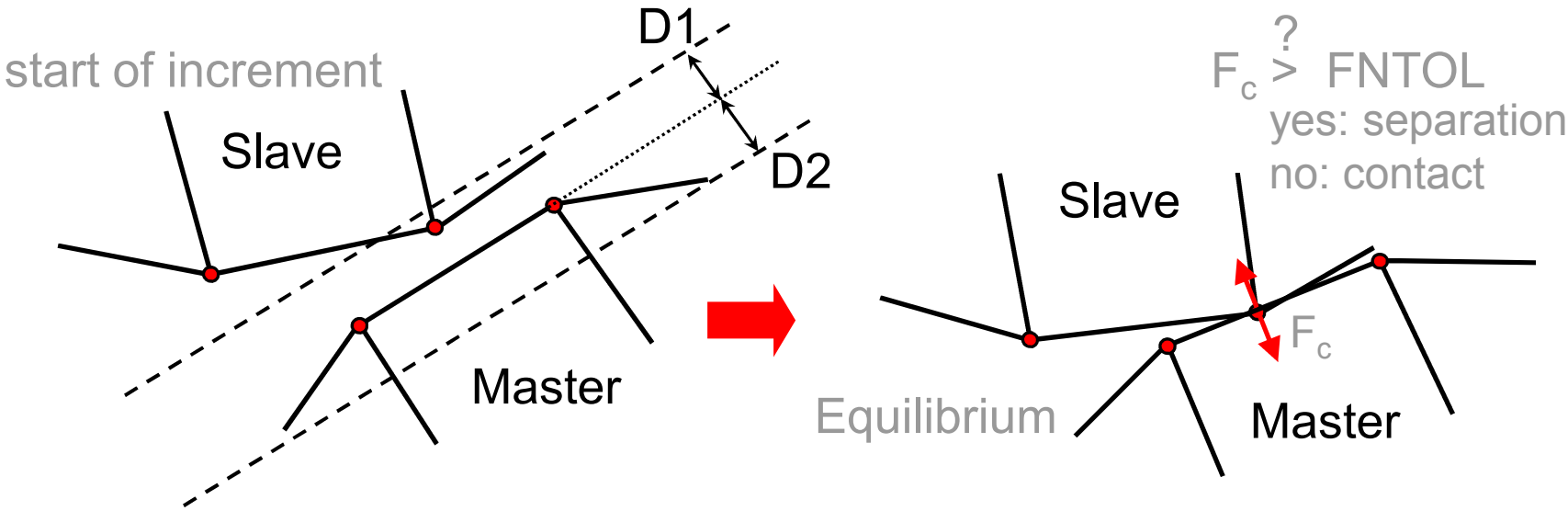
CONTACT DETECTION – SCENARIO 2

- **Slave grid <u>outside</u> master but <u>inside</u> D1**
  - Only at the start of an increment slave is considered for contact. Apply contact constraint and iterate until the solution converges (equilibrium).
  - Then check the contact force. In case of separation continue iterating. Otherwise go to the next increment.



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SEPARATION CHECK

- **BCPARA / IBSEP – separation force flag (default=0)**
  - 0: separation if the contact pulling force exceeds FNTOL (input in BCPARA or BCTABLE. Default: maximum residual force in the complete model).
  - 1: separation if the contact pulling fake stress (pulling force divided by its nodal area) exceeds FNTOL (default: maximum stress at a reaction node in the model times the convergence tolerance).
  - 2: separation if the contact pulling stress (from extrapolating and averaging integration point values) exceeds FNTOL (like 1)
  - 3: separation if the contact pulling fake stress exceeds FNTOL (default=0.1) times the maximum contact stress in the model
  - 4: separation if the contact pulling stress exceeds FNTOL (default=0.1) times the maximum contact stress in the model
  - Notice that for quadratic contact options 2 or 4 can only be used since the nodal forces do not provide proper values

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SEPARATION CONTROL

- **BCPARA / ICSEP – separation flag (default=0)**
  - 0: if the force on a node is greater than the separation force, the node separates and an iteration occurs
  - 1: if a node, which was in contact at the end of the previous increment, has a force greater than the separation force, the node does not separate in this increment, but separates at the beginning of the next increment
  - 2: if a new node comes into contact during this increment, it is not allowed to separate during this increment (prevents chattering)
  - 3: both 1 and 2 are in effect

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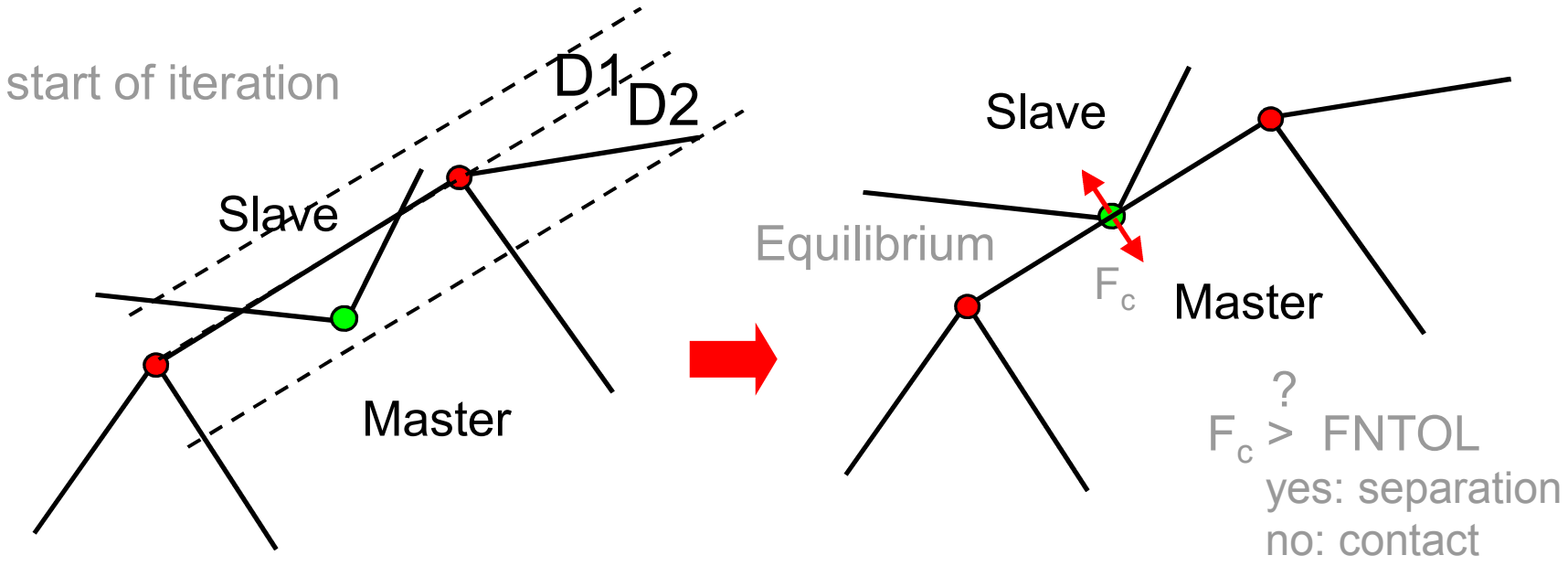
CONTACT DETECTION – SCENARIO 3

- **Slave grid <u>inside</u> master and <u>inside</u> D2**
  - Apply contact constraint and iterate until the solution converges (equilibrium)
  - Then check the contact force. In case of separation continue iterating. Otherwise go to the next increment.



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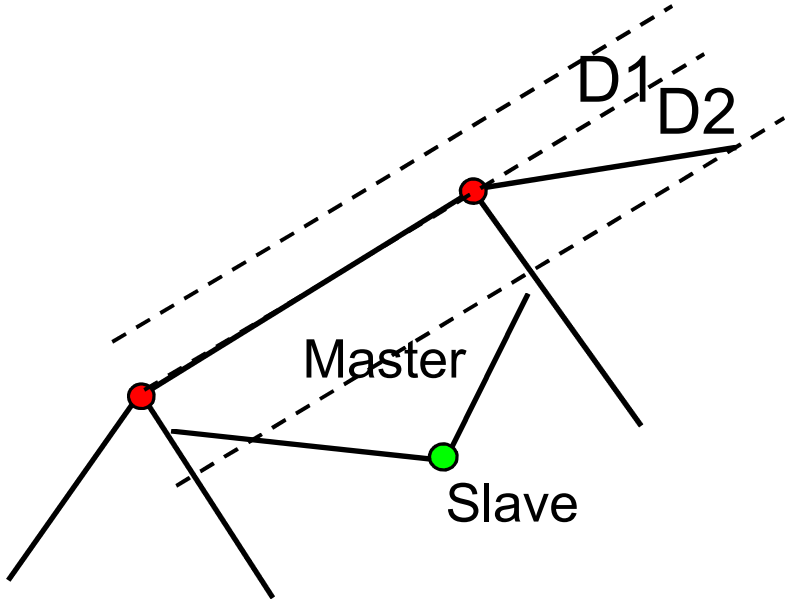
CONTACT DETECTION – SCENARIO 4

- **Slave grid <u>inside</u> master but <u>outside</u> D2**
  - Slave grid has penetrated
    - For statics: repeat iteration with scaled back Dui (maximum penetration: 10% of D2). If converged check for separation. If separated continue iterating. Otherwise go to the next increment.
    - For dynamics: scale back the timestep appropriately.
  - If this situation occurs at the beginning of the analysis, contact will not be found.
    - Prepare your model so that this situation does not occur initially



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EFFECT OF CONTACT TOLERANCES

- **The sizes of the contact tolerances D1 and D2 have a significant impact on the computational costs and the accuracy of the solution**
- **Contact tolerances too small:**
  - Detection of contact is difficult, leading to higher costs. Initial contact might not be detected.
- **Contact tolerance too large:**
  - Nodes are considered in contact prematurely, resulting in a loss of accuracy
  - Nodes might “penetrate” the surface by a large amount

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CONTACT SEARCH ORDER

- The contact search order is very important for node-to-segment contact.
- There are various options to control how the search is carried out (order in which bodies attempt to contact each other).
- It is important to understand how each search strategy works when used with contact bodies of different mesh densities, materials, etc.
- Simply using the defaults can result in contacts which, while they converge, do not well model the situation.

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CONTACT SEARCH ORDER

- **Single order search (ISTYP=1) on BCBODY**
  - by default, the lower numbered body is checked with itself and the higher numbered bodies. For instance, body 1 is checked against bodies 1, 2, 3, ... Body 2, however, is only checked against bodies 2, 3, ...
- **Double order search (ISTYP=0, default)**
  - checks possible contact between any two surfaces (surface i is checked for contact with surface j, and surface j is also checked for contact with surface i, where i, j = 1, 2, 3, ..., total number of surfaces in the problem)
- **In both cases, penetrations can occur (discussed next)**

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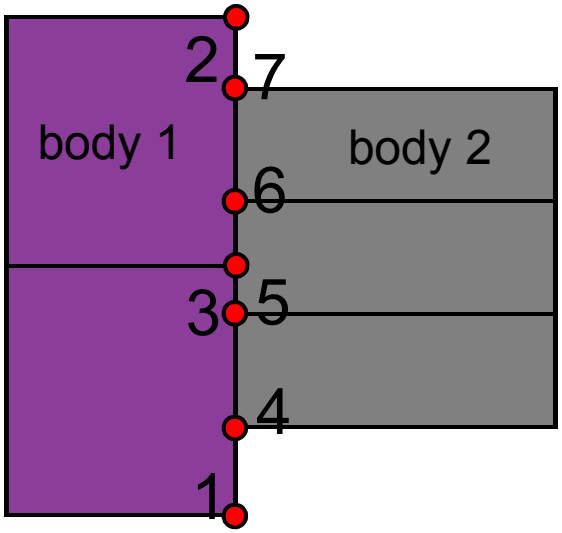
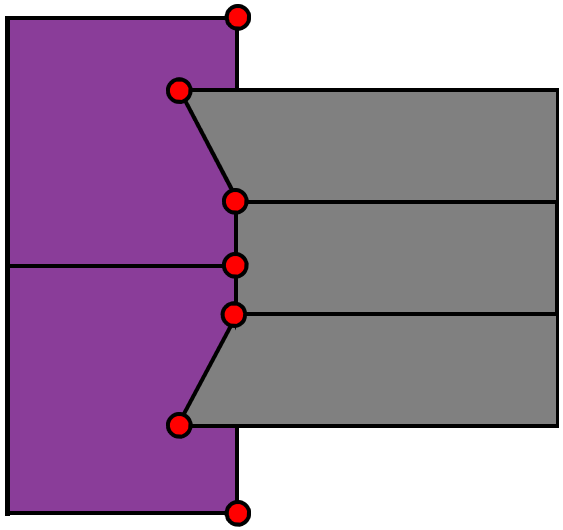
CONTACT SEARCH ORDER

- **Check Body 1:**



wrong body numbering



1.

$u_3 = u(u_5, u_6)$

dependent

independent

2. **Check Body 2:**

$u_4 = u(u_1, u_3)$

$u_5 = u(u_1, u_3)$

$u_6 = u(u_3, u_2)$

$u_7 = u(u_3, u_2)$

skipped, since node 3 has already been used as a slave node

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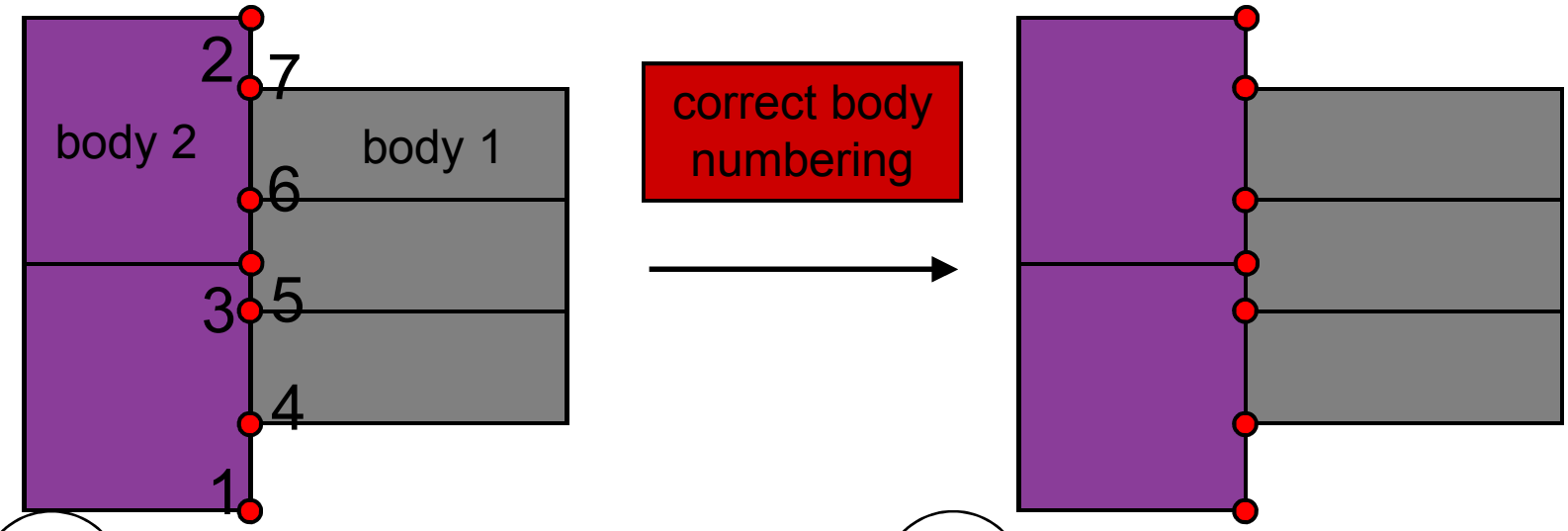
CONTACT SEARCH ORDER

- **Check Body 2:**



1. **Check Body 1:**

$u_4 = u(u_1, u_3)$

$u_5 = u(u_1, u_3)$

$u_6 = u(u_3, u_2)$

$u_7 = u(u_3, u_2)$

2. $u_3 = u(u_5, u_6)$

skipped, but okay!

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CONTACT SEARCH ORDER

- **The default search order can be overruled by specifying ISEARCH on the BCONPRG entry:**
  - 0: double search (lower numbered bodies first, i.e. 1,1; 1,2; 1,3; 2,1; 2,2; 2,3; 3,1; 3,2; 3,3). Default.
  - 1: searching from slave to master (single sided)
  - 2: body with finer mesh automatically becomes slave
- **ISTYP in BCBDPRP can also be set to 2 (ISEARCH must be 0)**
  - double order search with automatic optimization of contact constraint equations (“optimized contact”)
    - The decision is made for the areas in contact. The bodies which are softer and finer meshed in those areas come first. Soft has higher priority than mesh (based on HARDS in BCONPRG, the hard-soft ratio, default=2.0).

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SEGMENT TO SEGMENT CONTACT

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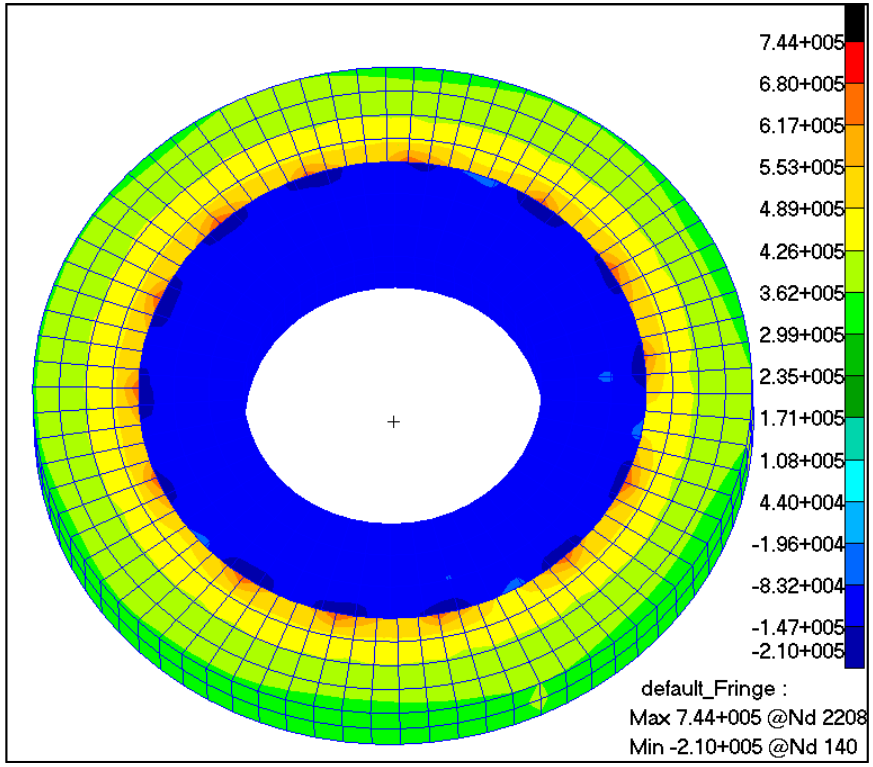
SEGMENT TO SEGMENT CONTACT ADVANTAGES

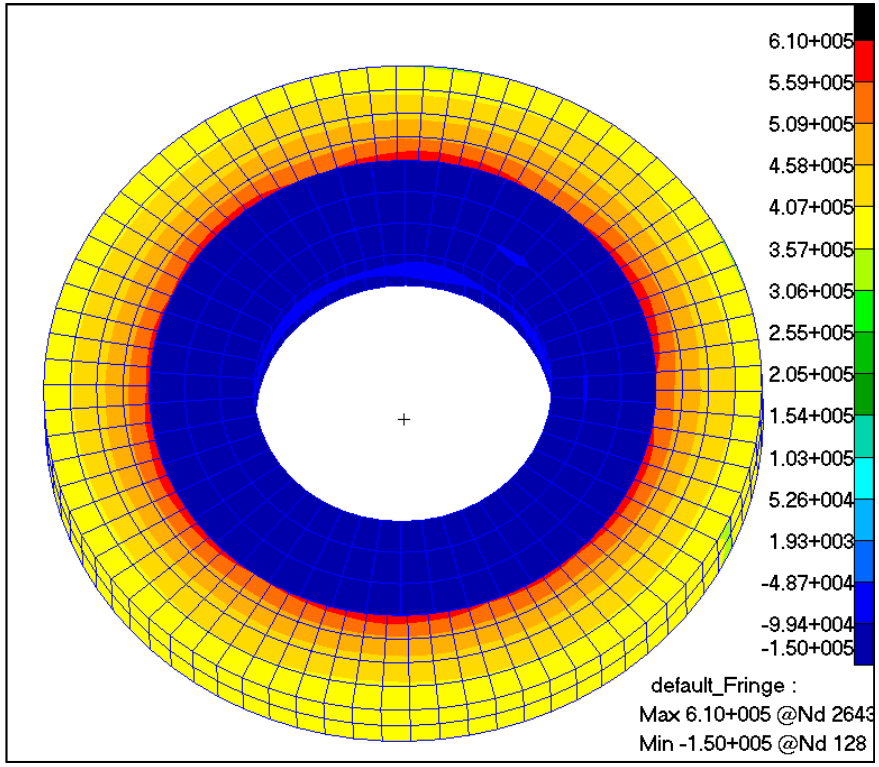
- **Node to Segment Contact (NTS) has some drawbacks which can be avoided using Segment to Segment Contact (STS)**

Improved accuracy

Node to Segment (Stress)



Segment to Segment (Stress)



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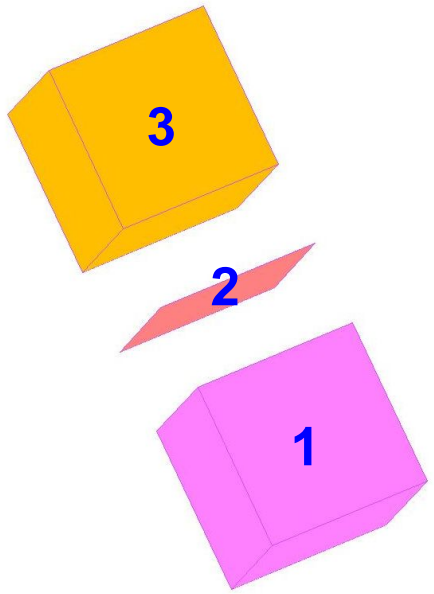
SEGMENT TO SEGMENT CONTACT ADVANTAGES

- **Advantages for Shell Contact**
  - For NTS a shell cannot be “clamped” between two rigid bodies. STS can do.
  - For NTS a shell contact between two deformable bodies needs some care. STS does not.

NTS

body 1 > body 2
body 2 > body 3
or
body 1 > body 2
body 3 > body 2

but not
Body 2 > body 1
Body 2 > body 3



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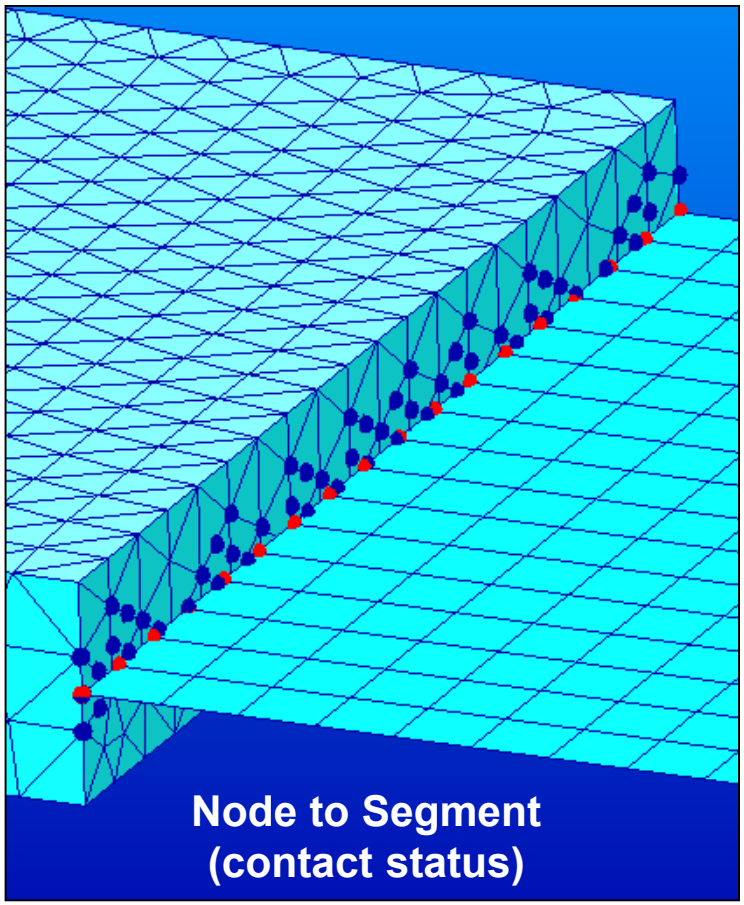
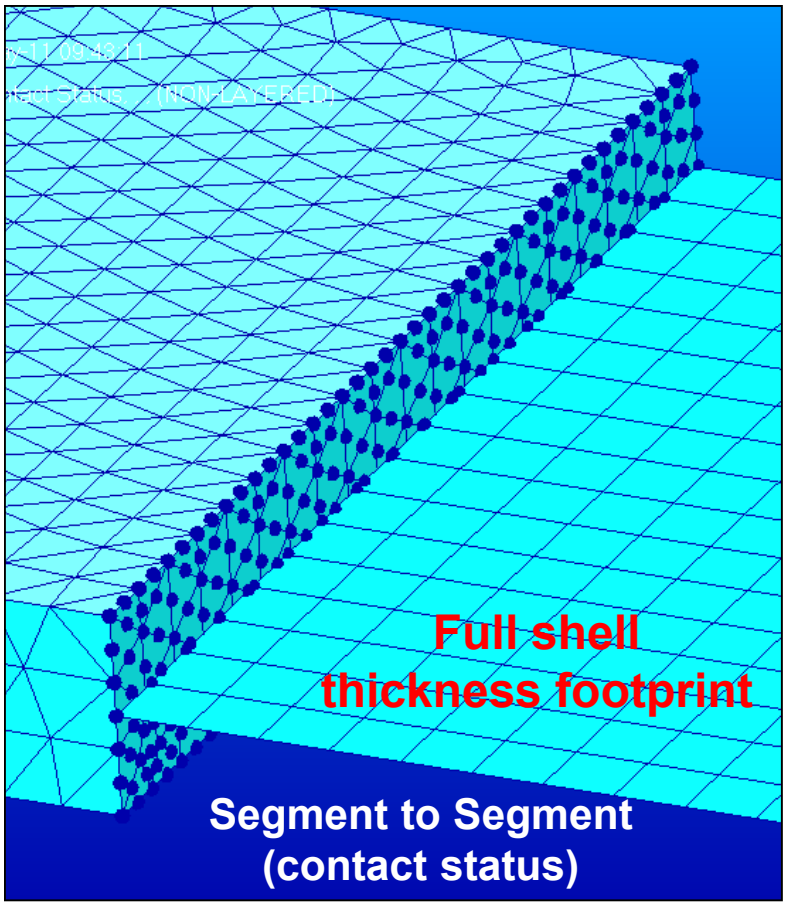
SEGMENT TO SEGMENT CONTACT ADVANTAGES

- **Advantages for Shell Contact (cont.)**
  - For NTS shell edge contact is described as a line. STS describes the "footprint".





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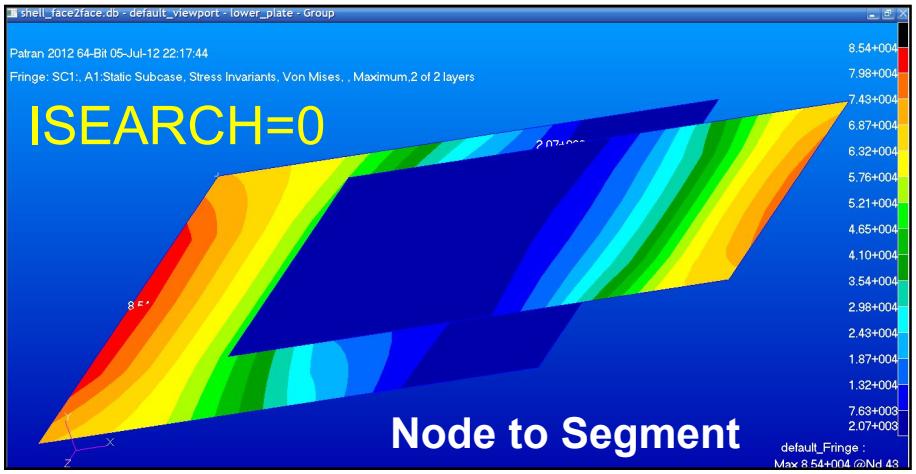
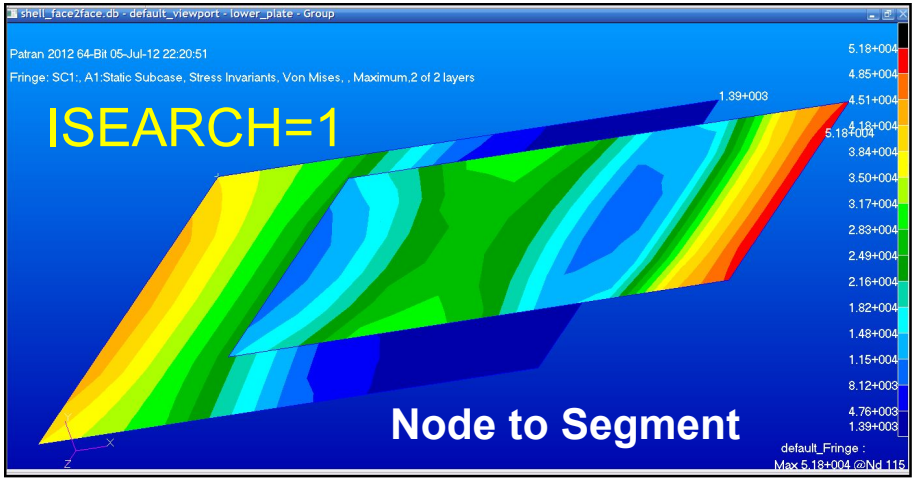
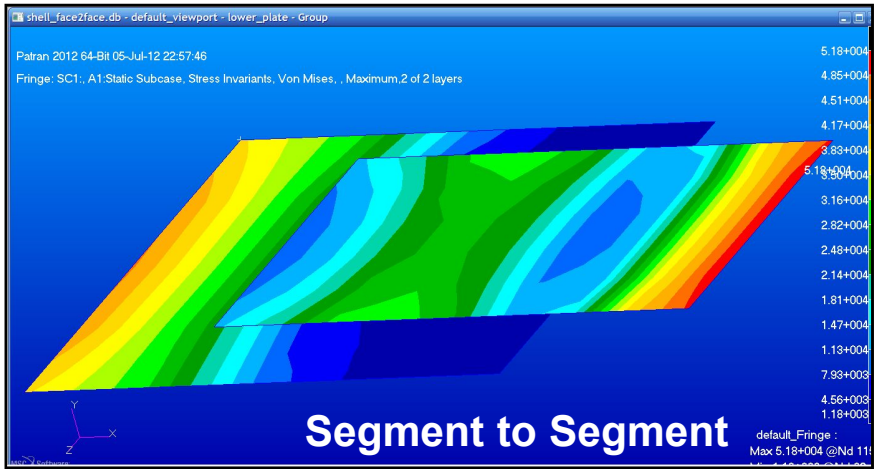
SEGMENT TO SEGMENT CONTACT ADVANTAGES

– No Master-Slave Concept (avoid slave master search order)







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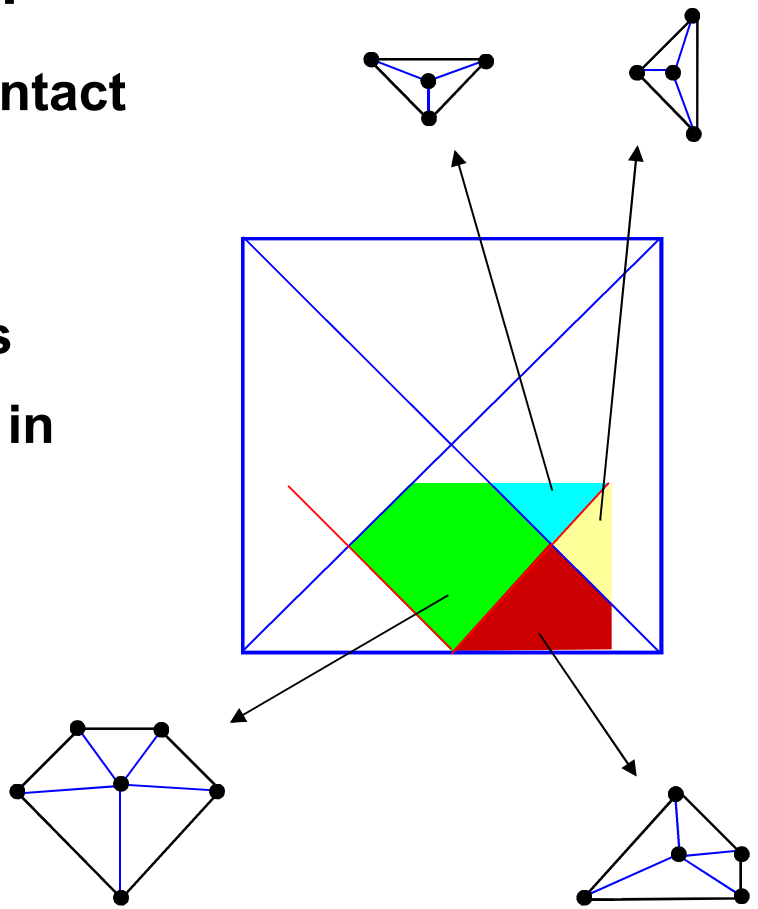
DEFINITION OF STS CONTACT

- Find the segments that are in contact
- Find the common areas of the segments that are in contact
- Divide these areas into polygons
- Find the polygon points that are in contact



- The polygon points define a local connection between two contact segments and the non-penetration constraints are enforced using augmented Lagrangian approach.

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STS CONTACT INPUT

- **STS Contact can be controlled via BCPARA**

METHOD	Flag to select Contact methods. (Character)	
	NODESURF	Regular 3D Contact (Default: node to surface contact)
	SEGSMALL	Segment to segment contact with small sliding.
	SEGLARGE	Segment to segment contact with finite sliding.
AUGMENT	Augmentation method used in a segment-to-segment contact analysis. (Integer)	
	0	No augmentation (Default)
	1	Augmentation based on a constant Lagrange multiplier field for linear elements and on a (bi)linear Lagrange multiplier field for quadratic elements
	2	Augmentation based on a constant Lagrange multiplier field
	3	Augmentation based on a (field
PENALT	Augmented Lagrange penalty factor; us contact algorithm only. (Real > 0.0; see	
AUGDIST	Penetration distance beyond which an a used by the segment-to-segment contac BCTABLE entry for default)	
SLDLMT	Maximum allowed sliding distance, bey redefined, for segment to segment cont deformation. (Real ≥ 0.0; Default = 0.0	

from QRG

SEGSYM	Specify symmetric or non-symmetric friction matrix in segment to segment contact analysis. (Integer 0 = symmetric matrix or 1 = non-symmetric matrix; Default = 0)
TAUGMNT	Augmentation for the sticking part of friction in a segment-to-segment contact analysis. (Integer 0 = no augmentation or 1 = use augmentation; Default = 0)
TPENALT	Augmented Lagrange penalty factor for sticking part of friction, used by the segment-to-segment contact algorithm only. (Real > 0.0) The default is PENALT/1000, where PENALT parameter is the Augmented Lagrange penalty factor for normal contact.
STKSLP	Maximum allowable slip distance for sticking, beyond it there is no sticking, only sliding exists, used by the segment-to-segment contact algorithm only. (Real ≥ 0.0; Default = 0.0) See Remark 11..

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STS CONTACT INPUT

- **STS Contact can be controlled for contact pairs via Geometric Contact Parameters in BCONPRG**
  - AUGDIST: Penetration distance beyond which an augmentation will be applied
  - PENALT: Augmented Lagrange penalty factor
  - STKSLP: Maximum allowable slip distance for sticking, beyond it there is no sticking, only sliding exists
  - TPENALT: Augmented Lagrange penalty factor for sticking part of friction

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STS CONTACT INPUT

- **METHOD to select small or large sliding STS**
  - NODESURF: NTS (default)
  - SEGSMALL: STS, small sliding
  - SEGLARGE: STS, large sliding
- **AUGMENT to select the Augmentation Method**
  - 0: no augmentation (default)
  - 1: constant Lagrange Multiplier field for linear elements, (bi)linear field for quadratic elements
  - 2: constant Lagrange Multiplier field
  - 3: (bi)linear Lagrange Multiplier field
  - For rigid-deformable contact Augmentation is always on

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STS CONTACT INPUT

- **PENALT, Augmented Lagrange penalty factor**
  - Default: depends on the contacting body stiffnesses and a characteristic length (unit=force/length^3)
- **AUGDIST, Penetration distance beyond which an augmentation will be applied**
  - Default: 1e-3 of the characteristic length
- **SLDLMT, for seglarge. Sliding distance beyond which contact segments are to be redefined**
  - Default: 5 times the default contact tolerance ERROR
- **SEGSYM, symmetric or non-symmetric friction, 0: symmetric (default), 1: non-symmetric**

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STS CONTACT INPUT

- **TAUGMNT, Augmentation for the sticking part of friction**
  - 0: no Augmentation (Default), 1: Augmentation
- **TPENALT, Augmented Lagrange penalty factor for sticking part of friction**
  - default is PENALT/1000
- **STKSLP, Maximum allowable slip distance for sticking**
  - 0.0: maximum sticking displacement (default)

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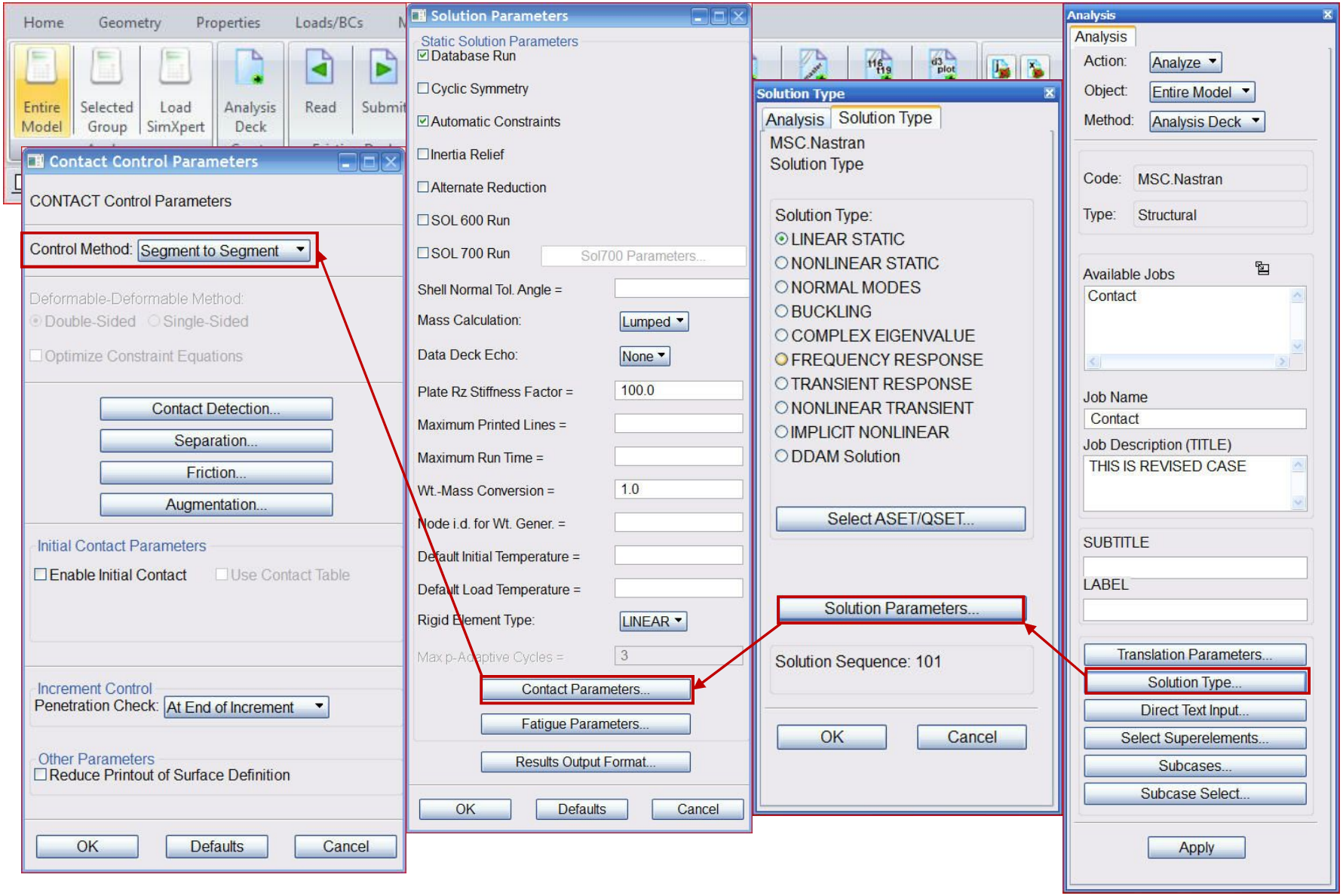
DEFINE STS IN PATRAN



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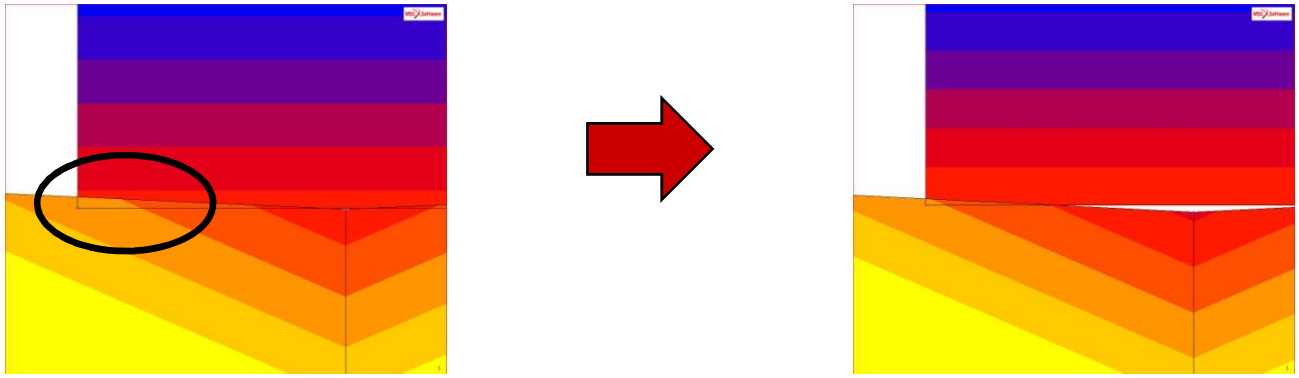
INFLUENCE OF AUGMENTATION

- **Augmentation enables minimization of penetration as the following example demonstrates**



- **The augmentation method will influence the number of iterations and the results, however to get a quick insight in a problem you could choose not to augment. This is therefore the default.**

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STS CONTACT DETECTION PARAMETERS

- **Contact Distance Tolerance, same as NTS, but**
  - SLDLMT is defaulted to 5 times ERROR. For small values of ERROR, this may unnecessarily result in the message “Recalculating Segments”, thus increasing the computational costs.
- **Separation Control**
  - Only stress based separation based upon absolute stresses is available. Be careful when an input deck comes from NTS and an FNTOL refers to force.
- **Search order is immaterial**
  - ISEARCH, ISTYP, HARDS are ignored

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STS CONTACT LIMITATIONS

- **At this time not available:**
  - Thermal analysis
  - Coupled analysis with multiple physics
  - Brake squeal analysis
  - Adaptive meshing
  - Beam to beam contact
  - Breaking glue
  - Output of normal contact stress and friction contact stress for glued or frictional contact
  - The following parameters are not supported:
    - MAXSEP, ICSEP, IBSEP, RVCNST, BEAMB and NLGLUE

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REVIEW QUESTIONS

1. What is contact distance tolerance in contact analysis?

2. How does “Bias factor” modify the distance tolerance?

3. Why is the order of contact bodies important?

4. Why does contact search order in node-to-segment contact affect results?

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REVIEW QUESTIONS

5. Does the slave-master concept apply to segment-to-segment contact?

6. Does segment-to-segment contact support permanent glued contact?

7. What is the range of values of Bias factor in contact analysis?

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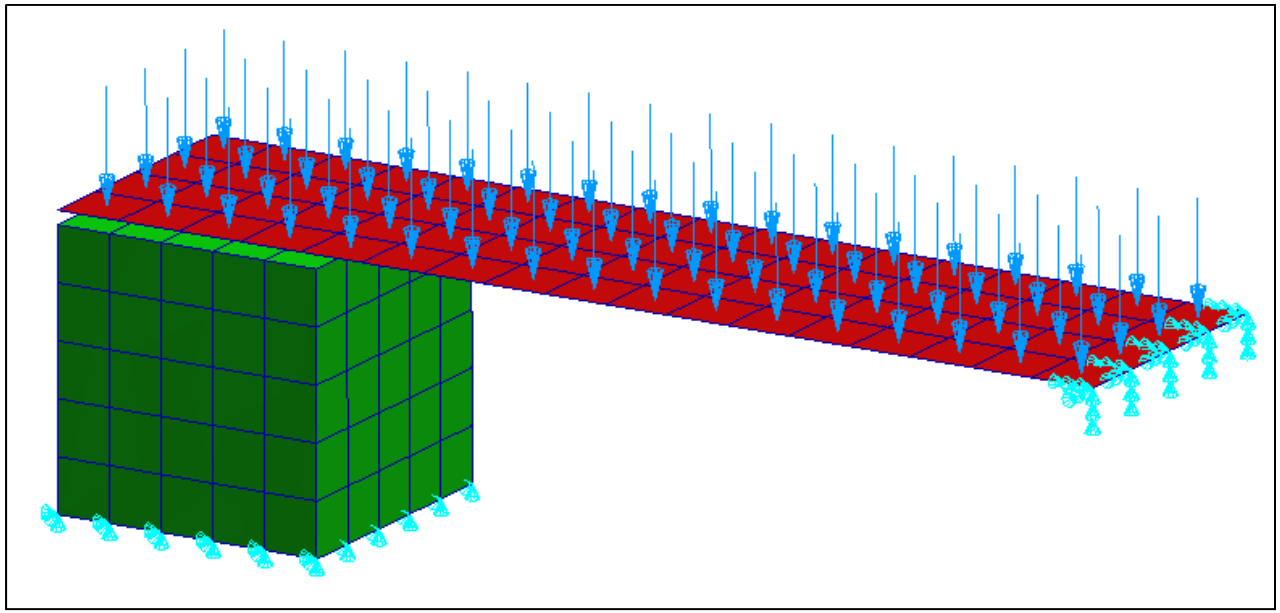
WORKSHOP 2 – SOLID TO SHELL CONTACT

– Perform a start to finish solid to shell contact analysis with MSC Nastran



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SECTION 4

CONTACT PAIRS IN MSC NASTRAN

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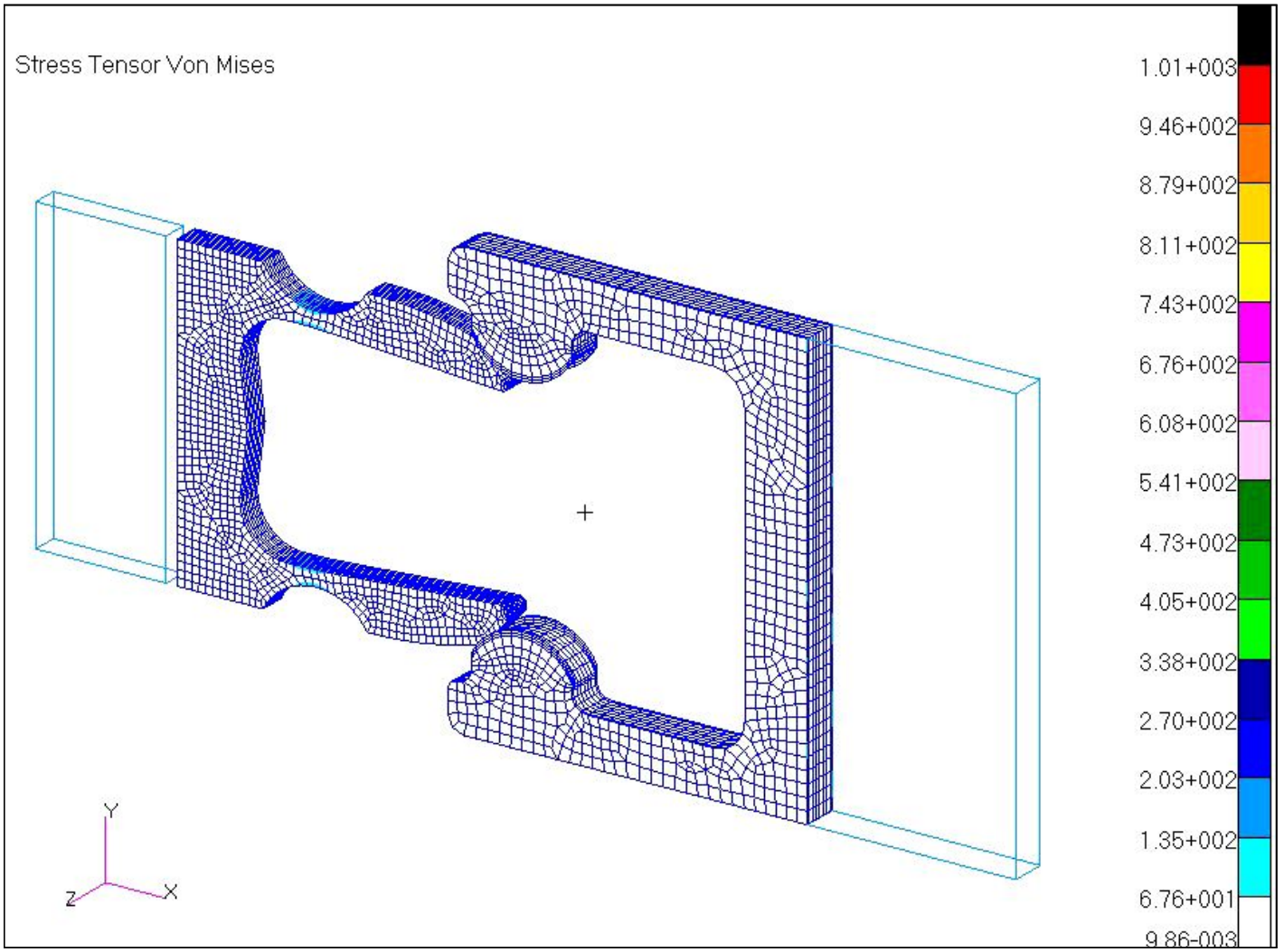
EXAMPLE



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REVIEW

- **Deformable Contact Bodies**
  - Collections of similar type elements (i.e. shells, solids, bars…)
  - Treated using 'normal' FEA approach (flexible)
- **Rigid Contact Bodies**
  - Collections of geometries to be treated as rigid
  - Can be moving or stationary
- **Contact can be deformable-deformable or rigid-deformable**
- **Contact Bodies can 'TOUCH', be 'GLUE'd, or ignore other Contact Bodies**

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CONTACT PAIRS/TABLES

- **Patran/MSC Nastran allows 2 methods to define which contact bodies are to be considered for contact with which other bodies**
  - 'Contact Table'
    - As the name implies, this method allows the user to populate a 'table' which defines which bodies contact which other bodies
    - Easy to use
    - Only practical for relatively small (typically<10) numbers of contact bodies
  - 'Contact Pair'
    - Explicit definition of which bodies are to touch which other bodies
    - Allows ease of use when many (>10) contact bodies exist
- **Further, each method, allows for specification of the contact type as**
  - Touching – allows intermittent contact
  - Glued – enforces a permanent connection between contact bodies
- **Both methods define the same characteristics/properties, the choice of which method is be used comes down to which is 'easier', typically determined by the number of contact bodies**

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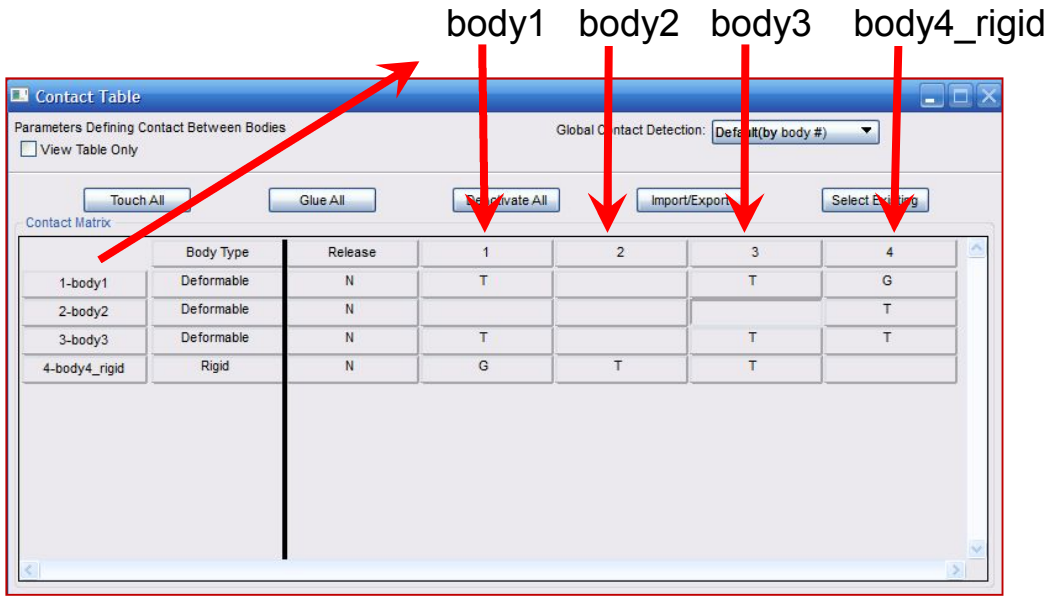
CONTACT TABLES

- **Best described using example:**



- **In this example:**
  - 'body1' is only allowed to 'touch' itself and 'body3'
  - 'body1' is 'glued' to 'body4_rigid'
  - 'body2' is only allowed to' touch' 'body4_rigid'
  - 'body3' is only allowed to 'touch' itself and 'body4_rigid'

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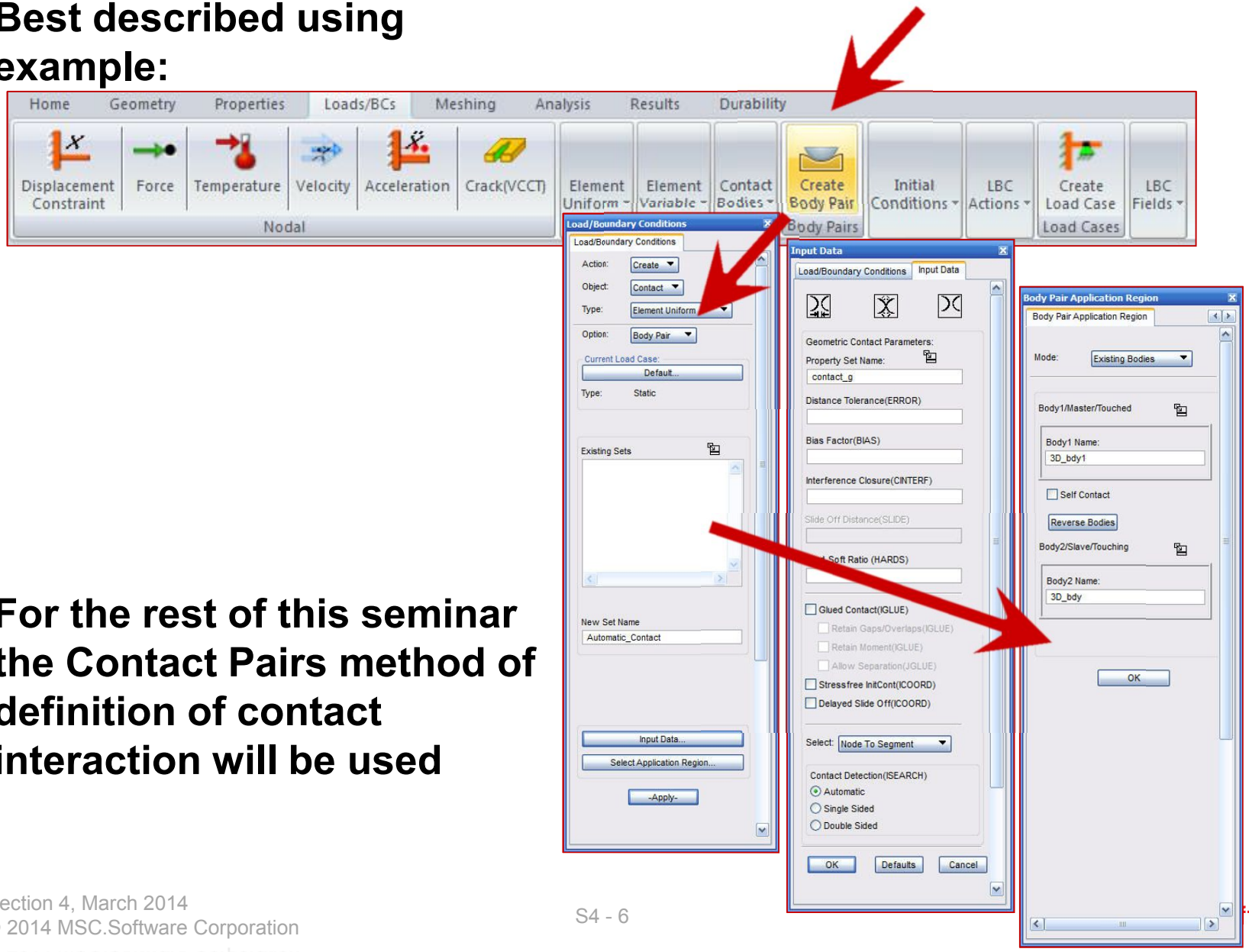
CONTACT PAIR

- **Best described using example:**



- **For the rest of this seminar the Contact Pairs method of definition of contact interaction will be used**

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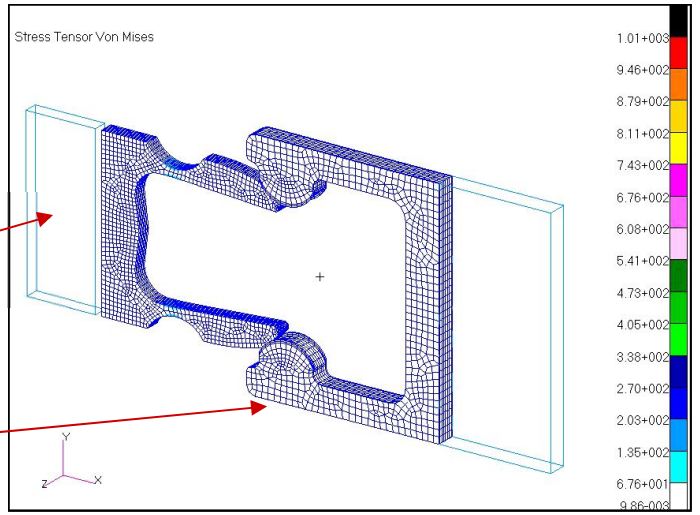
CONTACT PAIR

- **Determines which Contact Bodies interact with each other and how**
  - TOUCH or GLUE



- **Also allows 'tweaking' of contact body parameters on a Contact Body pair basis in the event of convergence or other difficulties**
  - Contact order
  - Distance Tolerance
  - Separation Force

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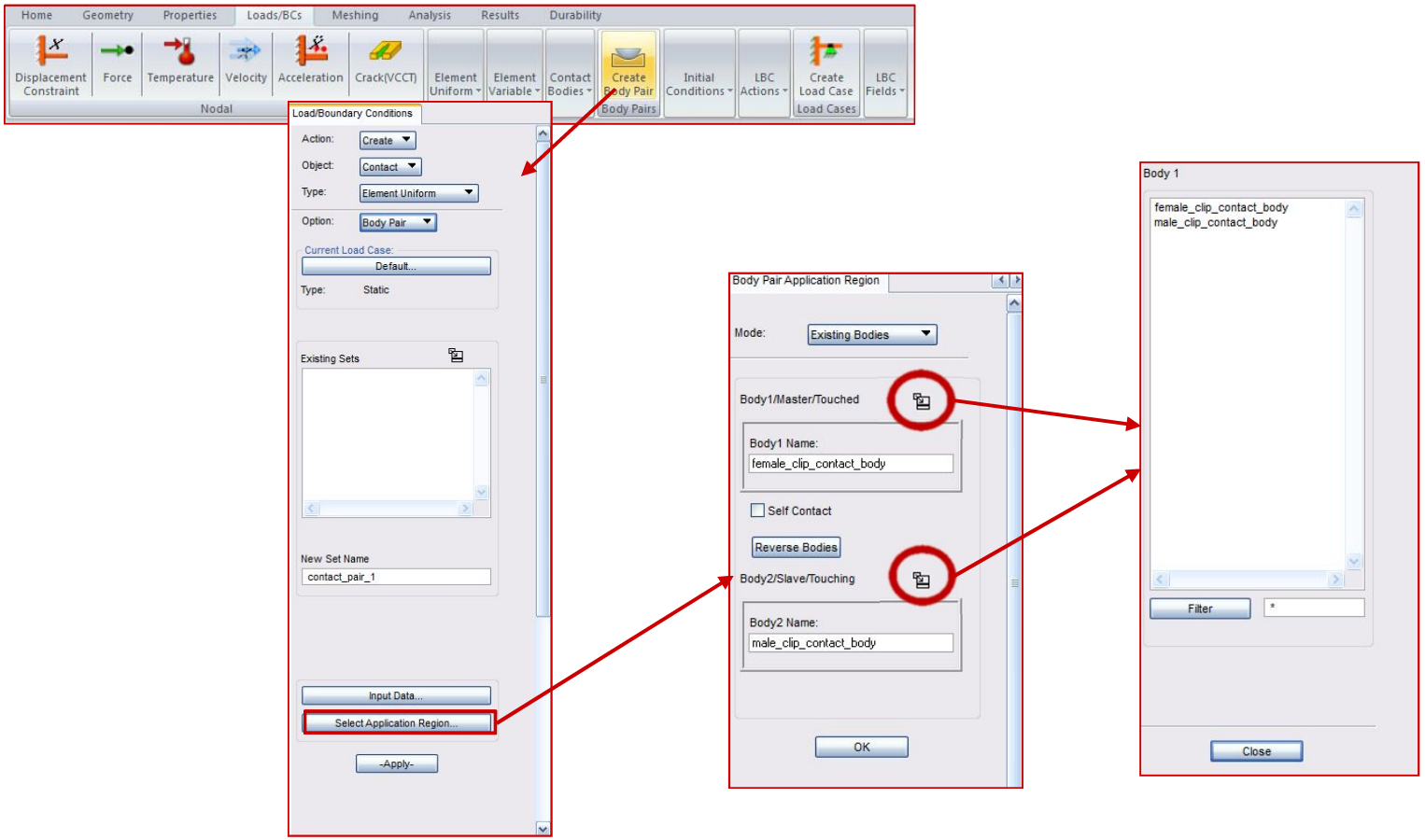
CONTACT PAIR

- **A ‘CONTACT PAIR’ is defined like other Loads/BCs and defines which bodies are to interact.**



- **Like other Loads/BCs the contact pair can active/inactive as desired by the user in each loadcase**

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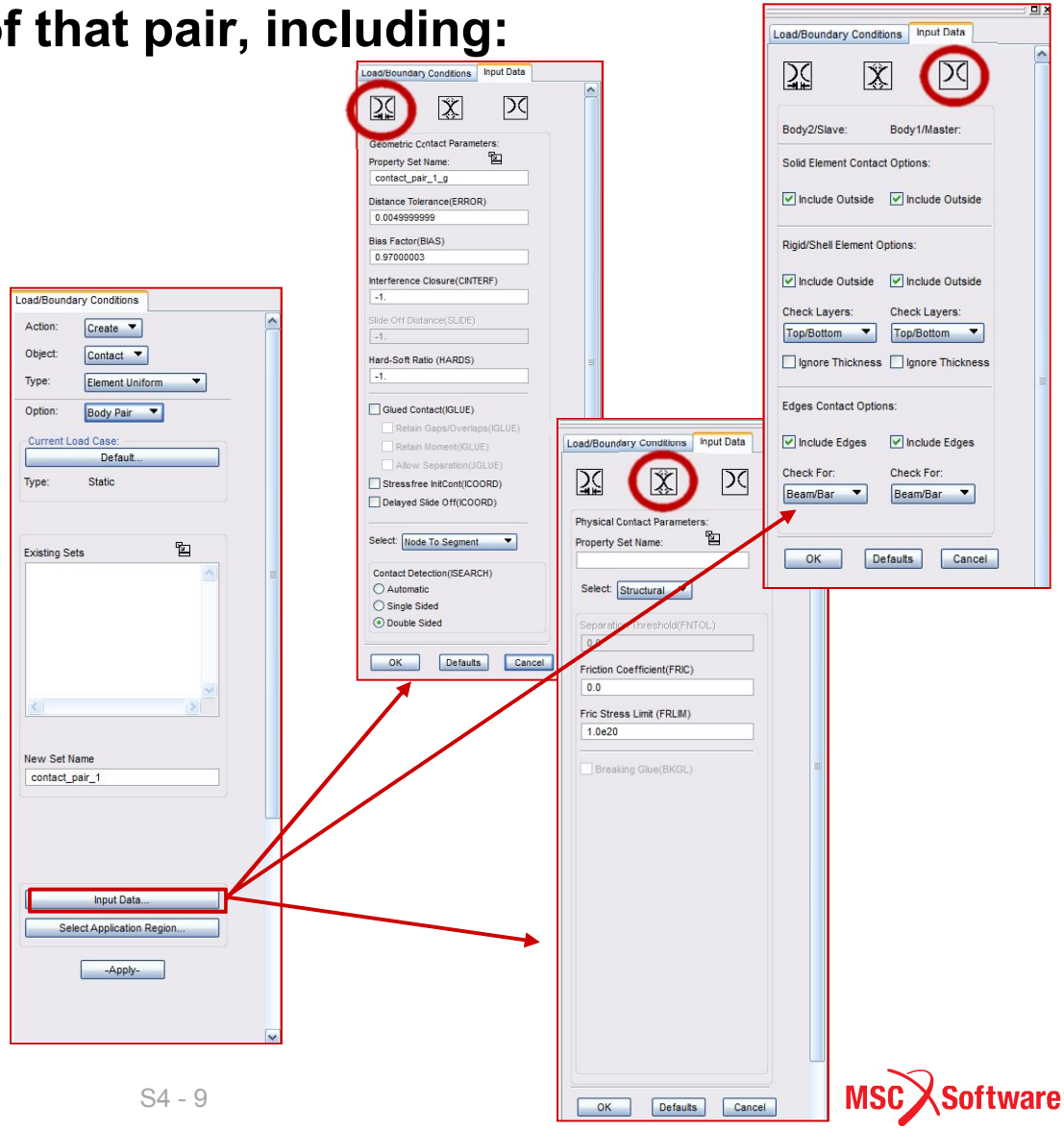
CONTACT PAIR

- **Each CONTACT PAIR can have a unique set of parameters that will affect the behavior of that pair, including:**
  - Distance tolerance
  - Bias factor
  - Separation force
  - Glue
  - Stress free initial contact
  - Order behavior
- **3 sub-forms are available via the 'Input Data' button to define the various parameters.**
- **Like other Loads/BCs the contact pair can be made active/inactive as desired by the user in each loadcase**



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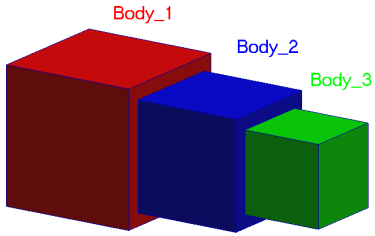
CONTACT PAIRS WRITTEN FROM PATRAN




```
NLPARM   1                                                        NO
BCTABL1  0        8004     8005
BCONECT  8004                       2        1
BCONECT  8005                       3        2
BCTABL1  1        8004     8005
$ Elements and Element Properties for region : block1

$ Loads for Load Case : Default
$ Deform Body Contact LBC set: Body_1
BCBODY1  1                  3D       DEFORM   1
BSURF    1        1         2        3        4        5        6        7
         8        9         10       11       12       13       14       15
         16       17        18       19       20       21       22       23
         24       25        26       27       28       29       30       31
         32       33        34       35       36       37       38       39
         40       41        42       43       44       45       46       47
         48       49        50       51       52       53       54       55
         56       57        58       59       60       61       62       63
         64
$ Deform Body Contact LBC set: Body_2
BCBODY1  2                  3D       DEFORM   2
BSURF    2        65        66       67       68       69       70       71
         72       73        74       75       76       77       78       79
         80       81        82       83       84       85       86       87
         88       89        90       91
$ Deform Body Contact LBC set: Body_3
BCBODY1  3                  3D       DEFORM   3
BSURF    3        92        93       94       95       96       97       98
         99
$ Referenced Coordinate Frames
ENDDATA 7486e87b
```

Specifies Interaction between Contact Body 1 and 2

Specifies Interaction between Contact Body 2 and 3

Use BCONECTs 8004 and 8005

Contact Body Definition

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CONTACT PAIRS IN MSC NASTRAN

- **BCONECT – MSC Nastran entry to define which contact bodies interact with which other contact body**
- **In its simplest form this will be a single line specifying 2 bodies**
- **Lists of bodies may also be defined if desired**

BCONECT	ID	BCGPID	BCPPID	IDSLAVE	IDMASTER				
	"SLAVES"	IDSL1	IDSL2	IDSL3	IDSL4	IDSL5	IDSL6	IDSL7	
		IDSL8	IDSL9	-etc.-					
	"MASTERS"	IDMA1	IDMA2	IDMA3	IDMA4	IDMA5	IDMA6	IDMA7	
		IDMA8	IDMA9	-etc.-					

Examples:

BCONECT	57	306		2	1002				

BCONECT	9		108						
	SLAVES	30	26						
	MASTERS	294	135	528					

- **BCTABL1 – specifies which BCONECTs are to be a simultaneously and is referenced at the Case Control level by BCONTACT:**

BCTABL1	BCID	ID1	ID2	ID3	ID4	ID5	ID6	ID7	
	ID8	ID9	-etc.-						

Examples:

BCTABL1	2	198	62	75	8	159	31	82	44
	17								

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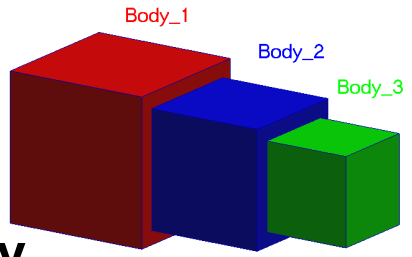
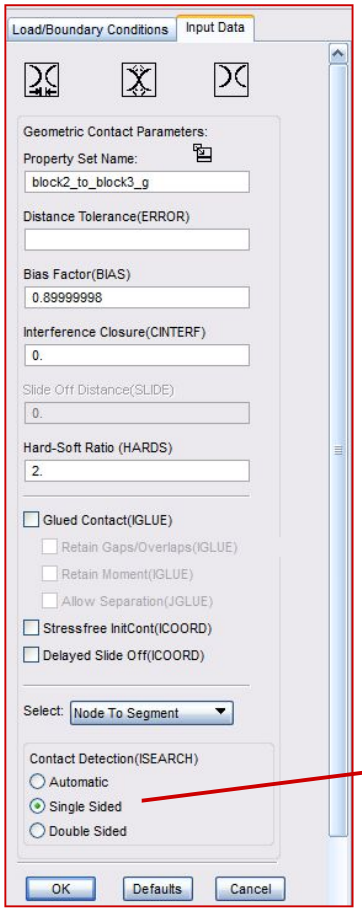
CONTACT PAIRS IN MSC NASTRAN

- **Example – bodies 1, 2 and 3 in a sequence**
- **User specified 'single sided' search sets appropriate value in MSC Nastran BCONPRG entry**






```
BCTABL1  0       8004    8005
BCONECT  8004                    2       1
BCONECT  8005    3006            3       2
BCONPRG  3006            ISEARCH 1
BCTABL1  1       8004    8005
$ Elements and Element Properties for region : block1
```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DISTANCE TOLERANCES

- **Measured normal to the contacted body**
- **Input on BCPARA,0,ERROR, .005 or BCONPRG**

BCONPRG	BCGPID		PARAM1	VAL1	PARAM2	VAL2	PARAM3	VAL3	
	PARAM4	VAL4	PARAM5	VAL5	-etc.-				

Example:

BCONPRG	90		**ERROR**	**.005**					

- **By default, ERROR is evaluated from:**
  - 1/20 x “smallest element edge“ for continuum elements within each contact pair
  - ¼ x “smallest thickness“ for beam and shell elements within each contact pair
- **By default, BIAS is 0.9**

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EFFECT OF DISTANCE TOLERANCES

- **The sizes of the contact tolerances D1 and D2 have a significant impact on the computational costs and the accuracy of the solution**
- **Contact tolerances are too small:**
  - Detection of contact is difficult, leading to higher costs. Initial contact might not be detected.
- **Contact tolerances are too large:**
  - Nodes are considered in contact prematurely, resulting in a loss of accuracy
  - Nodes might “penetrate” the surface by a large amount

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BCONTACT = ALLBODY

- **With this Case Control command the definition of contact pairs is eliminated**
  - All bodies can potentially contact each other
- **Care should be exercised**
  - Good for checking out runs
  - Convergence can be difficult
  - Run time can be longer

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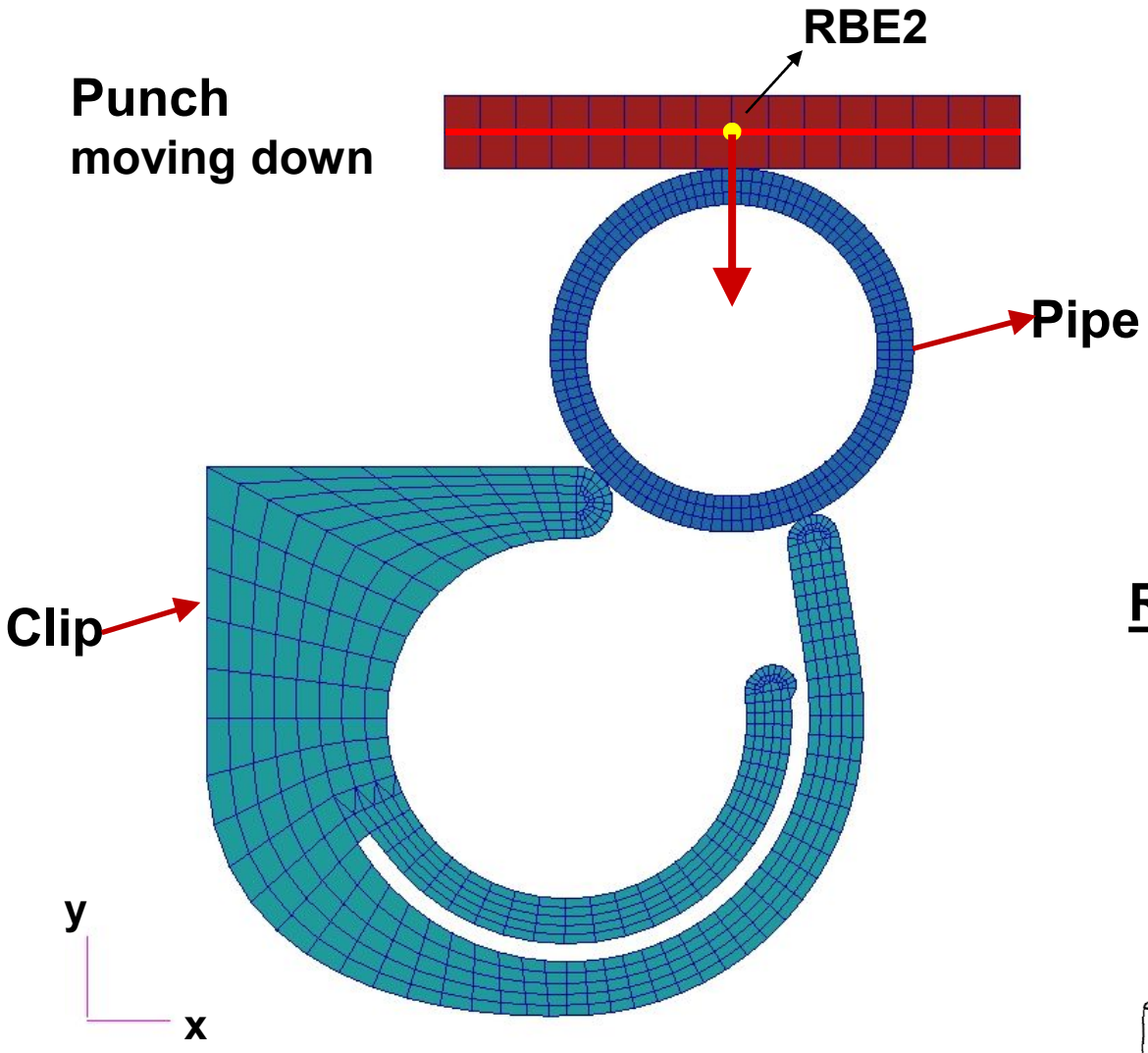
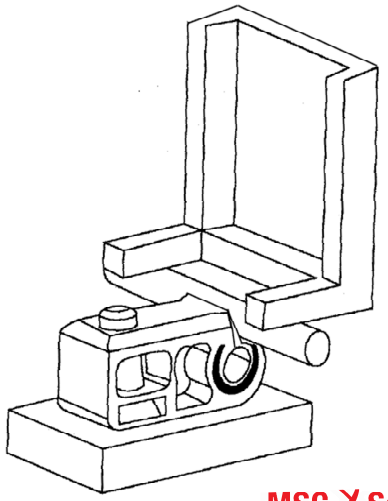
PIPE TO CLIP CONTACT EXAMPLE



Related Test



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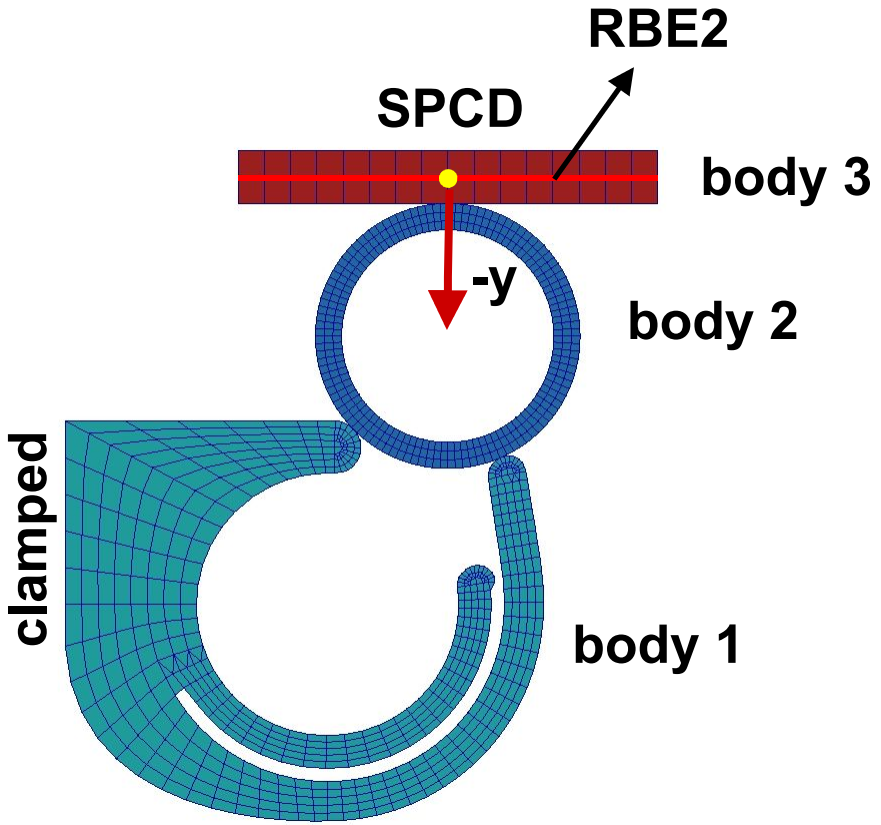
MODEL DESCRIPTION

- **Clip: plastics, E=2100., n=0.3**
  - 2D solids, inner∅ = 10 mm
- **Pipe: steel, E=2.1E5, n=0.3**
  - 2D solids, outer∅ = 10.1 mm
- **Punch: steel, like pipe**
  - 2D solids
- **Loading:**
  - Punch pushed in
  - Punch is pulled out
- **Boundary Conditions:**
  - Left side of clip is clamped
  - Punch and pipe vertically connected
  - To exclude dynamic effects (snap & eject)



Friction:

body 1-1, μ=0.25
bodies 1-2, μ=0.15
bodies 2-3, μ=0

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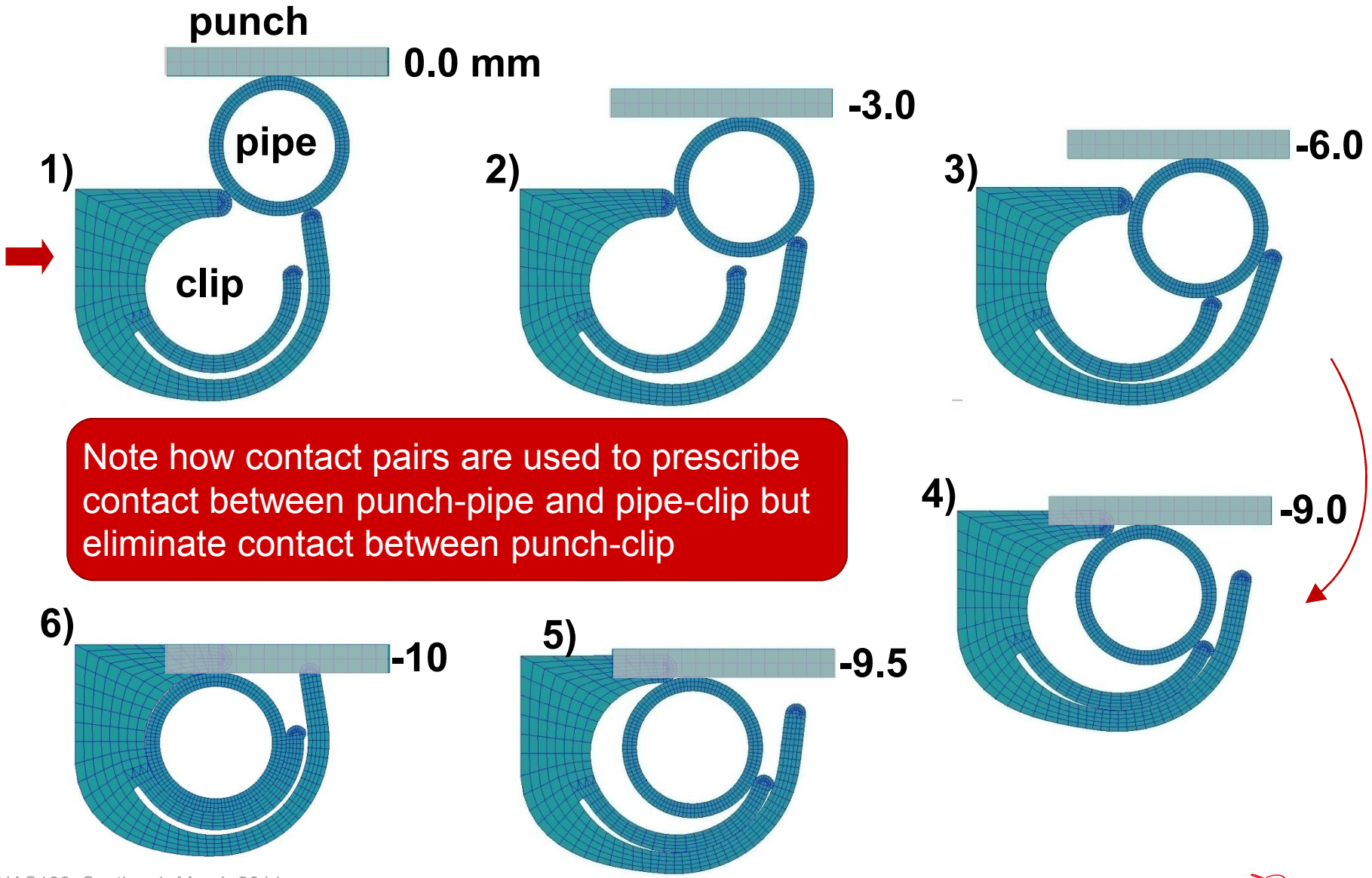
PUSHING DEFORMATIONS



Note how contact pairs are used to prescribe contact between punch-pipe and pipe-clip but eliminate contact between punch-clip

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CONTACT INTERFERENCE

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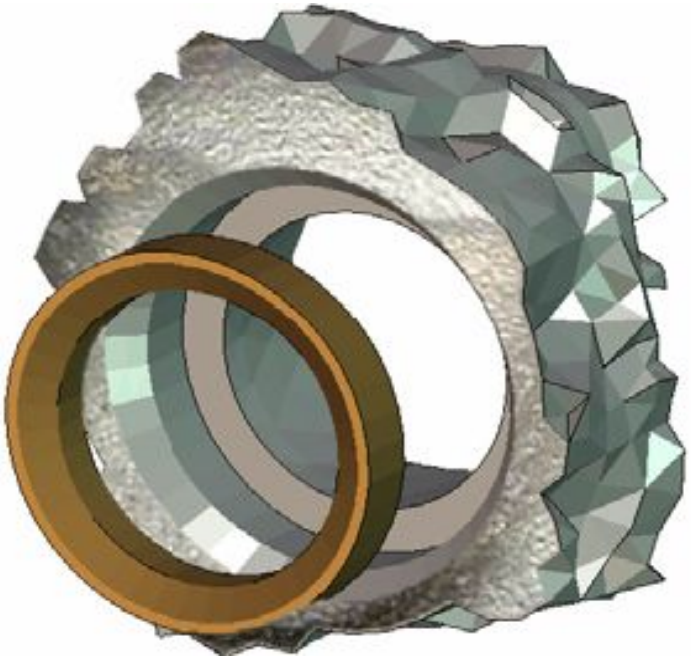
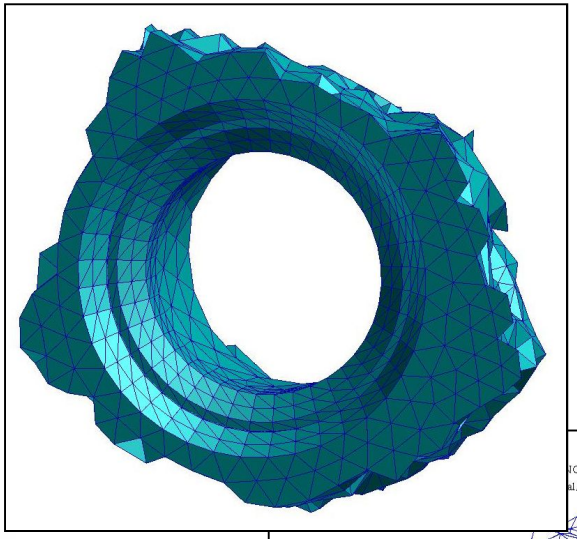
CONTACT INTERFERENCE – EXAMPLE

- **Valve Insert Fitted into Cylinder Head**



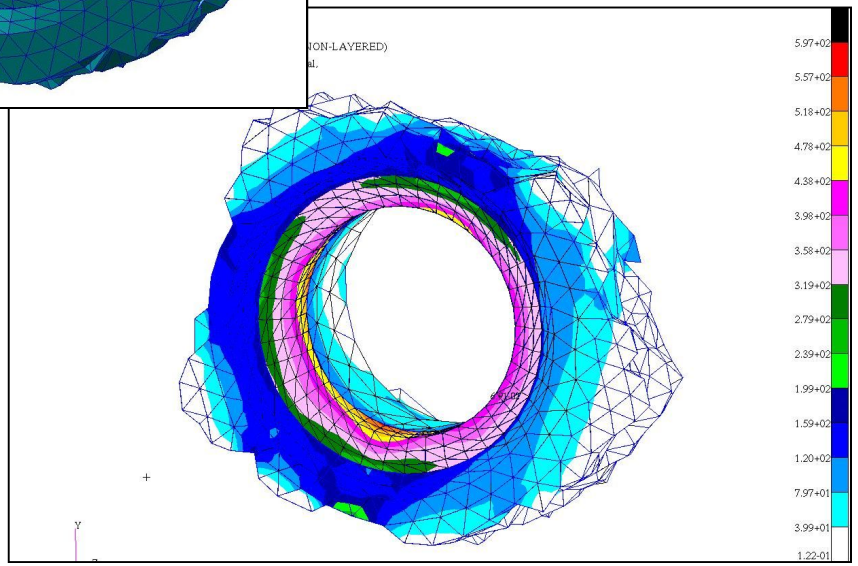
Real Model



FEM

- No load

- quadratic contact



von Mises

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CONTACT INTERFERENCE

- **The interference closure distance is defined via CINTERF in BCONPRG entry**
  - It only affects nodes which are already in contact
  - The regular contact-related incremental displacement is modified by:

$$\Delta\bar{v}_A := \Delta\bar{v}_A + d_i\bar{y}$$

  - d_i is CINTERF, the user-defined interference closure distance normal to the contact surface
- **When contact bodies are moving**
  - CINTERF>0: contact starts earlier by d_i (initial interference)
  - CINTERF<0: contact occurs after penetration of d_i (initial clearance)

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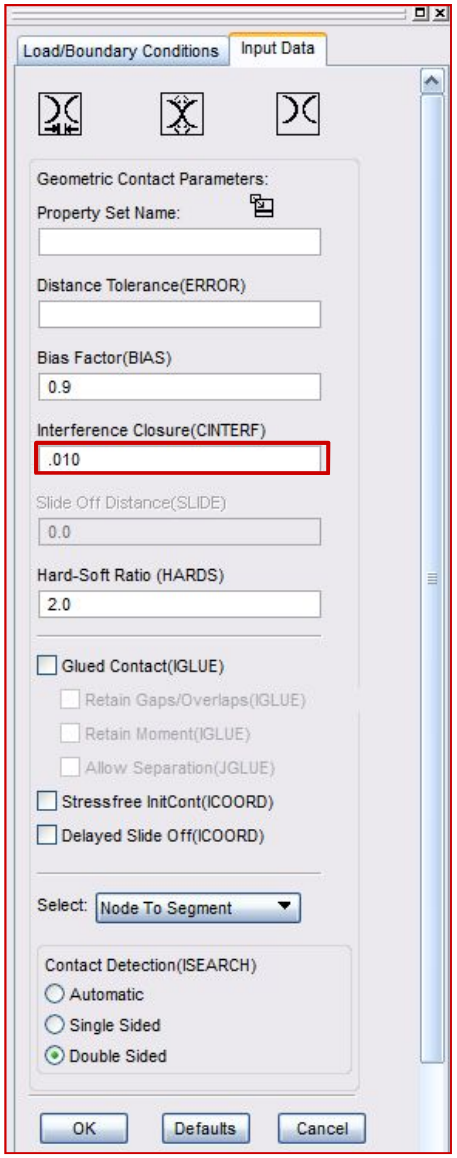
CONTACT INTERFERENCE

- **In Patran:**



Specification of interference

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CONTACT INTERFERENCE

- **BCONPRG – used to define CINTERF**

BCONPRG	BCGPID		PARAM1	VAL1	PARAM2	VAL2	PARAM3	VAL3	
	PARAM4	VAL4	PARAM5	VAL5	-etc.-				

Example:

BCONPRG	90		**CINTERF**	**.01**					

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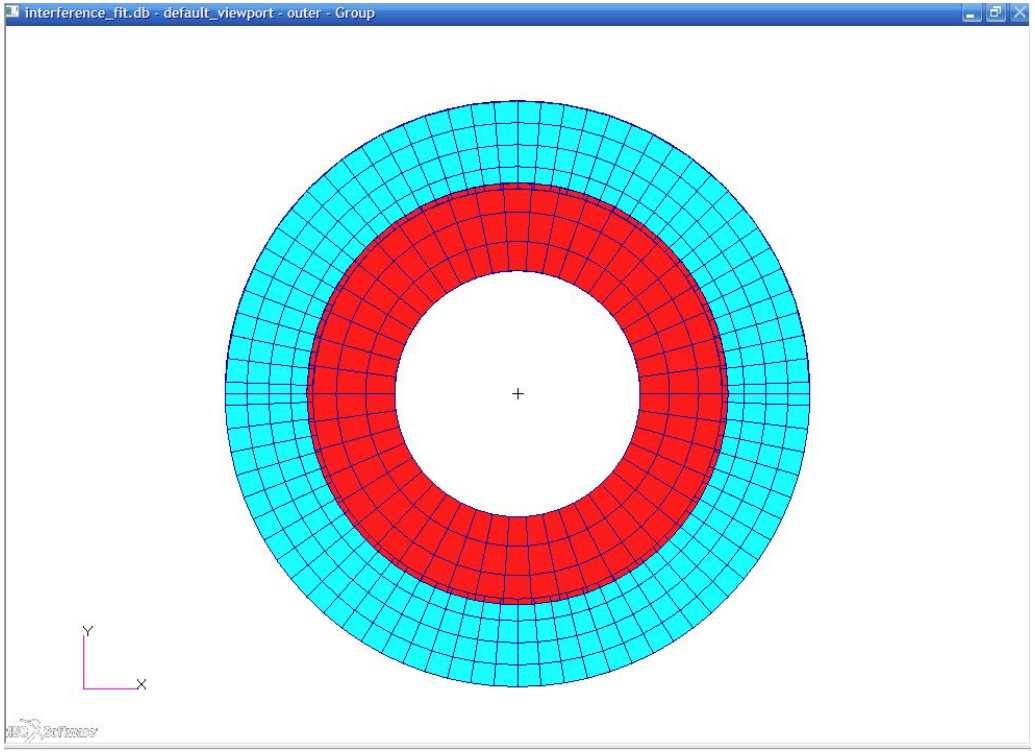
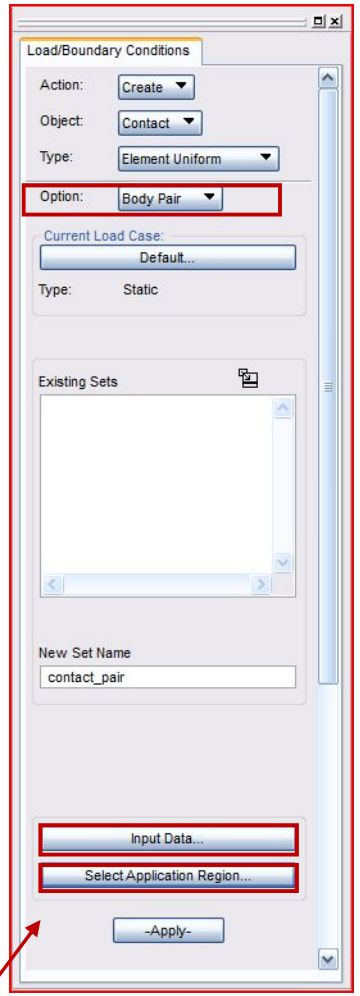
CASE STUDY: INTERFERENCE FIT

- **Define contact bodies**





Replaces Contact Table
(Used in Patran 2012 or older)

Play Case study video:
NAS133_S4_cs_interference_fit

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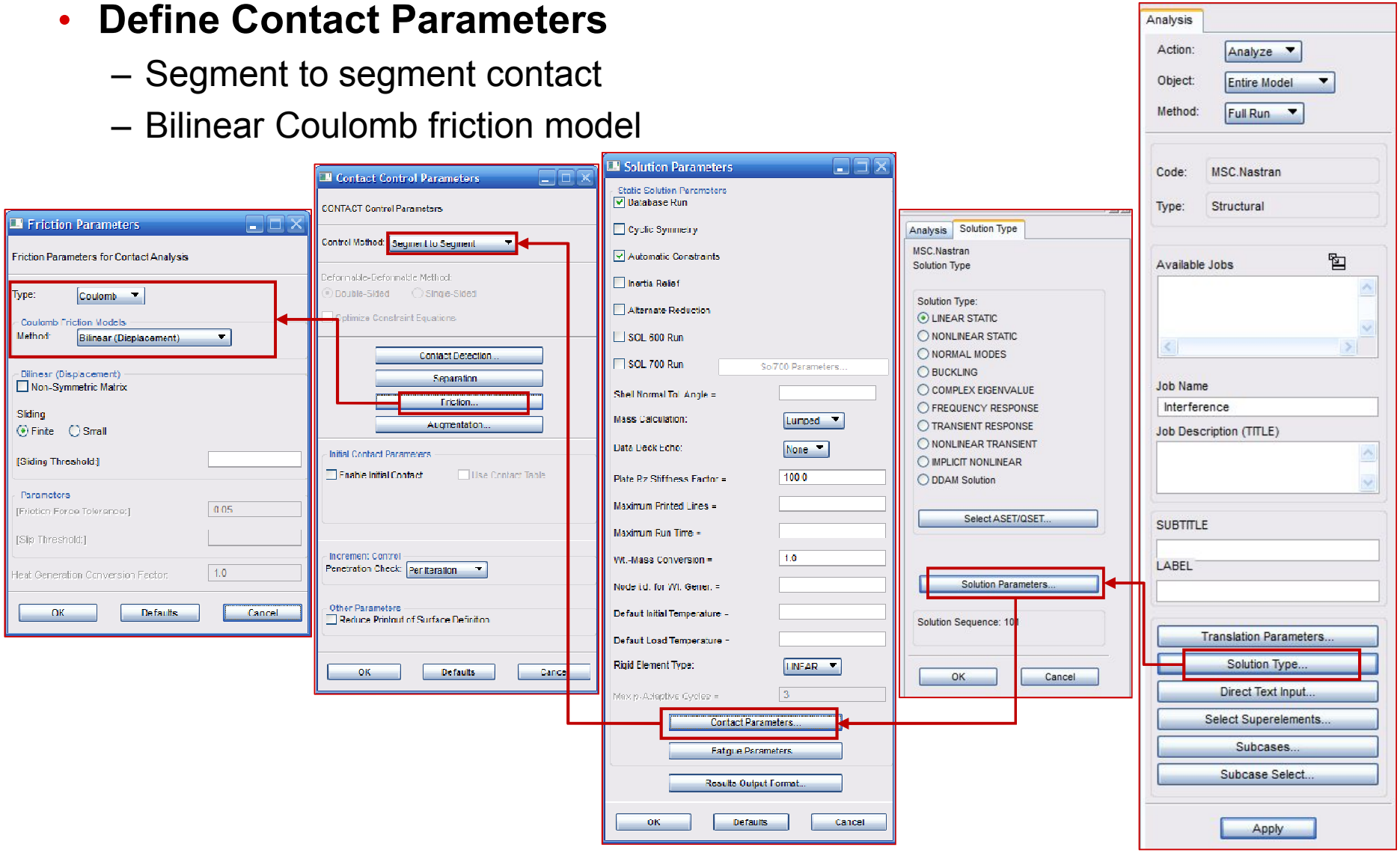
CASE STUDY: INTERFERENCE FIT

- **Define Contact Parameters**
  - Segment to segment contact
  - Bilinear Coulomb friction model



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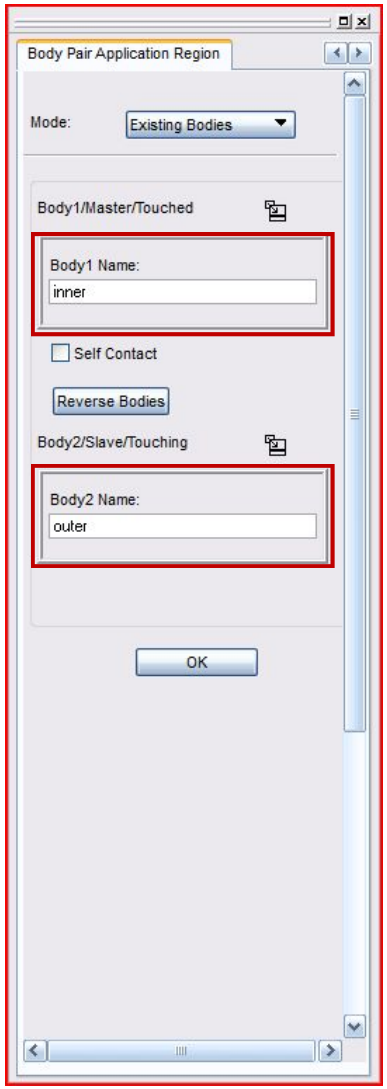
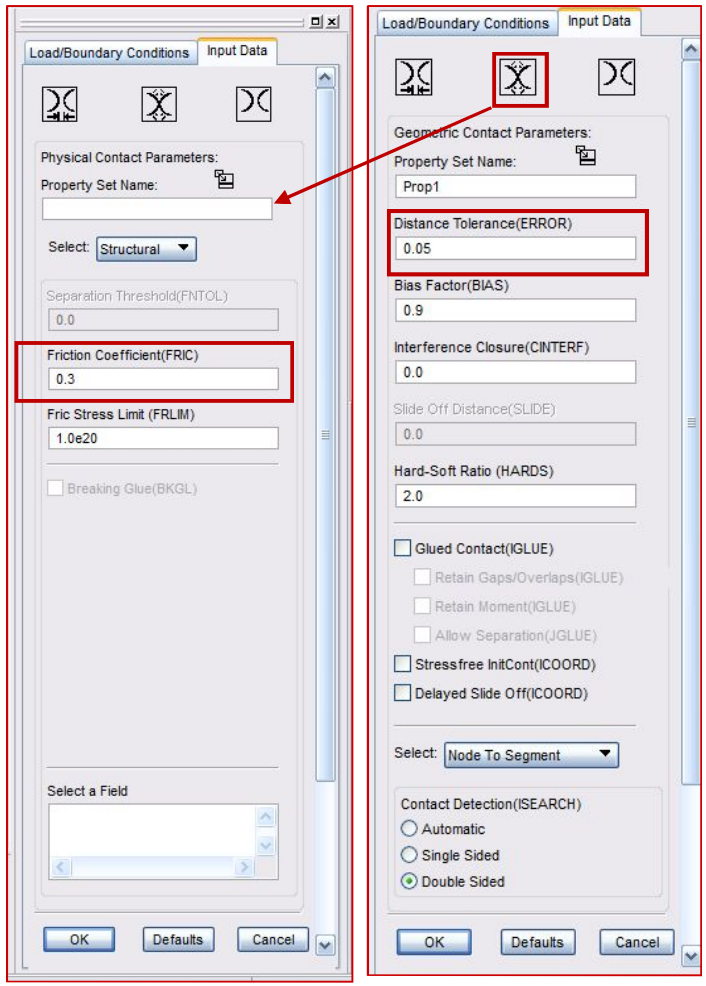
CASE STUDY: INTERFERENCE FIT

- **Define Contact Pair Parameters**
  - Set contact distance tolerance larger than interference fit amount
  - Enter friction coefficient
- **Define Application Region**
  - Assign master and slave bodies

Select Application Region



Input Data



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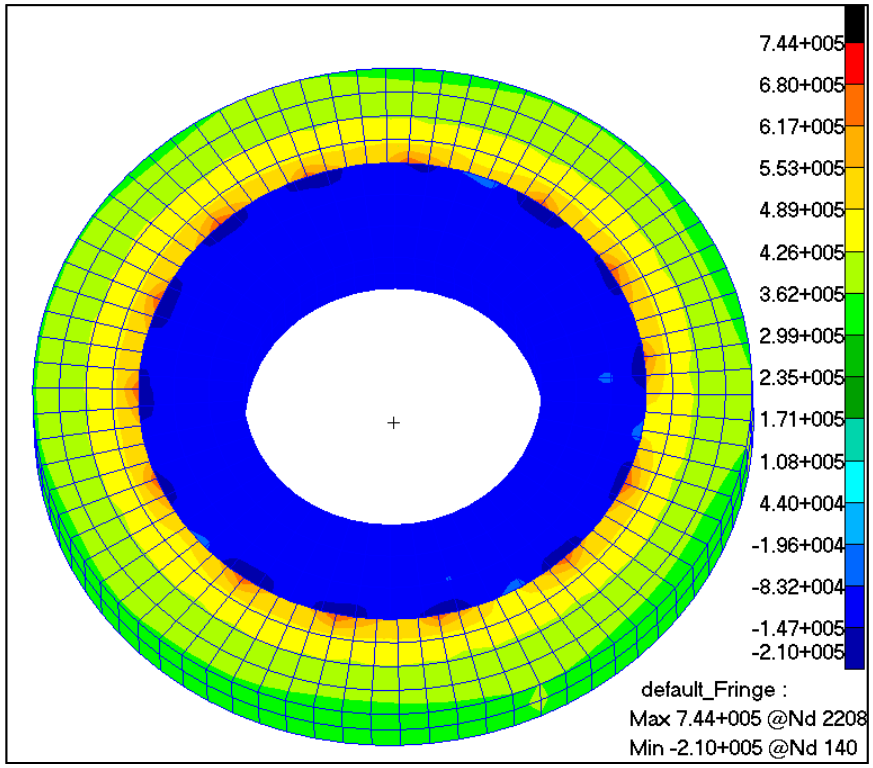
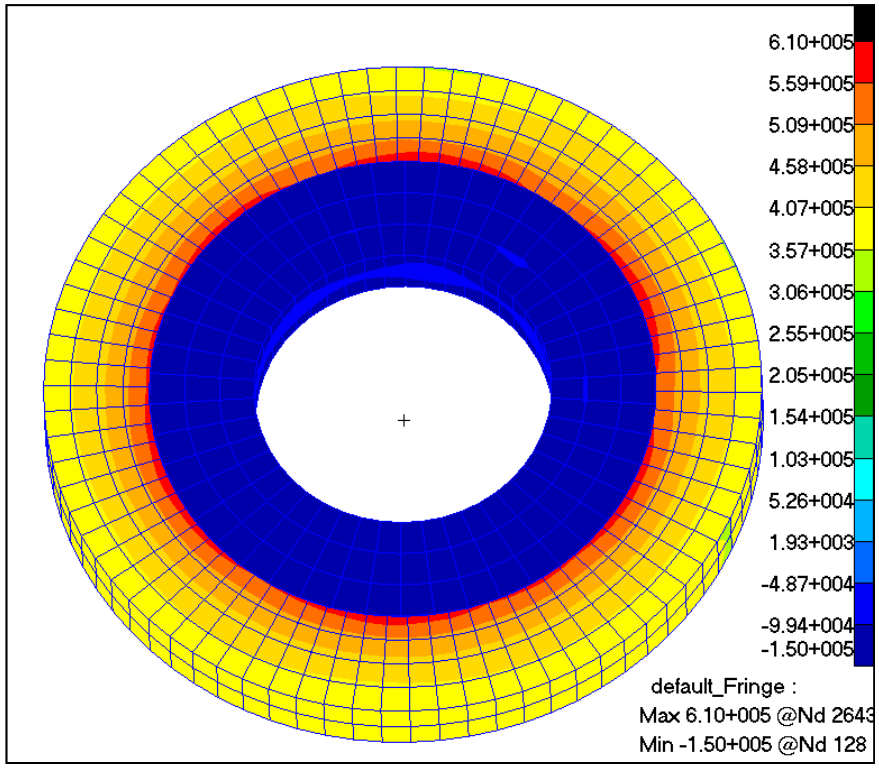
CASE STUDY: INTERFERENCE FIT

- **Plot circumferencial stress**

Node to Segment



Segment to Segment



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INITIAL STRESS FREE CONTACT

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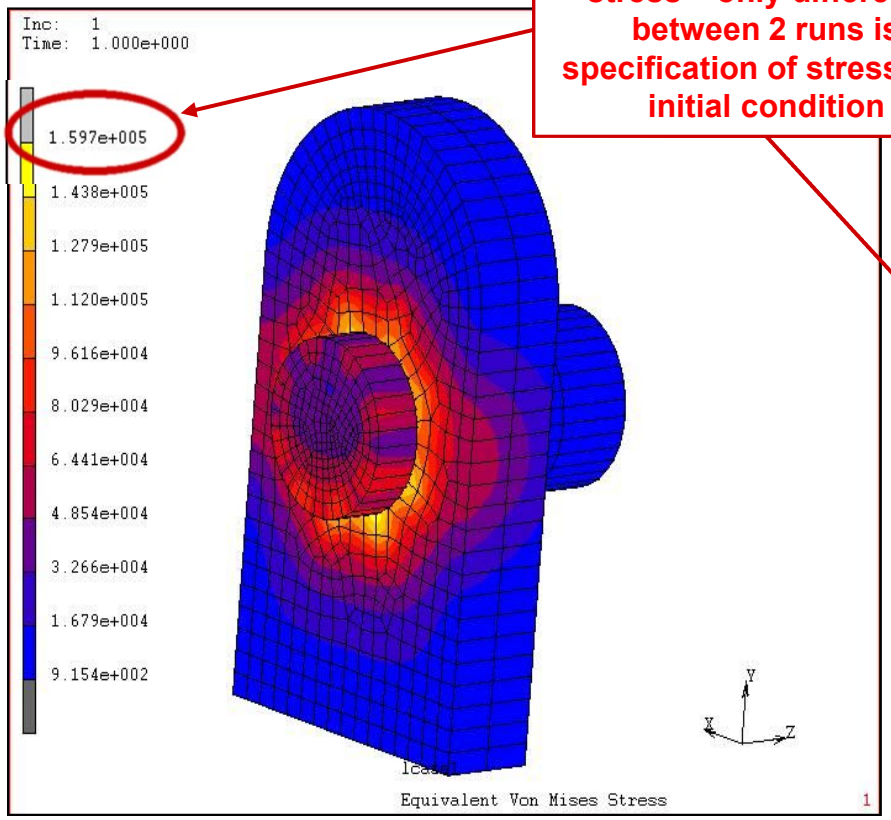
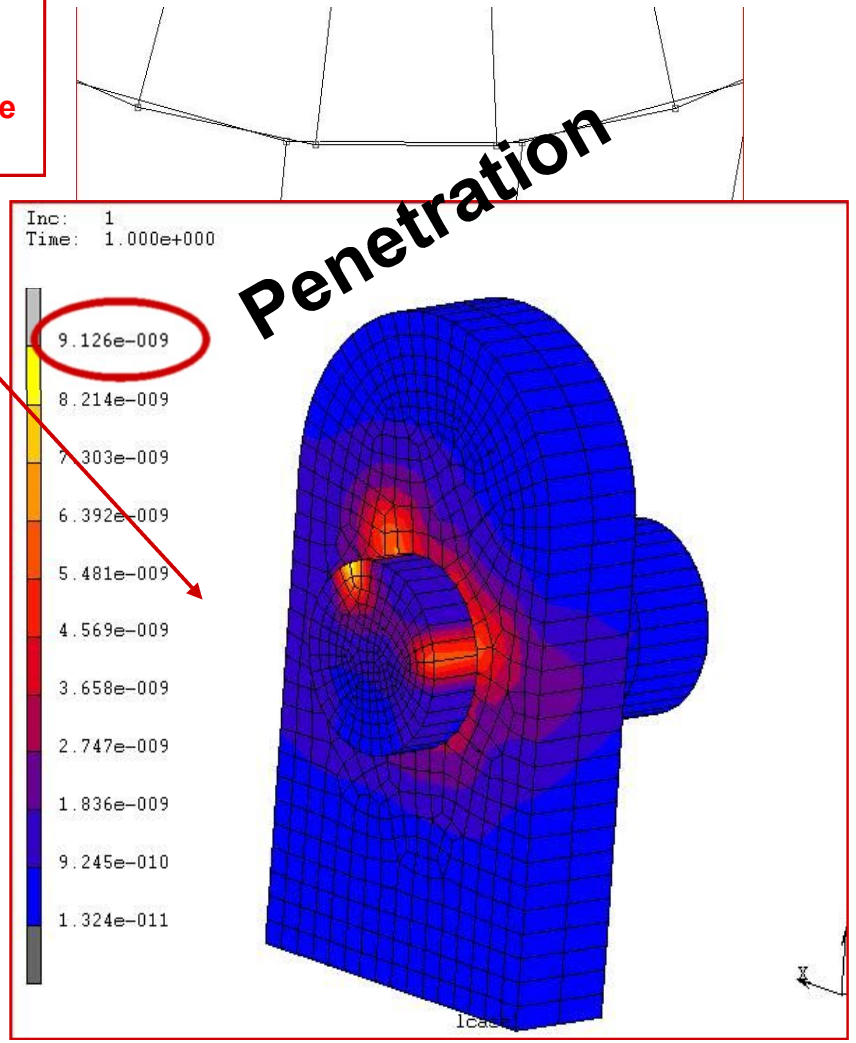
INITIAL STRESS FREE - EXAMPLE

Note difference in max stress – only difference between 2 runs is specification of stress-free initial condition



No Initial Stress-Free



Initial Stress-Free

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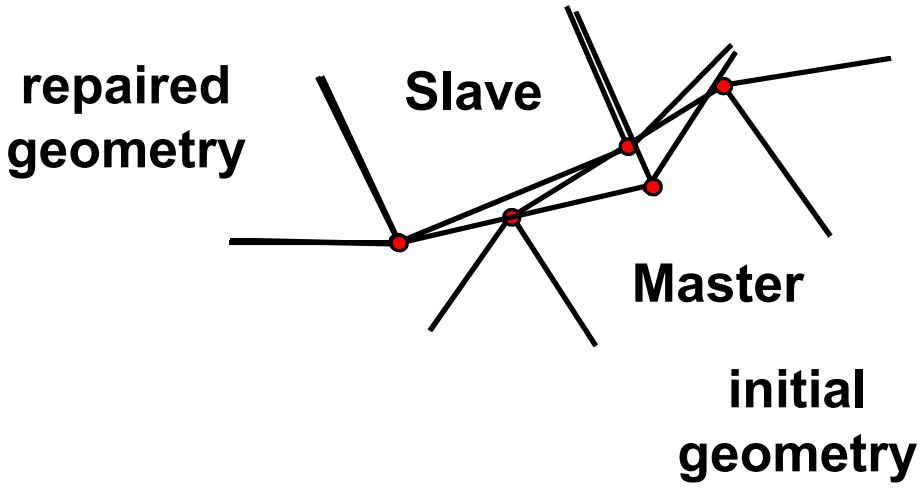
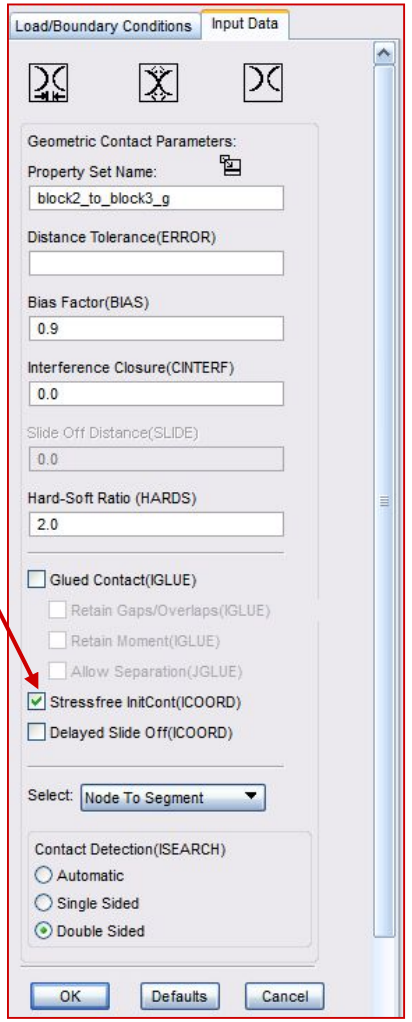
INITIAL STRESS FREE CONTACT

- **Before starting with the first increment a check is performed on initial contact (BCTABL1, 0)**
  - Upon penetration slave is constrained to master
  - As a result stresses may develop
  - For stress free initial contact is set by defining ICOORD to 1
    - BCONPRG in MSC Nastran input file or in Patran





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CONTACT INTERFERENCE

- **BCONPRG – used to define CINTERF**

BCONPRG	BCGPID		PARAM1	VAL1	PARAM2	VAL2	PARAM3	VAL3	
	PARAM4	VAL4	PARAM5	VAL5	-etc.-				

Example:

BCONPRG	90		**ICOORD**	**1**					

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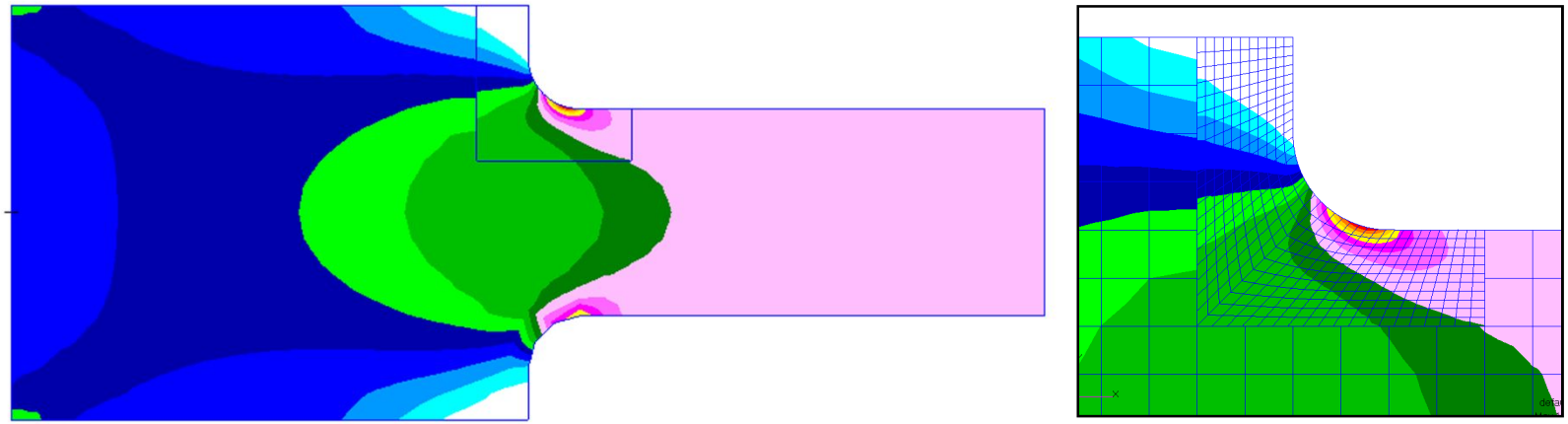
WORKSHOP 3 – SHELL EDGE TO EDGE GLUED CONTACT

- **Learn to create a shell edge-to-edge glued contact with moment transfer capability**



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REVIEW QUESTIONS

1. **Where can “contact distance tolerance” (ERROR) and “Bias factor” (BIAS) be input in MSC Nastran entries?**

2. **What is the difference between permanent glued contact and general glued contact?**

3. **What are two general recommendations to define a slave body?**

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REVIEW QUESTIONS

4. How can you activate a stress-free initial contact option?

5. Why should automatic contact search order be used?

6. How does Patran create deformable body ID order?

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SECTION 5

GLUED CONTACT

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GLUED CONTACT

- **SOL 101 and 400 support the general and permanent glued contact capability**
- **General glued contact is a nonlinear solution**
  - Simulates a glued joint
  - Bodies don't have to be initially in contact. They can come in contact during the analysis and become glued
  - After being glued together, bodies can separate again or stay glued based on user-specified criteria
  - Just like touching contact, the general glued contact utilizes the nonlinear solver which is an incremental and iterative process

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GLUED CONTACT

- **Permanent Glued Contact is a special case of glued contact**
  - Designed to help users quickly assemble components with dissimilar meshes
  - Bodies should be in contact initially since contact detection is performed only in the beginning of the analysis
  - Also available in SOL 103, 105, 107, 108, 109, 110, 111, 112, and 200
  - A linear solution. Permanent contact constraint MPC equations are used. No nonlinear increments or iterations involved

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SETTING UP GLUED CONTACT - IGLUE

- **Glued contact is activated by IGLUE parameter in contact pair geometric properties BCONPRG**
  - **0** – no gluing
  - **1** - Activates the glue option. In the glue option, all degrees-of- freedom of the contact nodes are tied in case of deformable-deformable contact once the node comes in contact. The relative tangential motion of a contact node is zero in case of deformable-rigid contact. This option is recommended when there is no gap or overlap between contact surfaces or initial stress free contact is specified.
  - **2** - Activates a special glue option to insure that there is no relative tangential and normal displacement when a node comes into contact. An existing initial gap or overlap between the node and the contacted body will not be removed, as the node will not be projected onto the contacted body. To maintain an initial gap, ERROR should be set to a value slightly larger than the physical gap.
  - **3** - Insures **full moment carrying glue** when shells contact. This option is recommended when there is no gap or overlap between contact surfaces or initial stress free contact is specified.
  - **4** - Insures **full moment carrying glue** when shells contact. The node will not be projected onto the contact body and an existing initial gap or overlap between the node and the contacted body will not be removed, as the node will not be projected onto the contacted body.

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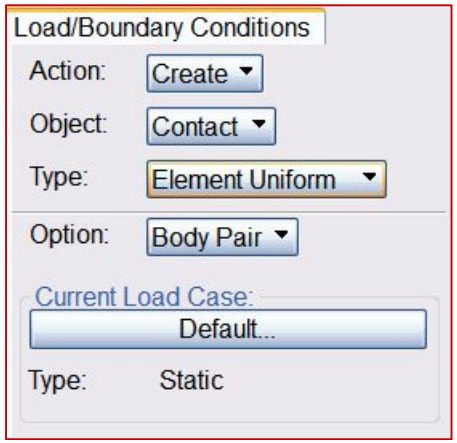
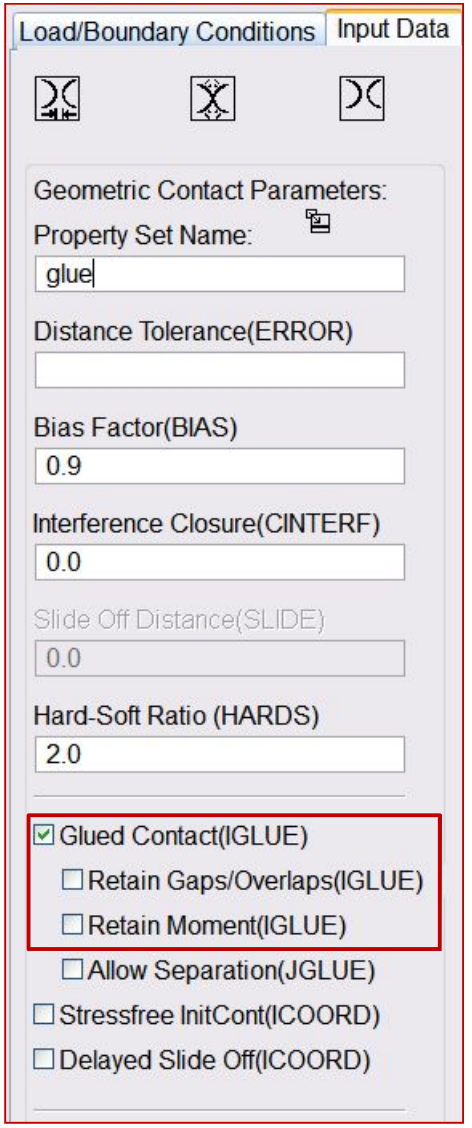
SETTING UP GLUED CONTACT IN PATRAN

- **Check Glued Contact to activate glued contact**
- **Select Retain Gaps/Overlaps to set IGLUE=2**
- **Select Retain Moment to set IGLUE=3 or 4**





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SETTING UP GLUED CONTACT - SEARCH

- When glued contact is used MSC Nastran will automatically create a network of MPCs connecting the bodies in contact
- The quality of this network does depend on the contact search order
- A good strategy is to use the Automatic search order when initially setting up glued contacts, and then double-check the MPCs created (discussion to follow)

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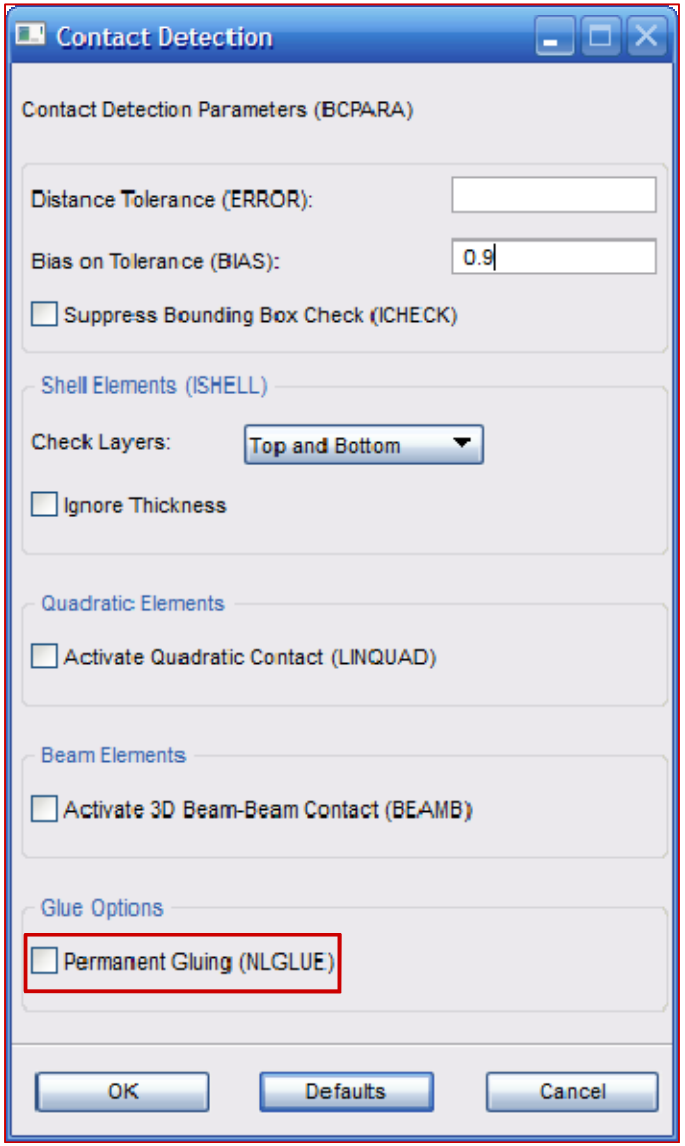
DEACTIVATE PERMANENT GLUED CONTACT

- If all contact pairs corresponding to the first load step contain IGLUE > 0, permanent glued contact will be used in the analysis
- For permanent glued contact, contact status never changes, any contact pair that is not within contact tolerance initially will not be glued
- To allow bodies come in contact and become glued during the analysis, general glued contact must be used
- Set NLGLUE to 1 in BCPARA entry for general glued contact
- Deactivate permanent glued contact in Patran Contact Detection form



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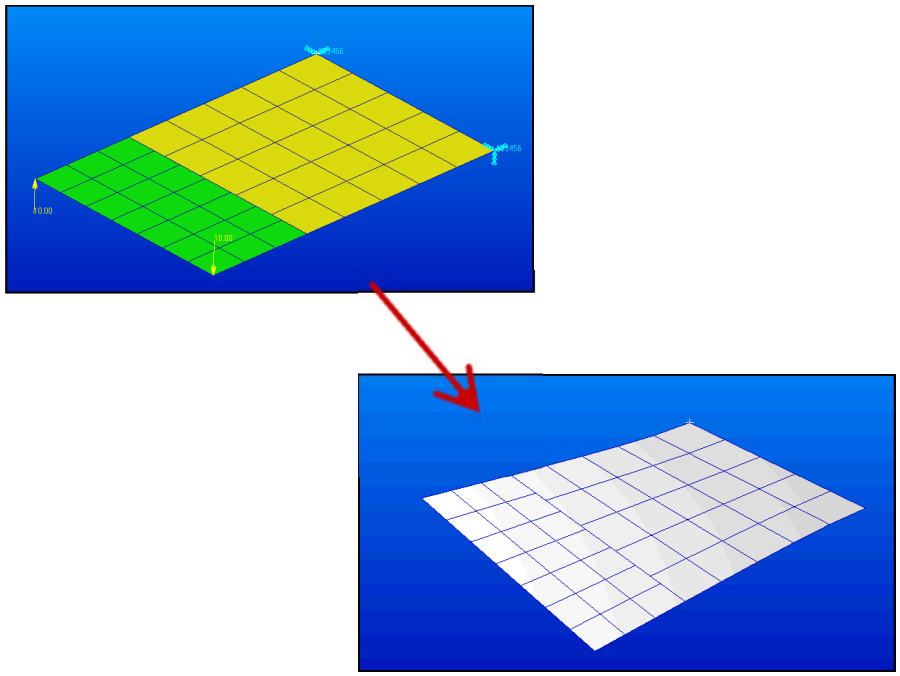
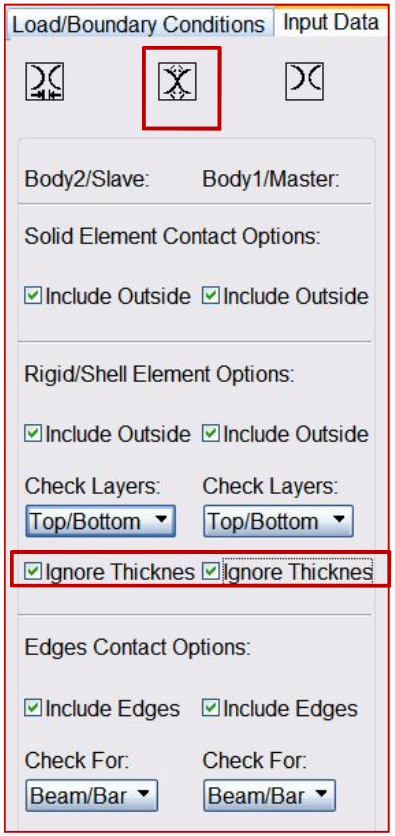
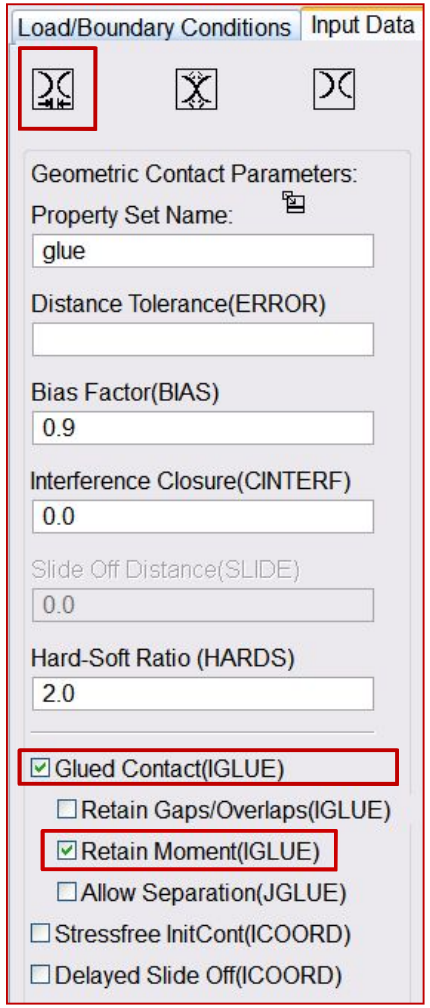
MOMENT CARRYING GLUED CONTACT

- **For shell Edge-to-Edge or shell Edge-to-Face glued contact, it is important to turn on the Retain Moment option to enable the glued joint to transfer moments**
- **Set contact option to ignore shell thickness to simply glue the mid-planes of the shells**







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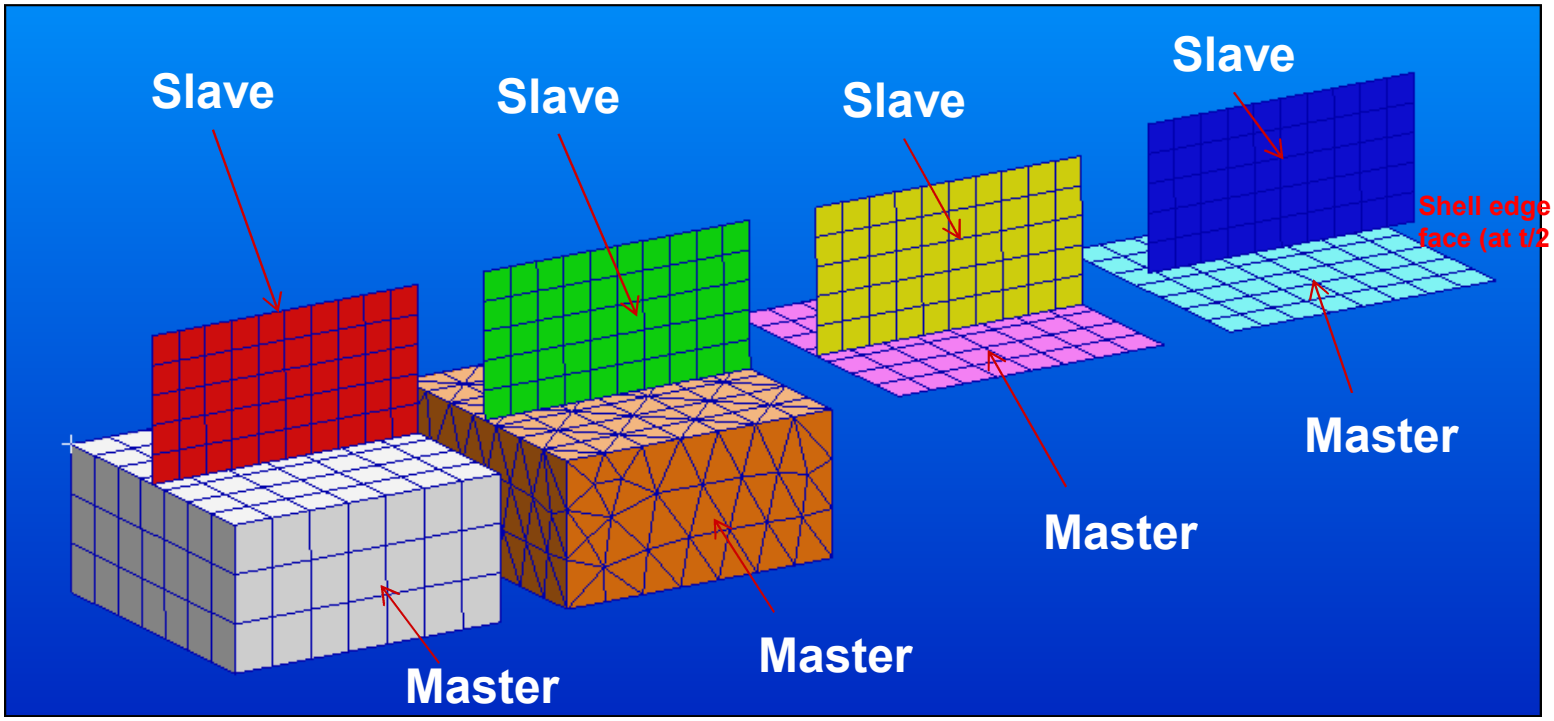
MOMENT CARRYING GLUED CONTACT

- **For shell Edge-to-Face glued contact, slave and master choices are important**
  - The shell edge body needs to be the slave.
  - The face body needs to be the master.



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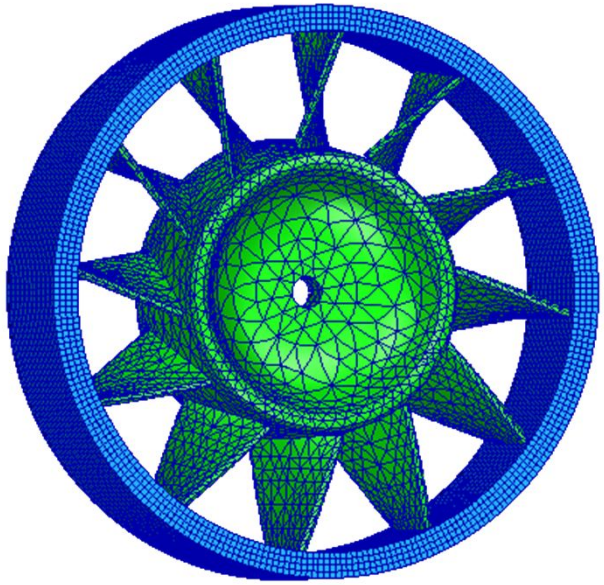
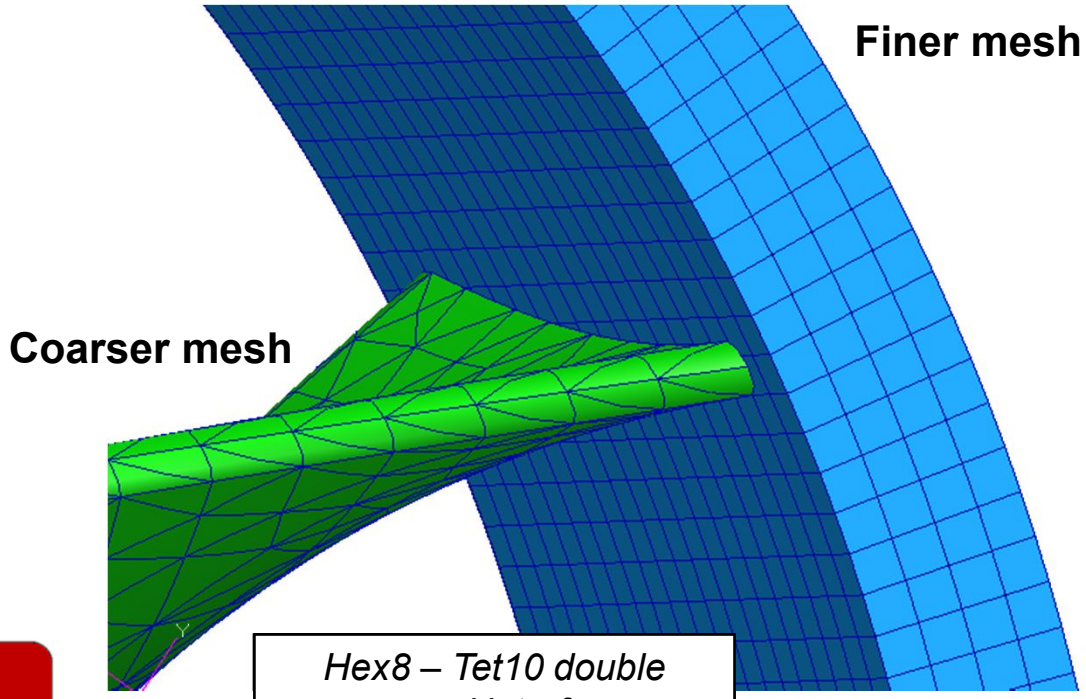
CASE STUDY: MODAL ANALYSIS WITH GLUED CONTACT

- **Analyze the shrouded vanes shown below**
  - This is the MSC Nastran Demonstration Problems Manual Example 25
  - Hub and vanes are meshed with Tet10 elements
  - Shroud is meshed with Hex8 elements
  - Glue the two bodies together and compute the first 10 free-free modes



Play Case study video:
NAS133_S5_cs_glued_contact



Hex8 – Tet10 double curved interface

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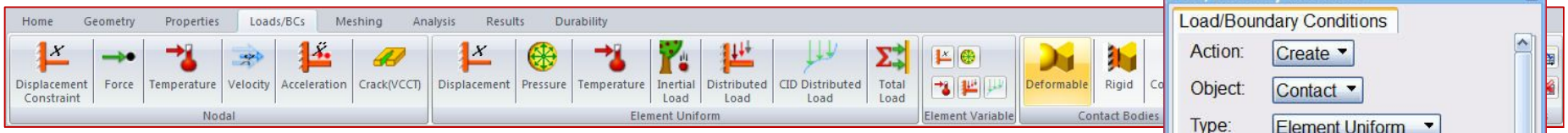
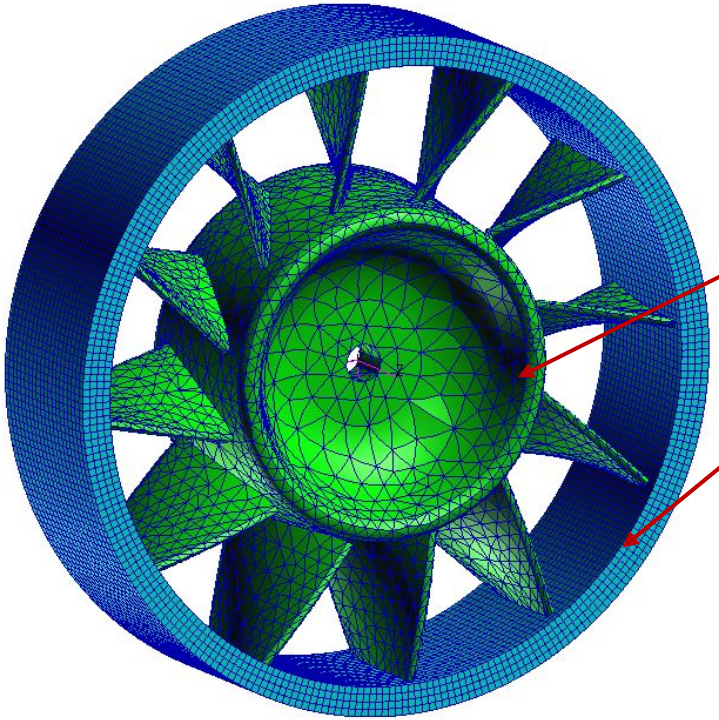
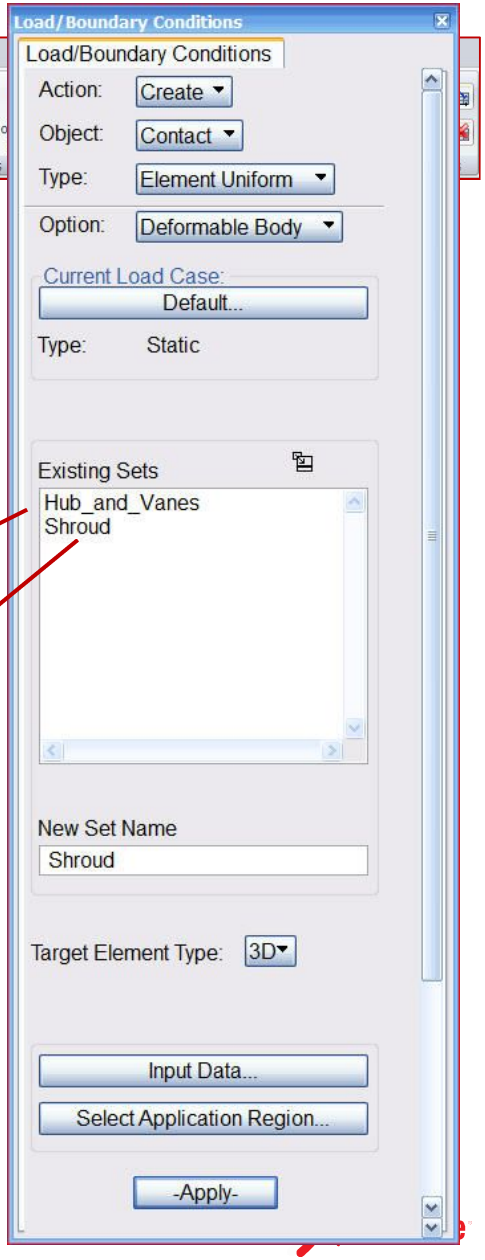
CASE STUDY: MODAL ANALYSIS WITH GLUED CONTACT



- **Import the MSC Nastran input file Vanes_and_Shroud.dat**
- **Create two contact bodies**





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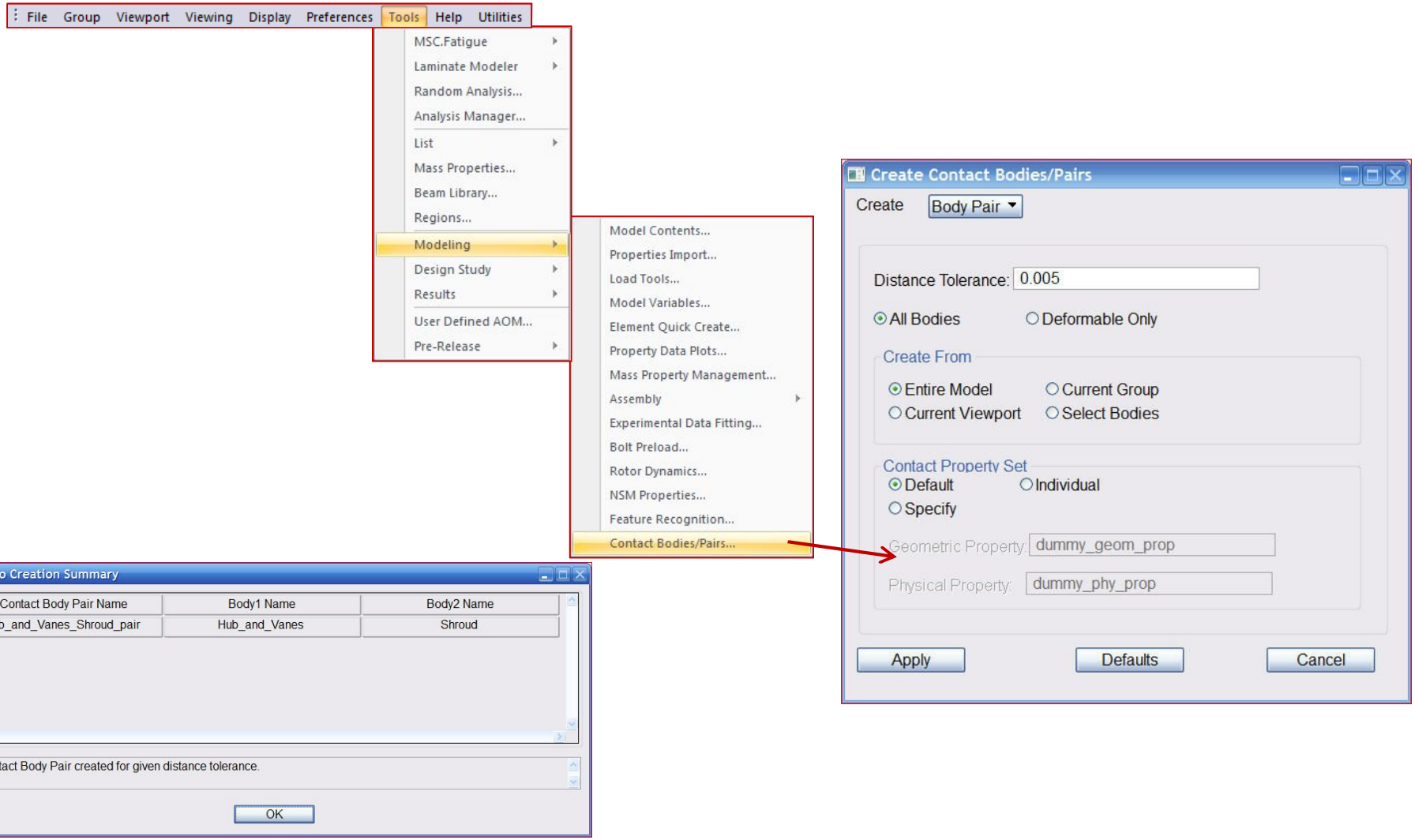
CASE STUDY: MODAL ANALYSIS WITH GLUED CONTACT

- **Define Contact Pair using Automatic feature in Patran.**



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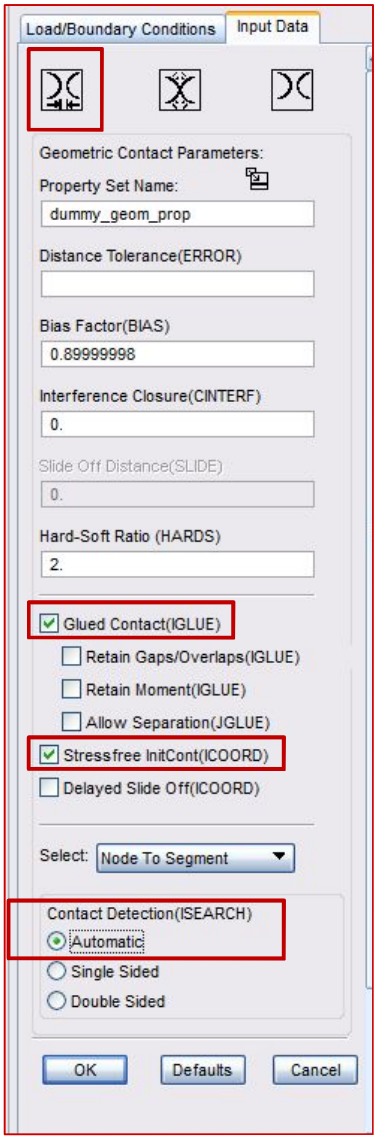
CASE STUDY: MODAL ANALYSIS WITH GLUED CONTACT

- **Check IGLUE**
- **Turn on Stress-Free Initial Contact (ICOORD = 1). This specifies stress-free initial contact which modifies the coordinates of the nodes in contact to close gaps and penetrations between the two bodies.**
- **Turn on Automatic Contact Detection (ISEARCH = 2).**
  - This is an important step to improve clean rigid-body modes and help the model pass the grounding check (discussed later). It also ensures no artificial stresses are induced.



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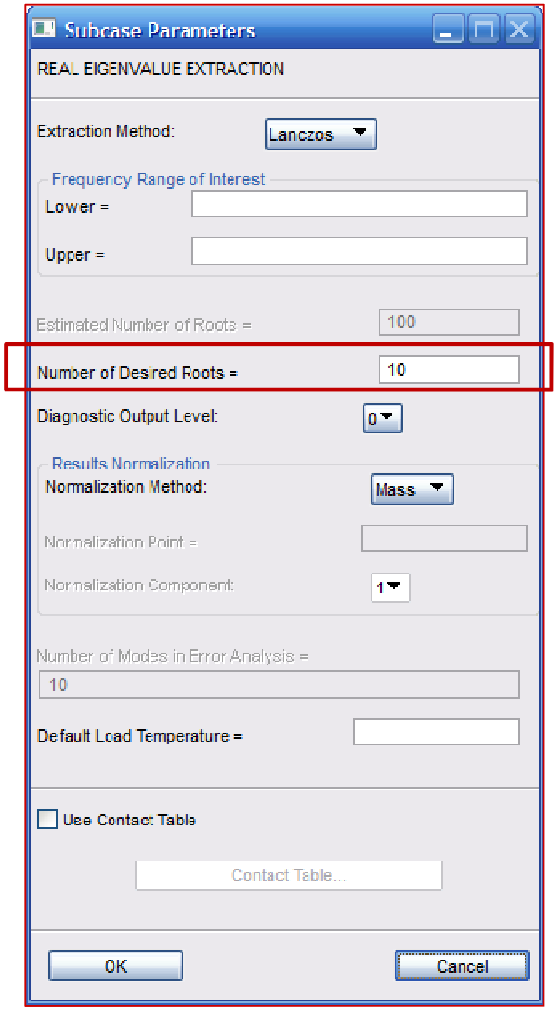
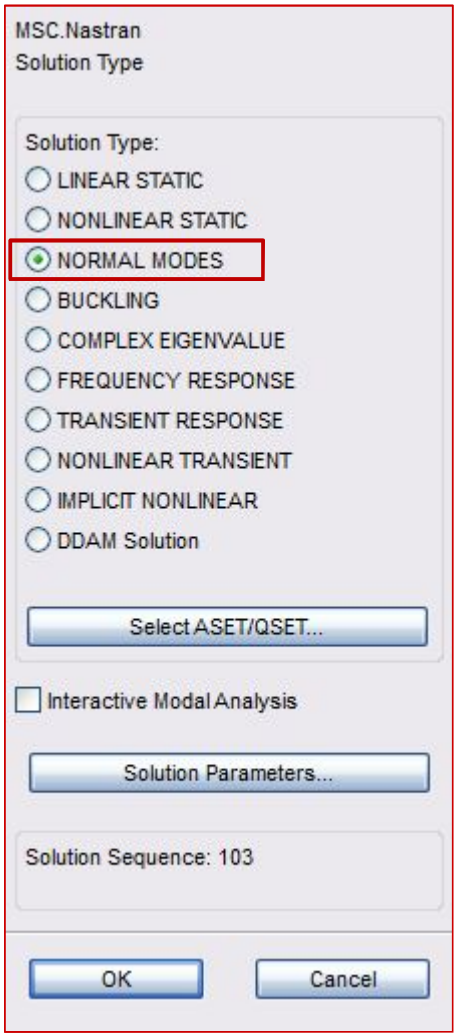
CASE STUDY: MODAL ANALYSIS WITH GLUED CONTACT

- **Set up a SOL 103 normal modes analysis and request the first 10 modes.**





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CASE STUDY: MODAL ANALYSIS WITH GLUED CONTACT

- **Review the BCONPRG entry.**
  - IGLUE=1
  - ICOORD=1
  - ISEARCH=2

```
BEGIN BULK
PARAM    POST    0
PARAM   PRTMAXIM YES
EIGRL    1                       10      0
BCTABL1  0       8004
BCONECT  8004    3003            2       1
BCONPRG  3003            ICOORD  1       IGLUE   1       ISEARCH 2
BCTABL1  1       8004
```

```
$ Deform Body Contact LBC set: Shroud
BCBODY    2        3D       DEFORM   1        0
BSURF     1        100000   100001   100002   100003
          100007   100008   100009   100010   100011
          100015   100016   100017   100018   100019
```

```
$ Deform Body Contact LBC set: Hub_and_Vanes
BCBODY    1        3D       DEFORM   2        0
BSURF     2        10000    10001    10002    10003
          10007    10008    10009    10010    10011
          10015    10016    10017    10018    10019
```

- **Important: BIAS is not specified, which defaults to 0.0 for glued contact. A Patran entry for BIAS will be ignored for glued contact.**

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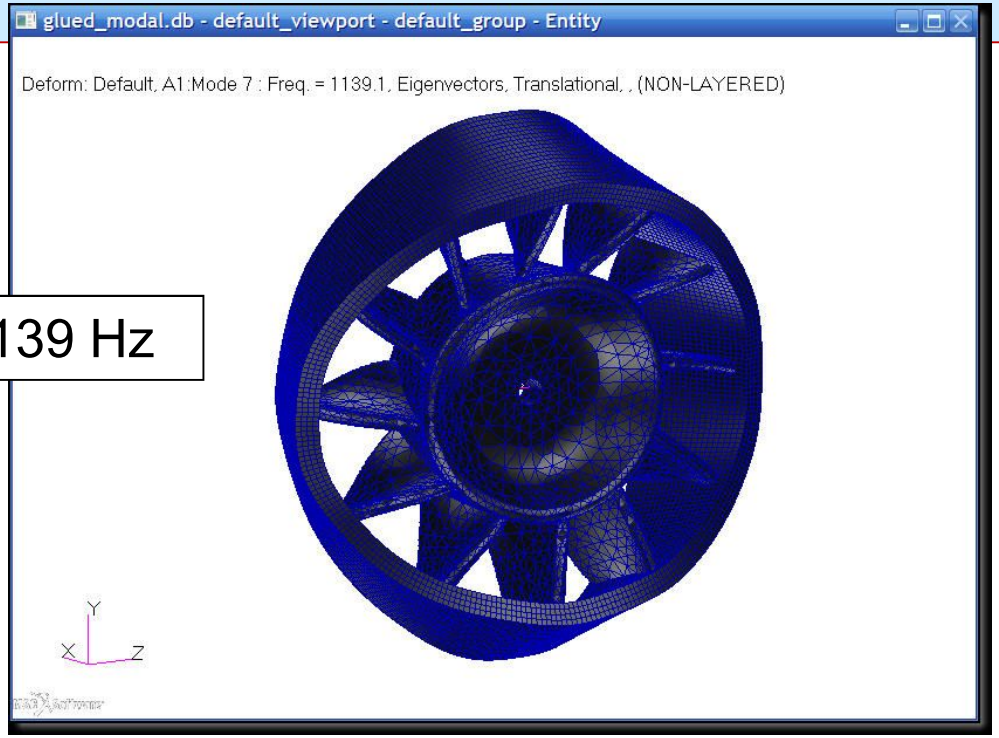
CASE STUDY: MODAL ANALYSIS WITH GLUED CONTACT

- **Review normal modes results:**
  - 6 clean rigid-body modes

R E A L E I G E N V A L U E S

MODE NO.	EXTRACTION ORDER	EIGENVALUE	RADIANS	CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS
1	1	-5.905578E-06	2.430140E-03	3.867687E-04	1.000000E+00	-5.905578E-06
2	2	-4.889644E-06	2.211254E-03	3.519320E-04	1.000000E+00	-4.889644E-06
3	3	-2.927081E-07	5.410251E-04	8.610681E-05	1.000000E+00	-2.927081E-07
4	4	6.376205E-06	2.525115E-03	4.018845E-04	1.000000E+00	6.376205E-06
5	5	9.417556E-06	3.068804E-03	4.884152E-04	1.000000E+00	9.417556E-06
6	6	1.275000E-05	3.570714E-03	5.682967E-04	1.000000E+00	1.275000E-05
7	7	5.122922E+07	7.157459E+03	1.139145E+03	1.000000E+00	5.122922E+07
8	8	5.129464E+07	7.162027E+03	1.139872E+03	1.000000E+00	5.129464E+07
9	9	5.581327E+07	7.470828E+03	1.189019E+03	1.000000E+00	5.581327E+07
10	10	1.348376E+08				



1st flexible mode 1,139 Hz

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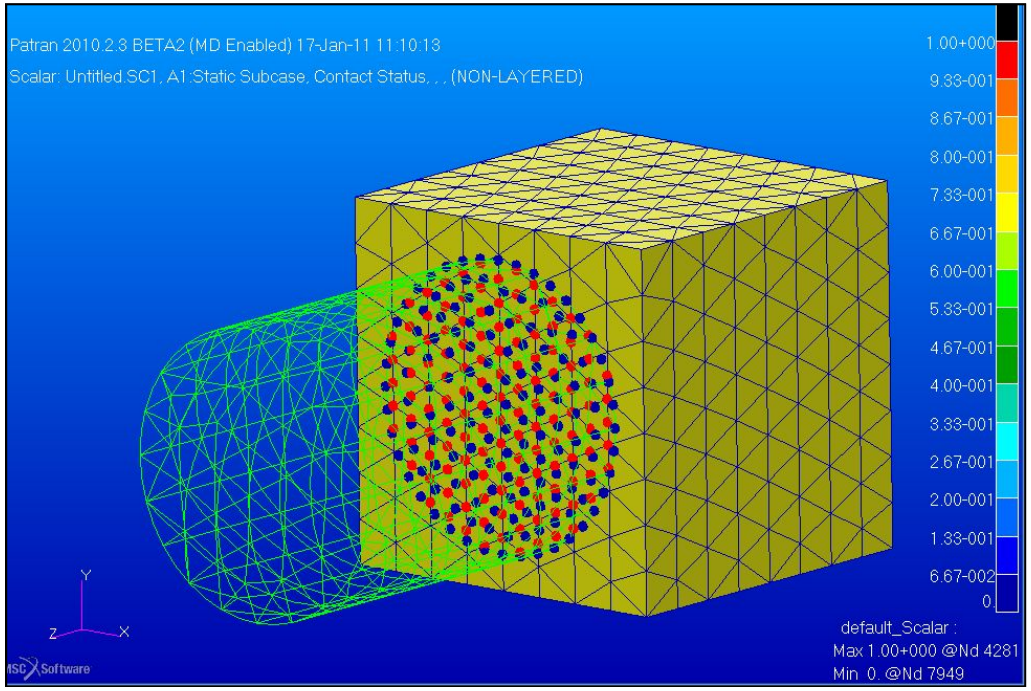
GLUED CONTACT – STATUS

- **Verifying the glued contact status is important. It is possible to glue only a few nodes on a large surface. This leads to incorrect deflections and stresses**
- **Glued contact can be evaluated by examining the deflected shapes and stresses of the model**
  - Glued contact can be visualized by making contact status marker plots



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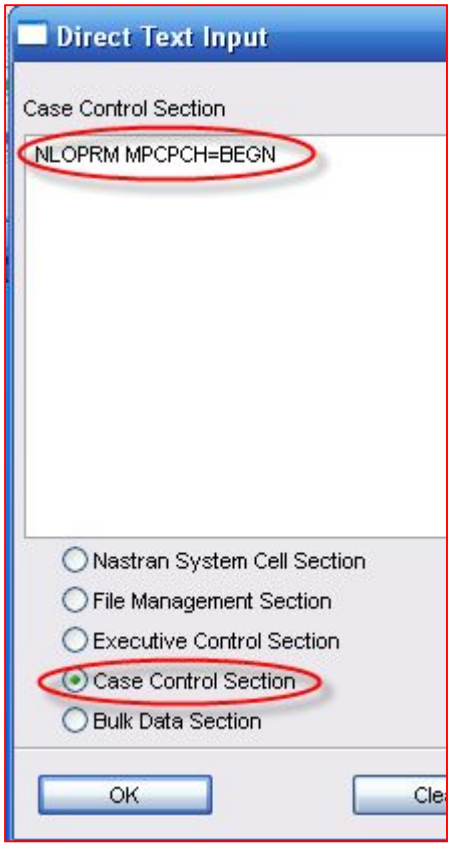
GLUED CONTACT – MPC EQUATIONS

- **MSC Nastran internally generates MPC equations to represent the glued contact**
- **The MPCs generated to model glued contact can be written during the analysis in a punch (*.pch) file**
- **These MPCs can then be directly imported into the Patran database to provide a visual reference to the glued contact**
- **The MPC punch file is created with the following Case Control Command:**
  - NLOPRM MPCPCH = BEGN



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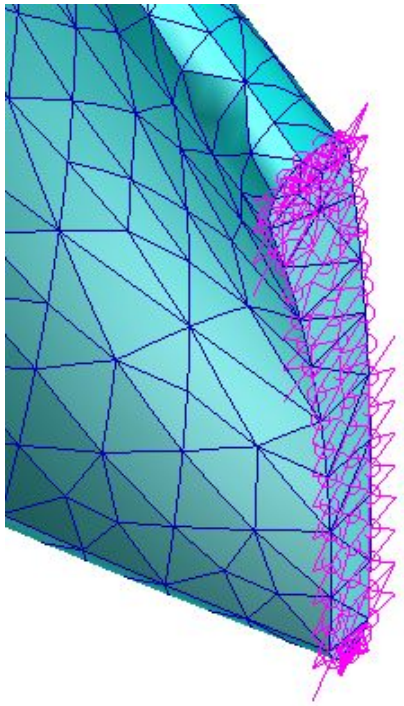
GLUED CONTACT – MPC DISPLAY

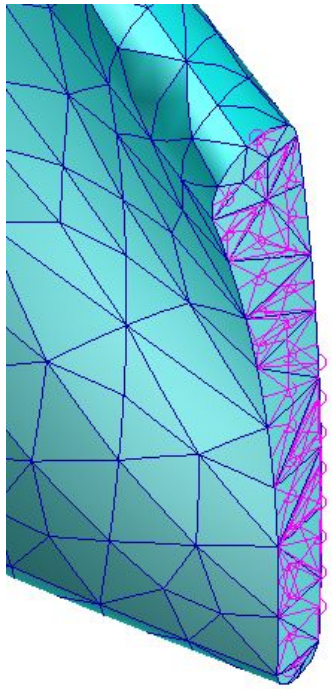
- **Confirm network of MPCs connecting contact bodies**
- **Use UNDO to remove MPCs from model, or delete them manually**



MPCs with Automatic Search

Vane from CASE STUDY 1

Details are discussed in the Contact Results Output section



MPCs with Default Search

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GLUED CONTACT GROUNDING ISSUES

- **What is Grounding?**
  - If an MSC Nastran model is properly created, then if it is completely unconstrained movement at one point of the model should cause the entire model to move as a rigid body, with no internal forces. If this is not the case the model has Grounding errors.
  - Grounding most often occurs with the misuse of CELAS and CBUSH elements, RBEs, and MPCs
  - The GROUNDCHECK command can be used in MSC Nastran to help determine in any such problems exist.
  - Glued contacts are covered by the GROUNDCHECK N-Set Output.

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GLUED CONTACT GROUNDING ISSUES

- **While glued contacts may work perfectly in a model, their use can still cause failures to be flagged via GROUNDCHECK**
- **IGLUE=1 or 3 will cause grounding if:**
  - There are gaps or overlaps between the contact surfaces (they are not perfectly aligned)
  - And permanent glued contact is used
  - And stress-free initial contact (ICOORD = 1) is not specified
- **The above scenario is a common occurrence in real world models**

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WHY DOES IGLUE CAUSE GROUNDING?

- **Glued contact creates a network of MPCs rigidly linking the contact bodies together**
  - IGLUE = 1 will create a network with 3 MPCs per slave node, linking the 3 Translational DOF.
  - IGLUE = 3 will create a network with 6 MPCs per slave node, linking the 3 Translational and 3 Rotational DOFs.
  - The MPC coefficients for these options will not take the geometry change caused by a gap or overlap properly into account, leading to “unbalanced” MPCs and a grounding problem.

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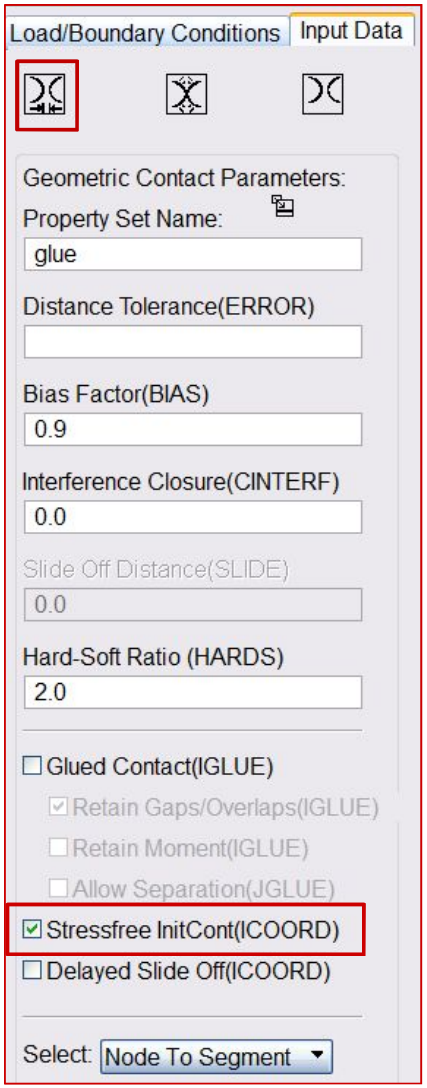
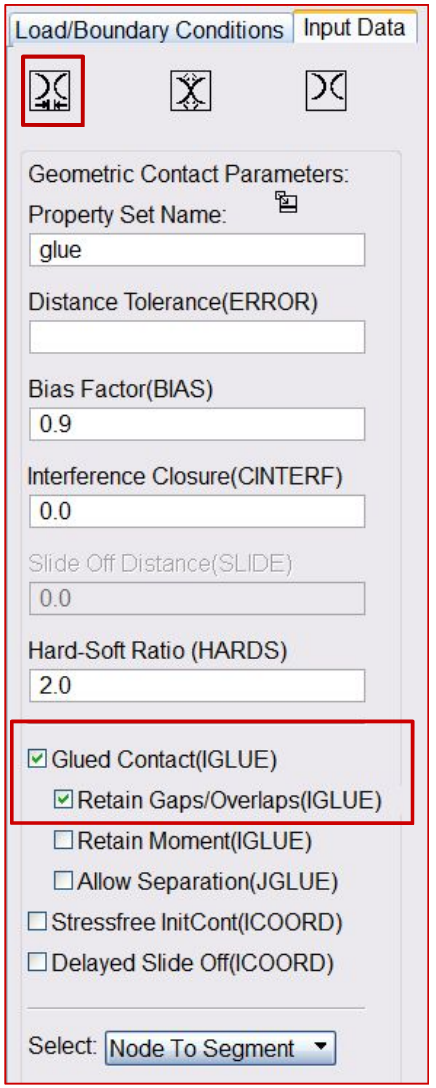
HOW TO PREVENT GROUNDING?

- **To prevent a grounding problem you can:**
  - Retain initial gaps or overlaps between the contact bodies
    - Check **Retain Gaps/Overlaps**
      - To use IGLUE = 2
    - Check **Retain Gaps/Overlaps** and **Retain Moment**
      - To use IGLUE = 4
  - Check **Stress-free Initial Contact**
    - To use ICOORD = 1 which maintains stress-free initial contact.

Use only one of these two options. Don't use both at the same time.





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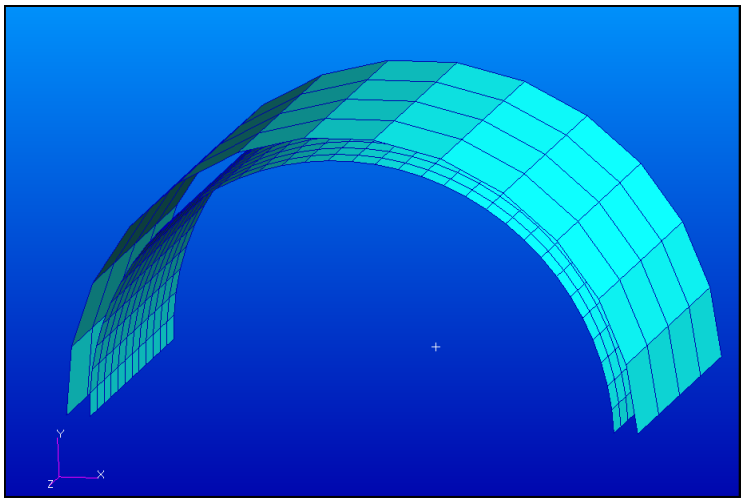
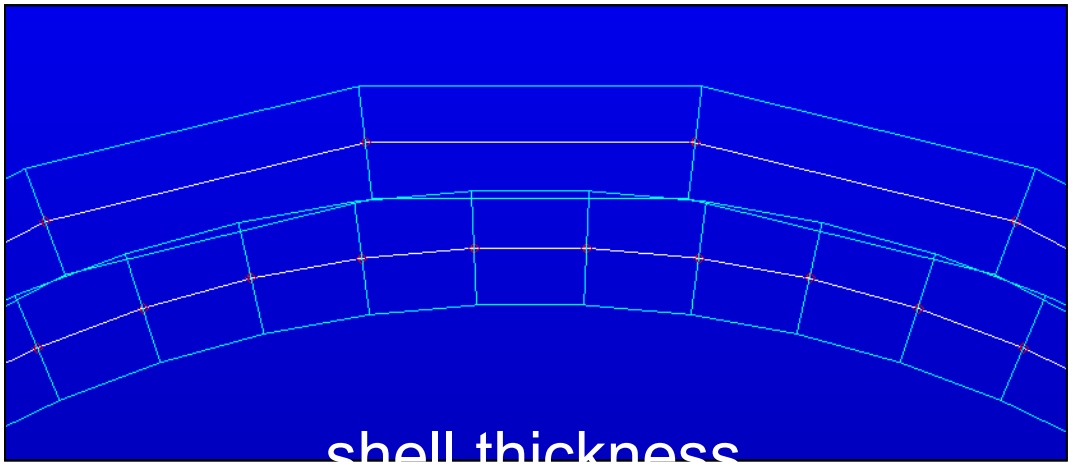
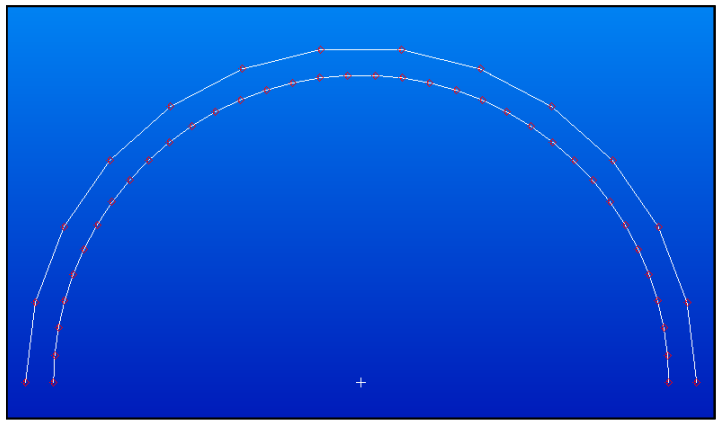
GROUNDING EXAMPLE 1

- **Faceted face glued contact**
- **Overlaps exist between the two contacting shell bodies**







GROUNDCHECK results with IGLUE=1

```
*** USER INFORMATION MESSAGE 7570 (GPWG1D)
    RESULTS OF RIGID BODY CHECKS OF MATRIX KNN      (N-SET)  FOLLOW:
    PRINT RESULTS IN ALL SIX DIRECTIONS AGAINST THE LIMIT OF   5.907310E-03
          DIRECTION        STRAIN ENERGY        PASS/FAIL
          ---------        -------------        ---------
              1             1.183101E-07          PASS
              2             6.440489E-08          PASS
              3             6.214191E-08          PASS
              4             2.752106E+05          FAIL
              5             2.920978E+05          FAIL
              6             1.679817E+06          FAIL
```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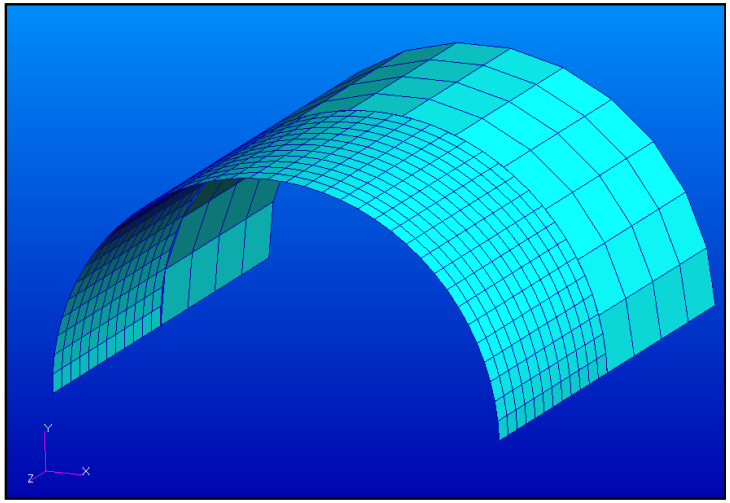
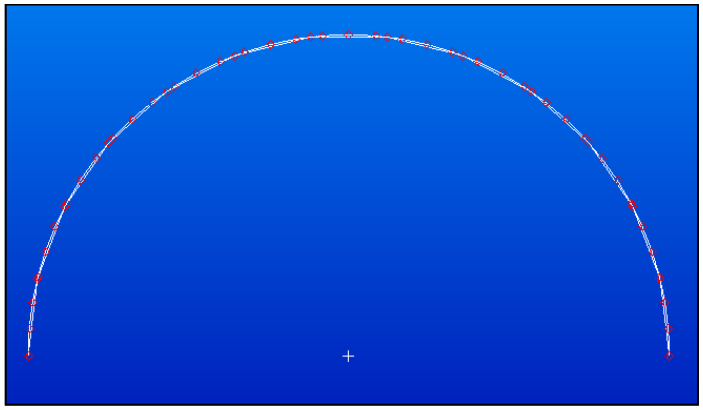
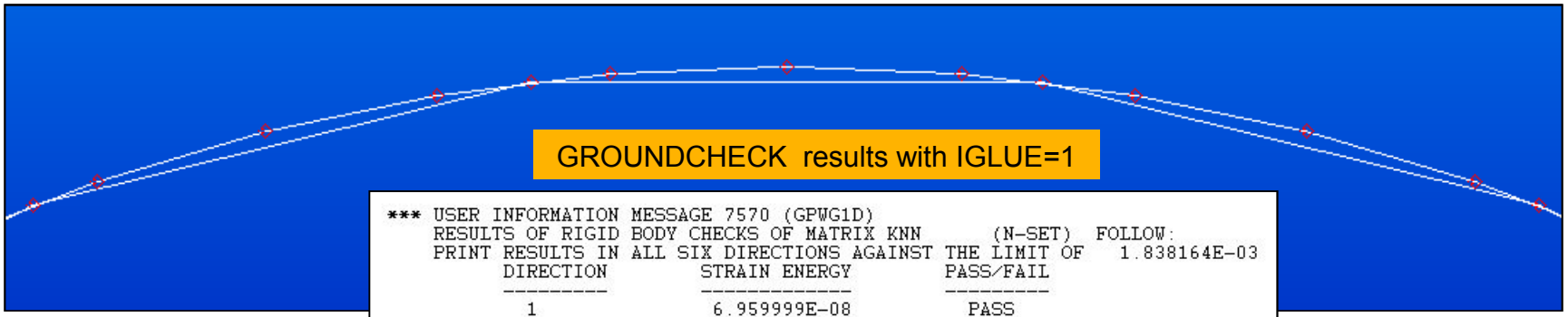
GROUNDING EXAMPLE 2

- **Faceted edge glued contact**
- **Gaps exist between the two contacting shell bodies**







GROUNDCHECK results with IGLUE=1

```
*** USER INFORMATION MESSAGE 7570 (GPWG1D)
    RESULTS OF RIGID BODY CHECKS OF MATRIX KNN      (N-SET)  FOLLOW:
    PRINT RESULTS IN ALL SIX DIRECTIONS AGAINST THE LIMIT OF   1.838164E-03
          DIRECTION        STRAIN ENERGY        PASS/FAIL
          ---------        -------------        ---------
              1             6.959999E-08          PASS
              2             6.073969E-08          PASS
              3             6.960909E-08          PASS
              4             4.546300E+04          FAIL
              5             8.072802E+03          FAIL
              6             5.370905E+04          FAIL
```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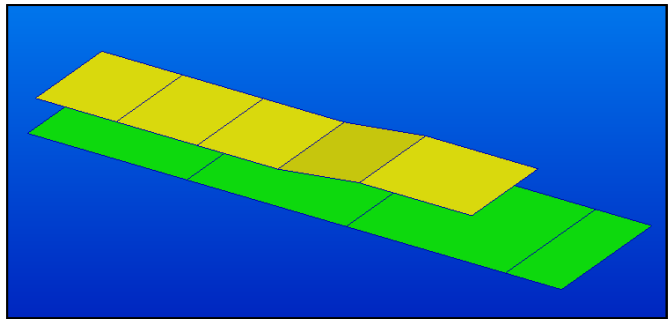
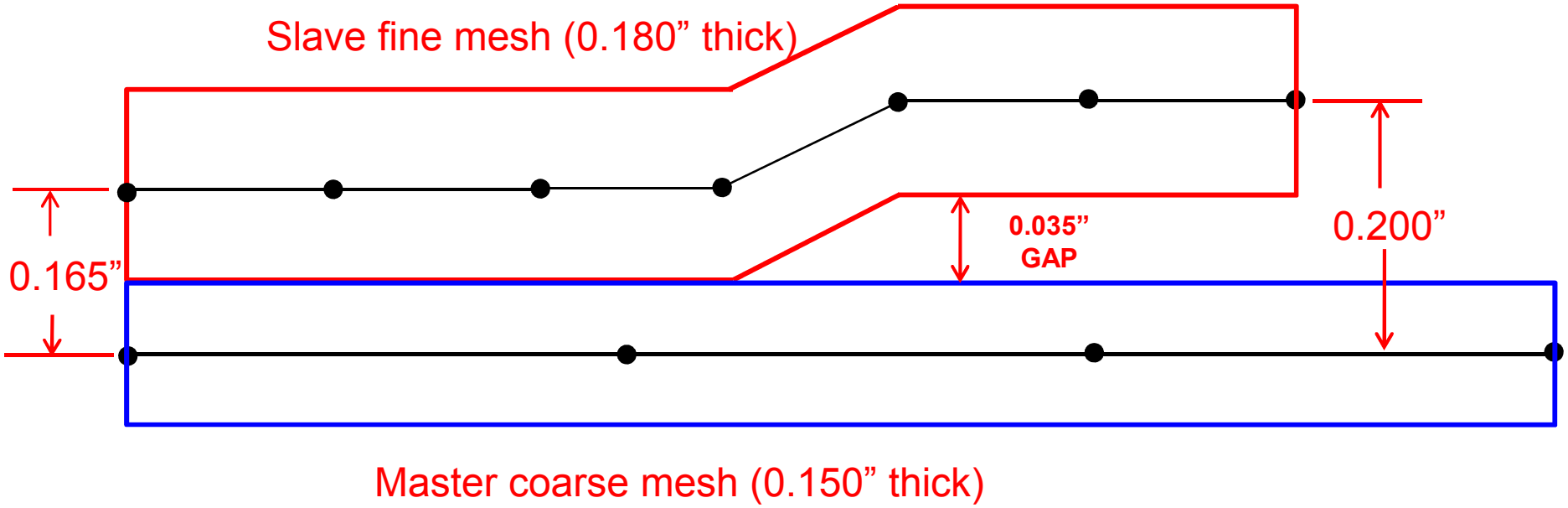
GROUNDING TEST MODEL – IGLUE = 1

- **This model has a gap between the two shell bodies**
  - 0.180”/2 + 0.150”/2 = 0.165”
  - 0.200” – 0.165” = 0.035”
  - Contact tolerance is 0.0359”
  - As contact tolerance is greater than the gap, all nodes will find contact and be glued





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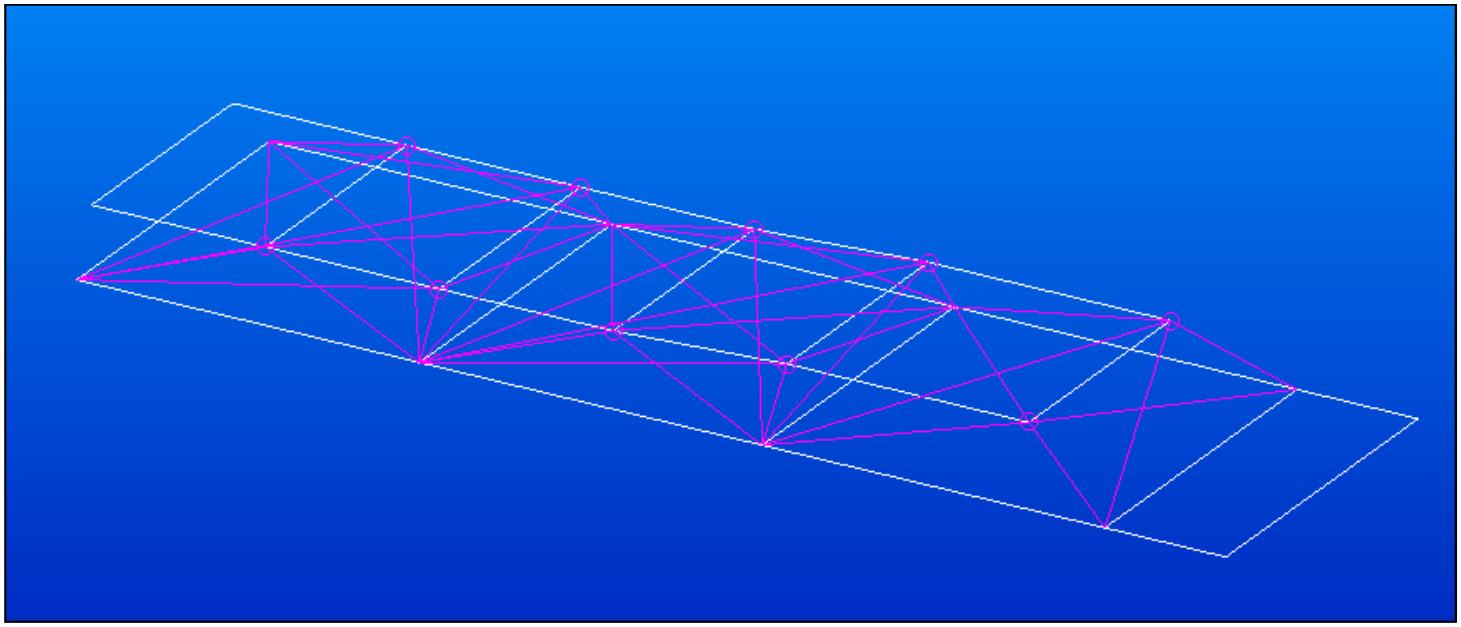
TEST MODEL – IGLUE = 1

- Glued contact MPCs shown in Patran
- Grounding check shows the model is grounded



```
*** USER INFORMATION MESSAGE 7570 (GPWG1D)
    RESULTS OF RIGID BODY CHECKS OF MATRIX KNN      (N-SET)  FOLLOW:
    PRINT RESULTS IN ALL SIX DIRECTIONS AGAINST THE LIMIT OF   2.699252E-04
          DIRECTION        STRAIN ENERGY        PASS/FAIL
          ---------        -------------        ---------
            1               9.822543E-11          PASS
            2               7.821654E-10          PASS
            3               6.848211E-11          PASS
            4               1.823675E+03          FAIL
            5               6.123739E+02          FAIL
            6               4.463135E-09          PASS
```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TEST MODEL – IGLUE = 1

- **Perform a free-free modal check**
  - Run a Normal Modes analysis with all boundary conditions removed
  - The model does not have 6 clean rigid body modes

R E A L E I G E N V A L U E S

MODE NO.	EXTRACTION ORDER	EIGENVALUE	RADIANS	CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS
1	1	-2.316665E-08	1.522059E-04	2.422433E-05	1.000000E+00	-2.316665E-08
2	2	3.419700E-09	5.847820E-05	9.307095E-06	1.000000E+00	3.419700E-09
3	3	6.868504E-09	8.287644E-05	1.319019E-05	1.000000E+00	6.868504E-09
4	4	9.895302E-09	9.947513E-05	1.583196E-05	1.000000E+00	9.895302E-09
5	5	2.384104E+03	4.882729E+01	7.771105E+00	1.000000E+00	2.384104E+03
6	6	7.225346E+03	8.500204E+01	1.352849E+01	1.000000E+00	7.225346E+03
7	7	7.629242E+05	8.734553E+02	1.390147E+02	1.000000E+00	7.629242E+05

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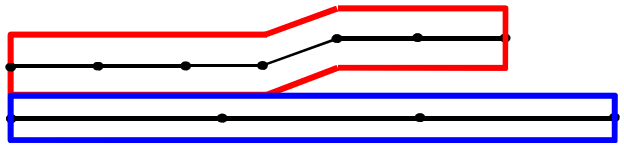
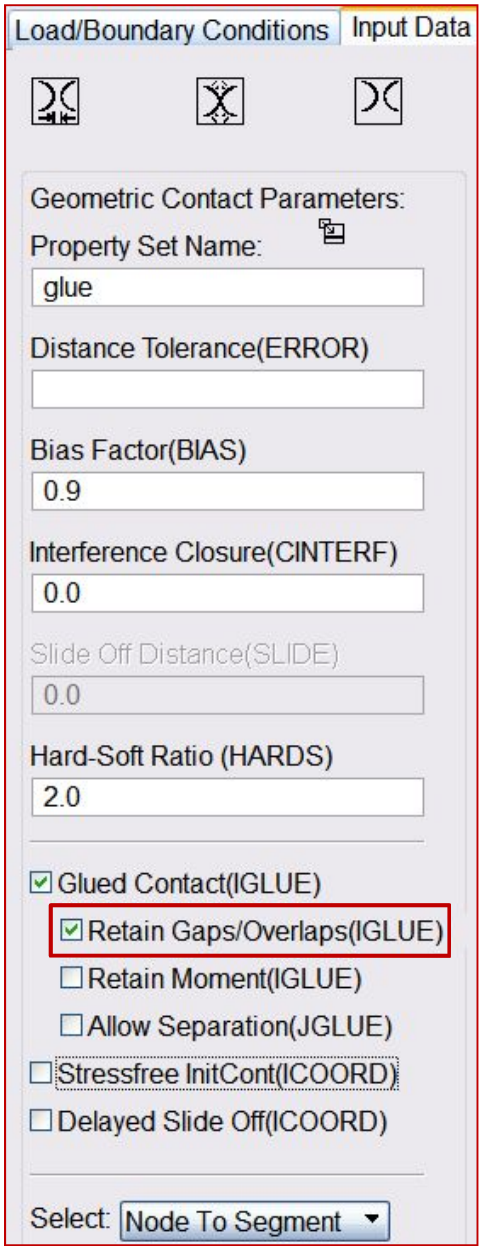
TEST MODEL – IGLUE = 2

- **Turn on Retain Gaps/Overlaps option**
- **Slave nodes will not be projected onto master surface**
- **No grounding**





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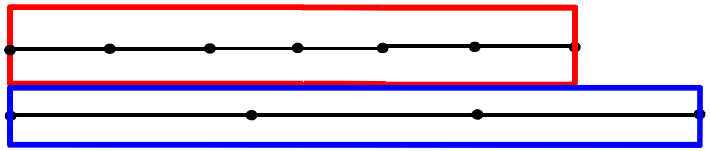
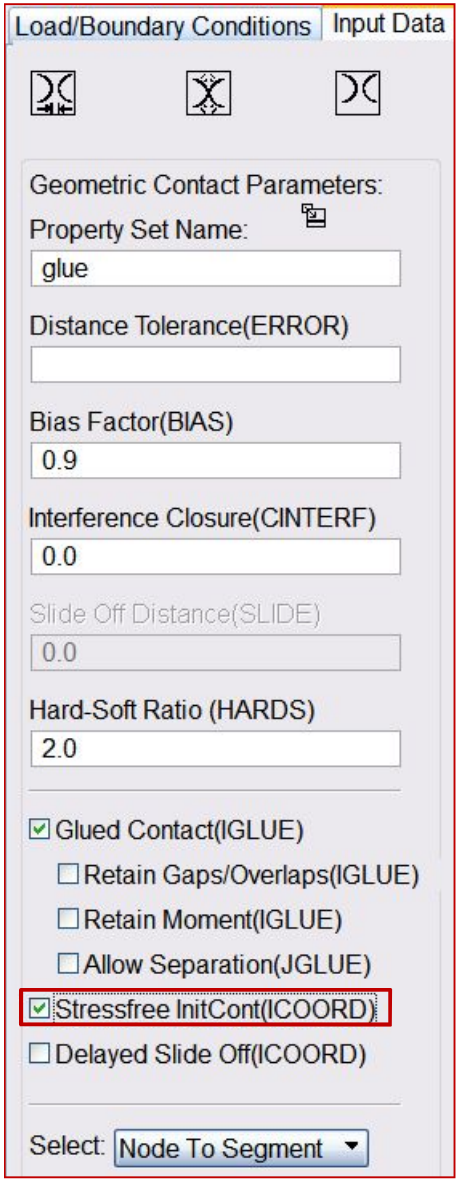
USING STRESS-FREE INITIAL CONTACT

- **If stress-free initial contact (ICOORD=1) is used, no grounding**
- **The user needs to beware that the model geometry has been changed during initial contact detection**





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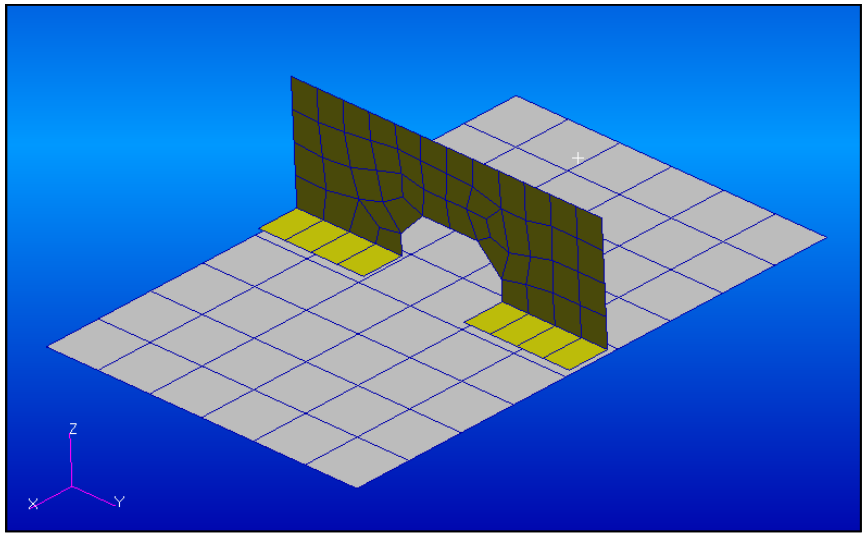
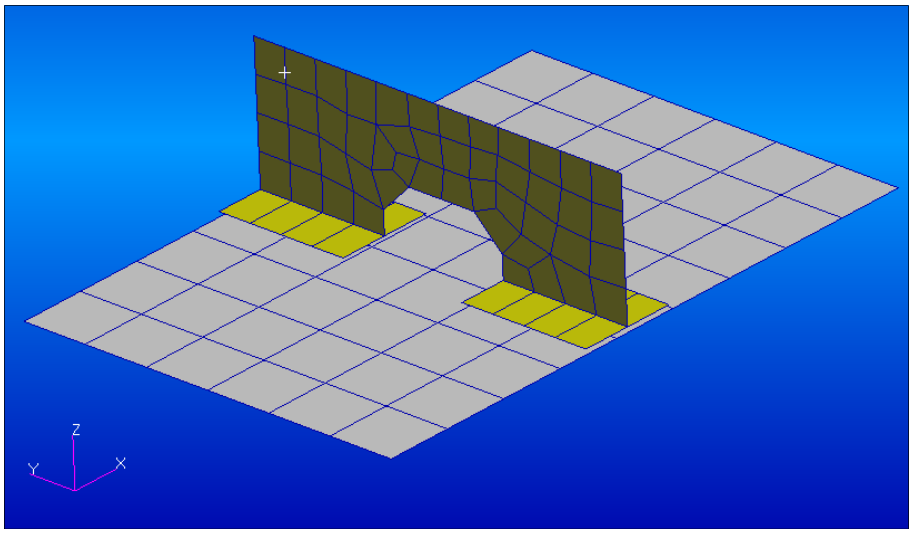
GROUNDING – ANGLE AND TEE CLIPS

- **A special case of grounding involves Angle or Tee shear clips, with or without mouse holes**
- **When the faces of the flanges are glued to the skin beneath, grounding issues and missing contact detection can occur at the junction of the clip flange and web**
- **Solution is to not include the web in the contact body created, only use the flange**



Angle clip



Tee clip

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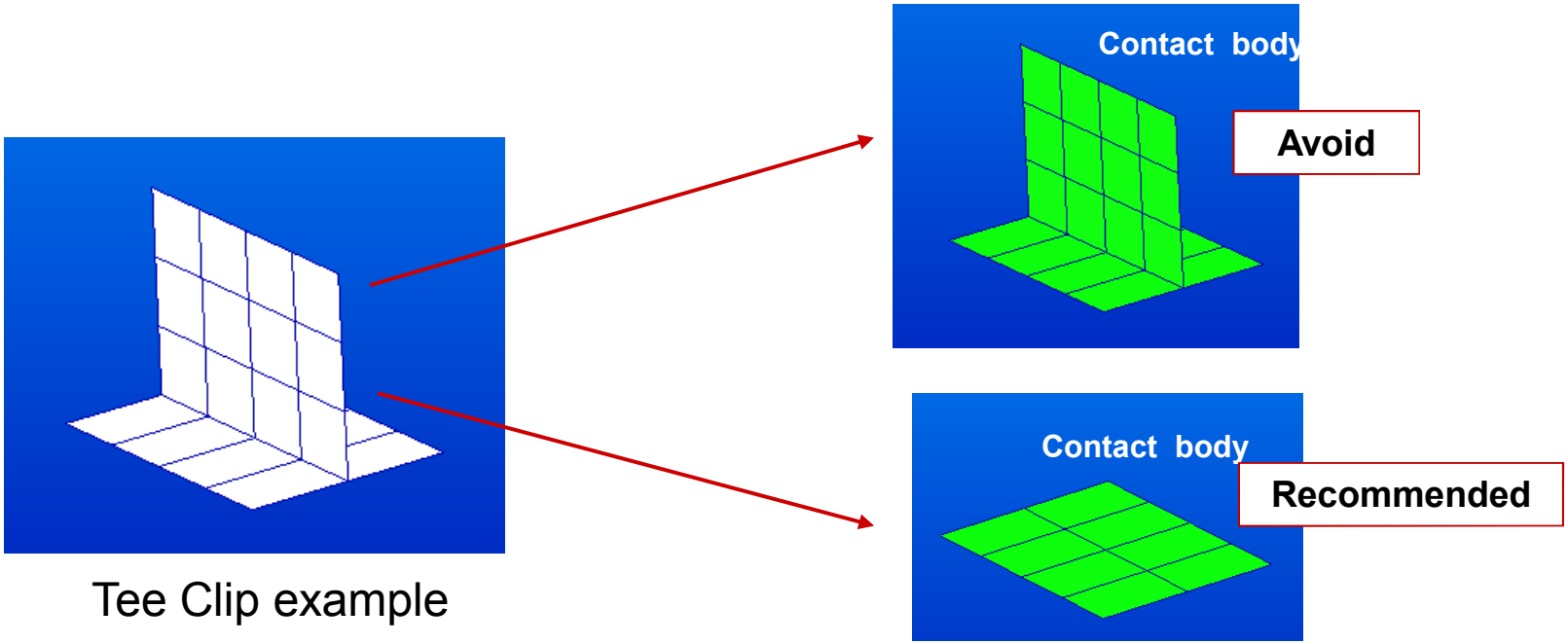
GROUNDING – ANGLE AND TEE CLIPS

- **Recommended practice**
  - Do not create a contact body which contains both the web and flanges, i.e., avoid corners and junctions in a contact body
  - When corners or junctions are included in a contact body, the contact detection behavior can be unexpected



Tee Clip example

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REVIEW QUESTIONS

1. **Why is the stress-free initial contact option important for some models?**

2. **What is the difference between permanent glued contact and general glued contact?**

3. **How can you define permanent glued contact?**

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REVIEW QUESTIONS

4. Can general glued contact be used in SOL103 or SOL105?

5. How can you turn off permanent glued contact?

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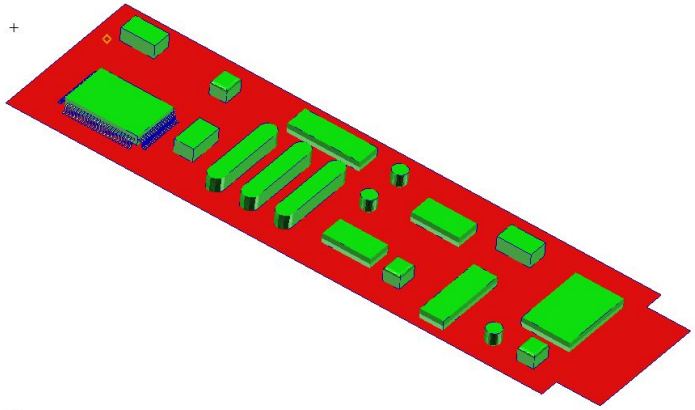
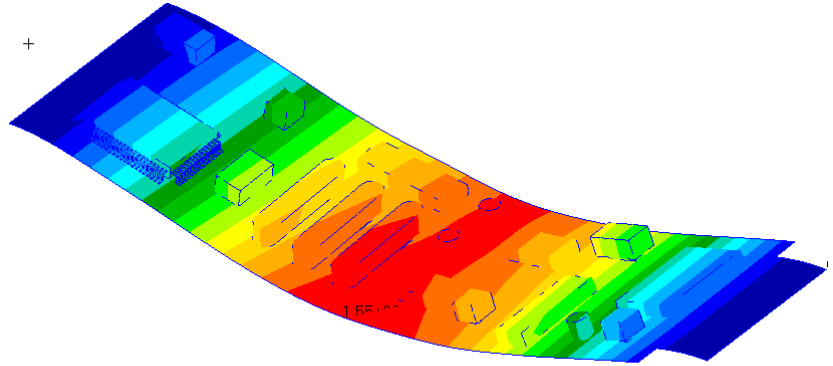
EXERCISE

- **Perform Workshop 4, “Natural Frequency Analysis with Glued Contact”**
  - Learn to perform a Natural frequency (SOL 103) analysis with glued contact between solids and shells.





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SECTION 6

OBTAINING CONVERGENCE AND FUNDAMENTAL CONTROLS IN LINEAR CONTACT

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CONVERGENCE AND CONTROL

- **Review of Nonlinear Solution Concepts**
- **Guidelines for contact**
- **What to do if non-convergence**

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SOLUTION OF 'LINEAR' CONTACT ANALYSIS

- **Even though we use the term 'Linear Contact' the simulations are actually nonlinear in nature due to the potential for intermittent contact**
- **As such, iterative solution techniques are required that are only considered 'successful' if they achieve 'convergence'**
- **There will be a chance of FAILED solutions**

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ACHIEVING CONVERGED SOLUTIONS

- **Follow general guidelines presented here to reduce chances of failure**
- **Confirm convergence (look in f06 file)**
  - Just because a job completes does not mean the results are ‘good’
  - Cases where completed solutions are not ‘converged’ solutions
    - Convergence specifications too high
    - User override of abort logic forcing solution to continue

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ACHIEVING CONVERGED SOLUTIONS

- **If non-convergence:**
  - Review the results that you have
  - Request intermediate results
  - Add additional output requests as necessary
  - Consider running without contact – if the problem still doesn't run then contact is likely not the problem (inadequate boundary conditions?)
- **Adjust as necessary based on the above output**

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CONTACT GUIDELINES

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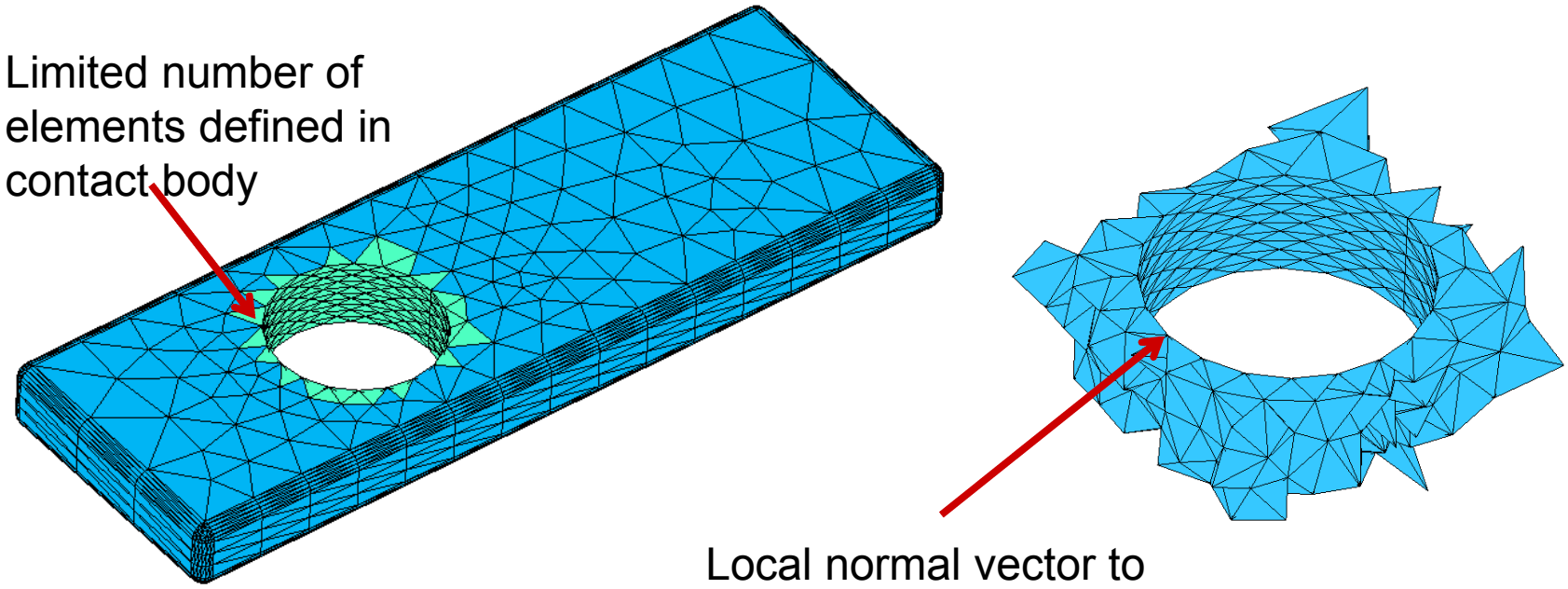
CONTACT GUIDELINES

- **When defining a deformable contact body, avoid selecting only a subset of elements:**



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CONTACT GUIDELINES

- **For contact problems, use the iteration methods FNT or PFNT**
  - CONV test flags available:
    - U = Displacement error
    - P = Load equilibrium error
    - W = Work error
    - V = Vector Component method
    - A = Auto switch
- **For contact problems with friction, use CONV test flags UPW**
- **For contact problems without friction, use CONV test flags PV**
- **When there are no external loads (for example, spring back), PV checking may not work well. Switch to UV or use PVA for Auto Switch.**
- **When there are no displacements (such as in thermal expansion), the UV checking will not work effectively. Switch to PV or use UVA.**
- **Avoid higher order shells (QUAD8) with contact**

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CONTACT GUIDELINES

- **The sizes of the contact tolerances D1 and D2 have a significant impact on the computational costs and the accuracy of the solution**
- **Contact tolerances too small:**
  - Detection of contact is difficult, leading to higher costs. Initial contact might not be found.
- **Contact tolerance too large:**
  - Nodes are considered in contact prematurely, resulting in a loss of accuracy
  - Nodes might “penetrate” the surface by a large amount

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CONTACT GUIDELINES

- **Set BIAS to 0.99 for frictional problems to get improved results.**
- **For shell contact set BIAS to 0.95.**
- **Use the default for the contact zone tolerance ERROR**
  - Default is 0.0 or blank
- **Use slave to master contact, single search, with**
  - The softer body as slave, for example, rubber should be slave and steel should be master
  - The finer meshed body defined as slave

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CONTACT GUIDELINES

- **Refine the mesh in the area of contact**
  - Coarse meshes can produce single point contact and promote instability
- **Consider smoothing the surfaces in contact, for example, insert a radius instead of a sharp corner for corner contact. If not possible then:**
  - define the body with sharp corners as slave body
  - increase ANG2D / ANG3D
  - set ICOORD to 2 (delay sliding off)
- **Use analytic contact (IDSPL in BCBODY)**
  - Advanced topic beyond scope of this course
- **Run without friction if possible**
  - May not be possible if friction is required for problem stability

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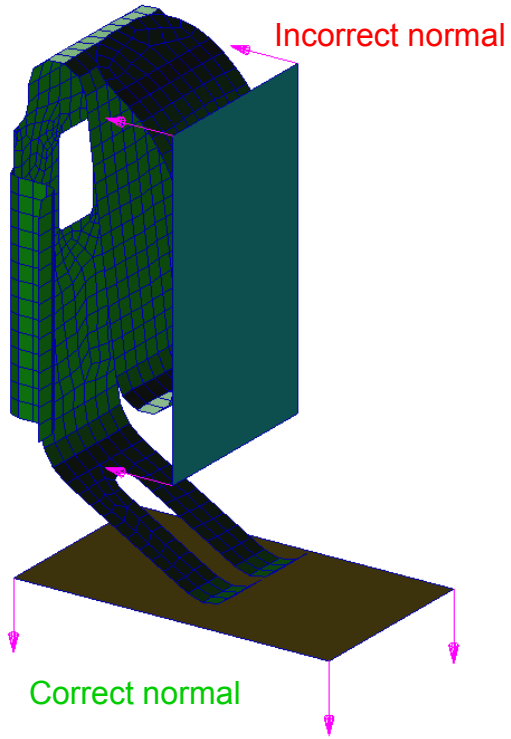
CONTACT GUIDELINES

- **Confirm rigid body normals face away from the deformable body – otherwise the code may not detect contact**

The rigid body normal should point away from the deformable body to be contacted



- **Contact can be lost or not found because of too large a load increment**
- **Analytical surface definition may be incorrect and causing "bulbous" corner/edge contact surfaces**

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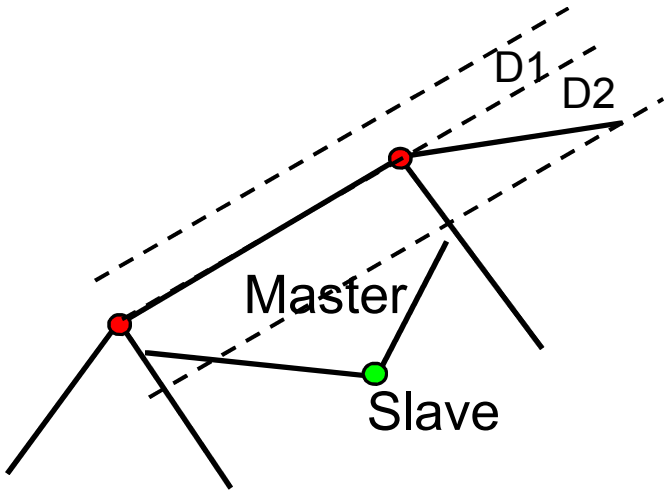
CONTACT GUIDELINES

- **Review and reconcile any initial contact over-closures and openings**
- **If nodes are modeled behind the contact zone, they will not be found**
- **If nodes move behind the contact zone during the analysis, the increment will be recycled with modified increment size**



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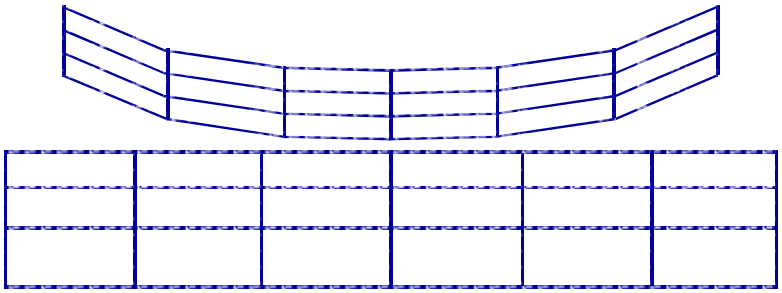
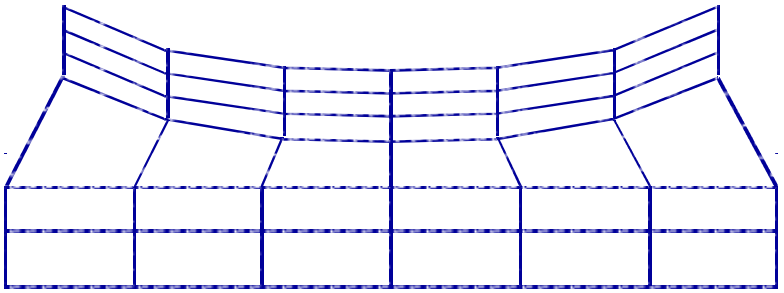
CONTACT GUIDELINES

- **Use BCPARA,0,NLGLUE,1 in SOLs 101/400:**
  - When some bodies are glued and others are not
  - Bodies are ultimately glued but there is no initial contact
- **If using Glued Contact and ICOORD: Make sure that the resulting elements will not be distorted too much**



Before



After

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WHAT TO DO IN THE EVENT OF CONVERGENCE DIFFICULTIES

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CONVERGENCE DIFFICULTIES

- **Before embarking on a thorough investigation of why the contact behavior is not converging, confirm that the contacts are in fact the problem by running without contact activated – define a contact table with no pairs active**
- **Additional boundary conditions may be necessary to prevent rigid body motion if the contacts were providing support of some kind**

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CONVERGENCE DIFFICULTIES

- **If contacts have been identified as the source of the non-convergence**
  - Review output
    - Output files (f06, sts)
    - Results files (.xdb, .MASTER/.DBALL, .op2)
  - Request additional diagnostic output to .f06
  - Request intermediate steps to results files

The **Contact Output** section of this course covers these topics in detail

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CONVERGENCE DIFFICULTIES

- **Options to consider**
  - Smaller timesteps
    - reduces numerical ‘effort‘ for any single increment
  - Increase separation force
    - must check results carefully to see if the results are ‘good‘
  - Adjust distance tolerance (typically increase) and bias (typically move closer to 1.)

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CONVERGENCE DIFFICULTIES

- **Options to consider**
  - In extreme cases try running with all contacts GLUED and then run additional test runs releasing (make TOUCH) one contact at a time to see if the offender can be isolated

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FUNDAMENTAL NONLINEAR CONTROL

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NONLINEAR CONTROL

- **Control of MSC Nastran nonlinear solutions is provided primarily by the MSC Nastran command NLSTEP**

Format: (For SOL 400)

1	2	3	4	5	6	7	8	9	10
NLSTEP	ID	TOTTIME	CTRLDEF						
	"GENERAL"	MAXITER	MINITER	MAXBIS	CREEP				
	"FIXED"	NINC	NO						
	"ADAPT"	DTINITF	DTMINF	DTMAXF	NDESIR	SFACT	INTOUT	NSMAX	
		IDAMP	DAMP	CRITTID	IPHYS	LIMTAR	RSMALL	RBIG	
		ADJUST	MSTEP	RB	UTOL				
	"ARCLN"	TYPE	DTINITFA	MINALR	MAXALR	SCALEA	NDESIRA	NSMAXA	
	"HEAT"	CONVH	EPSUH	EPSPH	EPSWH	KMETHODH	KSTEPH		
		MAXQNH	MAXLSH	LSTOLH					
	"MECH"	CONV	EPSU	EPSP	EPSW	KMETHOD	KSTEP	MRCONV	
		MAXQN	MAXLS	LSTOL	FSTRESS				
	"COUP"	HGENPLAS	HGENFRIC						
	"RCHEAT"	SOLVER	DRLXCA	ARLXCA	BALENG	DAMPC	GRVCON	CSGFAC	
		NRLOOP	OUTINV	DTIME1					

Format: (For SOL 101)

1	2	3	4	5	6	7	8	9	10
NLSTEP	ID		CTRLDEF						
	"LCNT"	NINCC	CONVC	EPSUC	EPSPC	EPSWC	MAXDIVC	MAXBIS	
		MAXITERC	MINITERC						

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NLSTEP BULK DATA ENTRY FOR SOLUTION 400

- **This entry for solution 400 contains all analysis disciplines**

1	2	3	4	5	6	7	8	9	10
NLSTEP	ID	TOTTIME							
	"GENERAL"	MAXITER	MINITER	MAXBIS	CREEP				
	"FIXED"	NINC	NO						
	"ADAPT"	DTINITF	DTMINF	DTMAXF	NDESIR	SFACT	INTOUT	NSMAX	
		IDAMP	DAMP	CRITTID	IPHYS	LIMTAR	RSMALL	RBIG	
		ADJUST	MSTEP	RB	UTOL				
	"ARCLN"	TYPE	DTINITFA	MINALR	MAXALR	SCALEA	NDESIR	NSMAXA	
	"HEAT"	CONVH	EPSUH	EPSPH	EPSWH	KMETHODH	KSTEPH		
		MAXQNH	MAXLSH	LSTOLH					
	"MECH"	CONV	EPSU	EPSP	EPSW	KMETHOD	KSTEP	MRCONV	
		MAXQN	MAXLS	LSTOL	FSTRESS				
	"COUP"	HGENPLAS	HGENFRIC						
	"RCHEAT"	SOLVER	DRLXCA	ARLXCA	BALENG	DAMPC	GRVCON	CSGFAC	
		NRLOOP	OUTINV	DTIME1					

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NLSTEP BULK DATA ENTRY FOR SOLUTION 101

- **ID: invoked by NLSTEP case control command**
- **CTRLDEF: keyword to select smart linear contact default, the values "LCPERF" or "LCACCU" are available along with blank**
  - LCPERF specifies the performance preference during analysis,
  - LCACCU prefers accuracy for analysis
  - Blank uses default parameters same as in the old NLPARM option

1	2	3	4	5	6	7	8	9	10
NLSTEP	ID		CTRLDEF						
	"LCNT"	NINCC	CONVC	EPSUC	EPSPC	EPSWC	MAXDIVC	MAXBIS	
		MAXITERC	MINITERC						

CTRLDEF	NINCC	CONVC	EPSUC	EPSPC	EPSWC	MAXDIVC	MAXBIS	MAXITERC	MINITERC
LCPERF	1	PV	1.e-3	1.e-3	1.e-7	3	5	25	0
LCACCU	1	UPV	1.e-2	1.e-2	1.e-2	5	5	25	0
	10	PV	1.e-2	1.e-2	1.e-2	3	5	25	0

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NLSTEP BULK DATA ENTRY FOR SOLUTION 101

1	2	3	4	5	6	7	8	9	10
NLSTEP	ID		CTRLDEF						
	"LCNT"	NINCC	CONVC	EPSUC	EPSPC	EPSWC	MAXDIVC	MAXBIS	
		MAXITERC	MINITERC						

- **You can specify nonlinear control parameters following LCNT keyword if smart default is not suitable for any contact model**
  - NINCC: Number of increments
  - CONVC: Flags to select convergence criteria (Character = “U”, “P”, “W”,”V”,”N”,”A” and combinations)
  - EPSUC, EPSPC, EPSWC: Error tolerances for displacement (U), load (P) and work (W) criteria.
  - MAXDIVC: Limit on probable divergence conditions per iteration
  - MAXBISC: Maximum number of bisections allowed for each increment
  - MAXITERC: Limit on number of iterations for each load increment
  - MINITERC: Minimum number of iterations of a load increment

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NLSTEP – ERROR CALCULATION METHODS

- **There are three methods to compute the error:**
  - Weighted Average Method
    - The errors are computed using the weighted average of all dof's of the model.
    - This is the default method.
  - Vector Component (V) Method
    - Convergence checking is performed on the maximum vector component of all dof's in the model.
  - The Length (N) Method
    - The length of a vector at a grid point is first computed by the SRSS method. Then the error checking is performed on the maximum length of all grid points in the model.

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NONLINEAR OUTPUT CONTROL

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NONLINEAR OUTPUT CONTROL

- **A status file will automatically be written for each SOL101 job with contact**

```
information summary of job:  ./demo_400_nlio_std
version: MSC Nastran 2013.0.0, Built on May 30, 2013
date:     Mar 26, 2014; Day Time: 13:00:34

  subcase      inc  cycl  sepa cut     cycl   split   separ   cut  rmesh time step   total time  wall time   cpu time    max resp. type
  /step #       #     #    #    #        #       #       #     #      of          of
       1          |--of the inc--|-----------of the analysis-----------|  the inc      the job
       1        0     0    0    0        0       0       0     0     0  0.0000E+00  0.0000E+00       2.00       1.40   0.0000E+00 disp
       1        1     4    0    0        4       0       0     0     0  1.0000E+00  1.0000E+00       2.00       1.44  -1.5486E+02 disp
 Job ends with exit number :       0
            total wall time:          2.00
            total cpu  time:          1.47

            exit DEFINITION -----
            = 0  job terminates normally
            = 1  job terminates abnormally (check Fatal Error Message in F06)
```

- **Further information can be found in the f06 file**

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NONLINEAR OUTPUT CONTROL

```
N O N - L I N E A R   I T E R A T I O N   S O L U T I O N   C O N T R O L   P A R A M E T E R S

    LOOP CONTROLS FOR :   SUBCASE       1,        STEP       1,        SUBSTEP       0


    SOLUTION CONTROL PARAMETERS FROM : NLSTEP                    ID :         1

         Total Time of Loading Case (TOTTIME) ....     1.00E+00

         Maximum Number of Iterations (MAXITER) ..           10
         Minimum Number of Iterations (MINITER) ..            1
         Maximum Number of Bisection (MAXBIS) ....           10
         Creep Option (CREEP) ....................            0

         Number of Fixed Increments (NINC) .......            1
         Interval of Output (NO) .................            1

         Convergence Criteria (CONV) .............      P  V
                   - Displacement   (EPSU) ......    -1.00E-01
         Tolerance - Residual Force (EPSP) ......     1.00E-03
                   - Work           (EPSW) ......     1.00E-01
         Option of Rotations and Moments (MRCONV).            3
         Matrix Update Option (KMETHOD) ..........         PFNT
         Matrix Update Increment (KSTEP) .........            1
         Maximum Quasi-Newton Vectors (MAXQN) ....            0
         Maximum Line Searches (MAXLS) ...........            0
         Line Search Tolerance (LSTOL) ...........     5.00E-01
         Error Tolerance in YF (FSTRESS) .........     2.00E-01

 *** USER INFORMATION MESSAGE 6204 (NL3EMA)
     0.000000E+00 SECONDS REQUIRED TO DECOMPOSE MATRIX.
%1.00000E+00   1  1 1.00E+00 2.69E+01 1.00E+00  1.000  1   1   0  4.92E+04 6.533E+06 1.06E+01 -1.587E+02        6 2  1.00 0  0   0    1
%1.00000E+00   1  2 9.33E-02 1.62E+00 8.19E+02  0.060  0   1   0  2.41E+03 3.233E+06 1.13E+01 -1.558E+02        6 2  1.00 0  0   1    2
%1.00000E+00   1  3 5.83E-03 1.66E-01 2.07E-02  0.063  0   1   0  1.60E+00 3.233E+06 1.12E+01 -1.549E+02        6 2  1.00 0  0   2    3
%1.00000E+00   1  4 3.07E-06 7.29E-07 8.63E-03  0.093  0   1   0  2.71E-05 3.233E+06 1.12E+01 -1.549E+02        6 2  1.00 0  0   3    4

 *** JOB CONVERGES FOR THE CURRENT STEP.
 *** SUBCASE      1 STEP      1 IS COMPLETED.
```

Standard F06 Output

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NONLINEAR OUTPUT CONTROL

- **LOAD STEP**
  - step number minus 1 plus fraction of step, i.e. 0.08 = 8% of first step
- **NO. INC**
  - increment number
- **ITR**
  - iteration number
- **DISP LOAD WORK**
  - displacement, load and energy errors, must be smaller than the tolerances EPSU, EPSP and EPSW
- **CONV RATE**
  - should be between 0 and 1, bigger than 1 means, the solution will never converge

```
        LOAD  NO.       - - ERROR FACTORS - -    CONV  ITR MAT NO.    AVG      TOTL       - - - - - DISP - - - - - -  LINE_S  NO. TOT TOT
        STEP  INC ITR  DISP     LOAD      WORK   RATE  DIV DIV BIS  R_FORCE   WORK      AVG        MAX     AT GRID C FACT NO QNV KUD ITR
 %1.00000E+00   1   1 1.00E+00 2.69E+01 1.00E+00  1.000  1   1   0  4.92E+04 6.533E+06 1.06E+01 -1.587E+02        6 2  1.00 0  0   0    1
```


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NONLINEAR OUTPUT CONTROL

- **ITR DIV**
  - divergence counter, > MAXDIV triggers the divergence process
- **MAT DIV**
  - divergence counter for element and material routines
- **NO. BIS**
  - number of bisections
- **AVG R_FORCE**
  - average residual force (forces and moments); should be small
- **TOTL WORK**
  - approximate total work
- **DISPLACEMENTS: AVG MAX AT GRID C**
  - average, maximum displacement at grid in direction c

```
       LOAD  NO.       - - ERROR FACTORS - -    CONV  ITR MAT NO.    AVG      TOTL       - - - - - DISP - - - - - -  LINE_S  NO. TOT TOT
       STEP  INC ITR  DISP     LOAD      WORK    RATE  DIV DIV BIS  R_FORCE   WORK      AVG        MAX     AT GRID C FACT NO QNV KUD ITR
%1.00000E+00   1   1 1.00E+00 2.69E+01 1.00E+00  1.000  1   1   0  4.92E+04 6.533E+06 1.06E+01 -1.587E+02        6 2  1.00 0  0   0    1
```


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NONLINEAR OUTPUT CONTROL

- **LINE_S: FACT NO**
  - line search factor a and number of line searches
- **NO. QNV**
  - number of Quasi Newton Vectors
- **TOT KUD / ITR**
  - total of stiffness updates / iterations

```
        LOAD  NO.        - - ERROR FACTORS - -    CONV  ITR MAT NO.    AVG      TOTL        - - - - - DISP - - - - - - -  LINE_S  NO. TOT TOT
        STEP  INC ITR  DISP      LOAD       WORK    RATE  DIV DIV BIS  R_FORCE   WORK       AVG         MAX     AT GRID C FACT NO QNV KUD ITR
%1.00000E+00   1   1 1.00E+00 2.69E+01 1.00E+00  1.000   1   1   0  4.92E+04 6.533E+06 1.06E+01 -1.587E+02        6 2  1.00 0  0   0    1
```


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NONLINEAR OUTPUT CONTROL

- **Case Control command NLOPRM is also available**

Format:

$$\text{NLOPRM} = [\text{OUTCTRL} = \{\text{STD,SOLUTION,INTERM}\}]$$

$$\left[\text{NLDBG} = \left\{\begin{array}{l}\text{NONE}\\ \text{NLBASIC,NRDBG,ADVDBG,}\left\{\begin{array}{l}\text{N3DBAS}\\ \text{N3DMED}\\ \text{N3DADV}\end{array}\right\}\end{array}\right\}\right]$$

$$\left[\text{DBGPOST} = \left\{\begin{array}{l}\text{NONE}\\ \text{LTIME}\\ \text{LSTEP}\\ \text{LSUBC}\\ \text{ALL}\end{array}\right\}\right], \left[\text{MPCPCH} = \left\{\begin{array}{l}\text{NONE}\\ \text{BEGN,OTIME,STEP}\\ \text{TBEGN,YOTIME,YSTEP}\end{array}\right\}\right]$$

Example(s):

```
NLOPRM          OUTCTRL=STD,SOLUTION          DBGPOST=LTIME
NLOPRM          OUTCTRL=(SOLUTION,INTERM),  MPCPCH=(OTIME,STEP)
```


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NONLINEAR OUTPUT CONTROL

- **Example using Case Control: NLOPRM NLDBG=ADVDBG**

```
 *** USER INFORMATION MESSAGE 6204 (NL3EMA)
     0.000000E+00 SECONDS REQUIRED TO DECOMPOSE MATRIX.

             maximum residual force  at node         6 degree of freedom  1 is equal to    5.566E+05
             maximum reaction force  at node         1 degree of freedom  1 is equal to    2.072E+04
             residual convergence ratio    2.687E+01

             maximum residual moment at node         5 degree of freedom  6 is equal to    4.656E+04
             maximum reaction moment at node         1 degree of freedom  6 is equal to    9.982E+04
             residual convergence ratio    4.664E-01

             maximum displacement  change   at node         6 degree of freedom  2 is equal to    1.587E+02
             maximum displacement increment at node         6 degree of freedom  2 is equal to    1.587E+02
             displacement convergence ratio   1.000E+00

             maximum   rotation    change   at node         6 degree of freedom  6 is equal to    2.381E-01
             maximum   rotation   increment at node         6 degree of freedom  6 is equal to    2.381E-01
             rotation convergence ratio   1.000E+00

             strain energy change at this iteration is    6.53309E+06
             strain energy change at this increment is    6.53309E+06
             relative energy error is                     1.00000E+00
%1.00000E+00   1  1 1.00E+00 2.69E+01 1.00E+00  1.000  1   1   0  4.92E+04 6.533E+06 1.06E+01 -1.587E+02        6 2  1.00 0  0   0    1
```

F06 Output: First iteration

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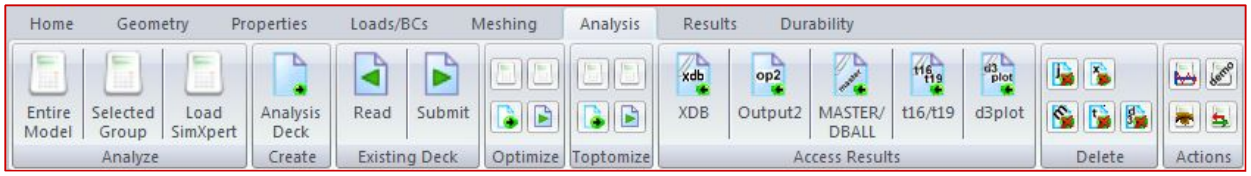
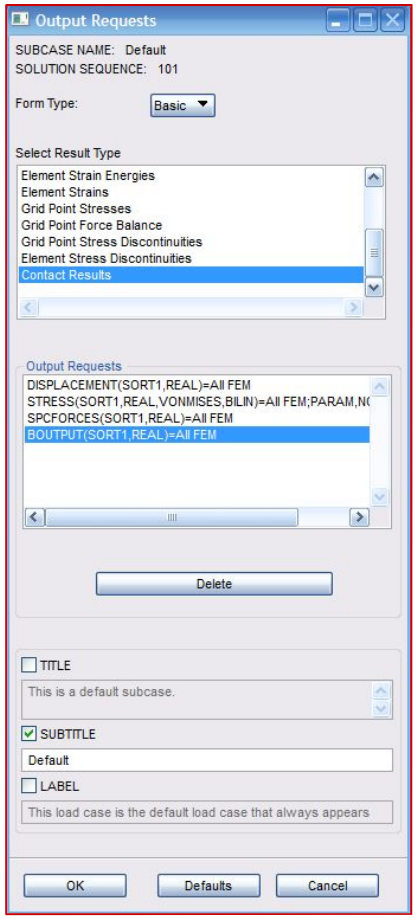
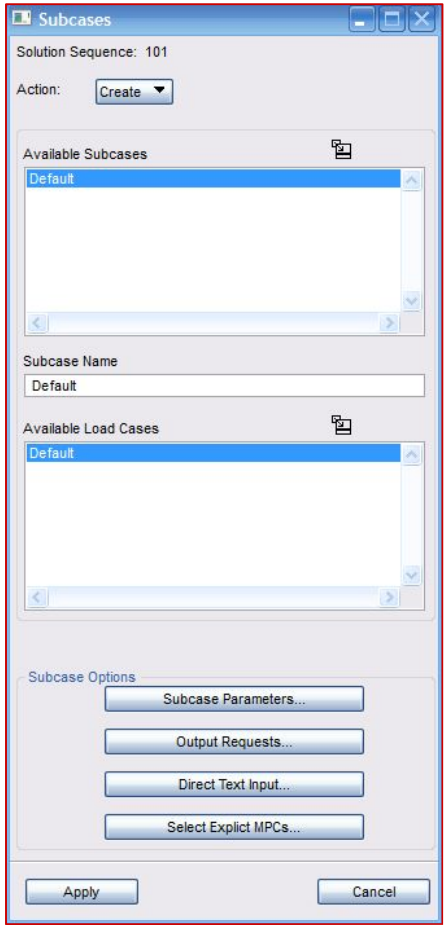
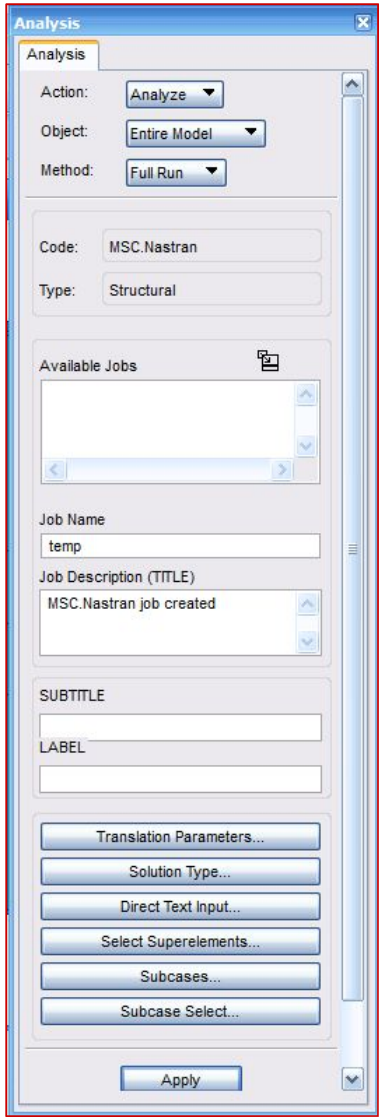
BOUTPUT DEFINITION IN PATRAN









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FUNDAMENTAL CONTROLS IN CONTACT – SUMMARY

- Contact analyses are nonlinear and require a nonlinear solution
- NLSTEP controls all nonlinear behavior
- Smart logic is built into NLSTEP and is a good starting point
- Additional output requests are available by NLOPRM if difficulties are encountered in gaining convergence
- General guidelines detailed in this section show path to convergence

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REVIEW QUESTIONS

1. **Which separation criteria should be used when quadratic elements are used in contact analysis?**

2. **Why could friction sometimes make a model more stable?**

3. **What should be the first thing to do if a contact analysis did not run to completion?**

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REVIEW QUESTIONS

4. When does a node separate from the contacted body?

5. What does contact chattering mean?

6. What values should I use for my contact parameters of distance tolerance, separation force, bias, etc.?

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SECTION 7

CONTACT WITH SHELLS IN MSC NASTRAN

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REVIEW

- **Deformable Contact Bodies**
  - Collections of similar type elements (i.e. shells, solids, bars…)
  - Treated using 'normal' FEA approach (flexible)
- **Rigid Contact Bodies**
  - Collections of geometries to be treated as rigid
  - Can be moving or stationary
- **Contact can be deformable-deformable or rigid-deformable**
- **Contact Bodies can 'TOUCH'ed, be 'GLUE'd, or ignore other Contact Bodies**

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CONTACT DETECTION FOR SHELLS

- **Shells can have contact at their bottom, top and mid-plane**
  - By default, contact is checked for top and bottom
  - Patran allows user specification, see next page

- **In order to define other scenarios the parameter COPT is introduced**

- **This parameter has additional functions (see following pages). In the future it will define which different element classes contribute to one single BCBODY**
  - At this time a BCBODY may consist only of one element class, for example quadratic shells

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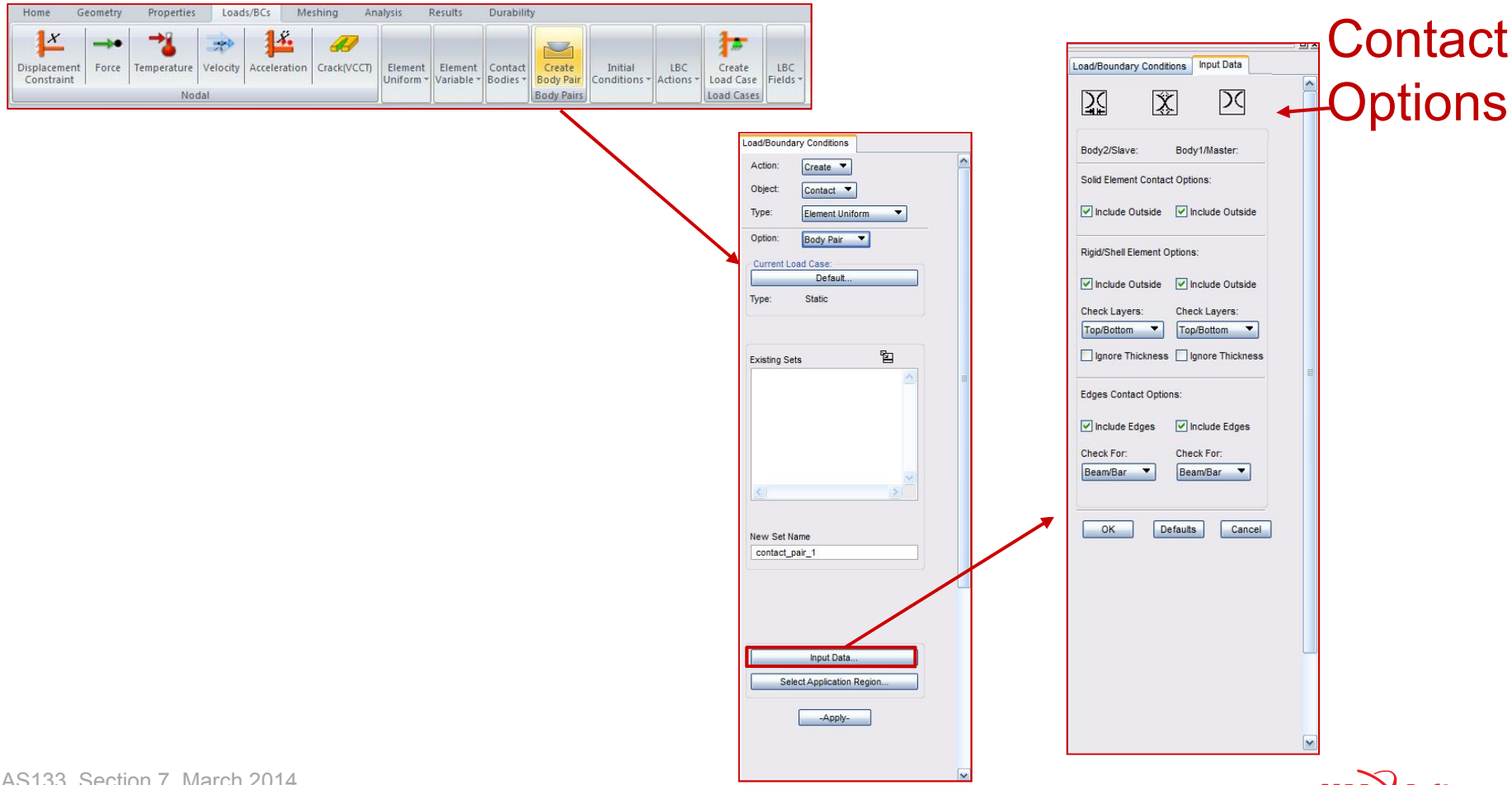
CONTACT DETECTION FOR SHELLS

- **Patran allows specification of what shell surface should be considered for contact**



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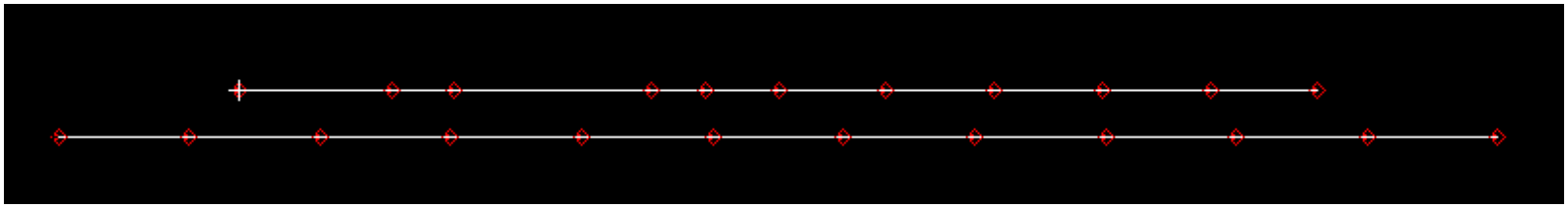
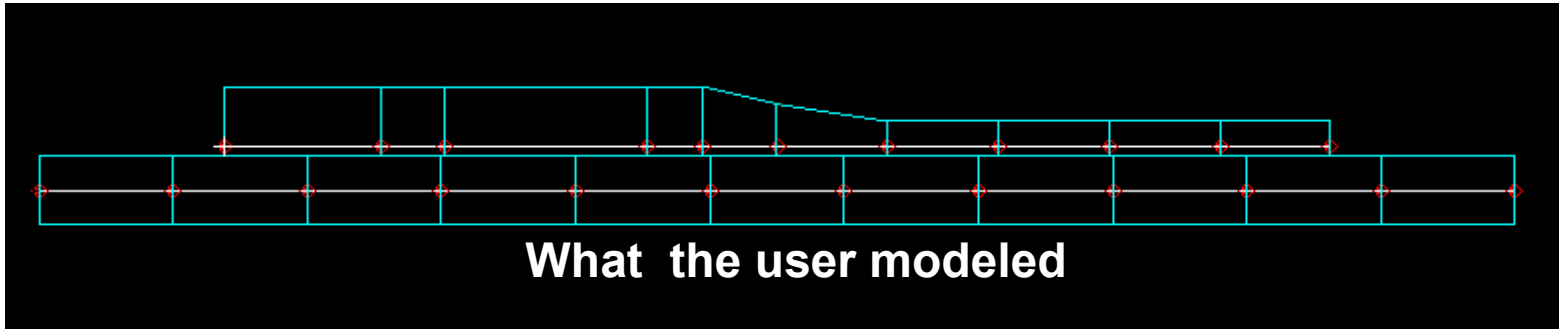
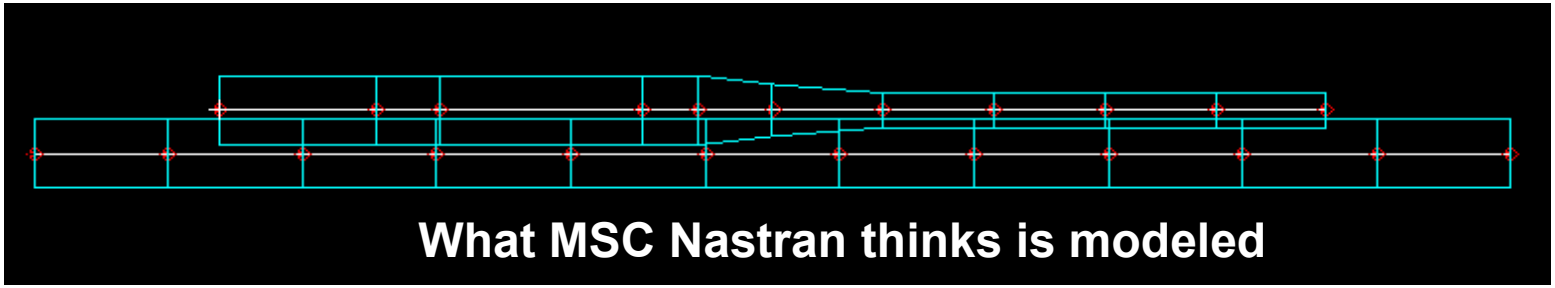
CURRENT LIMITATIONS

- **Composite Layup Offset**
  - MSC Nastran currently does not look at the Z0 definition in PCOMP and PCOMPG when doing contact search
  - It assumes the layup is centered about the grid plane
  - ZOFFS on the CQUAD4/8 entry is supported







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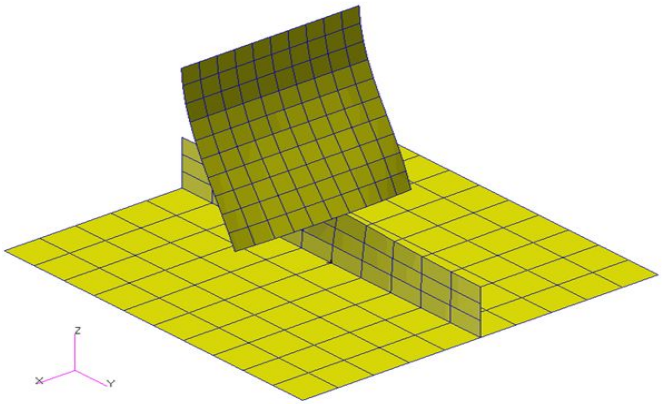
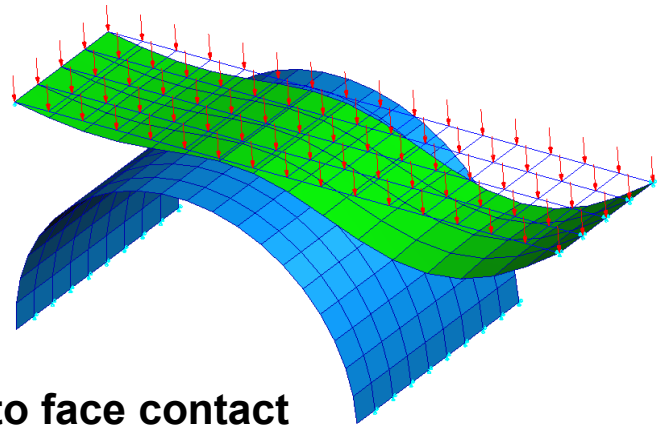
SHELL CONTACT ANALYSIS EXAMPLES

- **Shell and beam contact examples**



Edge-to-edge contact



Face to face contact

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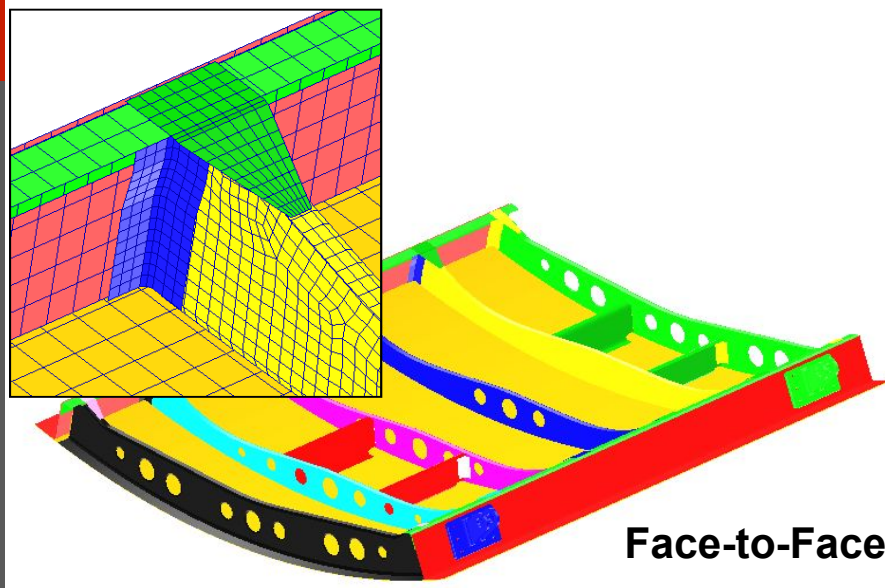
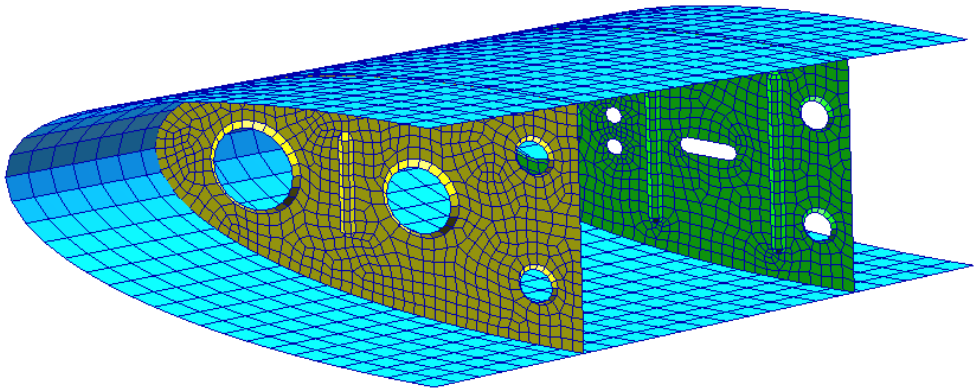
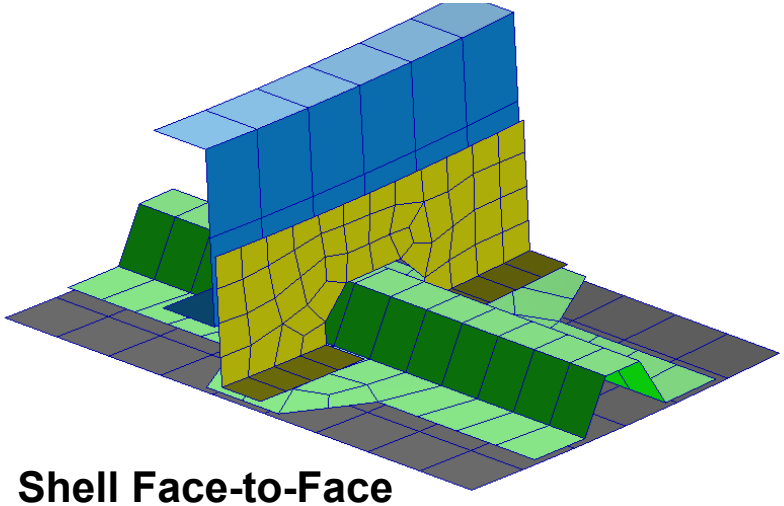
SHELL CONTACT ANALYSIS EXAMPLES



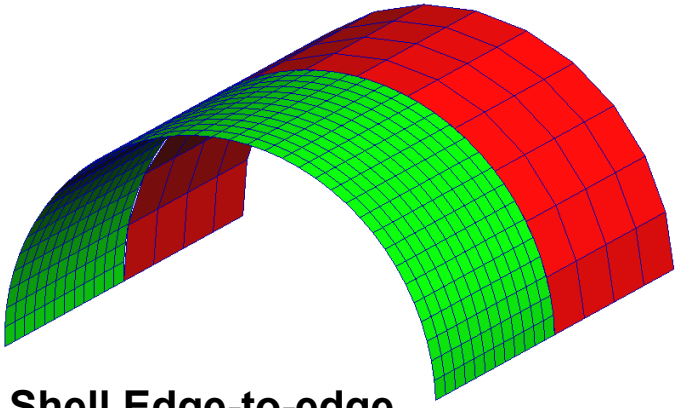
Face-to-Face



Shell Edge-to-Face



Shell Face-to-Face



Shell Edge-to-edge

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SHELL CONTACT ANALYSIS EXAMPLES

- **Shell Contact Analysis can be explained well by reviewing a series of Case studies**
- **The following page will introduce you to a live demo of Edge to Edge contact**
- **More examples of Shell contact can be found in Appendix D**
  - Shell Face-to-Face Touching Contact
  - Curved Shell Face-to-Face Touching Contact
  - Shell Edge-to-Face Glued Contact
  - Defining Contact With Tees & Clips

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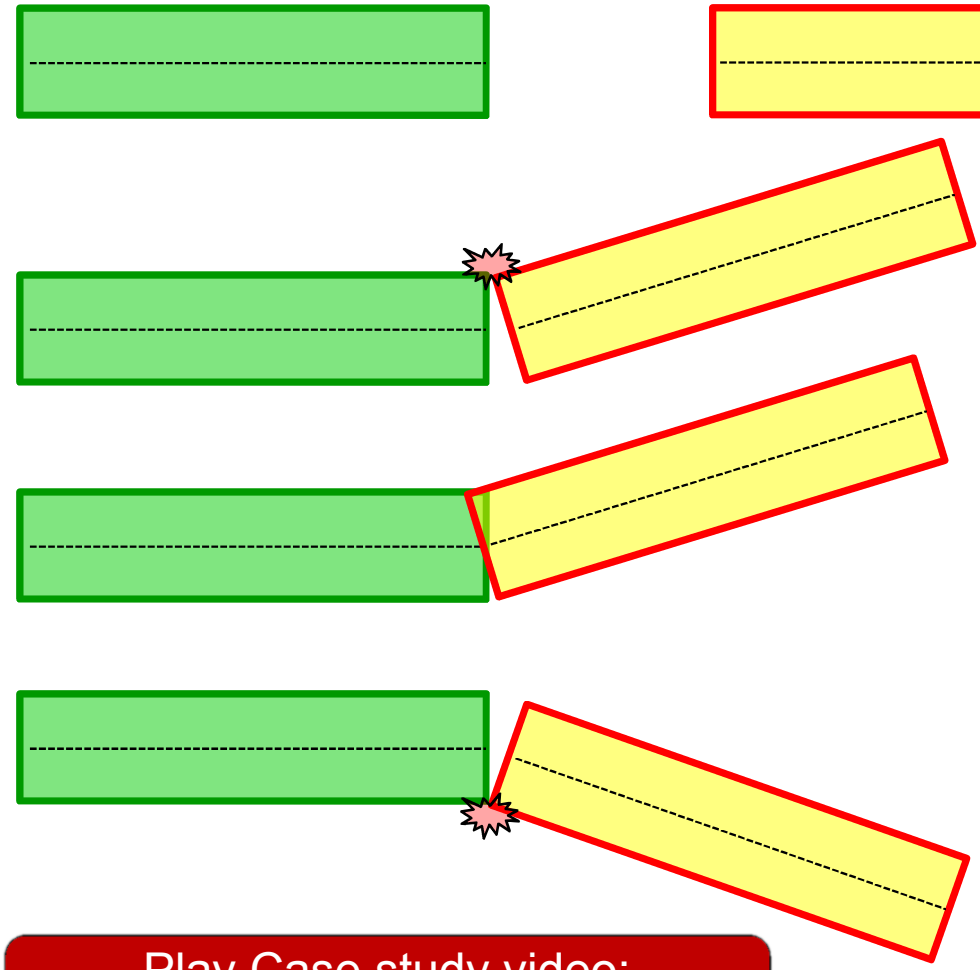
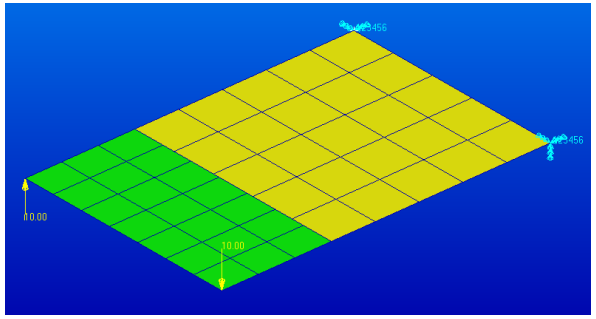
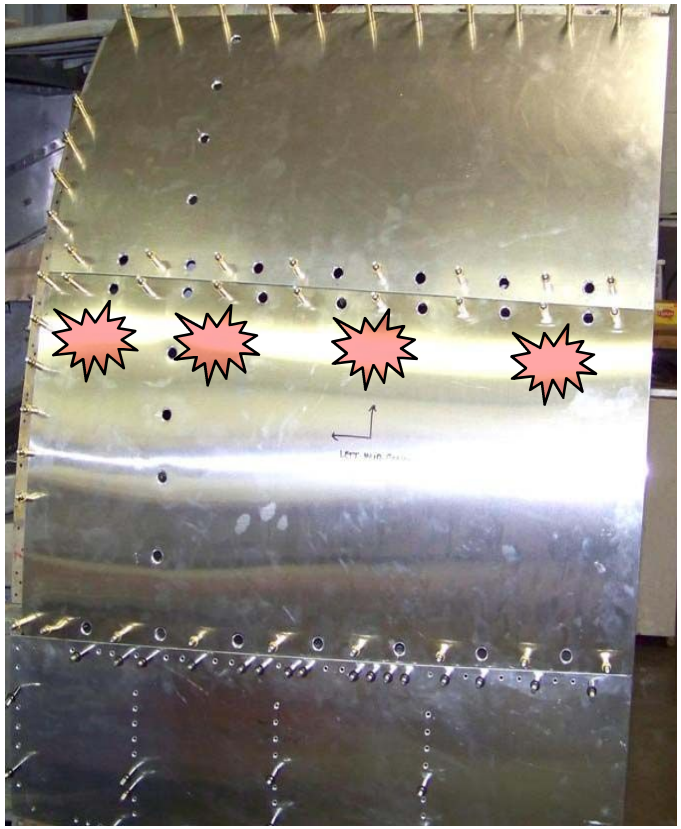
CASE STUDY: SHELL EDGE-TO-EDGE GLUED CONTACT

- **Meeting in the middle**







Play Case study video:
NAS133_S7_cs_edge_to_edge

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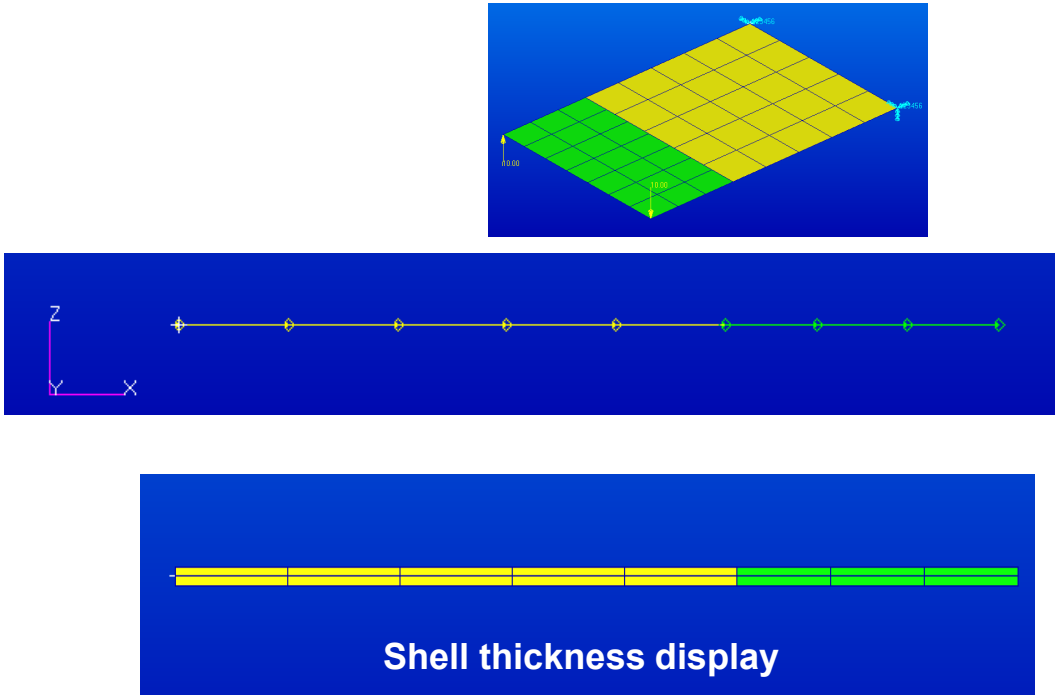
CASE STUDY: SHELL EDGE-TO-EDGE GLUED CONTACT

- **The contact bodies are located in the same plane, with the same thickness**



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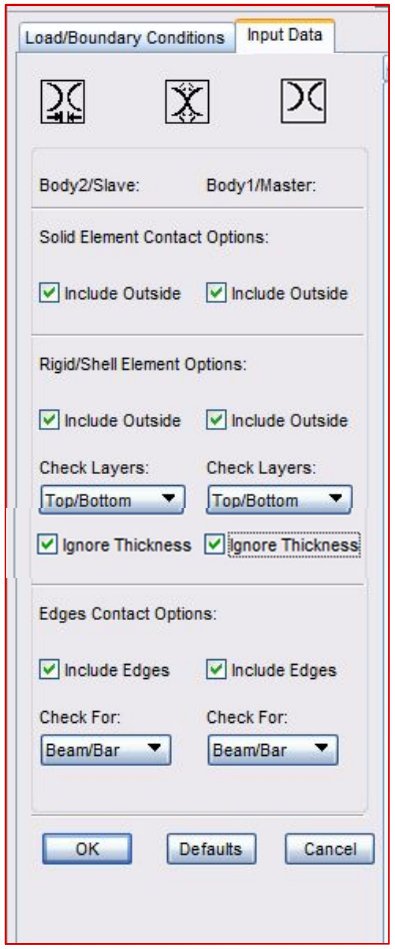
CASE STUDY 4: SHELL EDGE-TO-EDGE GLUED CONTACT

- **Edge-to-Edge Contact**
  - Ignore shell thickness for both bodies - simply glue the mid-planes of the shell bodies together (don't try to detect corner-to-corner contact)



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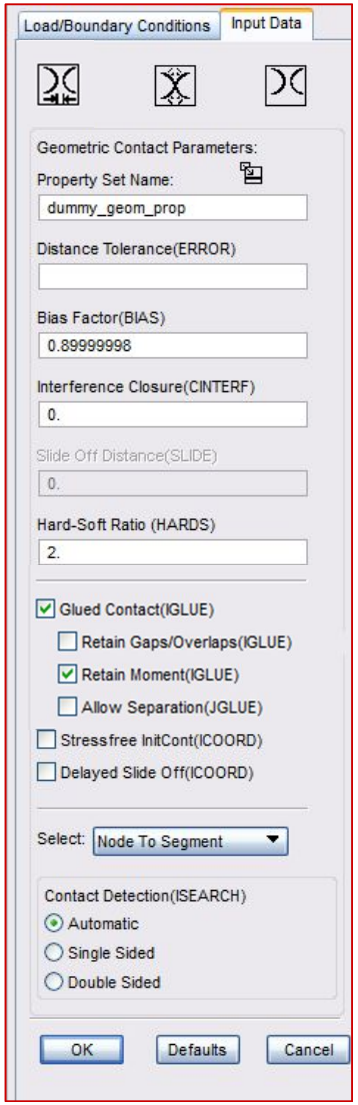
CASE STUDY: SHELL EDGE-TO-EDGE GLUED CONTACT

- **Wait just a *Moment*!**
  - Turn on *moment carrying capability* to enable the glued joint to transfer moments



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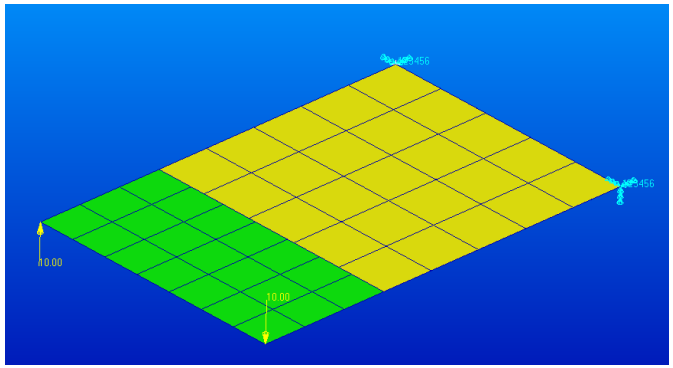
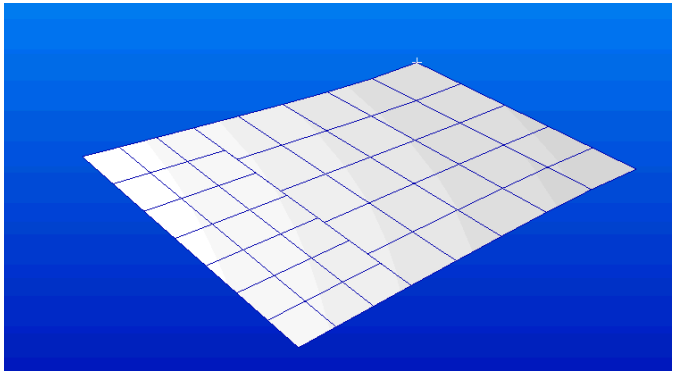
CASE STUDY: SHELL EDGE-TO-EDGE GLUED CONTACT

- **Plot the deformed shape**
  - The two plates appear to deform as one assembly





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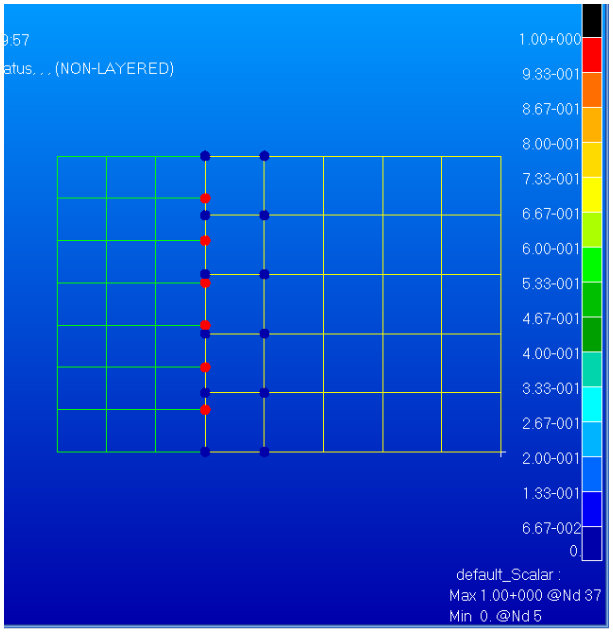
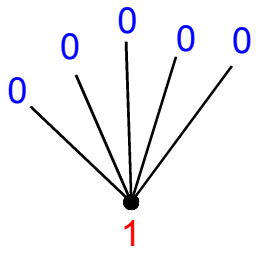
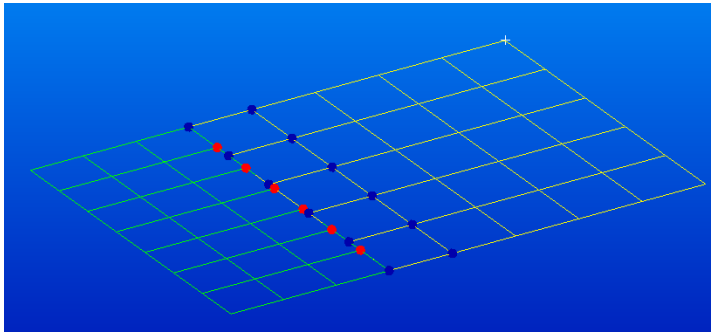
CASE STUDY: SHELL EDGE-TO-EDGE CONTACT

- **Plot the Contact Status**
  - 0 indicates a retained node (master)
  - 1 indicates a tied node (slave)







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REVIEW QUESTIONS

1. Contact can occur between which types of bodies?

2. Which shell surfaces can be used for contact?

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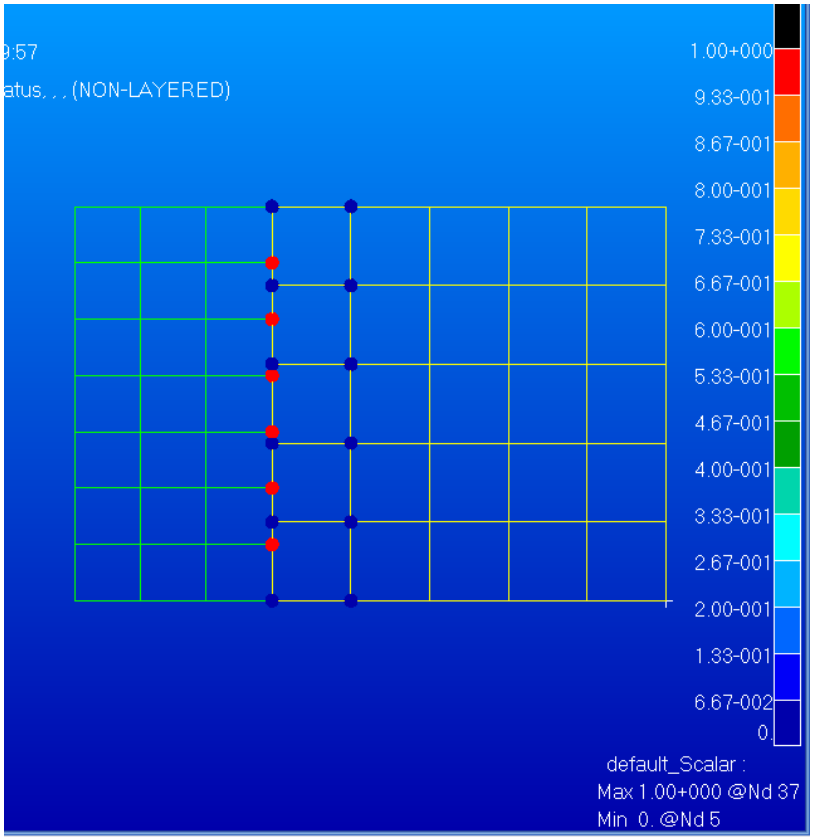
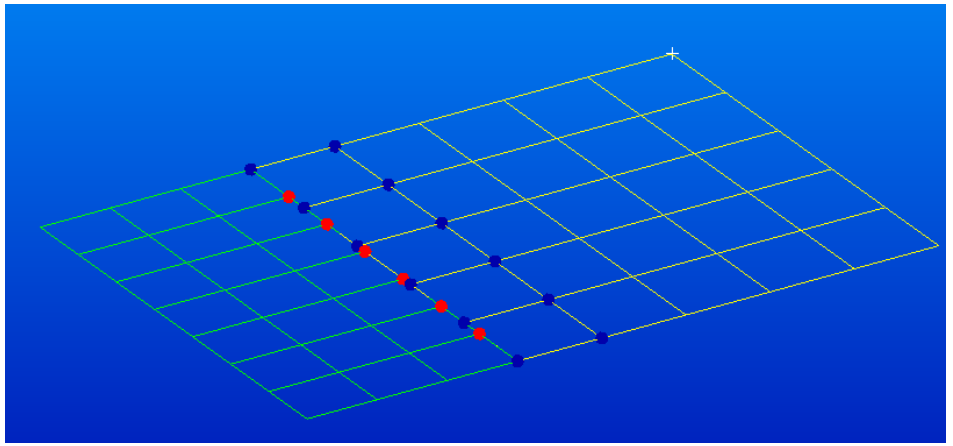
REVIEW QUESTIONS





3. Why is the second row of nodes inside the Master body marked as master nodes?

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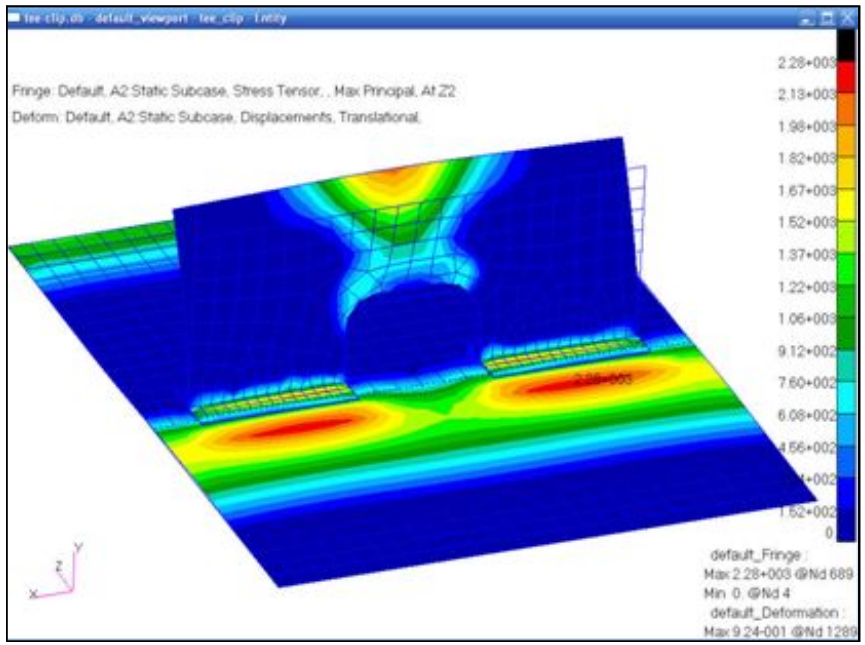
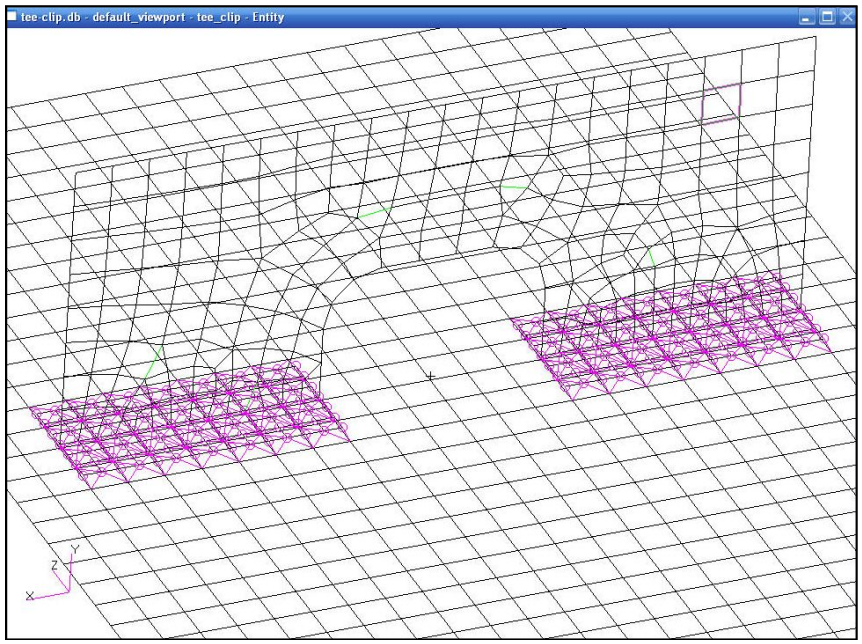
WORKSHOP 5 – SHELL FACE TO FACE CONTACT

- **Create glued contact between shell faces.**
- **Please perform Workshop 5**





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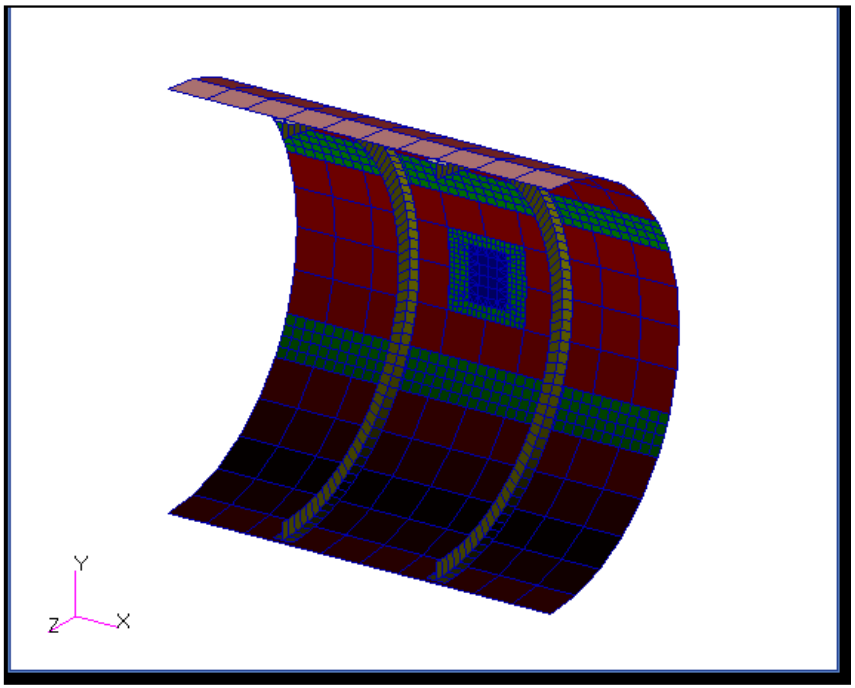
WORKSHOP 6 – CURVED SURFACE CONTACT

- **Demonstrate that in order to get good glued contact results the order of contact body creation is important for solver requirements.**
- **Please perform Workshop 6**



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SECTION 8

FRICTION

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FRICTION

- Friction is a complex physical phenomena that is dependent on surface roughness, temperature, normal stress, and relative velocity
- Bodies in contact that move tangentially to each other will develop shear stresses at their interface - these stresses are due to friction
- If the stresses reach a critical value the bodies will slip and move relative to each other
- As long as the stresses remain below this critical value the bodies are in “stick” status

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FRICTION

- **Two friction models, Bilinear Coulomb and Bilinear Shear, are supported in MSC Nastran**
- **Friction causes additional iterations in nonlinear analysis and usually leads to longer runtime**
- **Friction may make model more stable by preventing contact body free motion (such as free rotation of a pre-stressed bolt) and therefore improve convergence**

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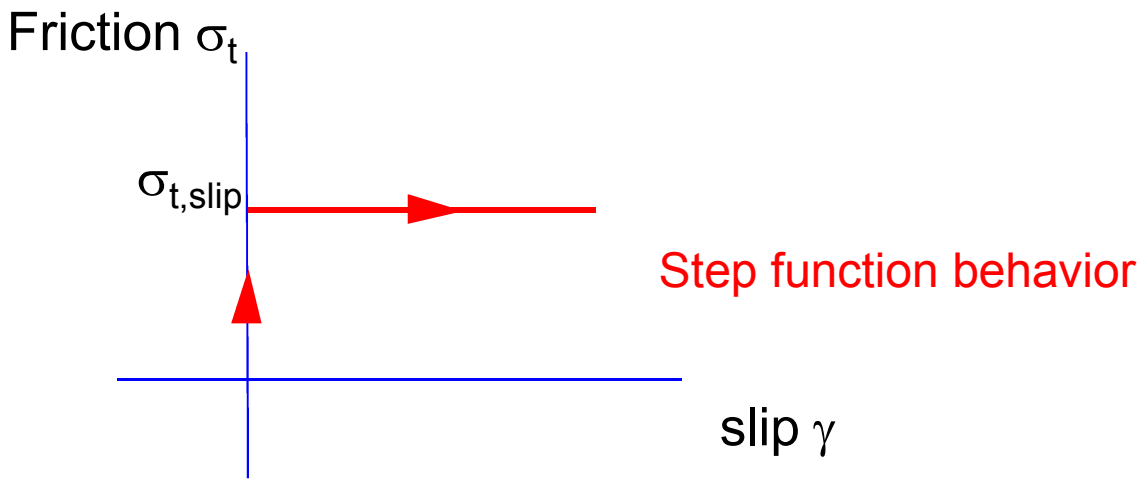
COULOMB FRICTION

- **The critical value when slipping starts to occur usually depends on the contact stress σ_n**
- **$\sigma_{t,slip} = -\mu \sigma_n$ t, with μ as the friction coefficient and t as the slip direction**



- **This friction model is called Coulomb Friction**
- **The step function is discontinuous since the status is either stick or slip**

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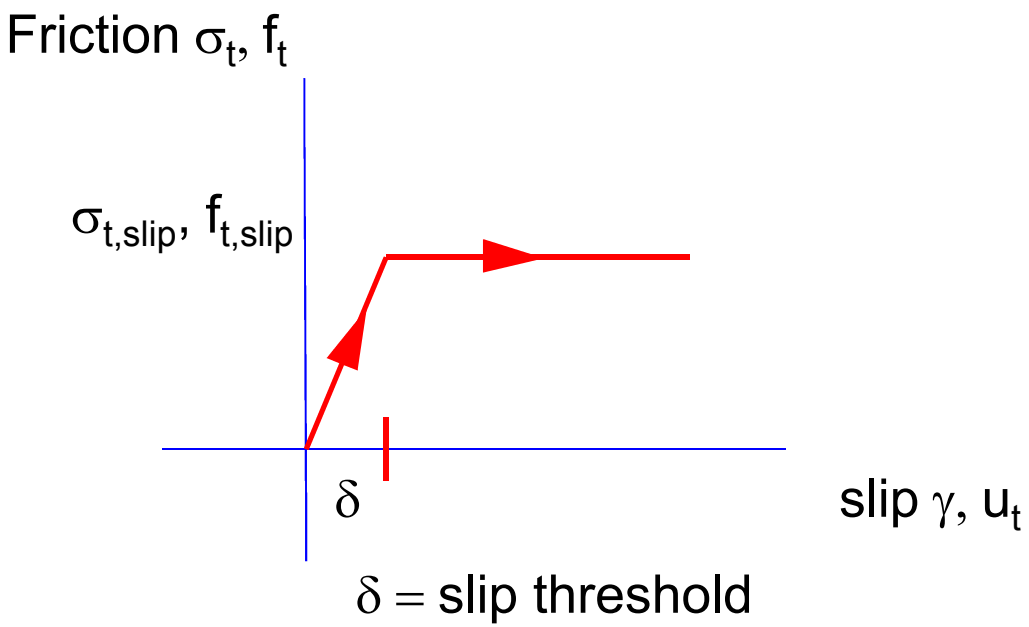
BILINEAR COULOMB FRICTION

- **Since stick means infinite stiffness, a bilinear function is applied to avoid numerical difficulties**
- **The bilinear model assumes stick and slip conditions correspond to reversible (elastic) and permanent (plastic) relative displacements**



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BILINEAR COULOMB FRICTION

- **The calculation proceeds as follows**
  - As for elastic-plastic material the rate of the relative tangential displacement is split into an elastic (stick) and a plastic part (slip)

$$\dot{\mathbf{u}}_t = \dot{\mathbf{u}}_t^e + \dot{\mathbf{u}}_t^p$$

  - The slip criteria is defined as:

$$\phi = \left\|\mathbf{f}_t\right\| - \mu f_n \quad ; \quad \phi < 0 (stick) \, , \, \phi = 0 (slip)$$

  - The rate of change of friction force vector is related to the elastic tangential displacement by

$$\dot{\mathbf{f}}_t = \mathbf{D}\dot{\mathbf{u}}_t^e = \mathbf{D}(\dot{\mathbf{u}}_t - \dot{\mathbf{u}}_t^p)$$

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BILINEAR COULOMB FRICTION

- **With these assumptions the rate of the resulting friction force can be expressed as**

$$\dot{\mathbf{f}}_t = \left(\mathbf{D} - \frac{\mathbf{D}\frac{\partial \psi}{\partial \mathbf{f}_t}\left(\frac{\partial \phi}{\partial \mathbf{f}_t}\right)^T \mathbf{D}}{\left(\frac{\partial \phi}{\partial \mathbf{f}_t}\right)^T \mathbf{D}\frac{\partial \psi}{\partial \mathbf{f}_t}} \right) \dot{\mathbf{u}}_t = (\mathbf{D} - \mathbf{D}^*)\dot{\mathbf{u}}_t$$

non-symmetric, but symmetrized

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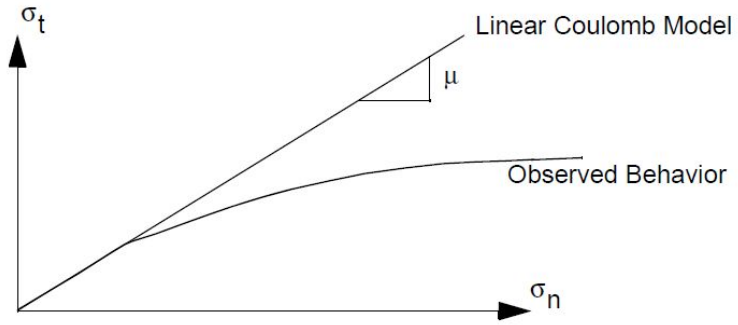
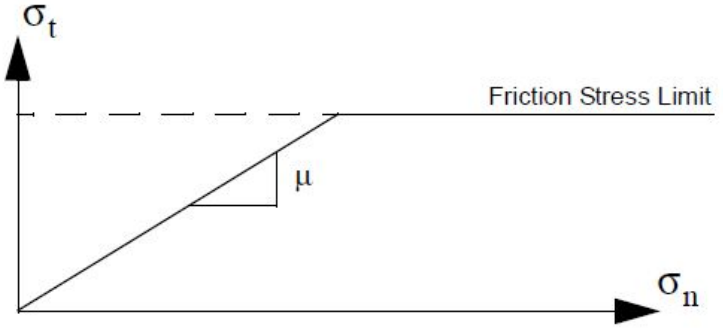
BILINEAR COULOMB FRICTION

- **The Coulomb friction model may not correlate well with experiment if the frictional tractions exceed the flow stress or failure stress of the material**



- **Therefore the user may define a friction stress limit $\sigma_{t,limit}$, FRLIM on the BCONPRP entry, so that the maximum friction stress will be**

$$\min(\mu\sigma_n, \sigma_{t,\,limit})$$



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BILINEAR SHEAR FRICTION

- **The second friction model available in MSC Nastran is the Shear Friction Model**
- **In this model the friction stress is a fraction of the equivalent stress $\bar{\sigma}$ in the material**

$$|\sigma_t| < m\frac{\bar{\sigma}}{\sqrt{3}} \ (stick) \text{ and } \sigma_t = -m\frac{\bar{\sigma}}{\sqrt{3}} \cdot \boldsymbol{t} \ (slip)$$

m is the friction factor

- **Similar to Coulomb friction, the bilinear model is adapted and the shear stress due to friction is limited by**

$$\sigma_t = min\left(m\sigma_n, m\frac{\bar{\sigma}}{\sqrt{3}}\right)$$

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FRICTION INPUT

- **The Input parameters for friction are**
  - NO friction, FTYPE=0. Default.
  - Coulomb Friction, FTYPE=6 in BCPARA
  - Shear Friction, FTYPE=7 in BCPARA
  - Friction coefficient, FRIC in BCBODY or BCONPRP (preferred)
  - Friction stress limit, FRLIM in BCONPRP
  - Slip threshold δ is input in BCPARA as
    - RVCNST for node to segment contact. Its default is 0.0025 times the average edge length of the elements defining the deformable contact bodies.
    - STKSLP for segment to segment contact. Its default is 0.0 for the maximum sticking displacement to be taken.

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SETUP FRICTION IN PATRAN

- **Friction is not taken into account by default**
- **User needs to do two things to activate friction effect**
  - Enter friction coefficient
  - Select friction model
- **Friction coefficient can be defined in the contact body or the contact pair**
- **It is preferable to enter friction coefficient for the contact pair since friction is between contact bodies**

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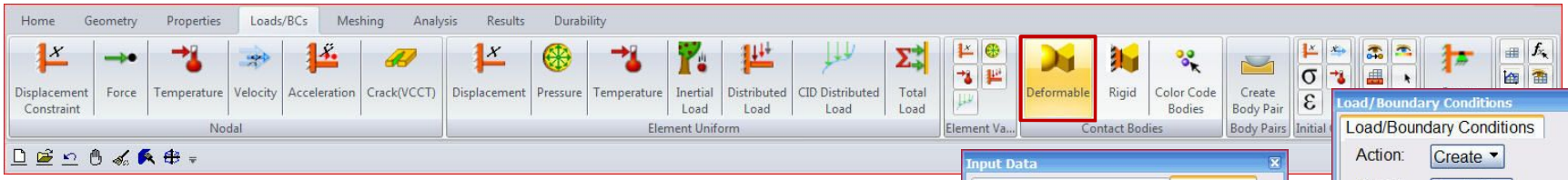
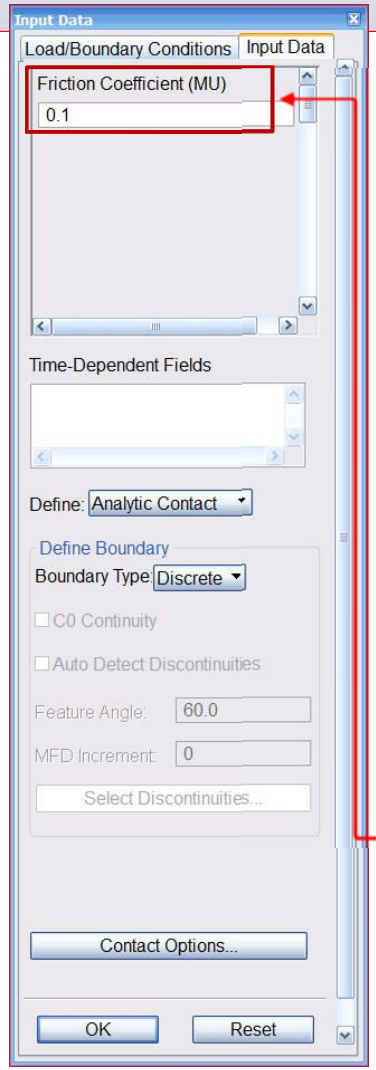
SETUP FRICTION IN PATRAN



- **If friction is entered through the contact body definition, the friction coefficient for a contact pair is determined by**
  - Average value for deformable-deformable contact
  - Value of the rigid body for deformable-rigid contact

Friction coefficient can be entered when defining individual contact body



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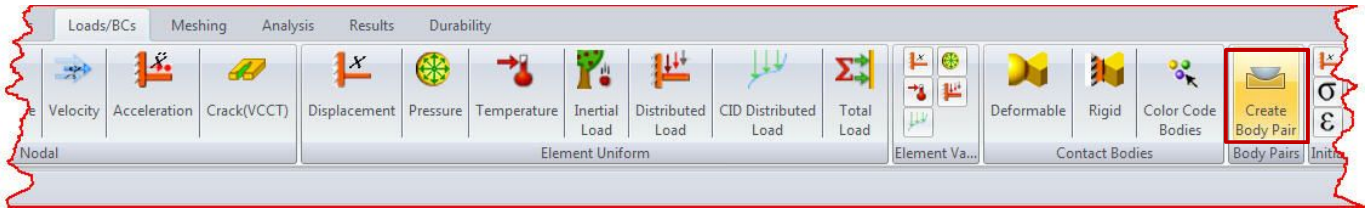
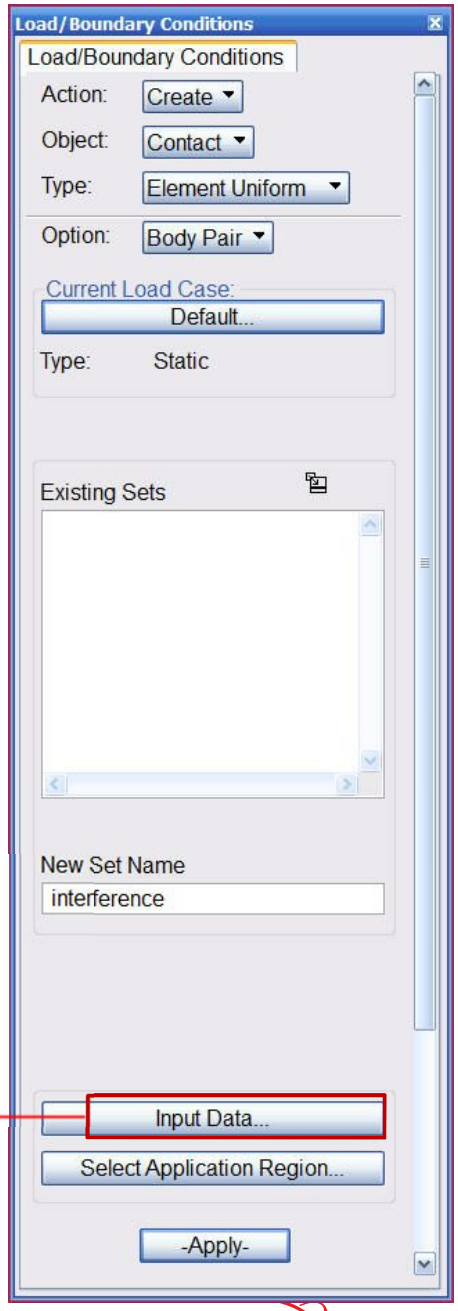
SETUP FRICTION IN PATRAN



- **Friction coefficient between a contact pair can be entered in the physical contact parameters form**



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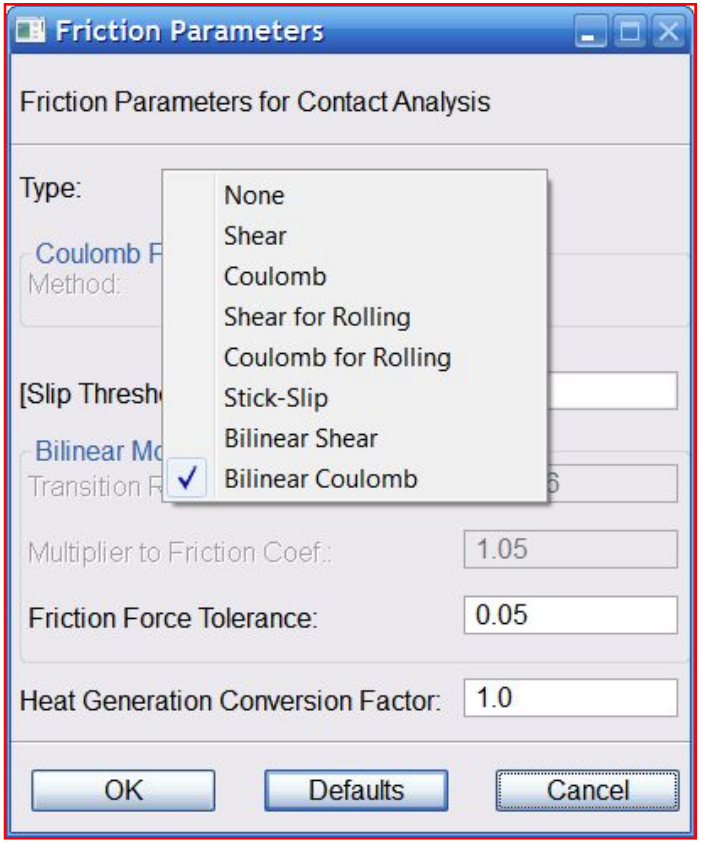
SETUP FRICTION IN PATRAN

- **Friction model is defined under Analysis / Solution Type / Solution Parameters / Contact Parameters / Friction**



Only Bilinear Coulomb and Bilinear Shear models are supported in solutions 101 and 400.

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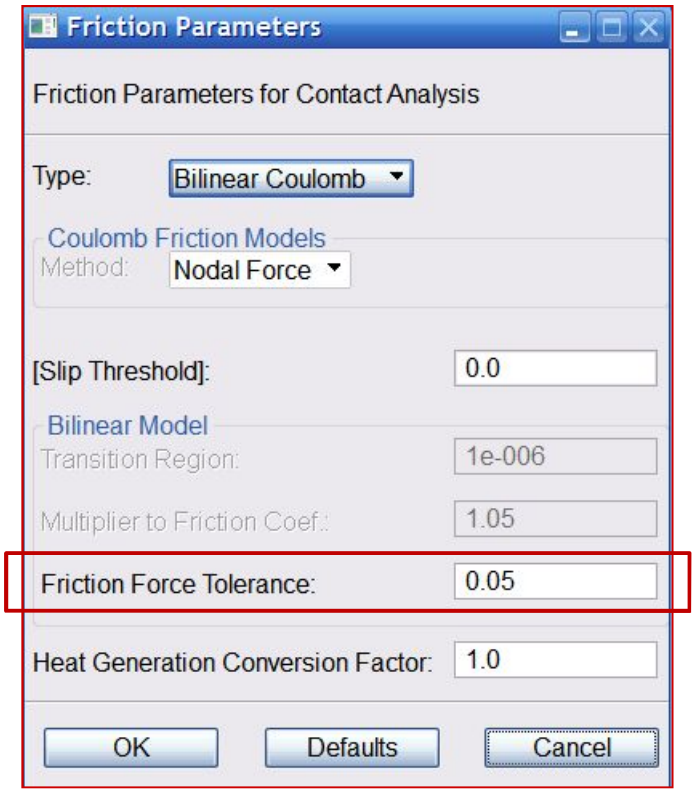
SETUP FRICTION IN PATRAN

- **Friction model uses an additional check on the convergence of the friction forces**
- **The convergence criterion is based on relative friction force. The default convergence tolerance is 0.05**

$$\frac{\left\|\mathbf{F}_t\right\| - \left\|\mathbf{F}_t^p\right\|}{\left\|\mathbf{F}_t\right\|} \leq e$$



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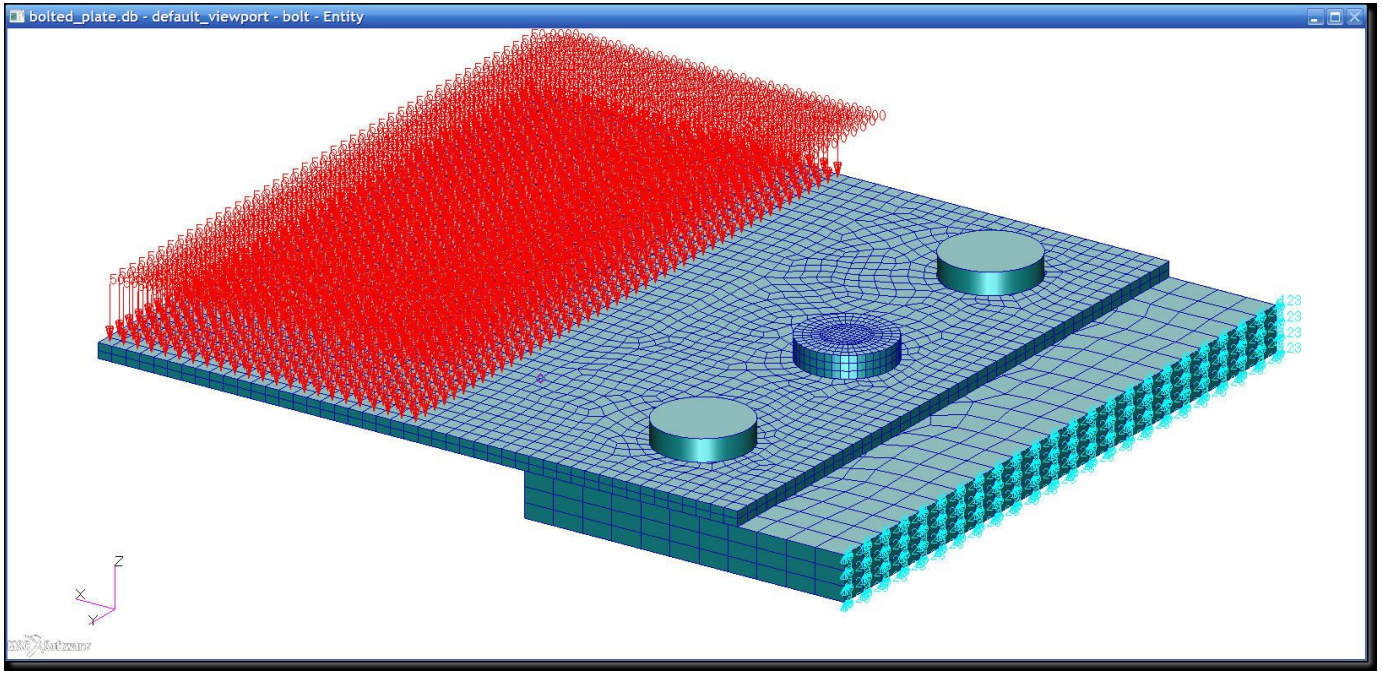
CASE STUDY: BOLTED PLATE

- **Two plates connected by a bolt**
- **Pressure on top plate and fixed bottom plate**



Play Case study video:
NAS133_S8_cs_bolted_plate

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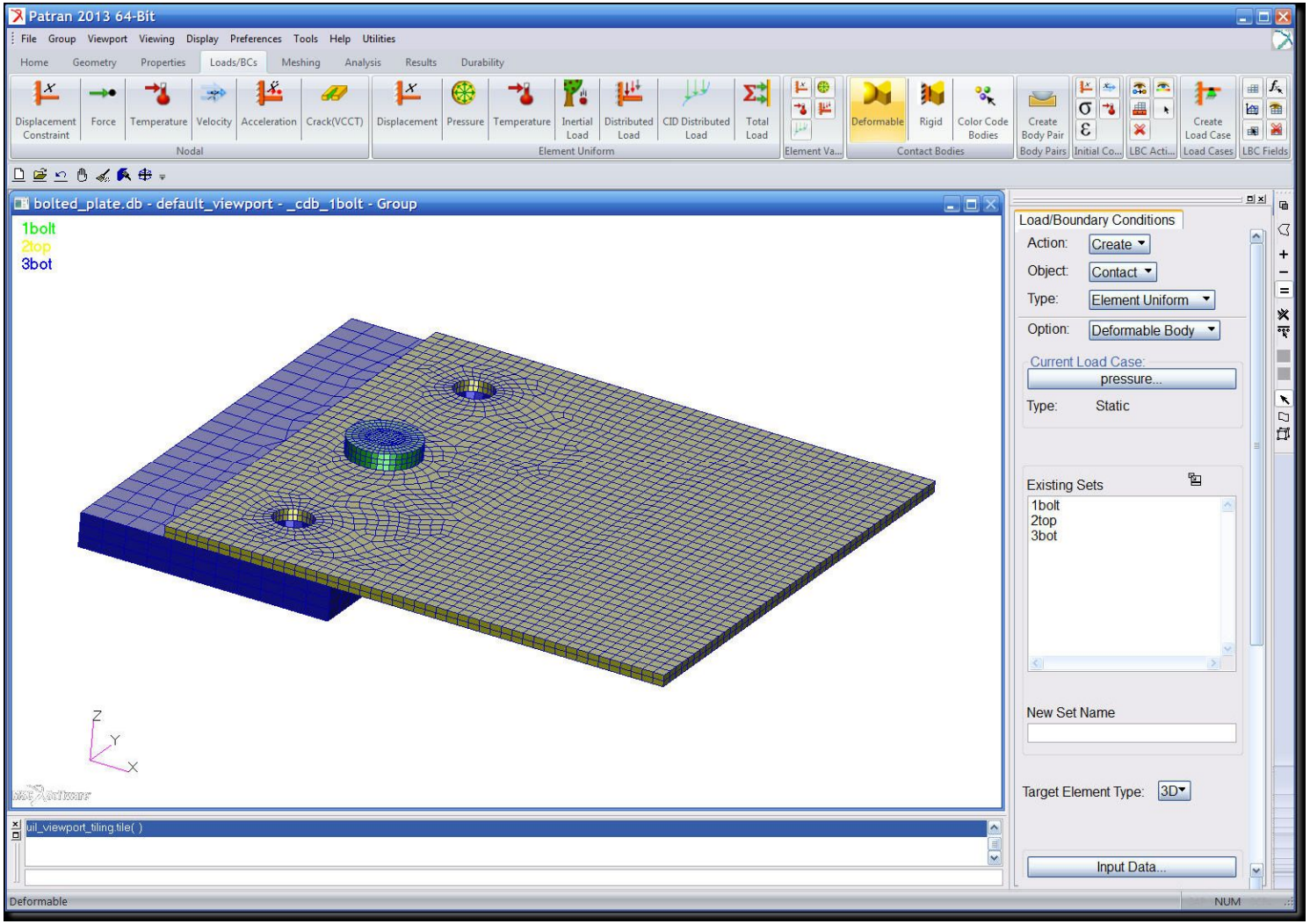
CASE STUDY: BOLTED PLATE

- **Create 3 contact bodies**



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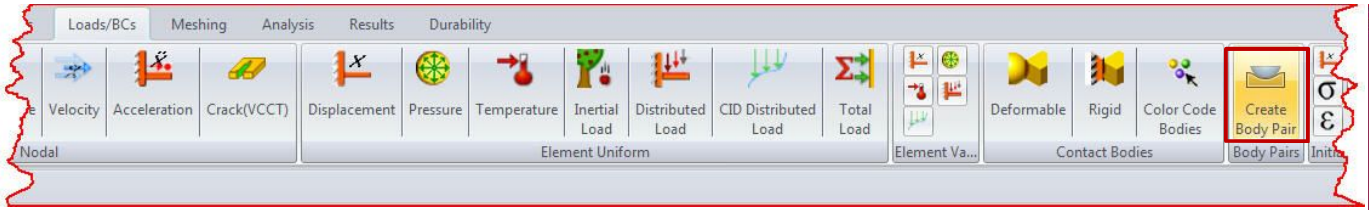
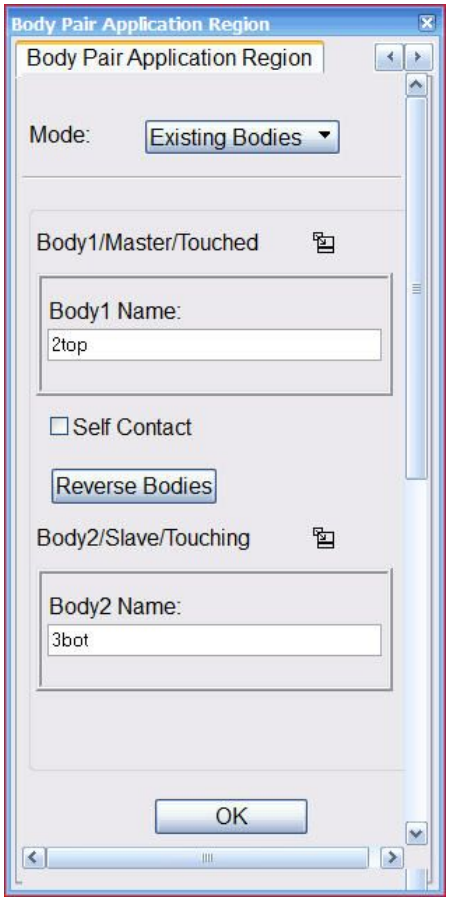
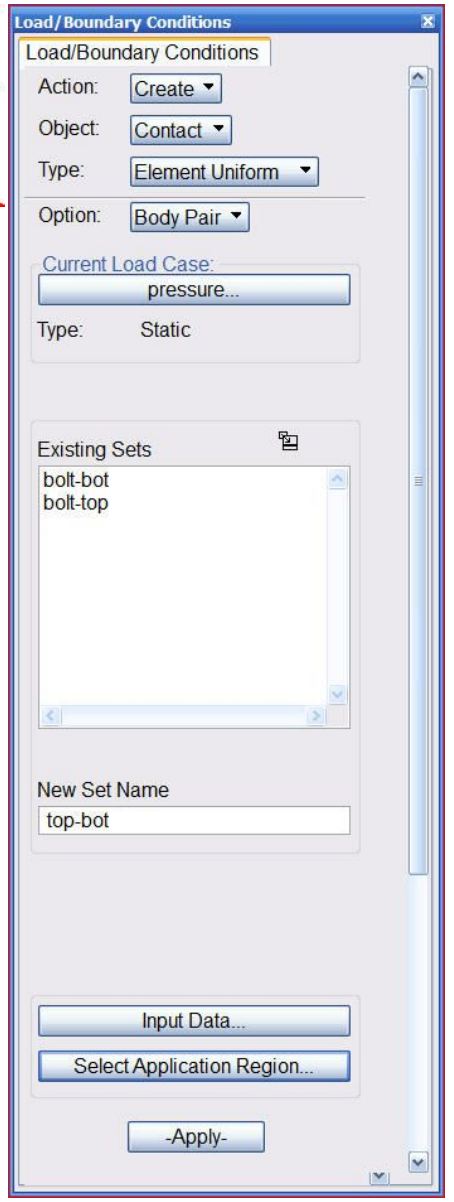
CASE STUDY: BOLTED PLATE



- **Define 3 contact pairs**
  - Bolt and top plate
  - Bolt and bottom plate
  - Top plate and bottom plate





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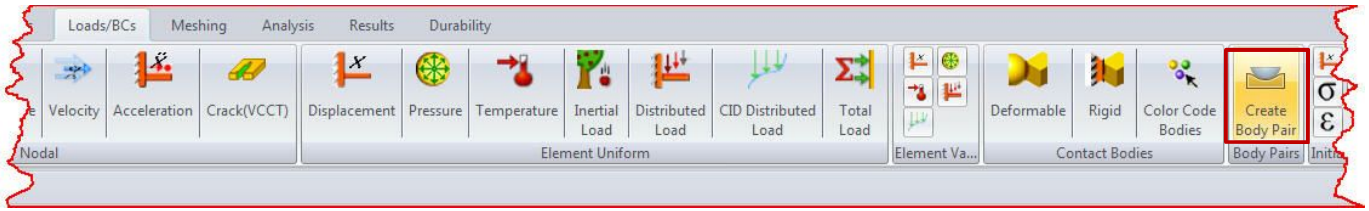
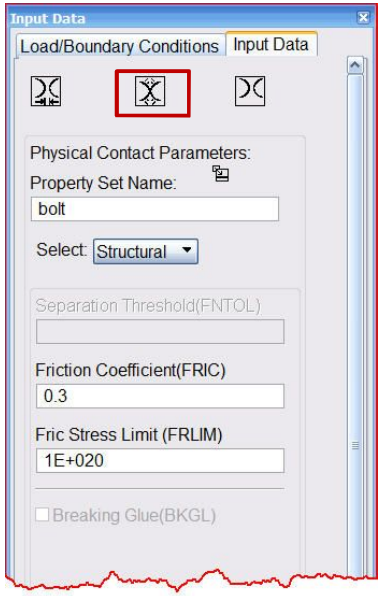
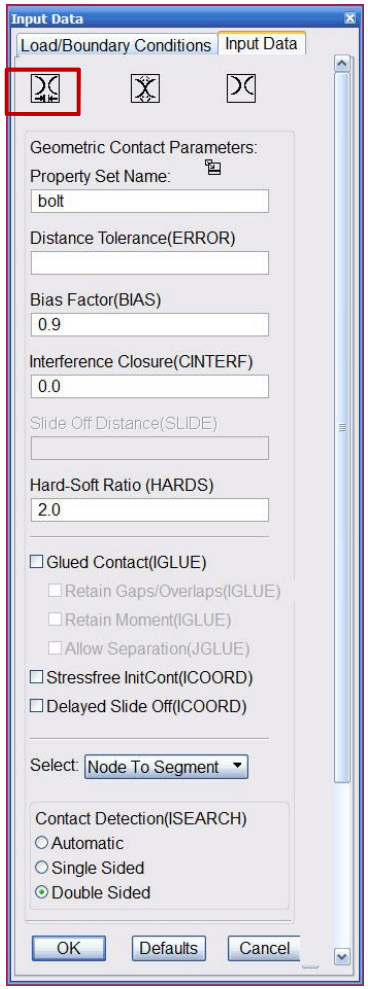
CASE STUDY: BOLTED PLATE



- **Enter geometric and physical contact parameters**
  - Use default geometric parameters
  - Set friction coefficient to 0.3

The bolt and the top plate are free to rotate about z-axis and the model is unstable without friction





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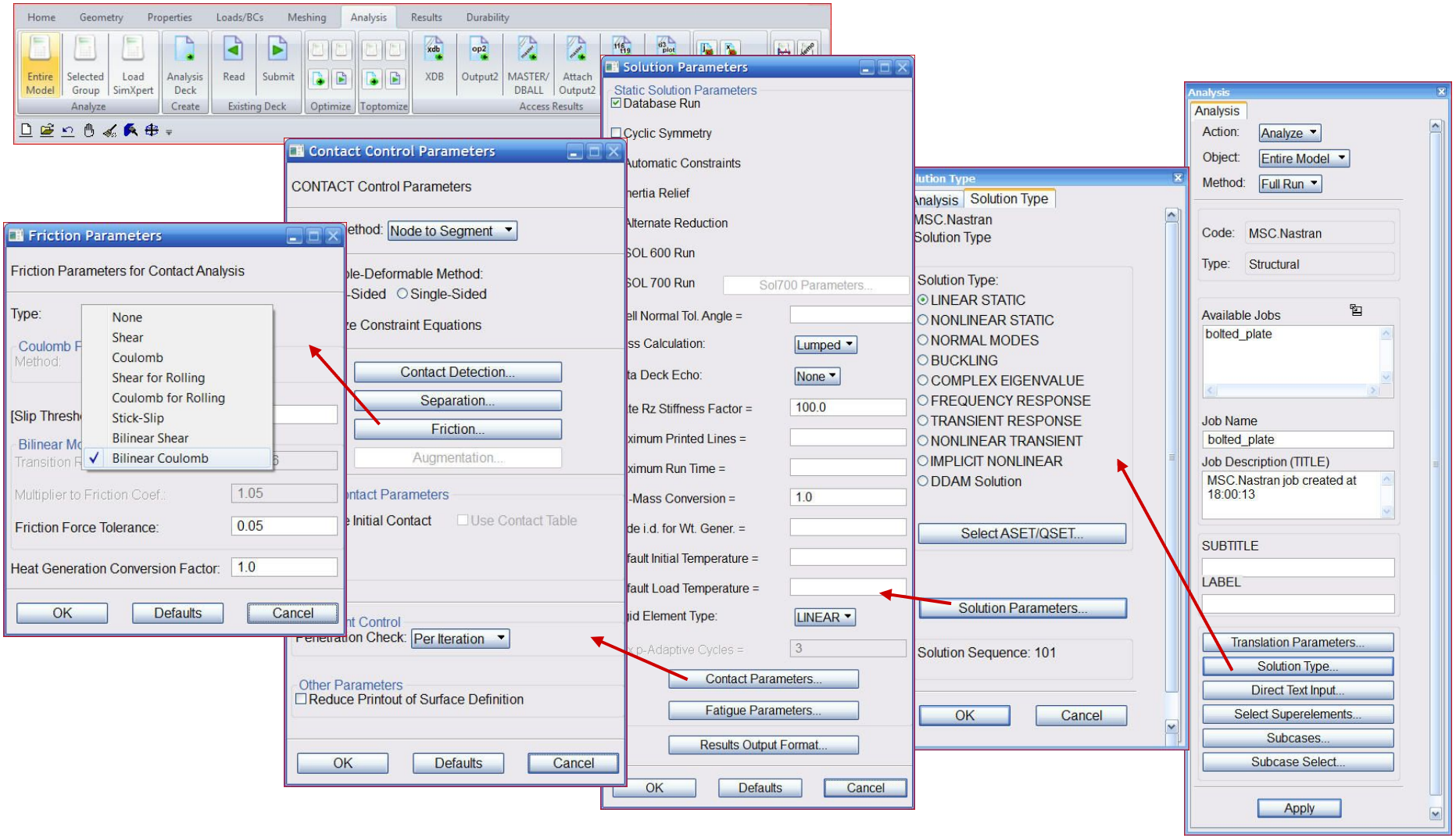
CASE STUDY: BOLTED PLATE

- **Select Bilinear Coulomb friction model**



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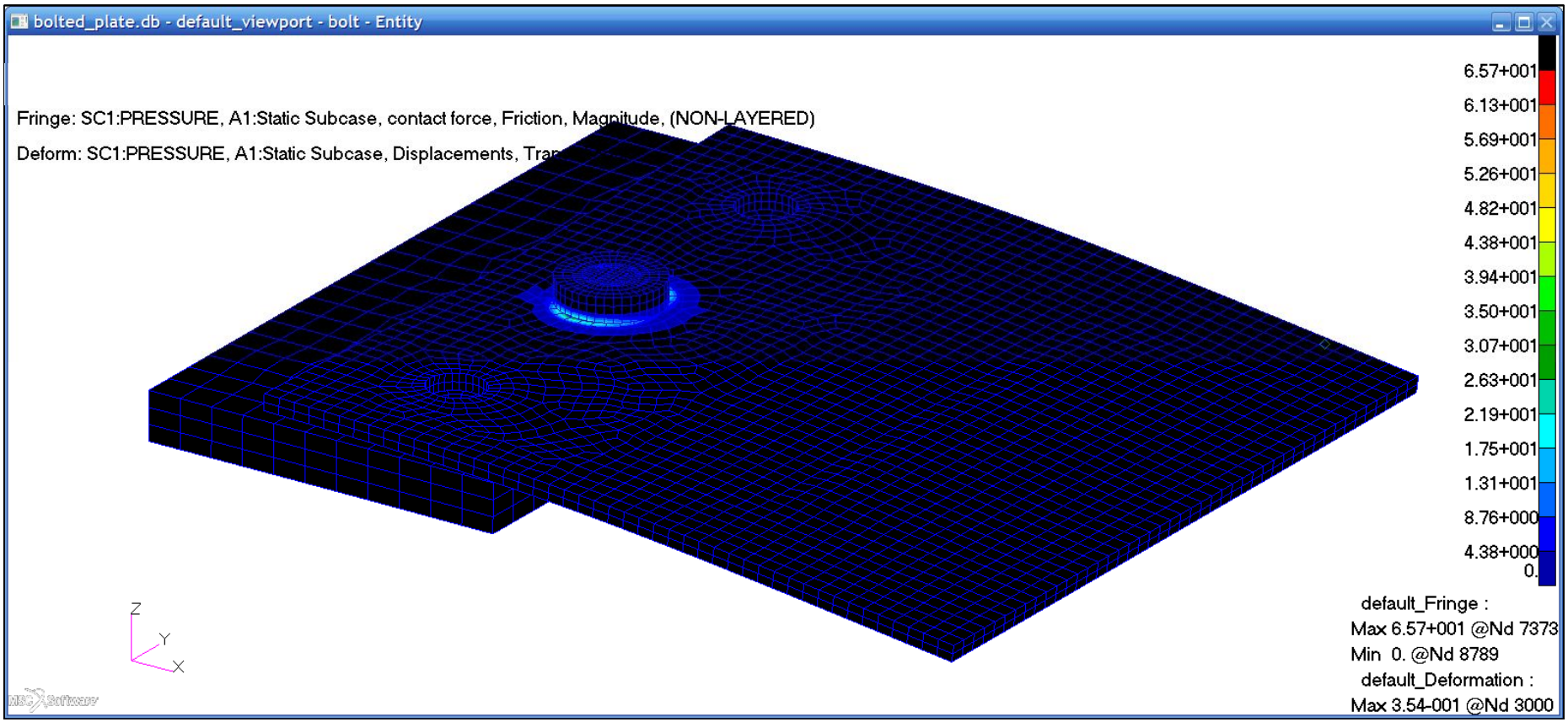
CASE STUDY: BOLTED PLATE

- **Plot contact friction force**



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REVIEW QUESTIONS

1. How do you activate friction?

2. How do you enter friction coefficients?

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SECTION 9

CONTACT RESULTS OUTPUT

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CONTACT RESULTS OUTPUT

- **BOUTPUT – Output of contact results**
  - contact status, contact forces and stresses
- **param,ph2out – phase 2 output (default=0)**
  - 0 – regular phase III output (performed when all steps and subcases have been completed)
  - 1 – phase II output only. This is useful when the run is terminated abnormally before the phase III outputs are formatted and printed. Prints in SORT1 format. There will be no output for the upstream superelements.
  - 3 – both phase II and phase III outputs. In this case, some of the outputs for the residual structure may be redundant.

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CONTACT RESULTS OUTPUT

N O D A L F O R C E S A N D S T R E S S E S I N 3 D C O N T A C T A N A L Y S I S

LOAD STEP = 1.00000E+00 SUBCASE 1 STEP 1

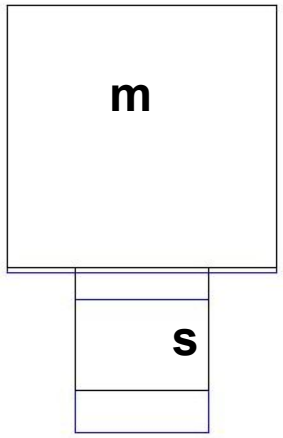
GRID	STATUS	CONTACT FORCES - RESIDUALS EXCLUDING FRICTION - IN GLOBAL SYSTEM -			FRICTION FORCES - IN GLOBAL SYSTEM -			NORMAL STRESS - IN CONTACT LOCAL SYSTEM -	FRICTION STRESS 1	FRICTION STRESS 2
1	0	0.0000E+00	0.0000E+00	4.5417E-01	0.0000E+00	0.0000E+00	0.0000E+00	1.8167E-02	0.0000E+00	0.0000E+00
2	0	0.0000E+00	0.0000E+00	4.5417E-01	0.0000E+00	0.0000E+00	0.0000E+00	1.8167E-02	0.0000E+00	0.0000E+00
3	0	0.0000E+00	0.0000E+00	4.5417E-01	0.0000E+00	0.0000E+00	0.0000E+00	1.8167E-02	0.0000E+00	0.0000E+00
4	0	0.0000E+00	0.0000E+00	4.5417E-01	0.0000E+00	0.0000E+00	0.0000E+00	1.8167E-02	0.0000E+00	0.0000E+00
15	1	-3.1514E-18	1.3866E-17	-4.5417E-01	0.0000E+00	0.0000E+00	0.0000E+00	7.2667E-02	0.0000E+00	0.0000E+00
16	1	-3.1514E-18	1.7648E-17	-4.5417E-01	0.0000E+00	0.0000E+00	0.0000E+00	7.2667E-02	0.0000E+00	0.0000E+00
17	1	1.2606E-18	1.7648E-17	-4.5417E-01	0.0000E+00	0.0000E+00	0.0000E+00	7.2667E-02	0.0000E+00	0.0000E+00
18	1	1.2606E-18	1.3866E-17	-4.5417E-01	0.0000E+00	0.0000E+00	0.0000E+00	7.2667E-02	0.0000E+00	0.0000E+00

STATUS DEFINITION -----

= 0 node is a retained node
= 1 node is a tied node (touching node)

f06 file

Model



1, 2, 3, 4

15, 16, 17, 18

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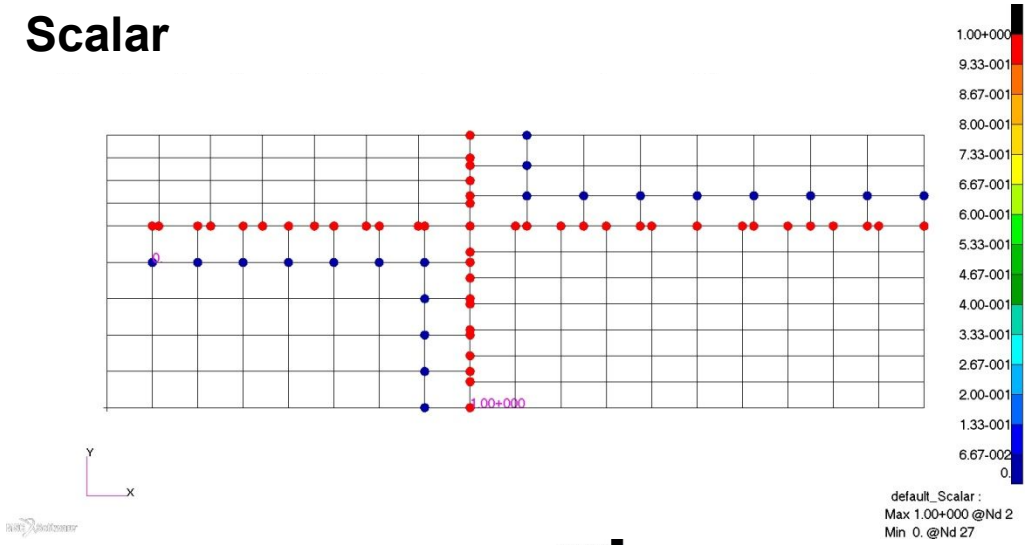
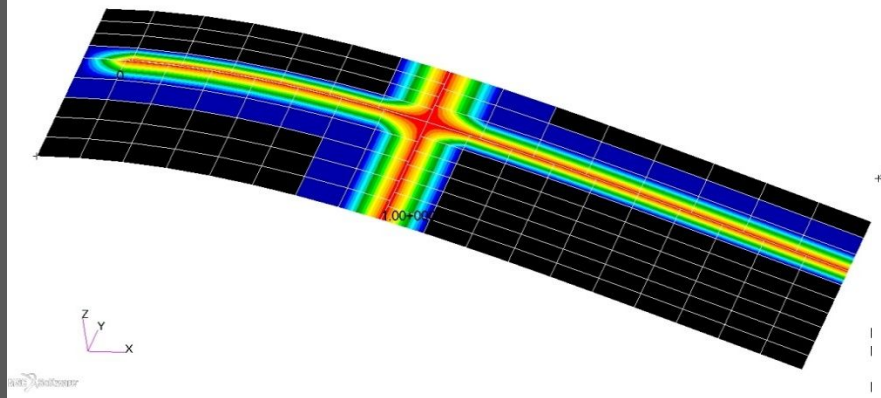
CONTACT RESULTS OUTPUT

- **Patran Contact Status Plots**

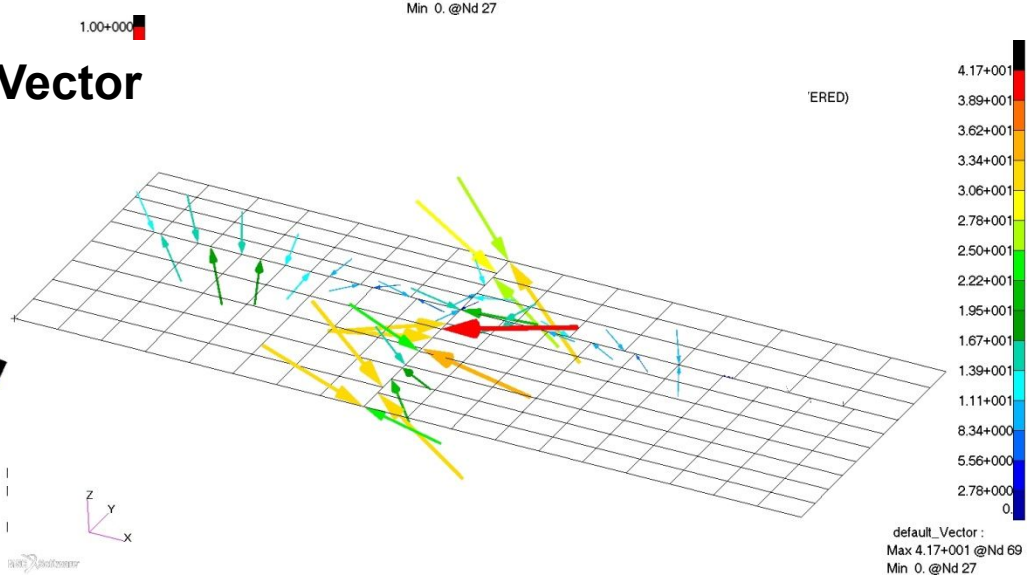
Scalar



Fringe



Vector



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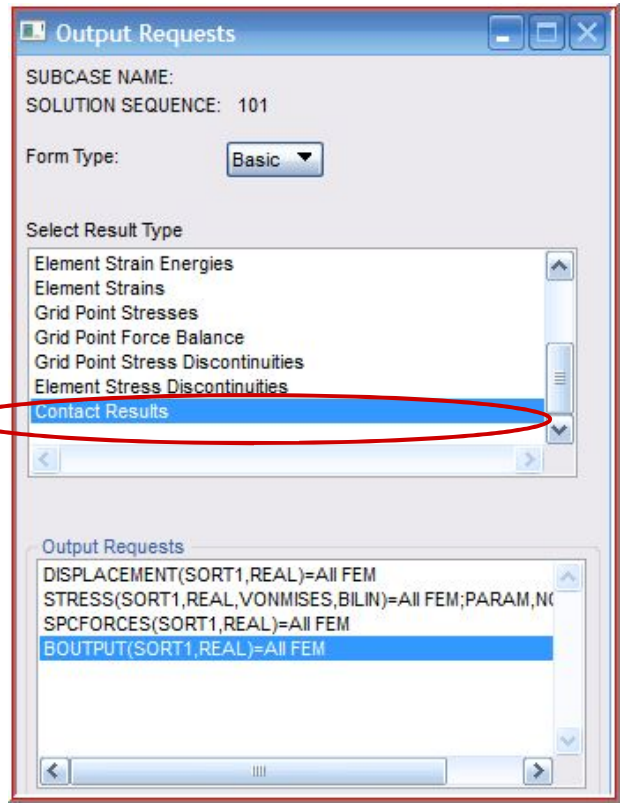
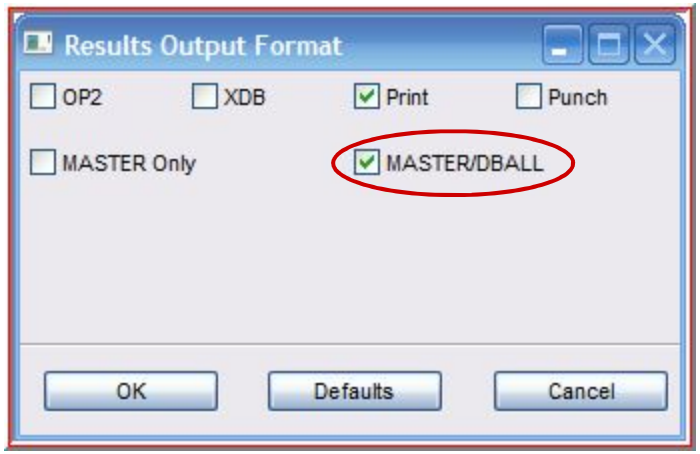
PLOT THE CONTACT STATUS

- **Plotting the Contact Status**
  - First request **Contact Results** as an output quantity
  - Next specify **MASTER/DBALL** as results output format (contact results are not available in the XDB format)





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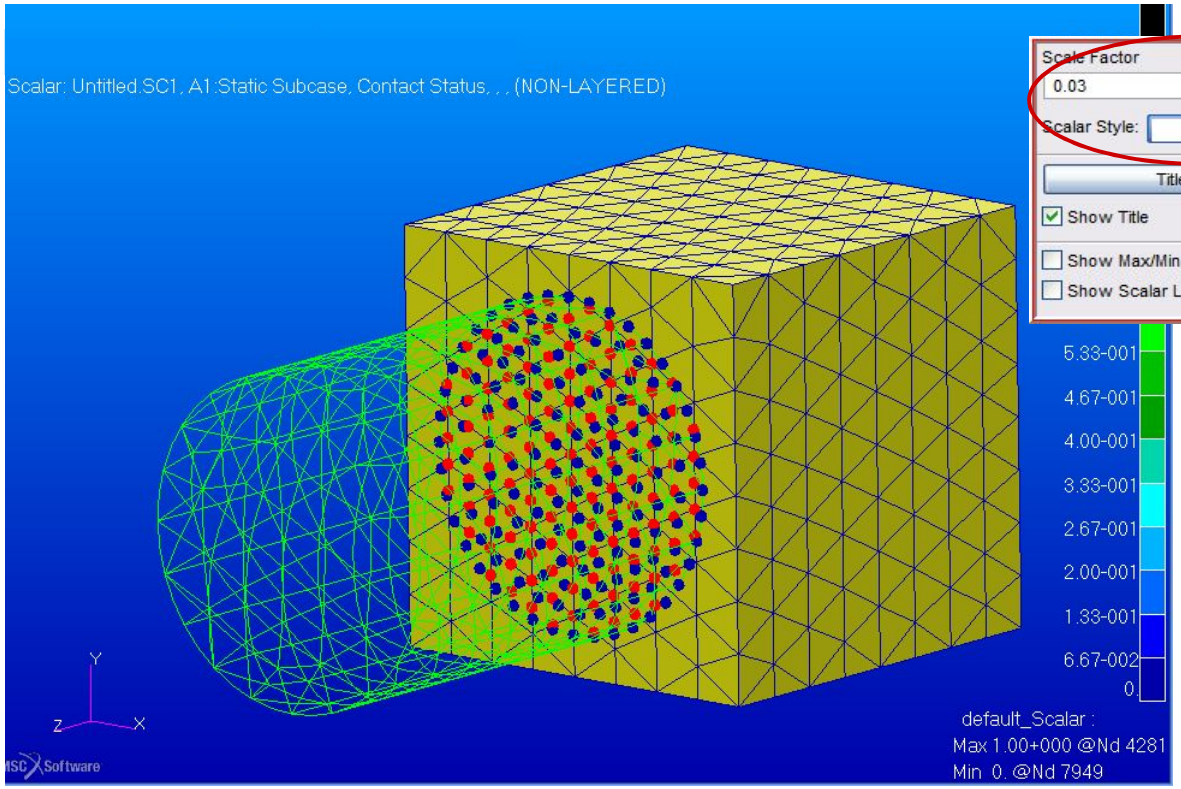
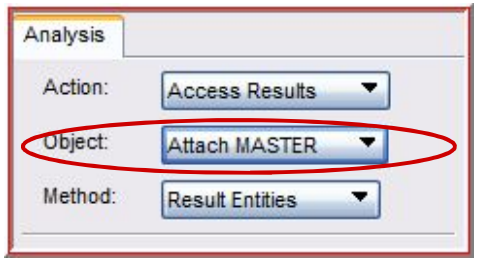
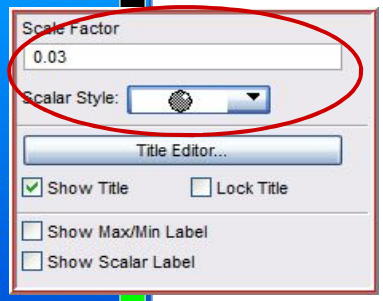
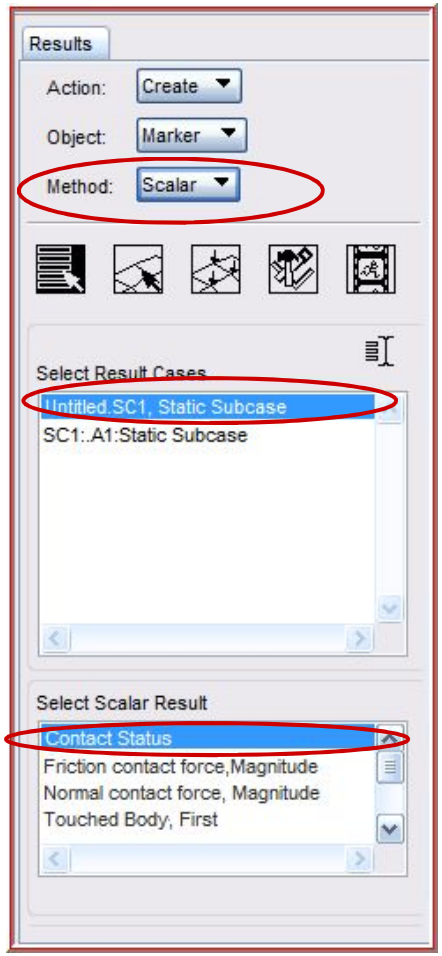
PLOT THE CONTACT STATUS

- **Plotting the Contact Status**
  - Attach the MASTER/DBALL
  - Make a scalar marker plot









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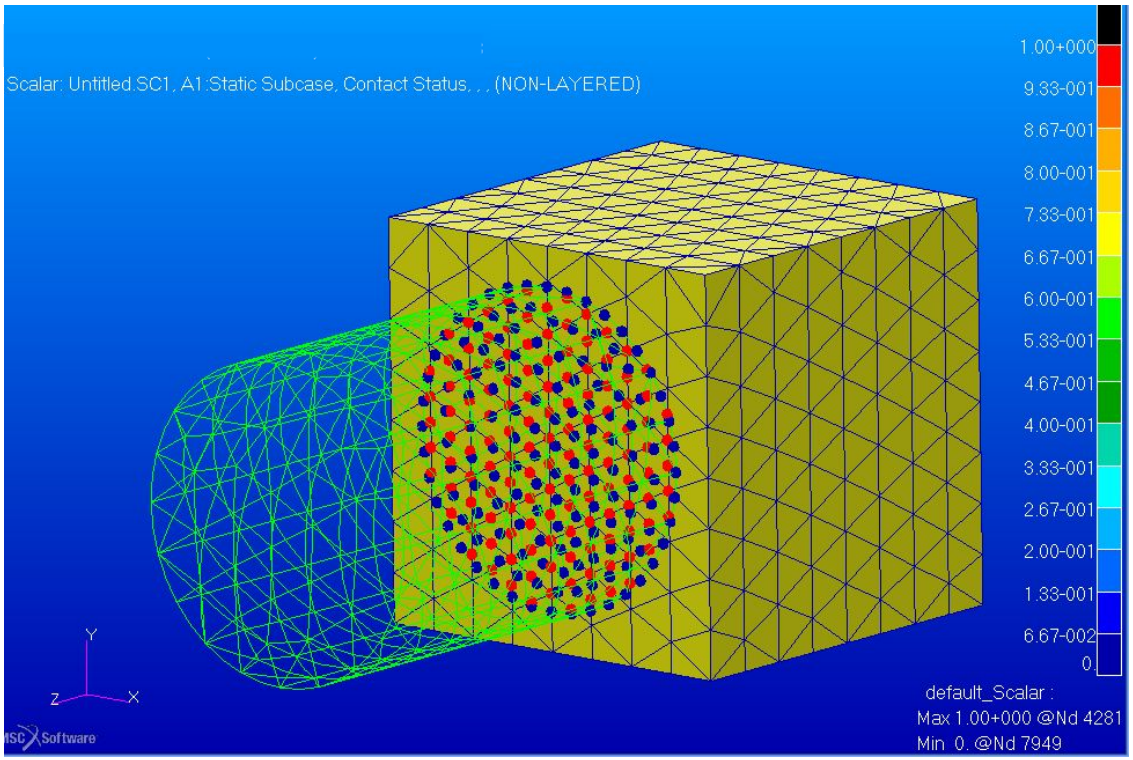
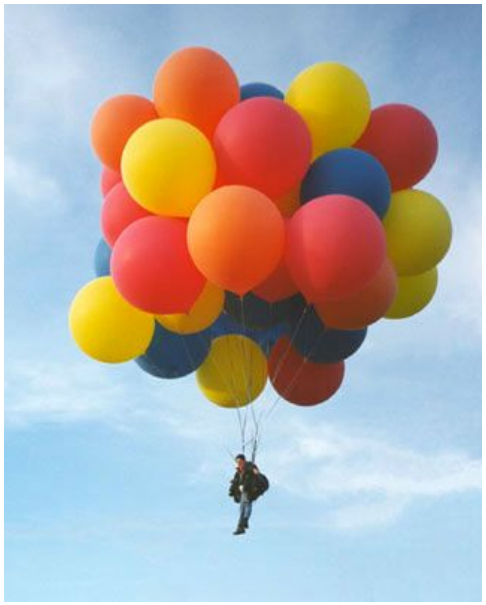
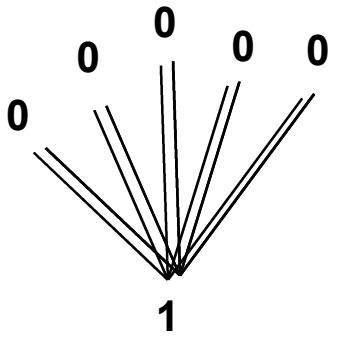
PLOT THE CONTACT STATUS

- **Contact status shows 0's and 1's**
  - 0 indicates a retained node (master)
  - 1 indicates a tied node (slave)







Memory aid

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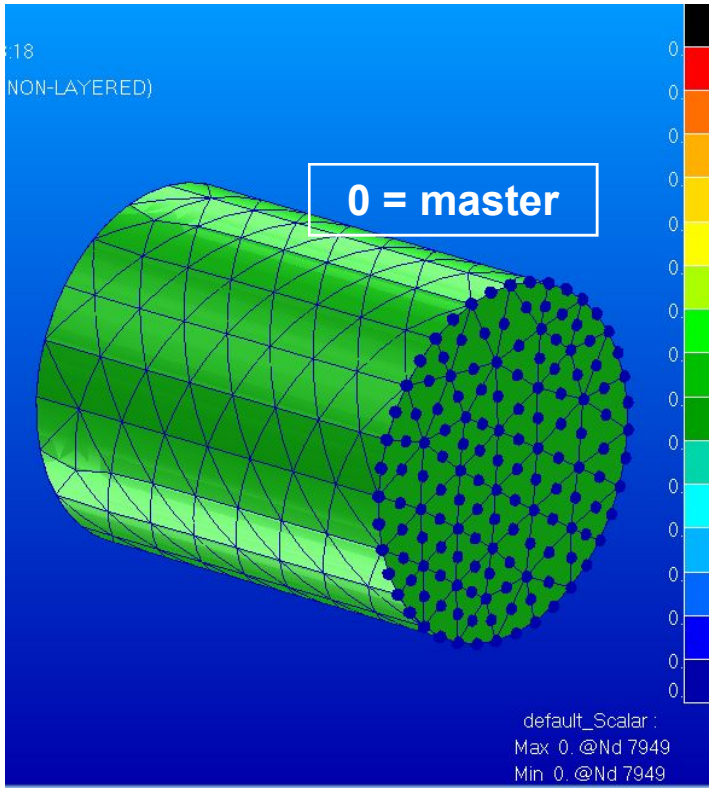
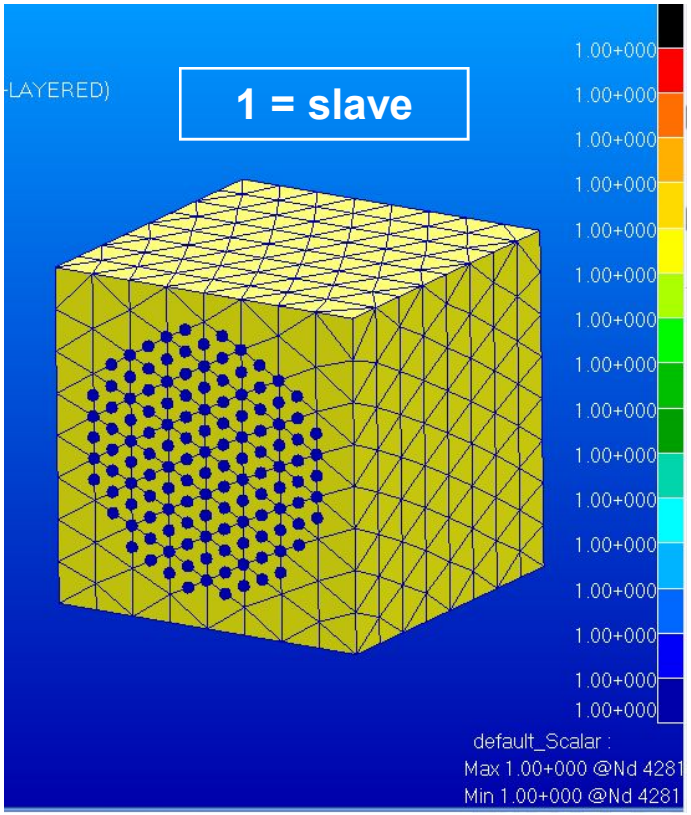
PLOT THE CONTACT STATUS

- **0 indicates a retained node (master)**
- **1 indicates a tied node (slave)**





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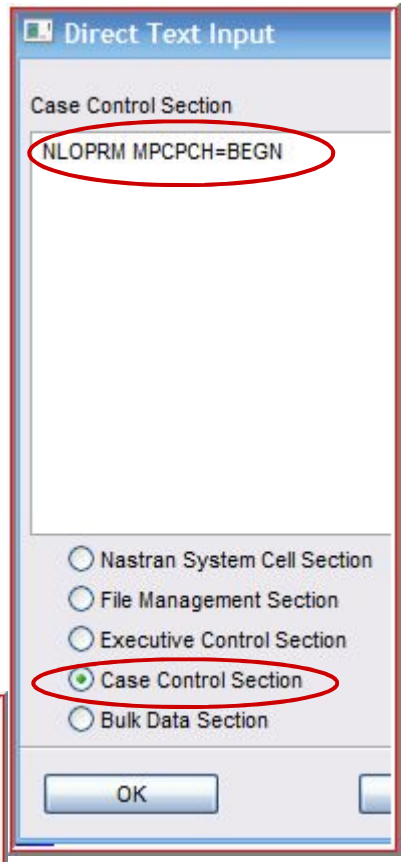
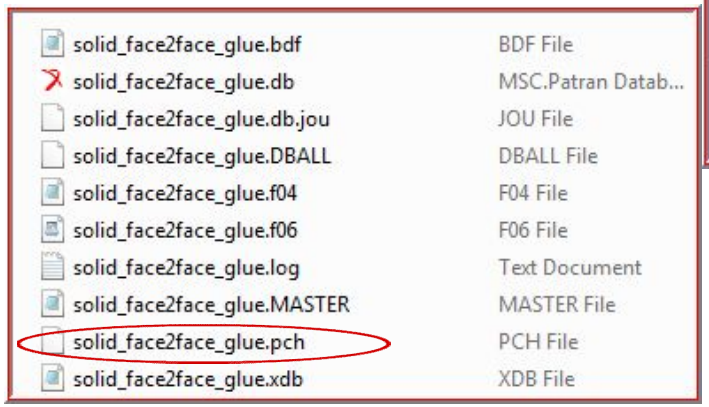
PLOT THE GLUE MPC EQUATIONS

- **MSC Nastran internally generates MPC equations to represent the permanent glued contact**
- **The user can request for these equations be output to a punch file**
  - Specify NLOPRM MPCPCH=BEGN in the Case Control section





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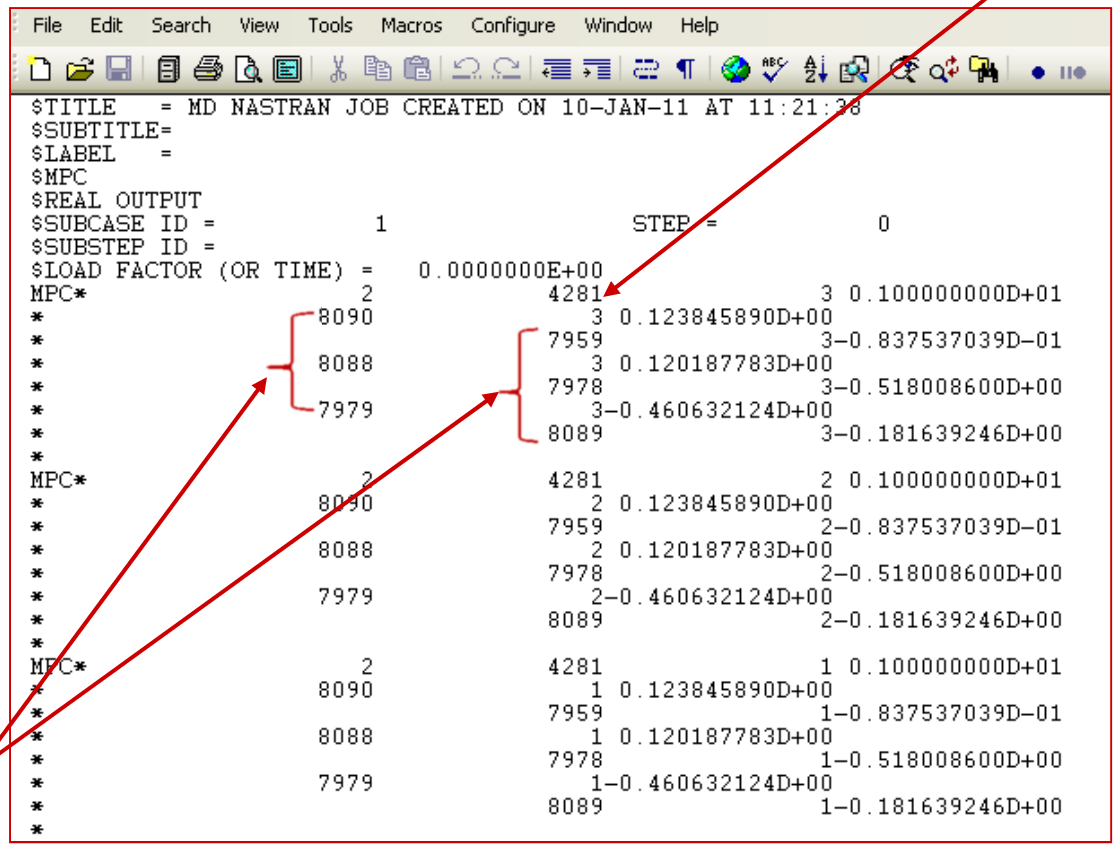
PLOT THE GLUE MPC EQUATIONS

- **Review the MPC equations**
  - Open the .pch file in any text editor

Slave node

Master nodes



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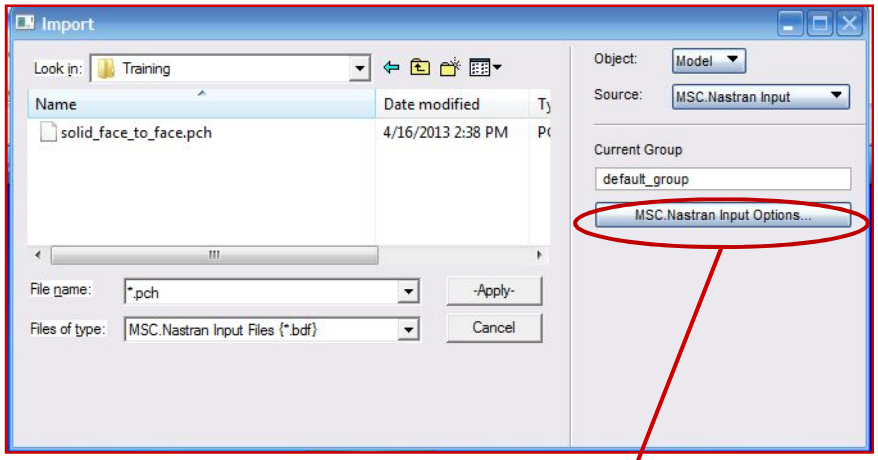
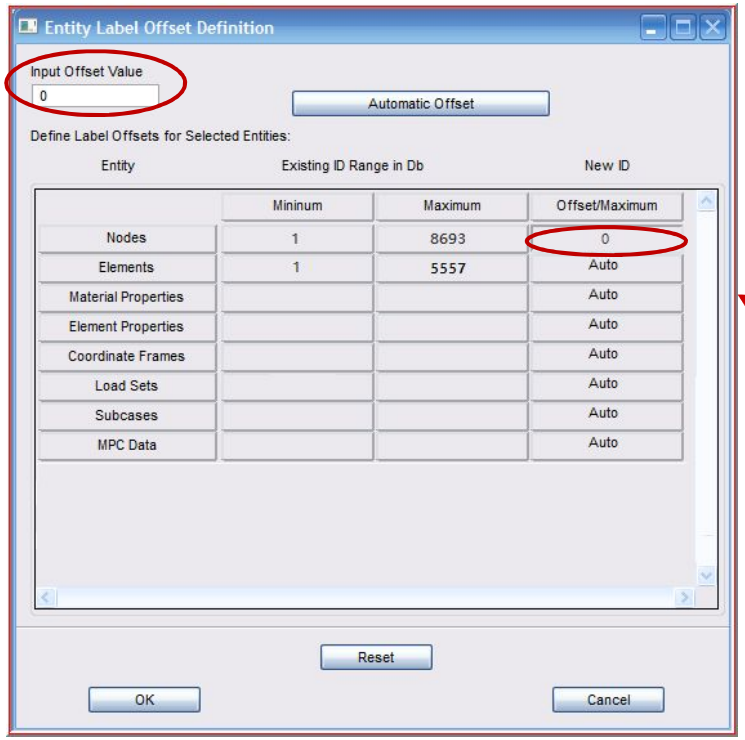
PLOT THE GLUE MPC EQUATIONS

- **Plot the MPC equations**
  - Import the .pch file into Patran
  - Need to set Nodes ID offset to 0 before importing





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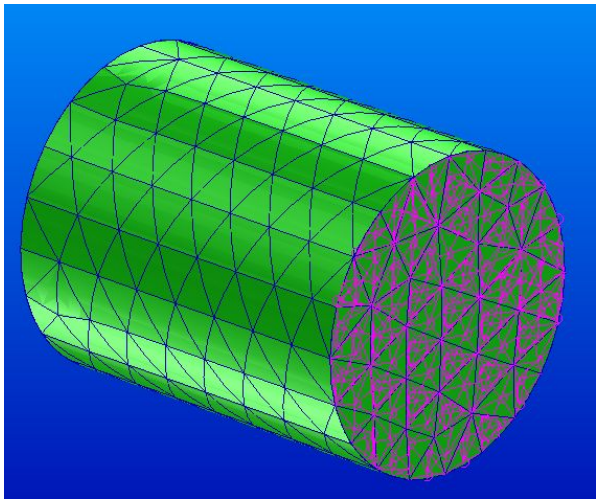
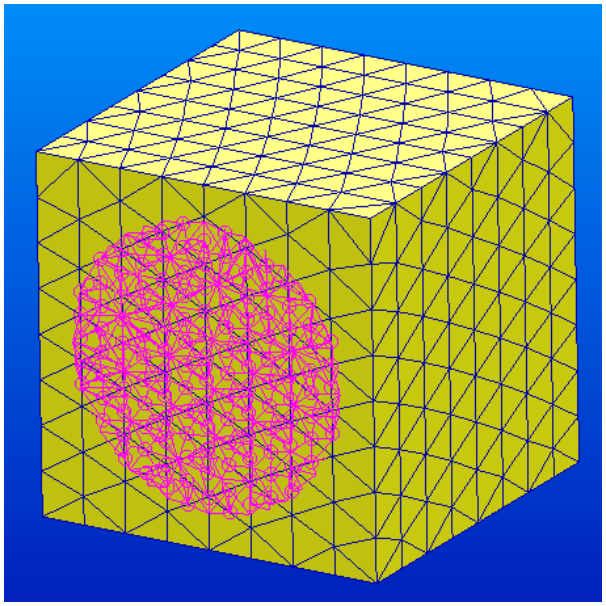
PLOT THE GLUE MPC EQUATIONS

- **Plot the MPC equations**
  - Visually inspect the glued joint. Does the MPC pattern make sense? Is it uniformly distributed or spotty? Would reversing the contact search order improve the glued joint?
  - After reviewing the MPCs, don't forget to remove them from the database by using UNDO or deleting them manually.





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NLOPRM

- **This Case Control command provides additional information on the contact procedure and can be used for debugging.**
- **It can additionally provide direct access to nonlinear solutions even when the job is still running.**
- **NLOPRM NLDBG: Provides information in F06 file**
  - = N3DBAS: For 3D contact, prints error tolerance of each contact body.
  - = N3DMED: For 3D contact, prints summary table of all contact parameters (in addition to N3DBAS)
  - = N3DADV: For 3D contact, prints body contact information in long form (in addition to N3DBAS and N3DMED)
  - This information is available for touching contact only.

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NLOPRM

- **NLOPRM DBGPOST: Selects POST options**
  - = LTIME: Output all iterations in last load or time increment
  - = LSTEP: Output all iterations in last STEP
  - = LSUBC: Output all iterations in last SUBCASE
  - = ALL: Output all iterations

- **NLOPRM MPCPCH: Create Punch file of contact constraint equations as MPC Constraints**
  - = BEGN: MPC Punch at beginning of very first iteration
  - = OTIME: MPC Punch at every user requested output step
  - = STEP: MPC Punch at end of each load case

- **Complete description of this command can be found in the Quick Reference Guide**

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GLUE CONTACT – STATUS

- Contact Status and other contact results for glued contact are NOT available for post-processing in Patran
- Determining the glued contact status is important. It is possible to glue only a few nodes on a large surface. This leads to incorrect deflections and stresses
- Glued contact can be evaluated by examining the deflected shapes and stresses of the model
- The MPCs used to model linear contact can be created during the MSC Nastran run in a punch (*.pch) file

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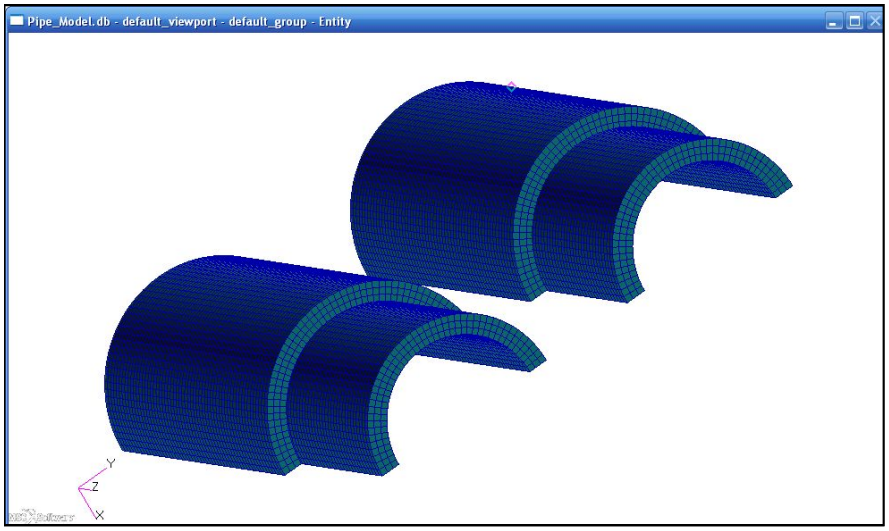
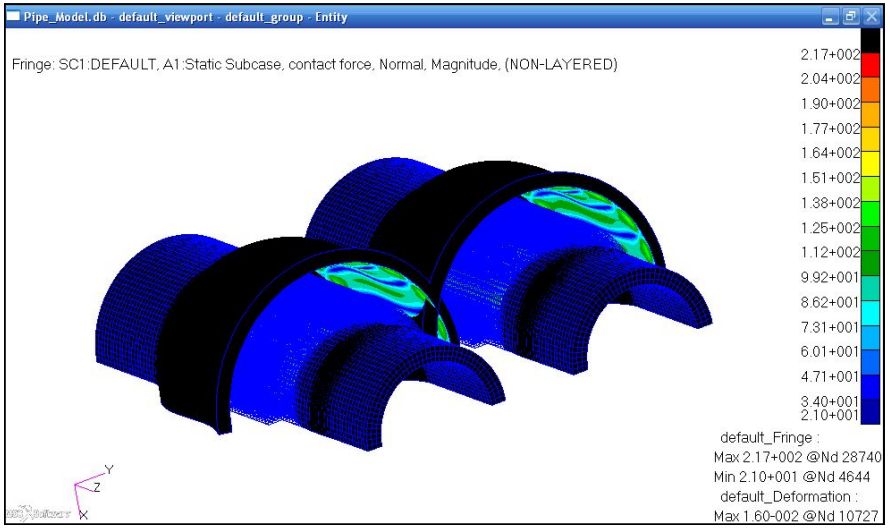
WORKSHOP 7 – INTERFERENCE FIT

- **Perform an interference fit using both a fitted closure and geometric overlap**





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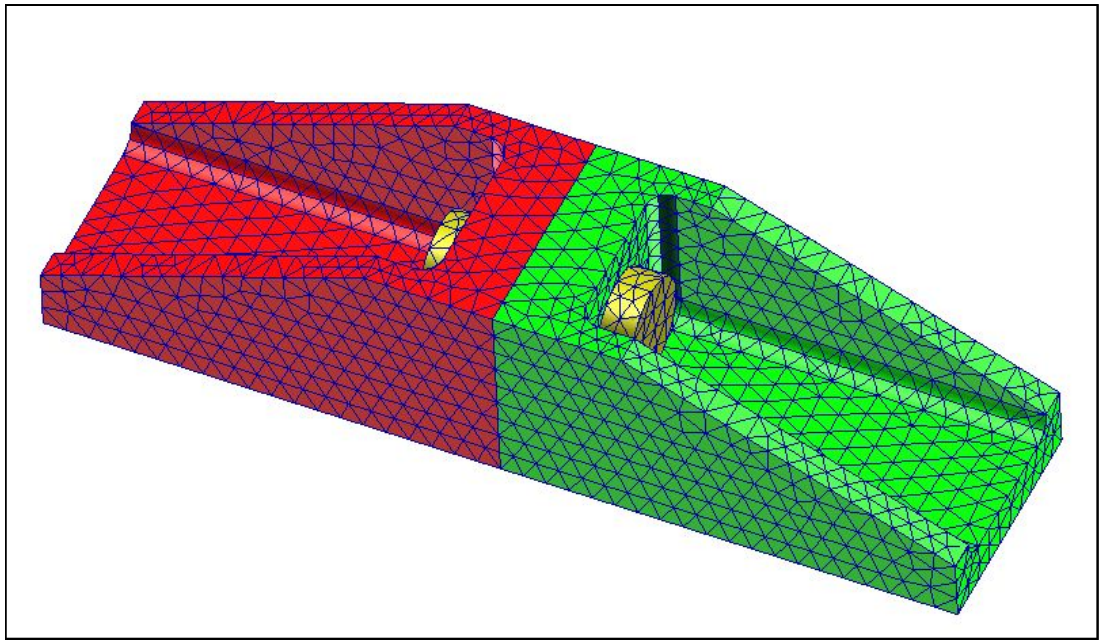
WORKSHOP 8 – BOLTED JOINT ANALYSIS

- **Compare SOL 101 and SOL 400 analyses for a bolted joint.**



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REVIEW QUESTION

- **How can you request additional output for model debugging?**

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APPENDIX A

TYPES OF OUTPUT SUPPORTED

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TYPES OF OUTPUT SUPPORTED

	Possible MSC Nastran Output Files			
	xdb	op2	enhanced op2*	master/ dball
MSC Nastran entry	param, post, 0	param, post, -1	param, post, 1	system(316) =19
Types of output				
displacement	yes	yes	yes	yes
constraint force	yes	yes	yes	yes
stress/strain	yes	yes	yes	yes
gpforce	yes	yes	no	no
contact	no	no	yes	yes
composite failure	no	no	yes	yes

- *** Attach to Patran as MASTER**

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APPENDIX B

SIMCOMPANION EXAMPLES OF GLUED/TOUCHING CONTACT

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LINK TO SIMCOMPANION EXAMPLES

- **Below is the link to MSC Nastran 2013 Demonstration Problems Manual found on SimCompanion. It contains several examples of contact problems:**

  http://simcompanion.mscsoftware.com/infocenter/index?page=content&id=DOC10447

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LIST OF PERTINENT CHAPTERS FROM MANUAL

- **Chapters that include examples of either glued or touching contact**
  - Chapter 04: 3-D Loaded Pin with Friction
  - Chapter 23: Bolted Plates
  - Chapter 25: Modal Analysis with Glued Contact
  - Chapter 26: Interference Fit Contact
  - Chapter 47: Dynamic Impact of a Rigid Sphere on a Woven Fabric
  - Chapter 49: Shell Edge Contact

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APPENDIX C

NODE TO SEGMENT CONTACT

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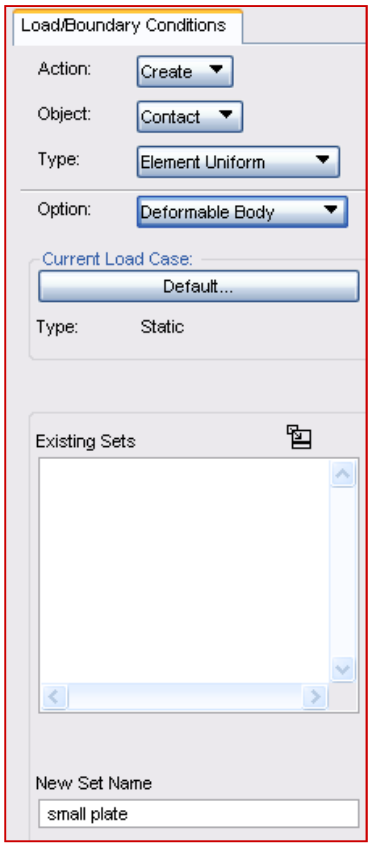
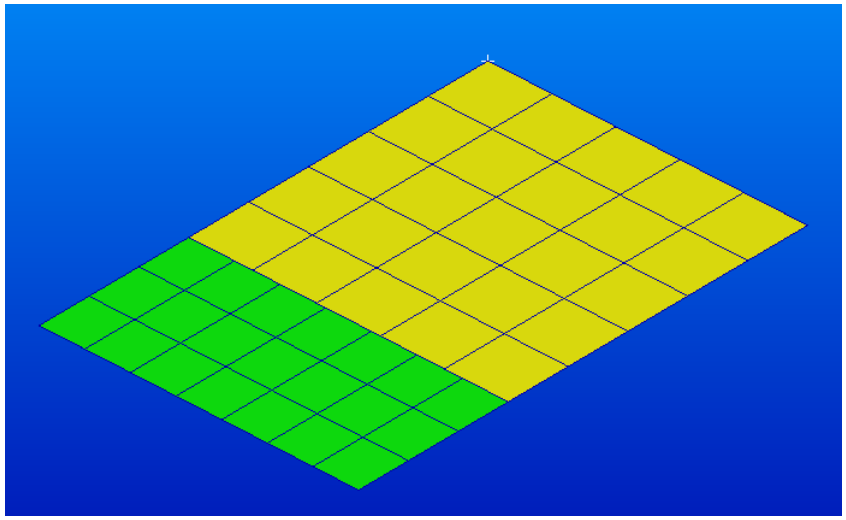
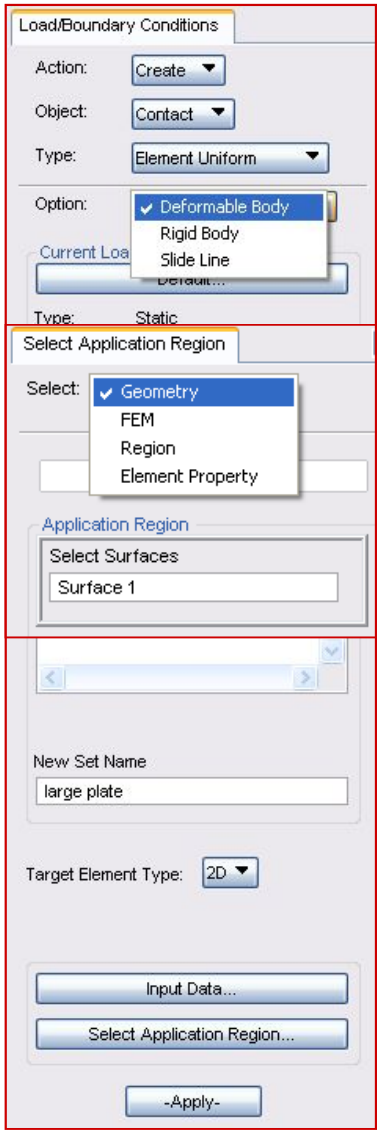
CASE STUDY 1: SHELL EDGE-TO-EDGE GLUED CONTACT

- **First define the contact bodies**







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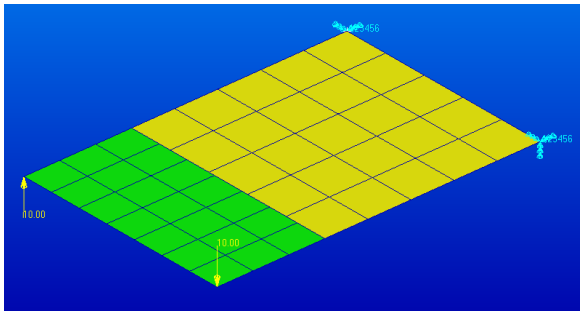
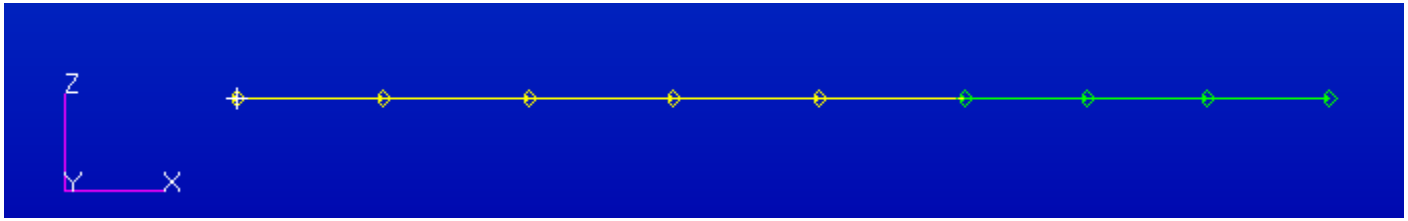
CASE STUDY 1: SHELL EDGE-TO-EDGE GLUED CONTACT

- **The contact bodies are located in the same plane with the same thickness**





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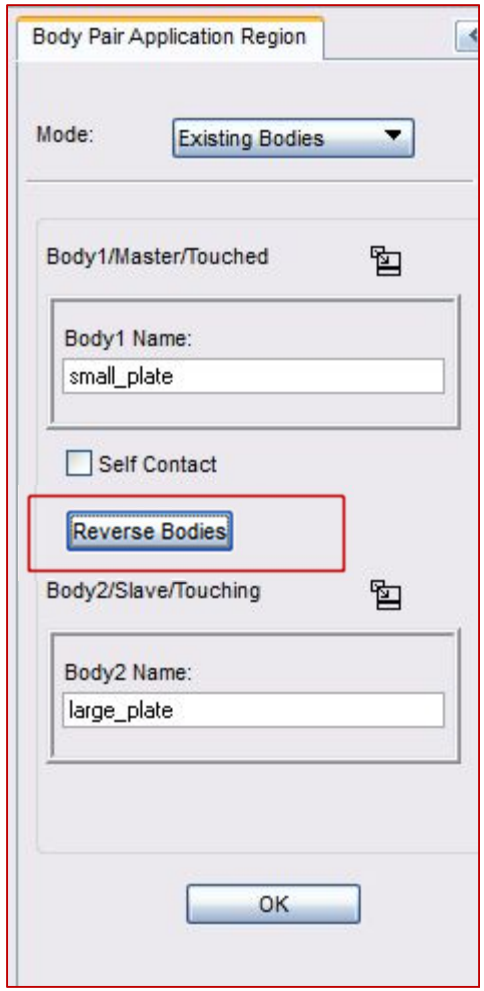
CASE STUDY 1: SHELL EDGE-TO-EDGE GLUED CONTACT

- **Next define the Contact Pair**
  - Set Small_Plate as Master
  - Large_Plate as Slave.
    - Use the Reverse Bodies to switch the order.



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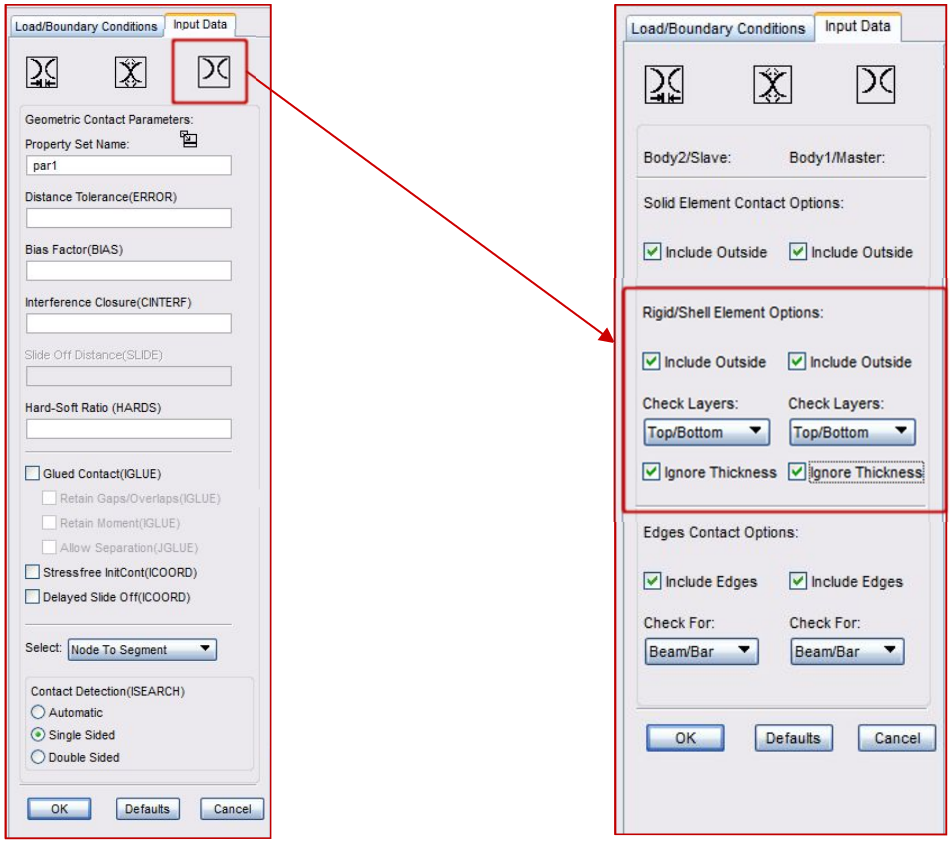
CASE STUDY 1: SHELL EDGE-TO-EDGE GLUED CONTACT

- **Next define the contact table**
  - Important step: Set contact option to ignore shell thickness for both bodies. This tells MSC Nastran to ignore the top and bottom faces of the shell elements and simply glue the mid-planes of the shell bodies together.



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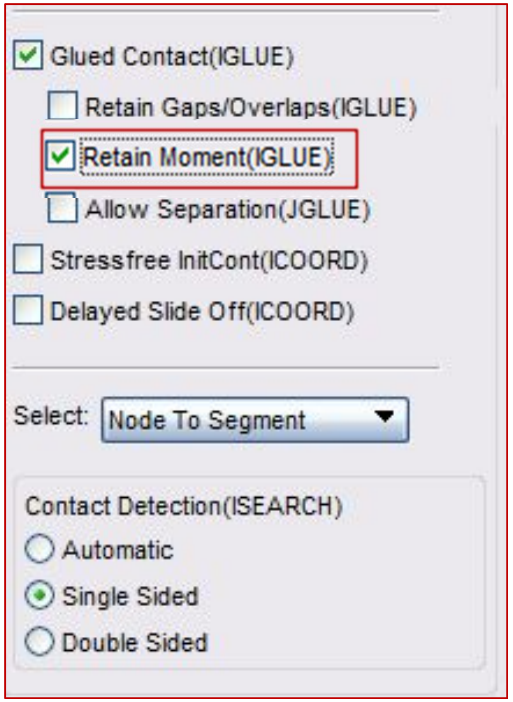
CASE STUDY 1: SHELL EDGE-TO-EDGE GLUED CONTACT

- **Next define the contact table**
  - Important step: Turn on moment carrying capability to enable the glued joint to transfer moments



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CASE STUDY 1: SHELL EDGE-TO-EDGE GLUED CONTACT

- **What the MSC Nastran entry looks like**

BCONPRP **Physical Contact Parameters of Touching Bodies in SOLs 101 and 400**

Defines physical contact parameters of touching bodies used in SOLs 101 and 400 only.

Format:

1	2	3	4	5	6	7	8	9	10
BCONPRP	PID		PARAM1	VAL1	PARAM 2	VAL2	PARAM3	VAL3	
	PARAM4	VAL4	PARAM5	VAL5	-etc.-				

Example:

BCONPRP	90		FRIC	0.3					

```
BCONECT  8003    3001            2       1
BCONPRG  3001            COPTM   1061    COPTS   1061    IGLUE   3
         ISEARCH 1
BCTABL1  1       8003
```


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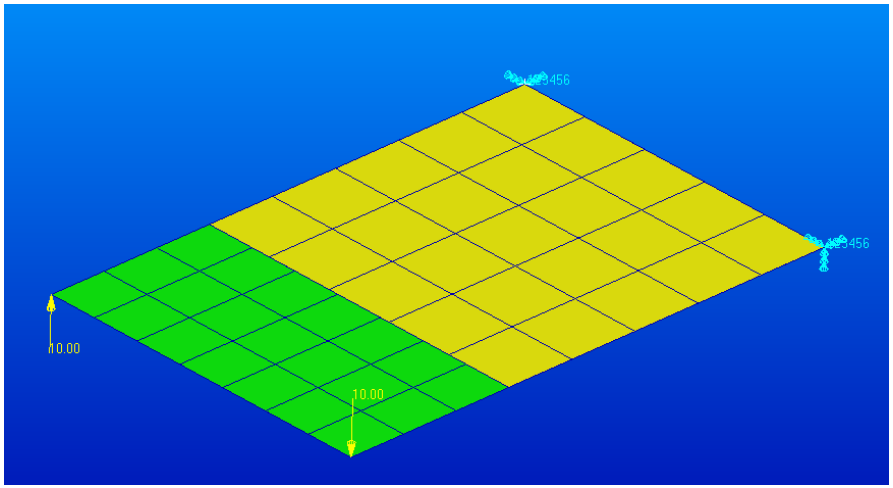
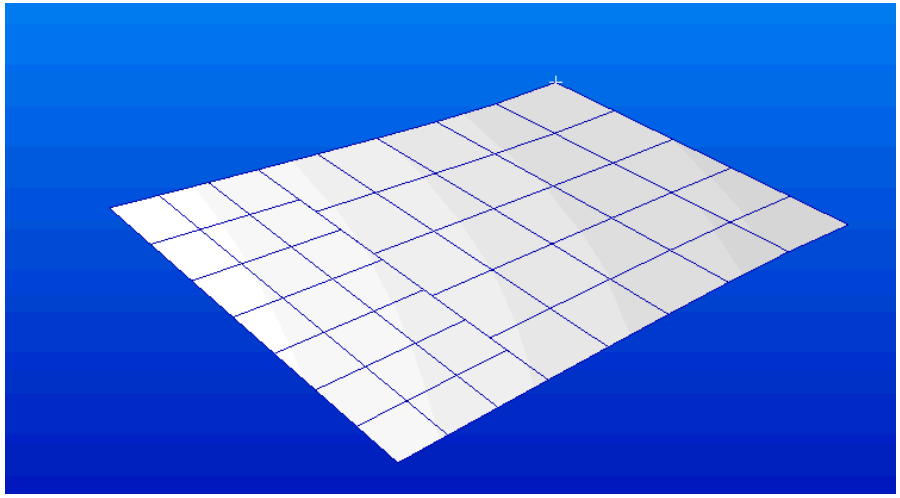
CASE STUDY 1: SHELL EDGE-TO-EDGE GLUED CONTACT

- **Plot the deformed shape**
  - The two plates appear to deform as one assembly





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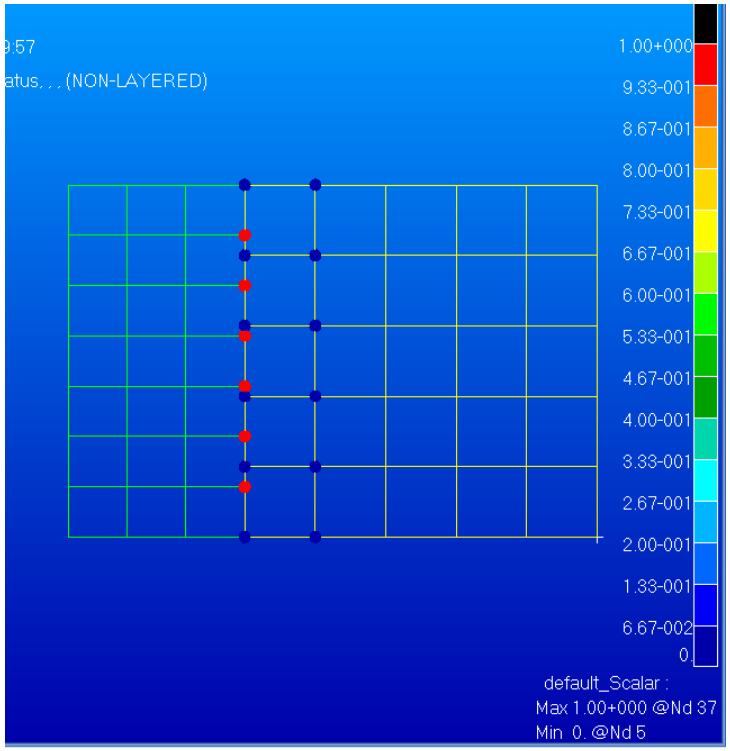
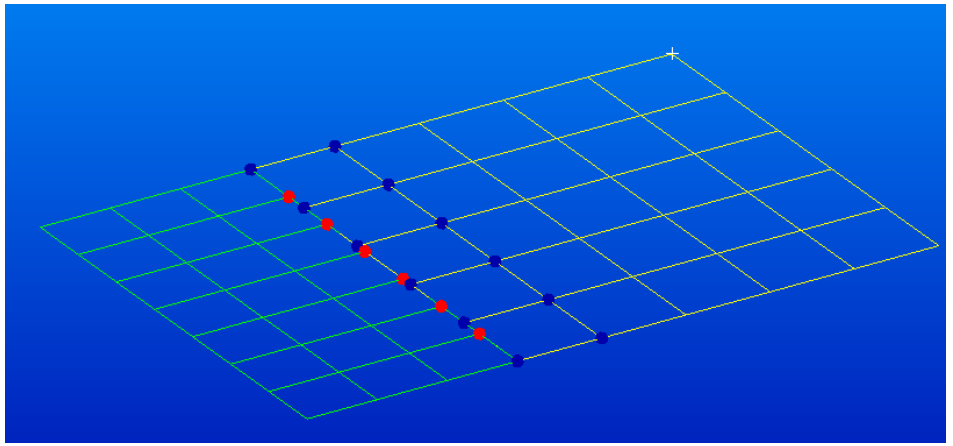
CASE STUDY 1: PLOT THE CONTACT STATUS

- **Plotting the Contact Status**
  - 0 indicates a retained node (master)
  - 1 indicates a tied node (slave)





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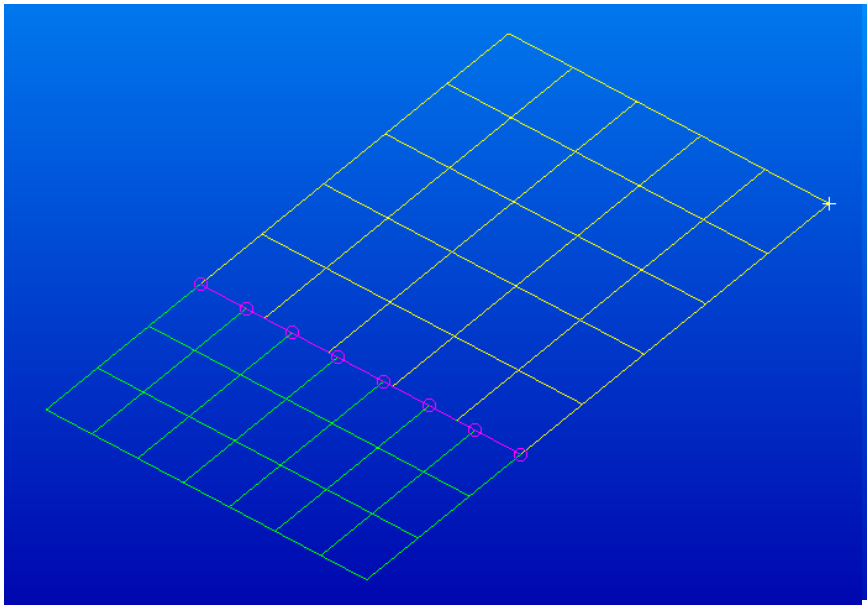
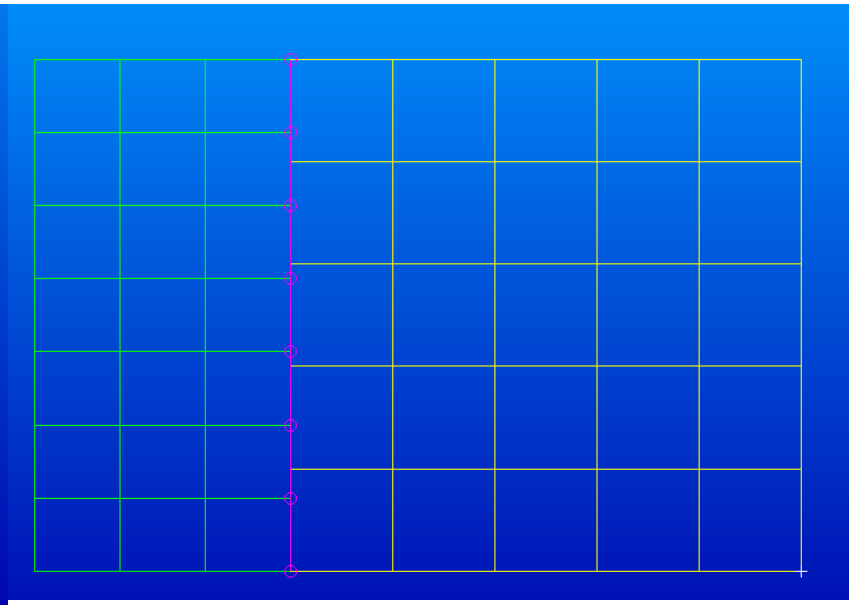
CASE STUDY 1: PLOT THE GLUE MPC EQUATIONS

- **Plot the MPC equations**





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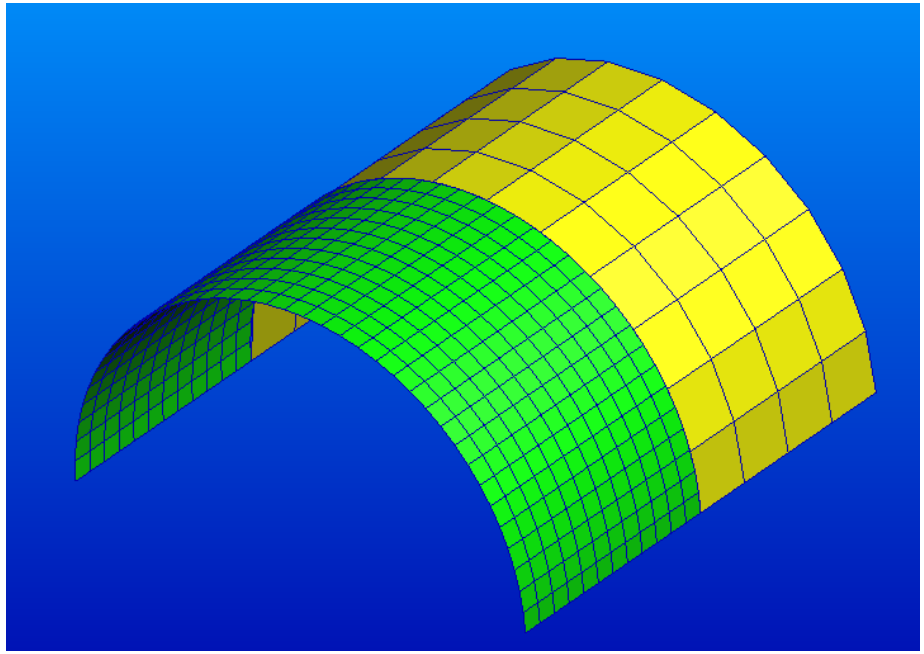
CASE STUDY 2: CURVED SHELL EDGE-TO-EDGE CONTACT

- **Just like curved face-to-face glued contact presented earlier, curved shell edge-to-edge contact also typically involves gaps and overlaps between contact bodies**



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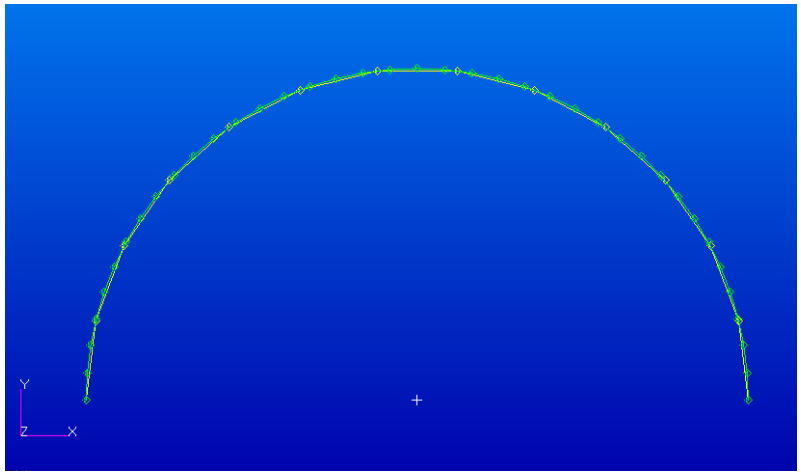
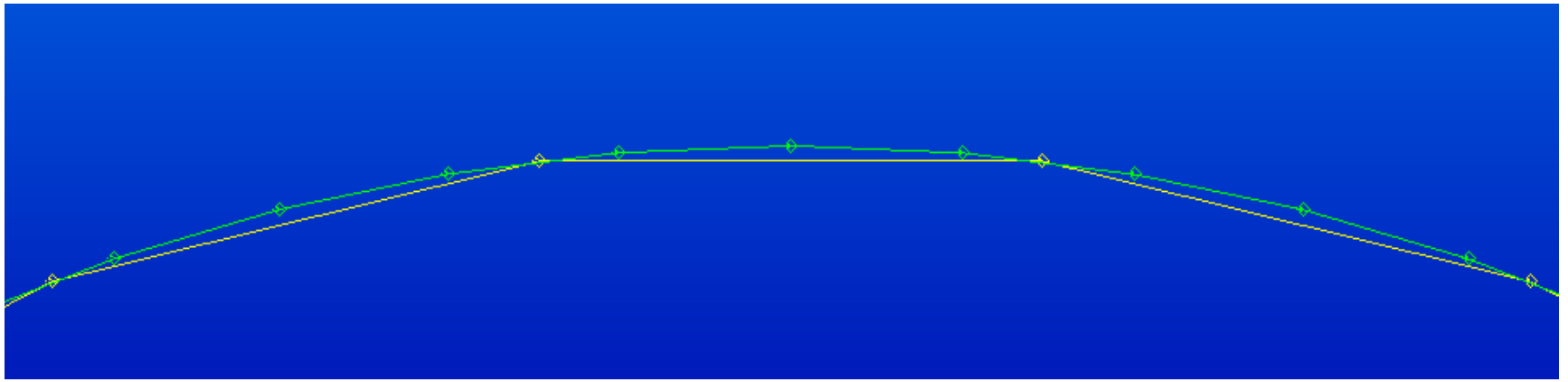
CASE STUDY 2: CURVED SHELL EDGE-TO-EDGE CONTACT

- **Gaps and overlaps**





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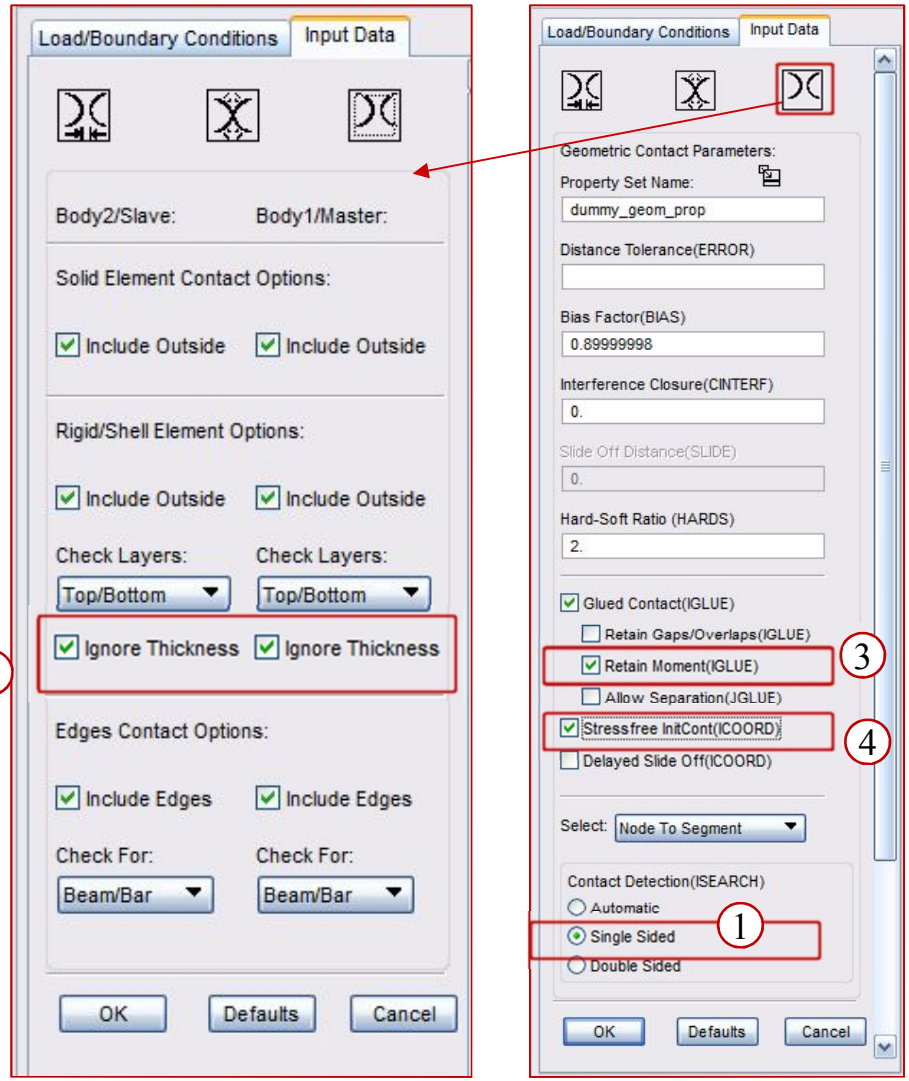
CASE STUDY 2: CURVED SHELL EDGE-TO-EDGE CONTACT

1. Search from fine mesh to coarse mesh
2. Ignore shell thickness
3. Activate moment carrying capability
4. Activate stress-free initial contact (recall that this will moved the slave nodes to the master surfaces to close the gaps and overlaps)



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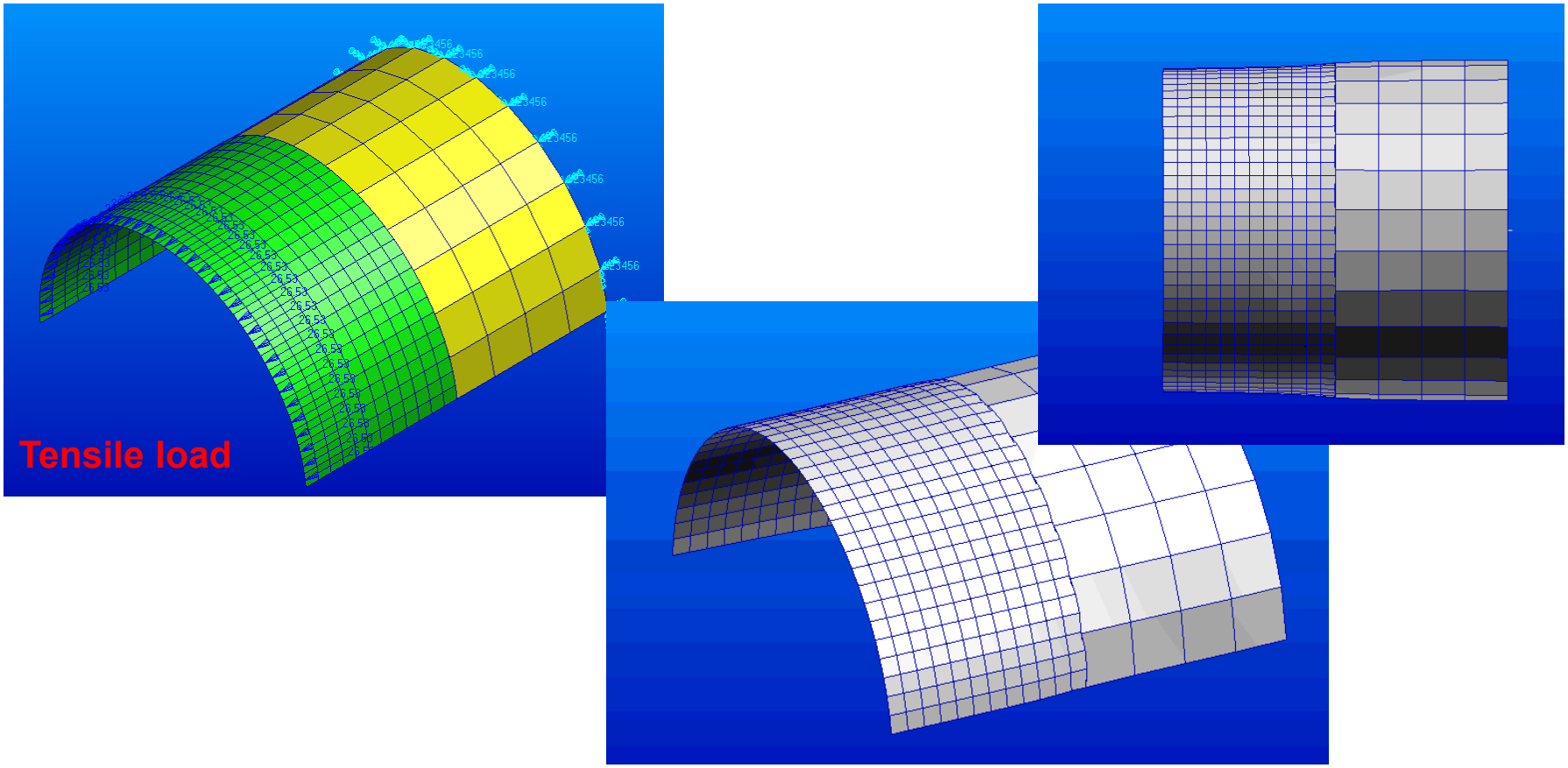
CASE STUDY 2: CURVED SHELL EDGE-TO-EDGE CONTACT

- **Plot the deformed shape**
  - The mesh interface appears to be partially glued



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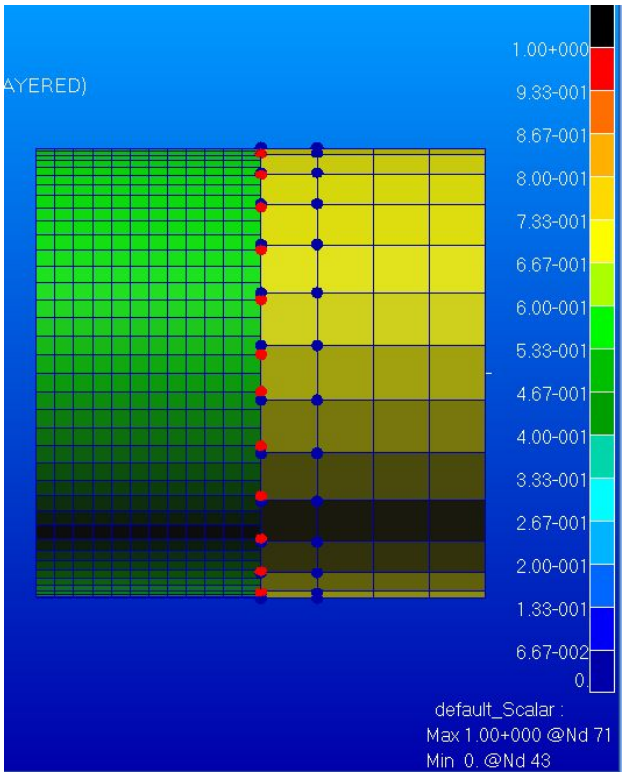
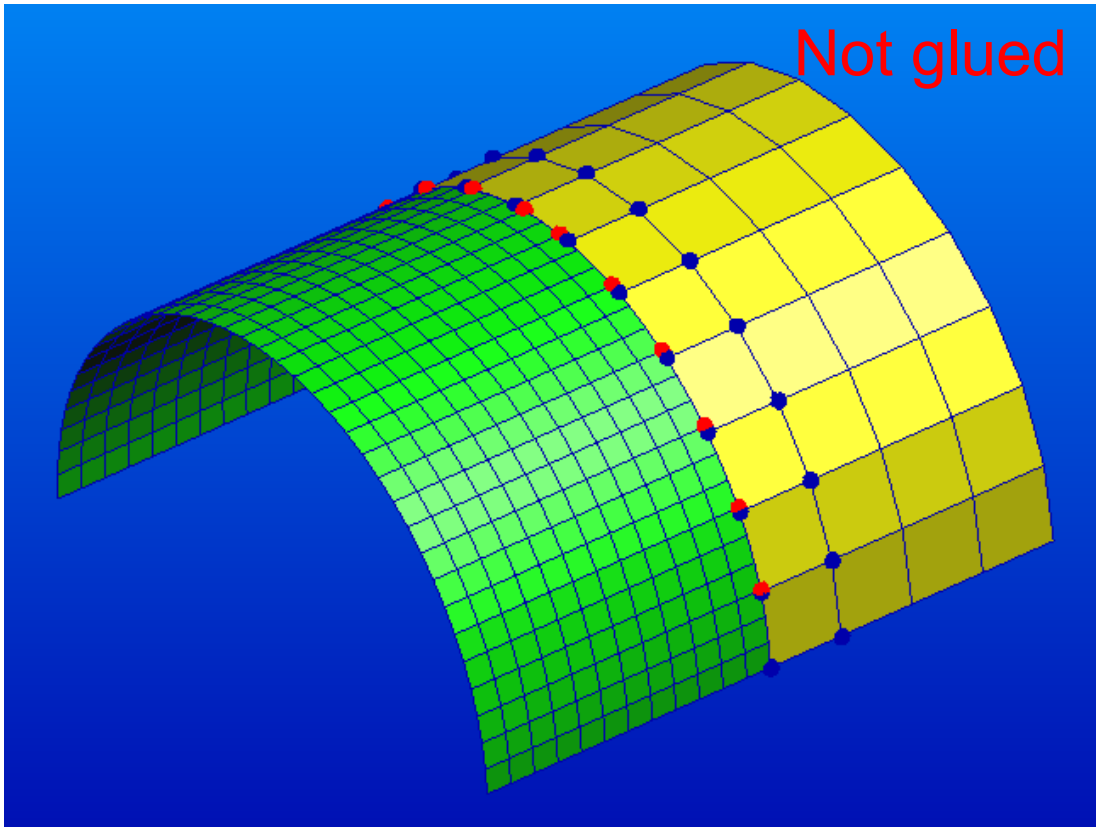
CASE STUDY 2: CURVED SHELL EDGE-TO-EDGE CONTACT

- **Plot the contact status**
  - The glued contact status appears “spotty”. A number of fine mesh nodes did not get glued.





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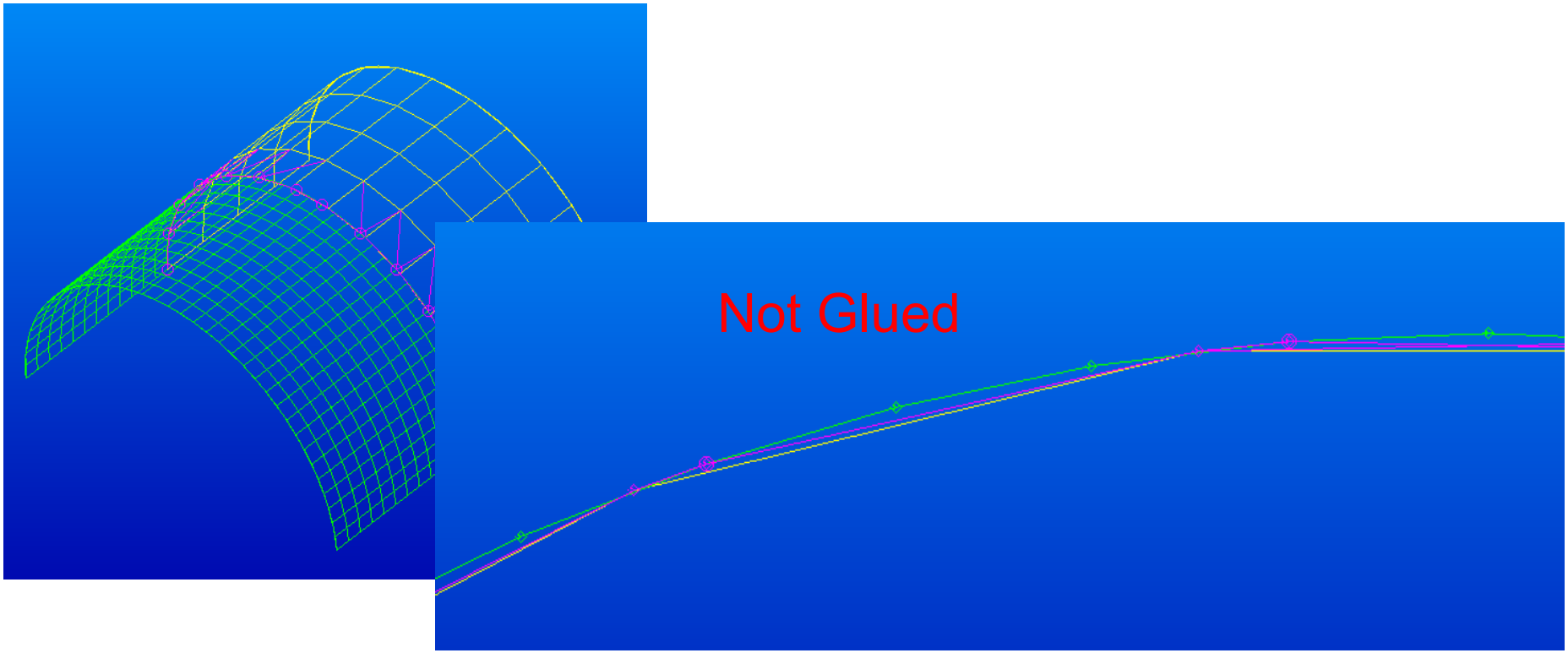
CASE STUDY 2: CURVED SHELL EDGE-TO-EDGE CONTACT

- **Plot the MPC equations**
  - A number of fine mesh nodes were not found during contact search
  - The default contact tolerance is probably too small



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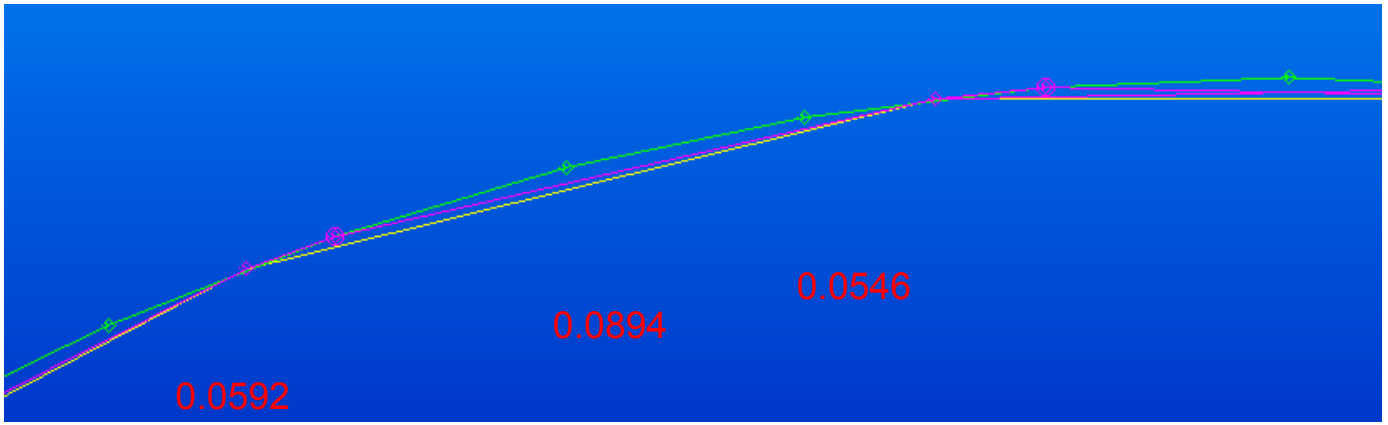
CASE STUDY 2: CURVED SHELL EDGE-TO-EDGE CONTACT

- **Adjust the contact tolerance**
  - The default contact tolerance is 0.0495 which is too small
  - Change the contact tolerance to 0.090



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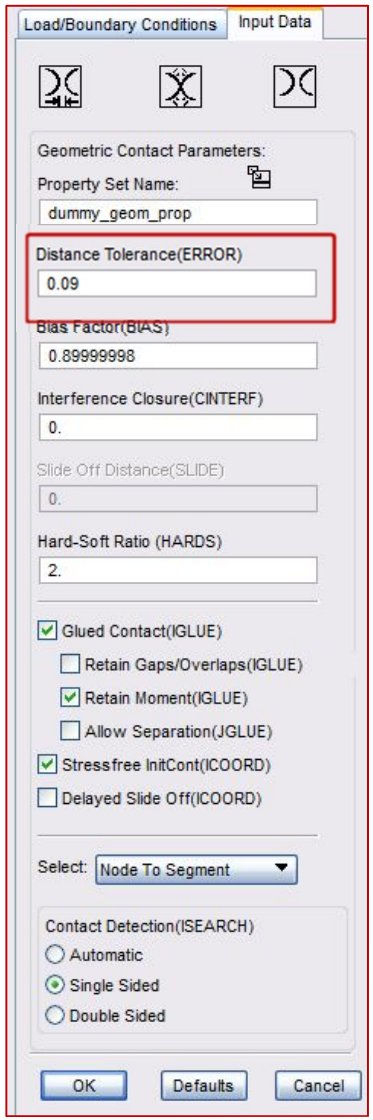
CASE STUDY 2: CURVED SHELL EDGE-TO-EDGE CONTACT

- **Adjust the contact tolerance**
  - Change the contact tolerance to 0.090 so it is larger than the largest gap



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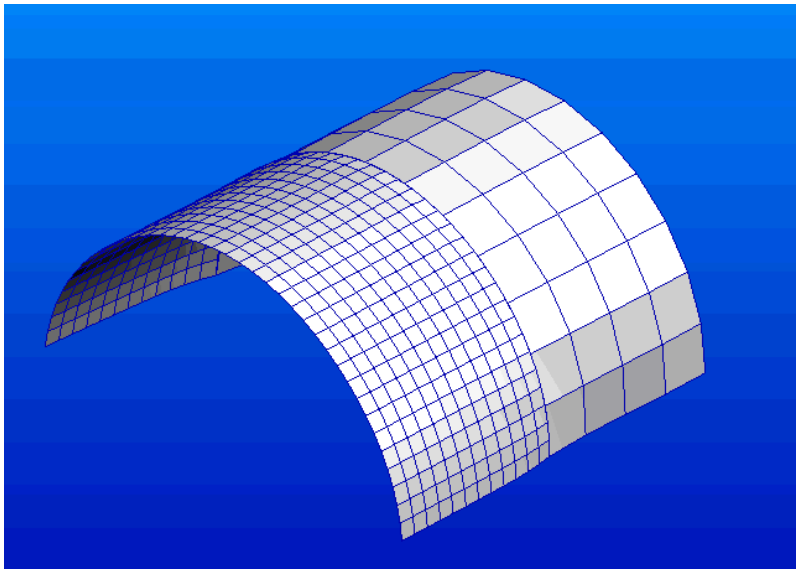
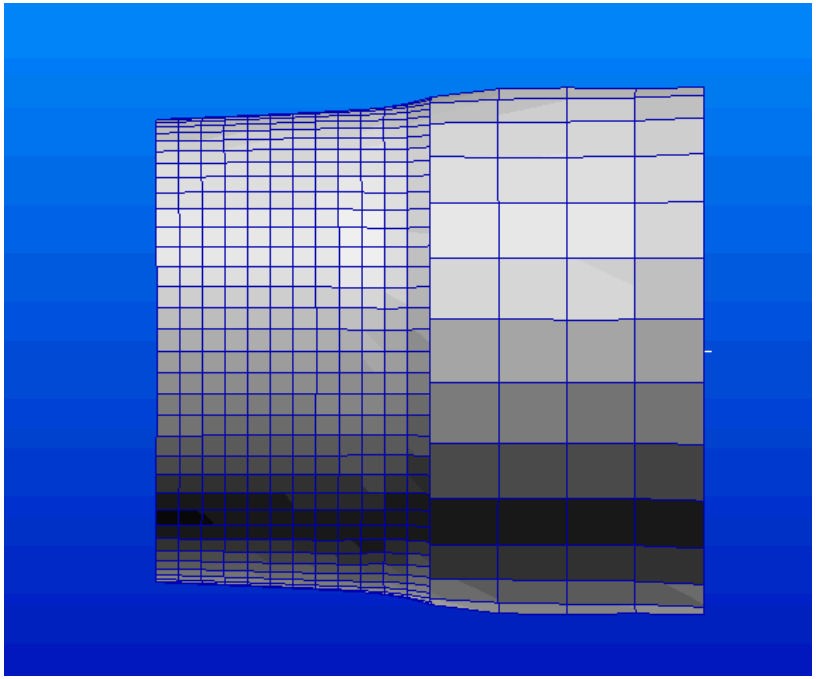
CASE STUDY 2: CURVED SHELL EDGE-TO-EDGE CONTACT

- **Plot the deformed shape**
  - The glued joint looks much better





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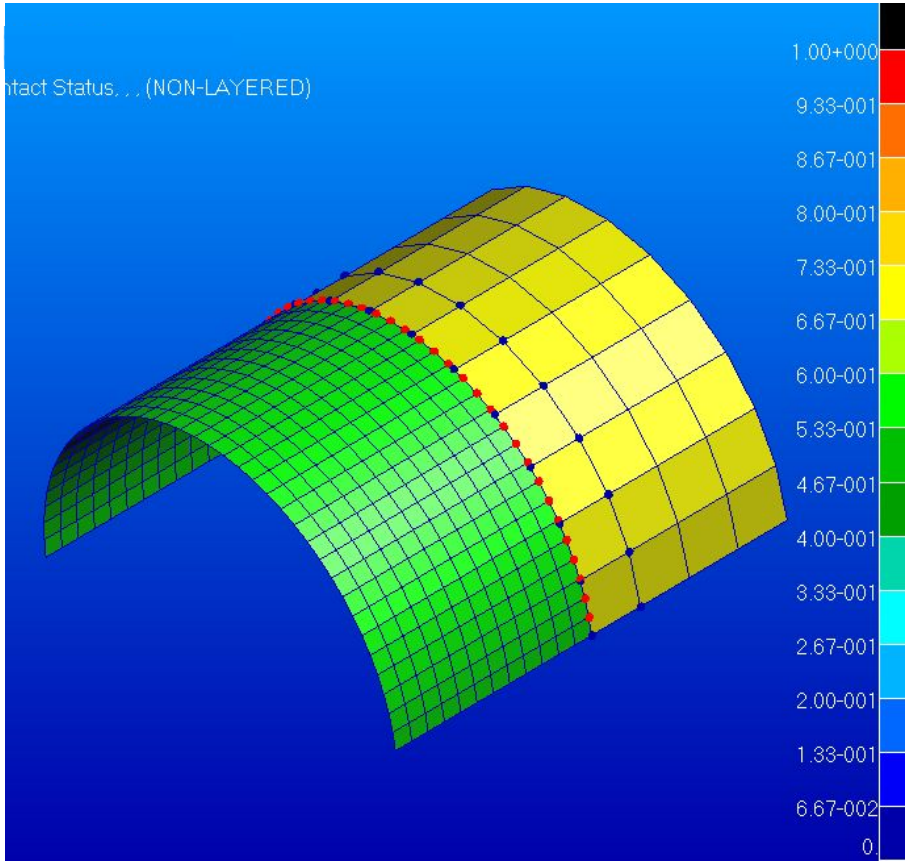
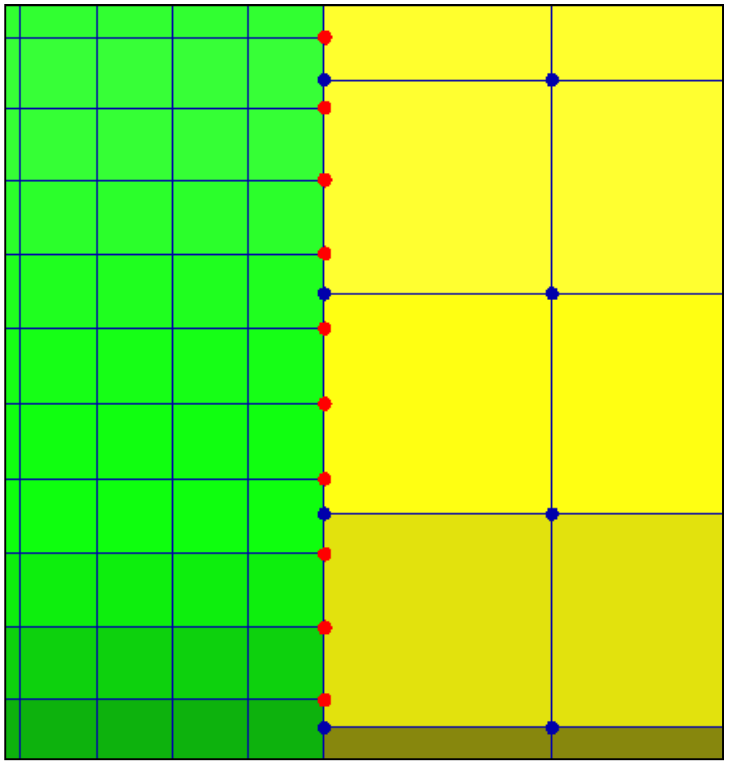
CASE STUDY 2: CURVED SHELL EDGE-TO-EDGE CONTACT

- **Plot the contact status**





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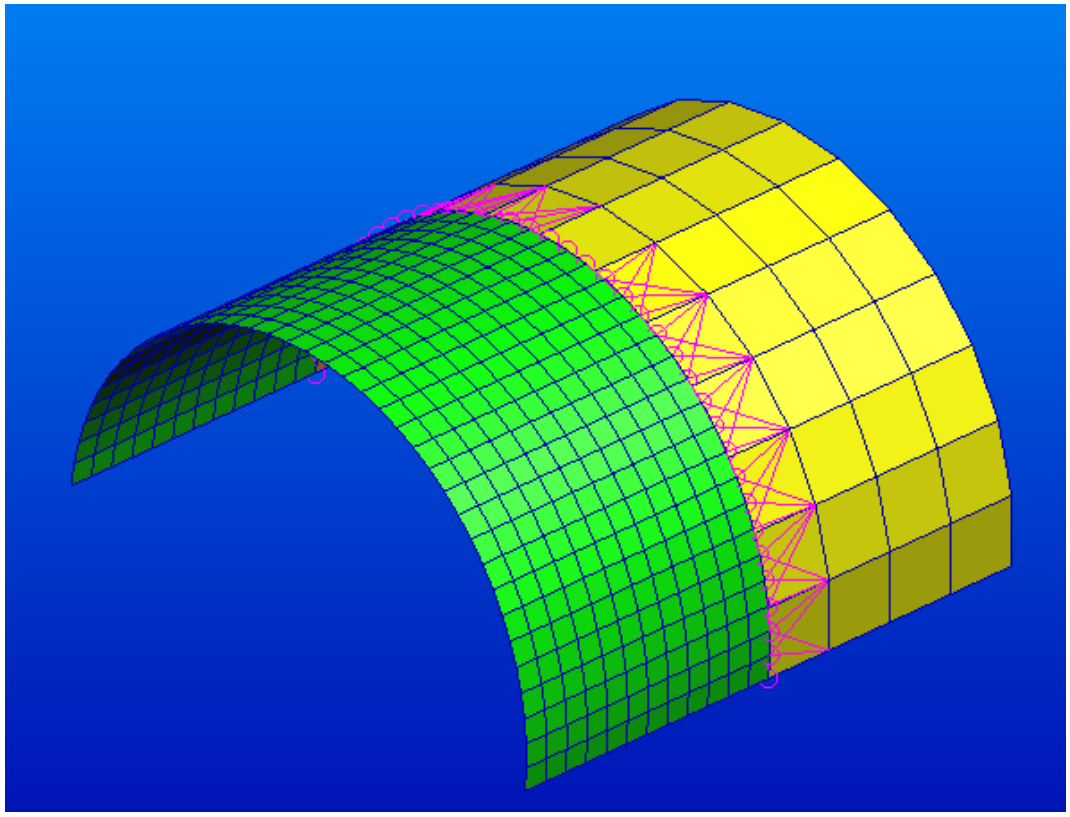
CASE STUDY 2: CURVED SHELL EDGE-TO-EDGE CONTACT

- **Plot the MPC equations**



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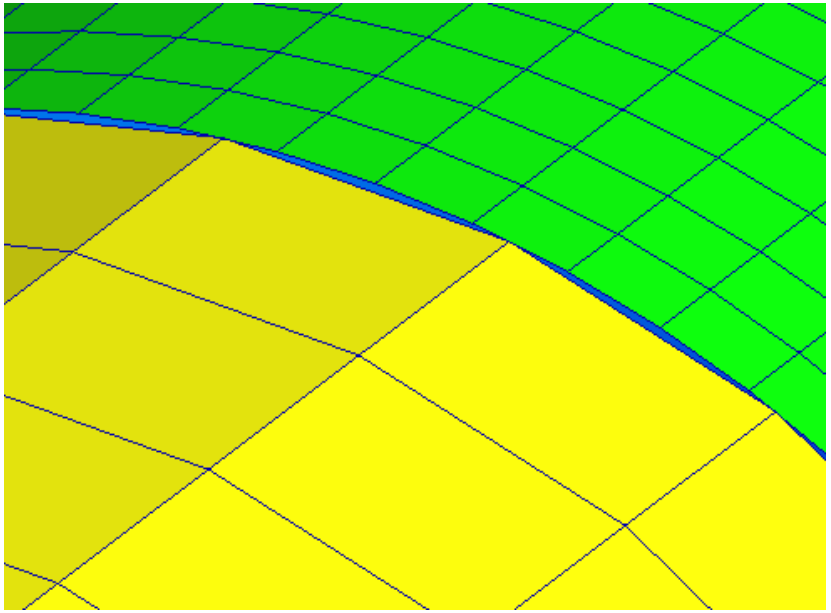
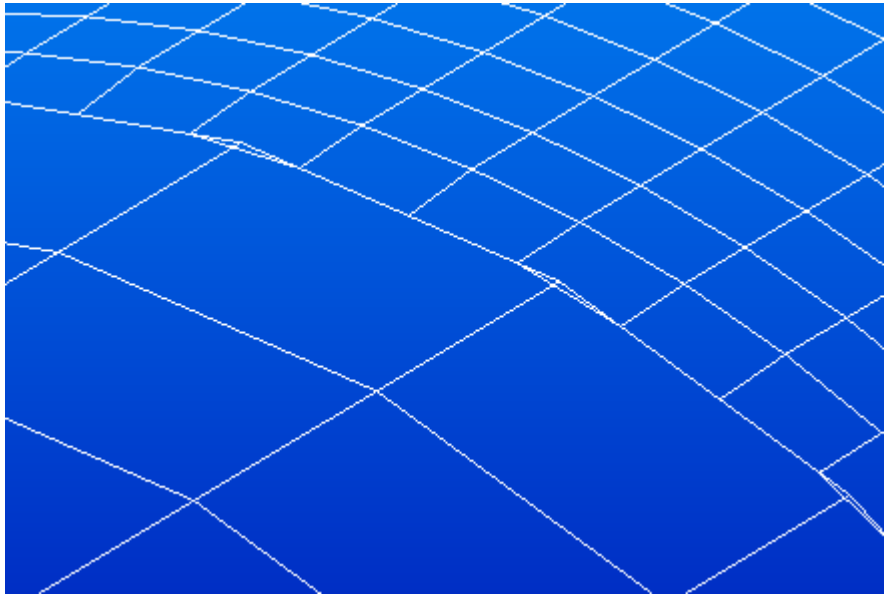
CASE STUDY 2: CURVED SHELL EDGE-TO-EDGE CONTACT

- **What the model looks like after stress-free initial coordinates adjustments (ICOORD=1)**



Original model



After adjustments

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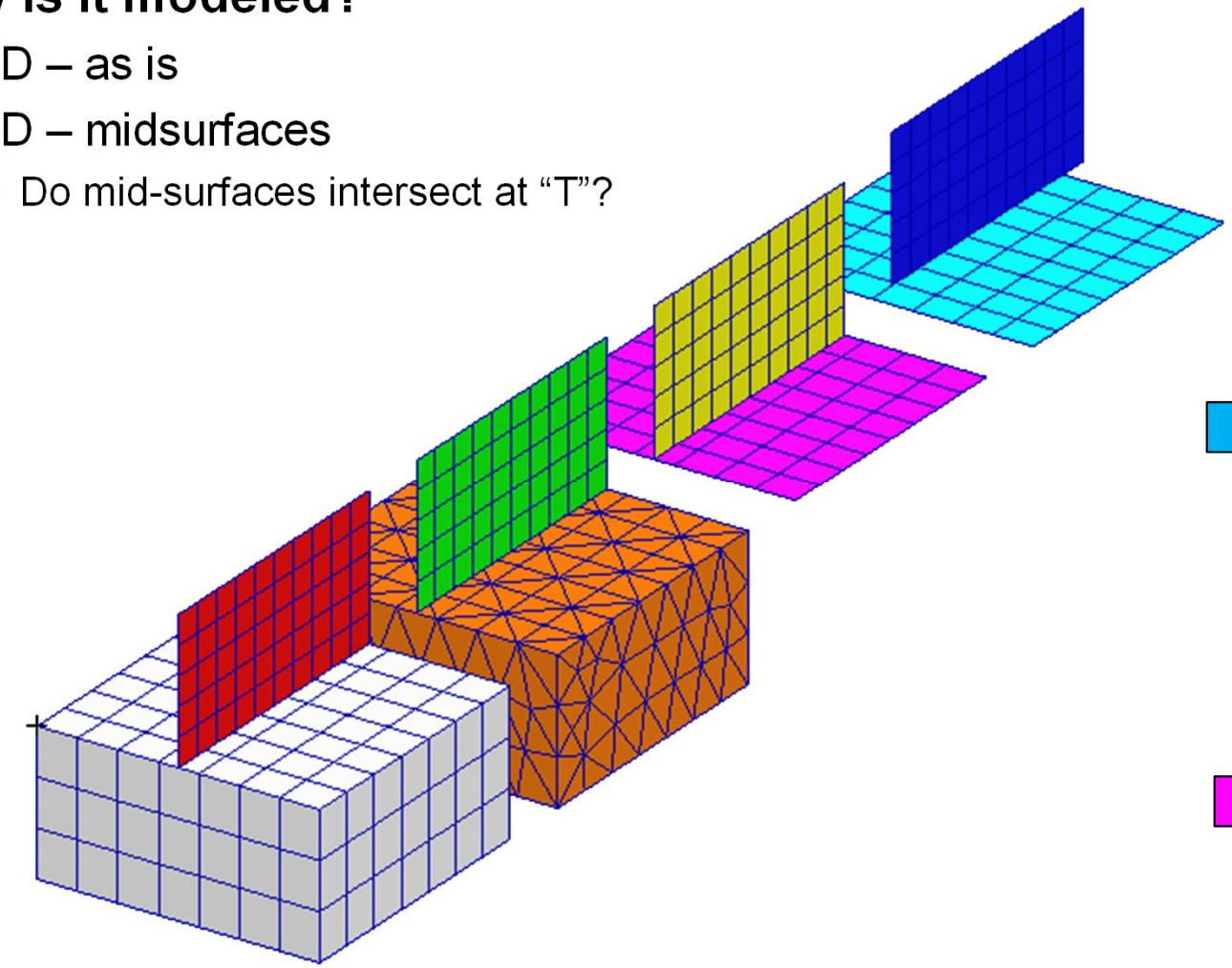
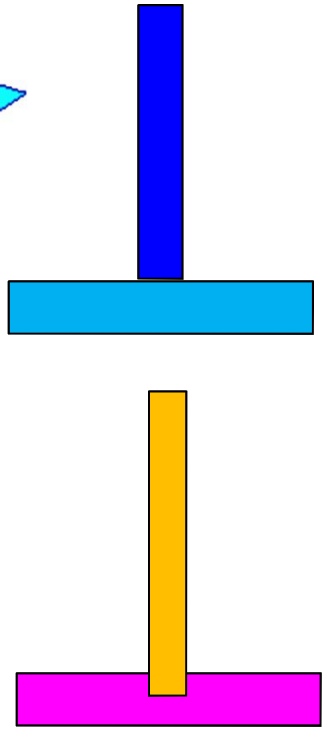
CASE STUDY 3: SHELL EDGE-TO-FACE GLUED CONTACT

- **Idealized mid-plane – to – surface connections**
- **How is it modeled?**
  - 3-D – as is
  - 2-D – midsurfaces
    - Do mid-surfaces intersect at “T”?





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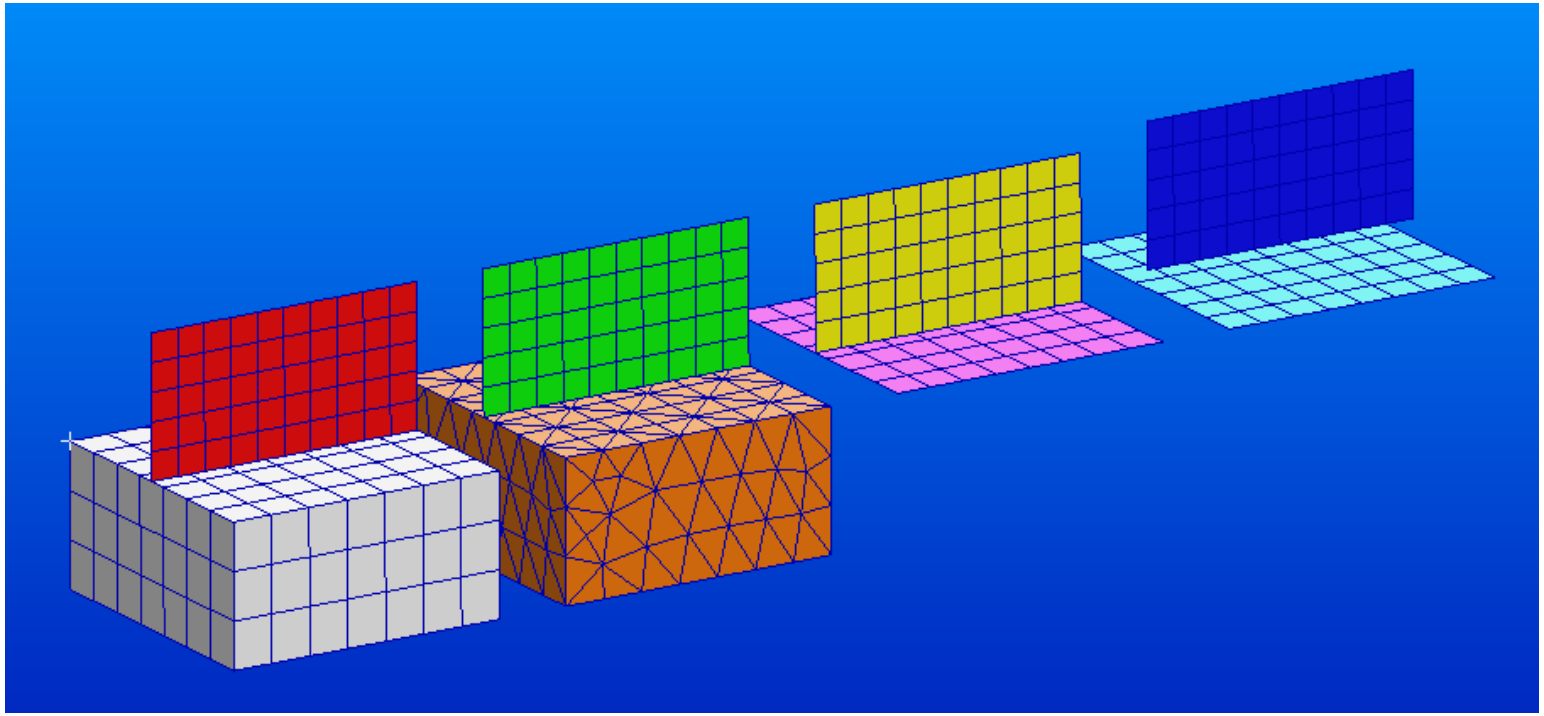
CASE STUDY 3: SHELL EDGE-TO-FACE GLUED CONTACT



Shell edge to hex face

Shell edge to tet face

Shell edge to shell face

Shell edge to shell face (at t/2 away)

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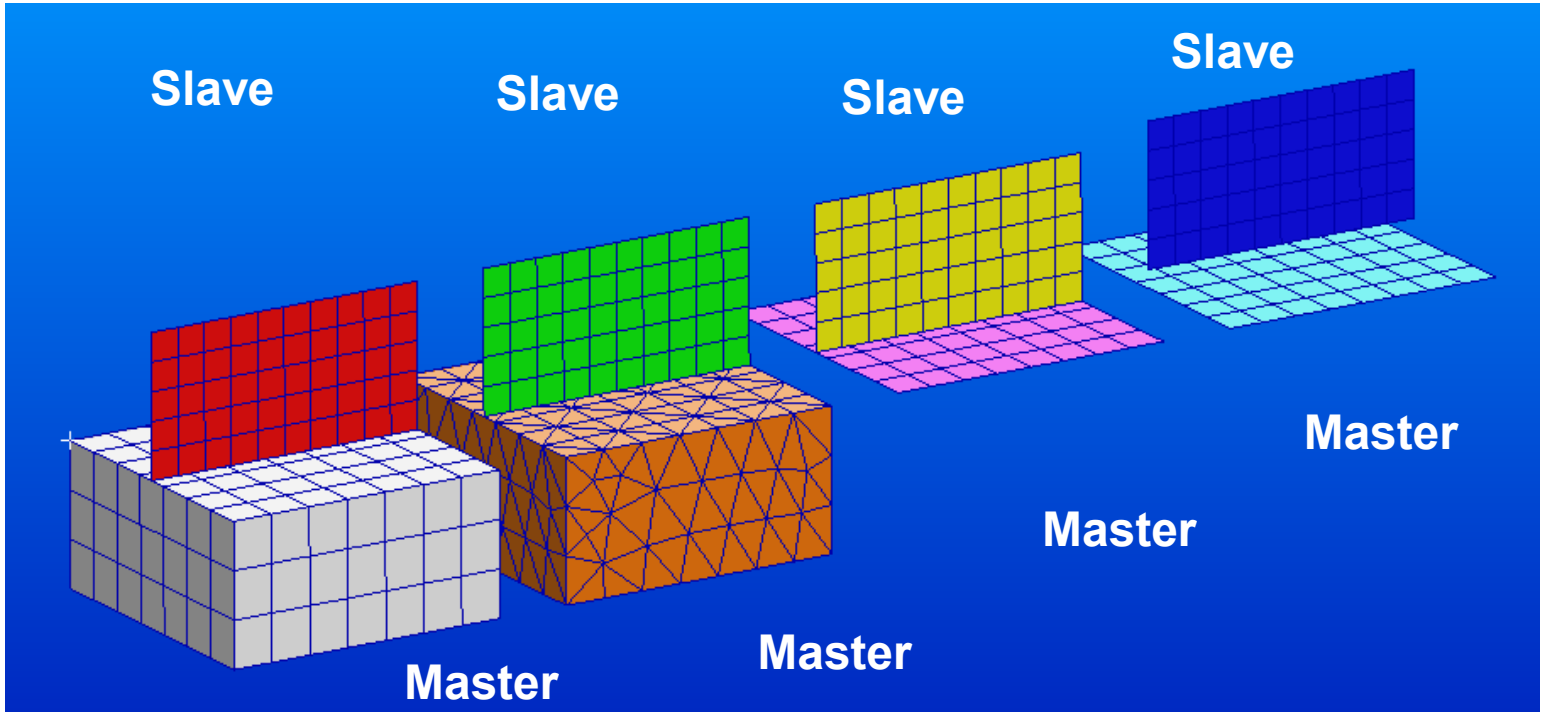
CASE STUDY 3: SHELL EDGE-TO-FACE GLUED CONTACT

- **Slave and Master choices are important**
  - The shell edge body needs to be the Slave.
  - The face body needs to be the Master.



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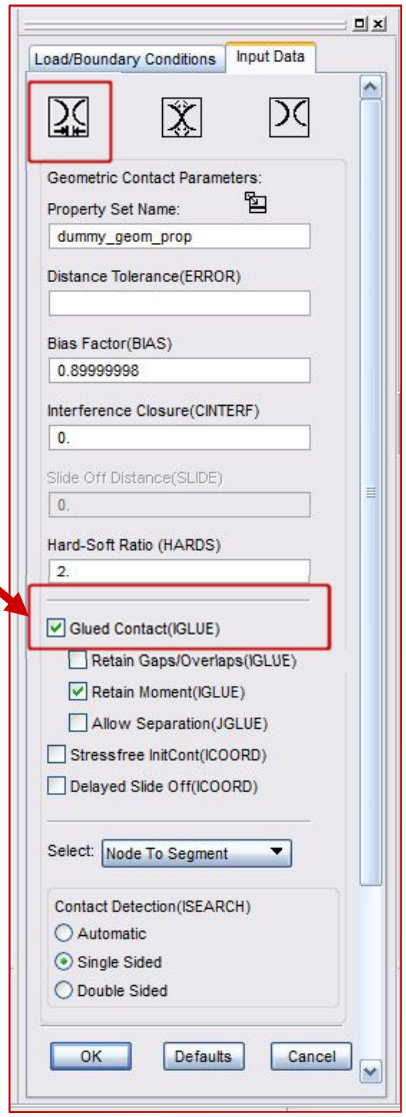
CASE STUDY 3: SHELL EDGE-TO-FACE GLUED CONTACT

- **Turn on the moment carrying capability**



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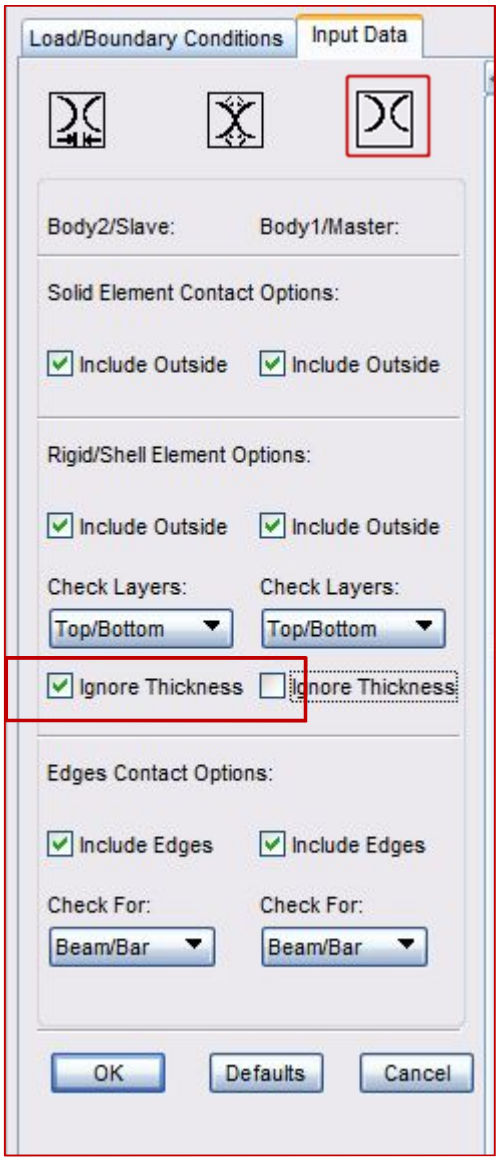
CASE STUDY 3: SHELL EDGE-TO-FACE GLUED CONTACT

- **Set the Slave body to ignore shell thickness**
  - This is the recommended practice
  - Not ignoring the shell thickness can lead to unexpected results



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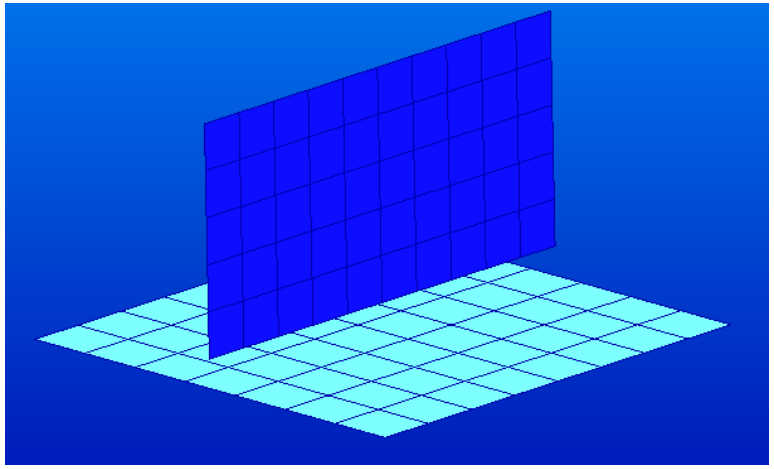
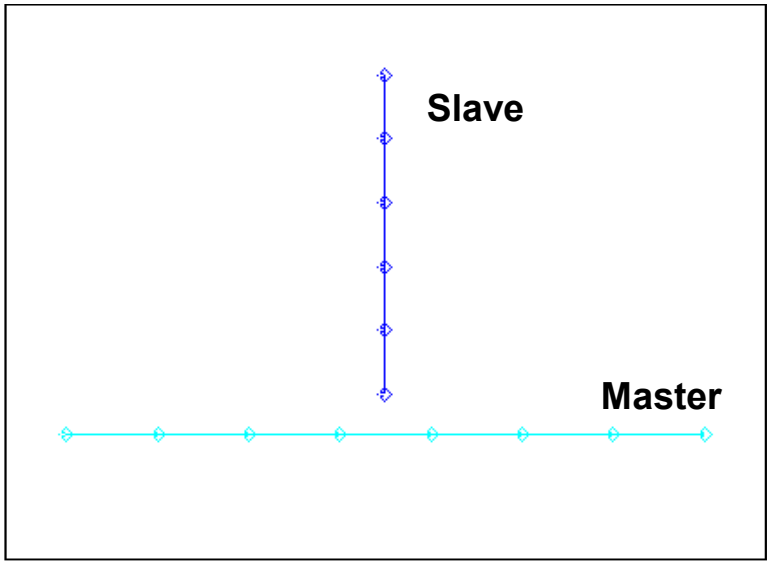
CASE STUDY 3: SHELL EDGE-TO-FACE GLUED CONTACT

- **Shell body at t/2 away**
  - No special modeling technique is required
  - Contact is found at the shell element face

Ignore shell thickness (Slave)





Shell body at t/2 away

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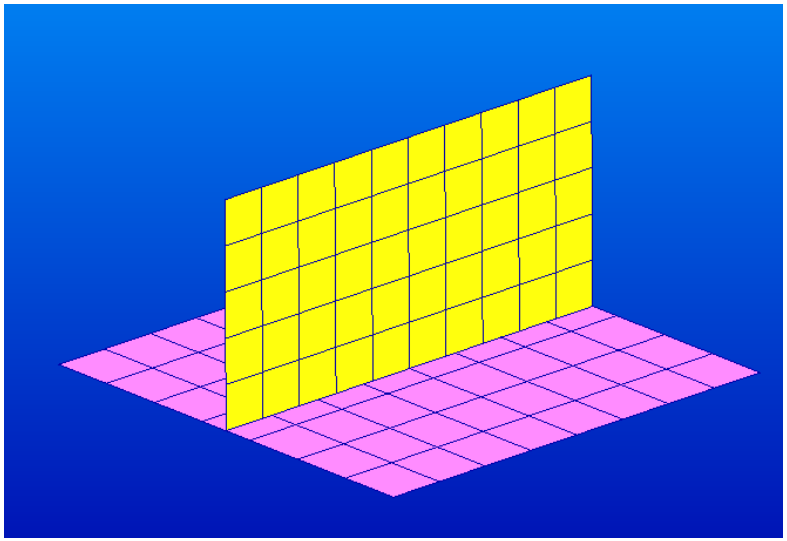
CASE STUDY 3: SHELL EDGE-TO-FACE GLUED CONTACT

- **Shell bodies right against each other**
  - Need to ignore shell thickness in order for contact to be found
  - If shell thickness is not ignored on the Master, the Slave nodes will search for the Master upper and lower faces and not find them.



Ignore shell thickness (both)

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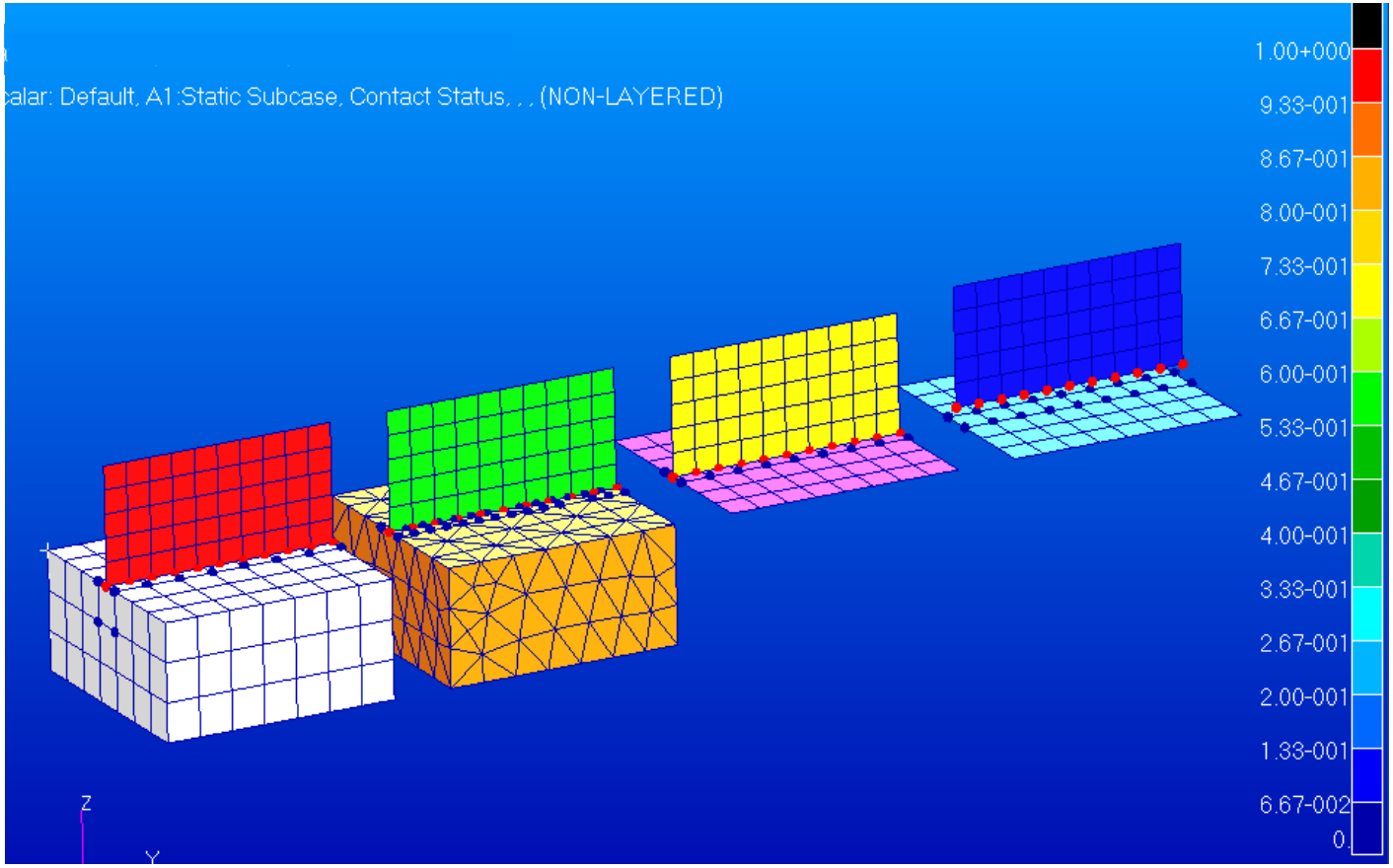
CASE STUDY 3: SHELL EDGE-TO-FACE GLUED CONTACT

- **Plot contact status**



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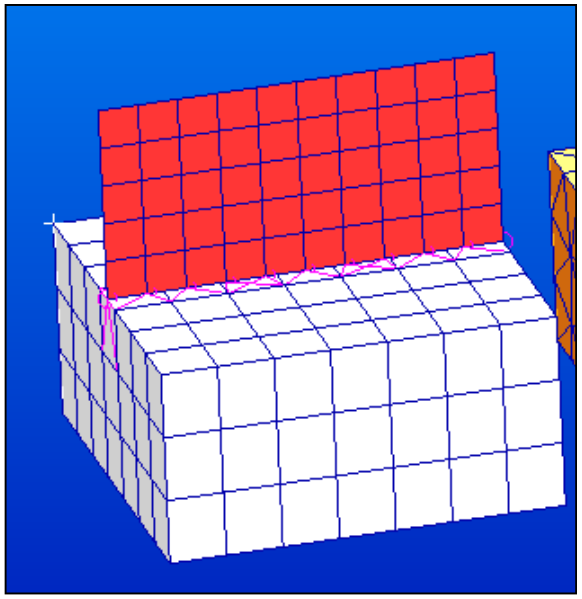
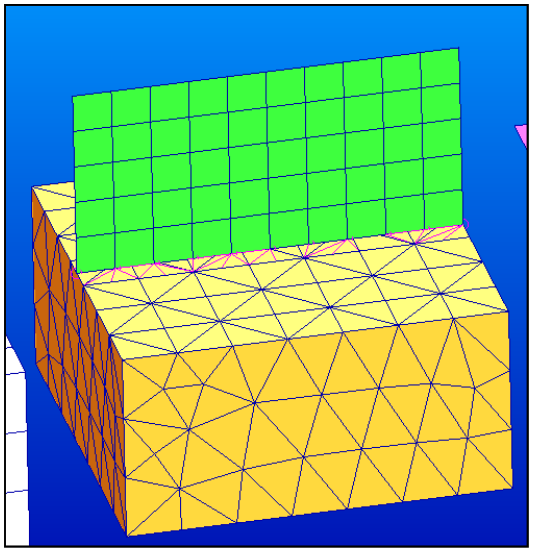
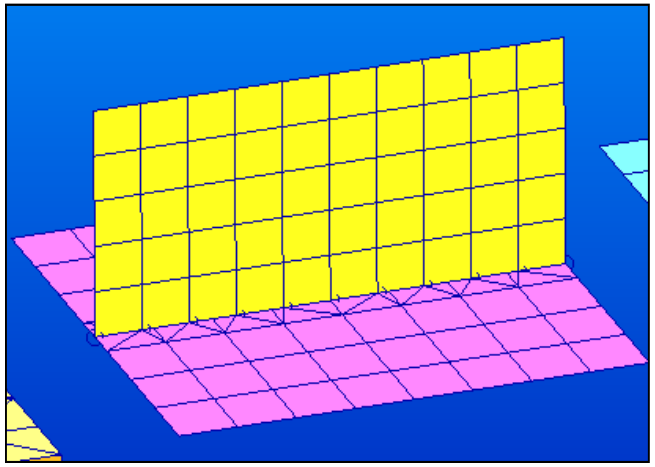
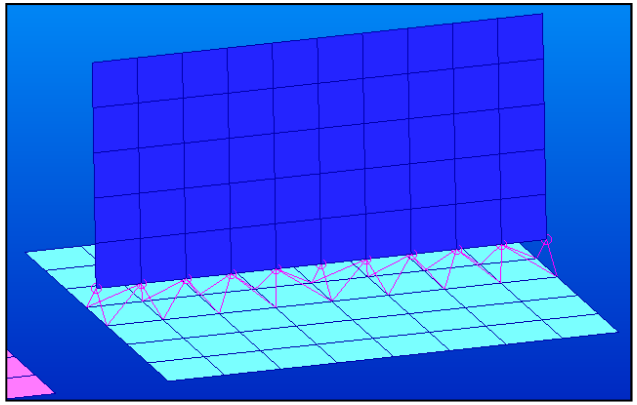
CASE STUDY 3: SHELL EDGE-TO-FACE GLUED CONTACT

- **Plot MPC equations**









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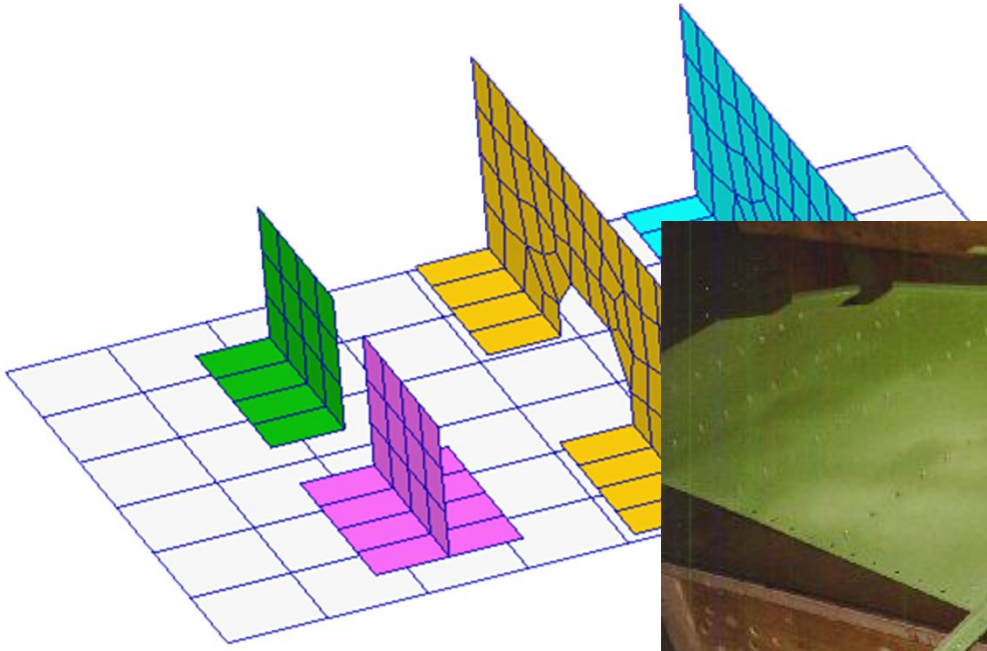
CASE STUDY 4: DEFINING CONTACT WITH TEES & CLIPS

- **Surface-to-Surface contact?**
- **Edge-to-Surface contact?**
- **Both?**



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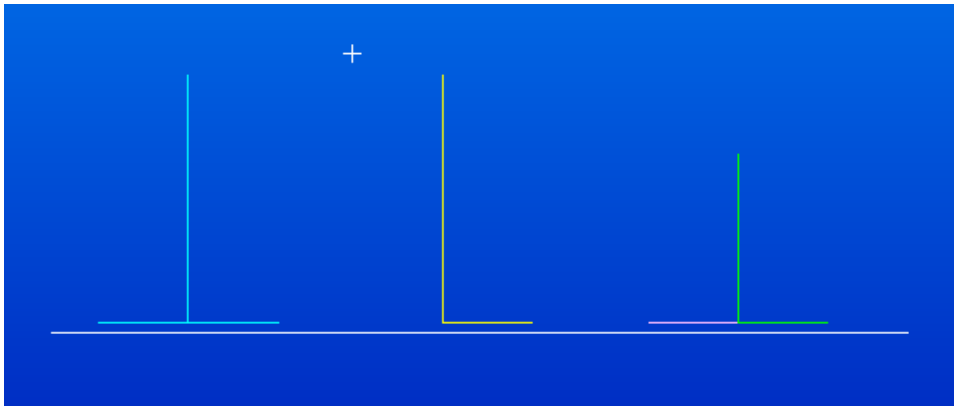
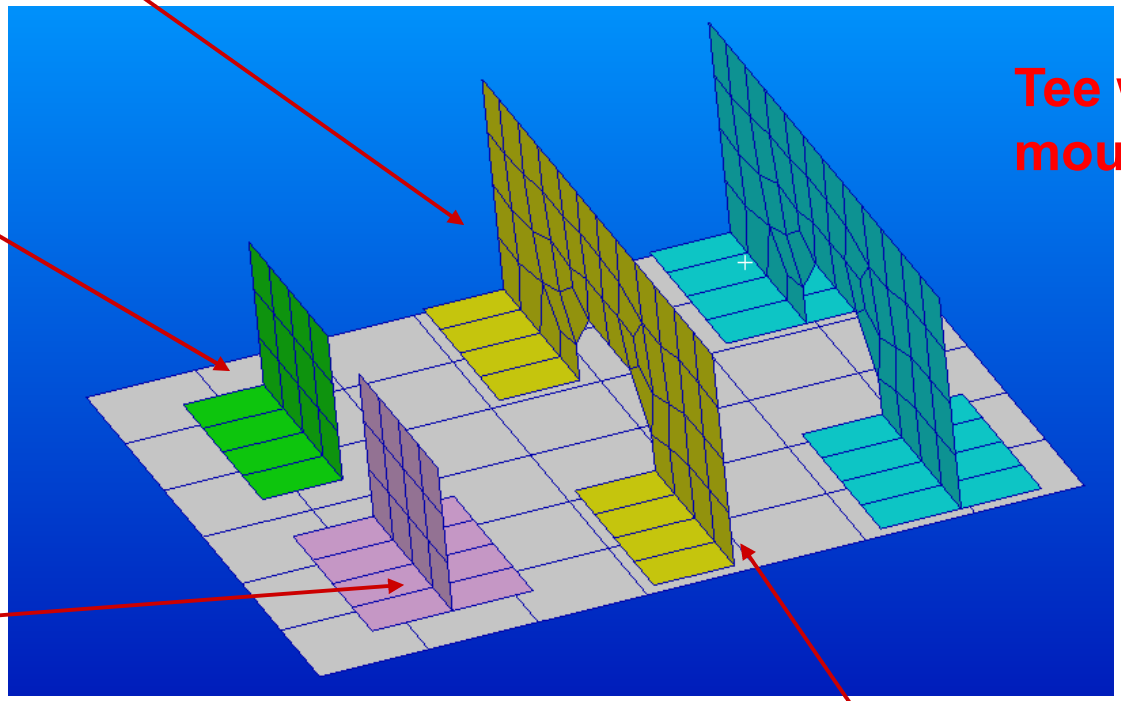
CASE STUDY 4: ANGLE AND TEE CLIPS





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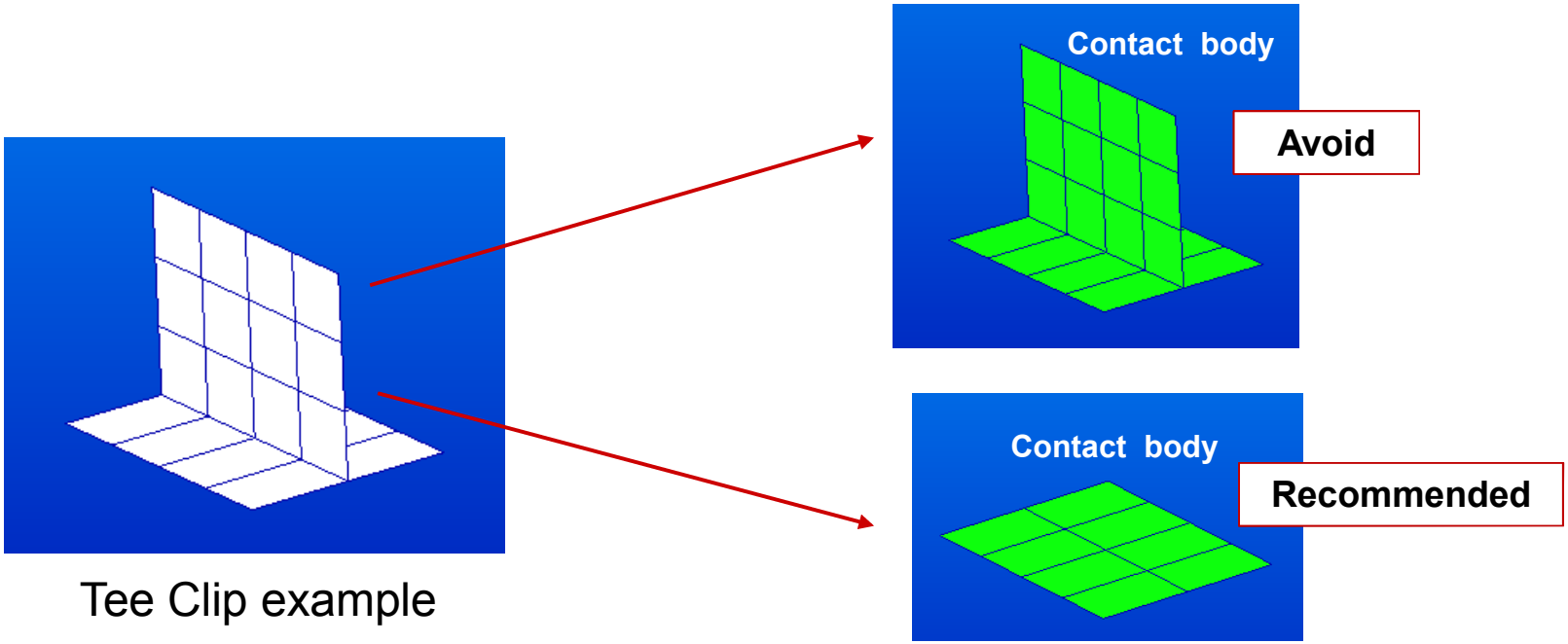
CASE STUDY 4: ANGLE AND TEE CLIPS

- **Recommended practice**
  - Do not create a contact body which contains both the web and flanges, i.e., avoid corners and junctions in a contact body
  - When corners or junctions are included in a contact body, the contact detection behavior can be unexpected



Tee Clip example

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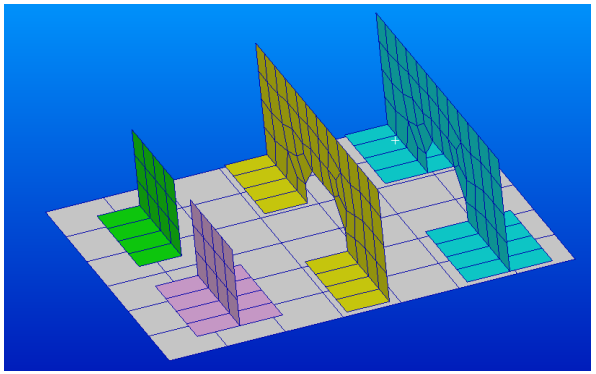
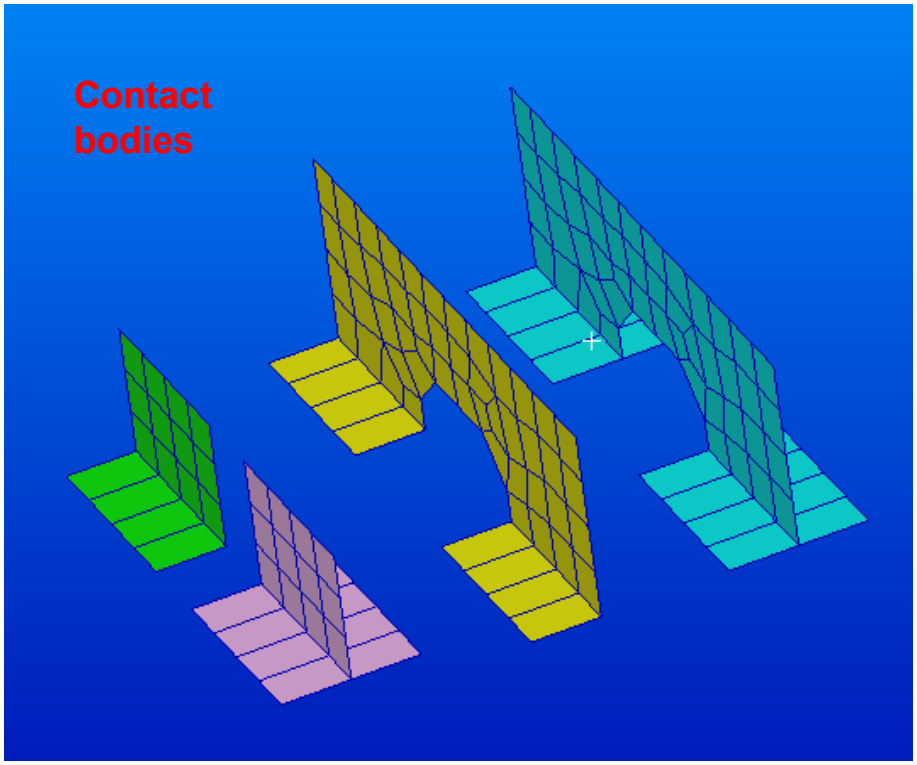
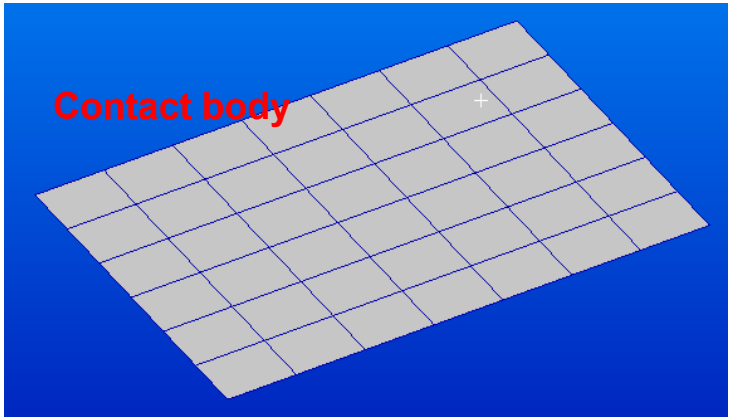
CASE STUDY 4: ANGLE AND TEE CLIPS

- **Define contact bodies**







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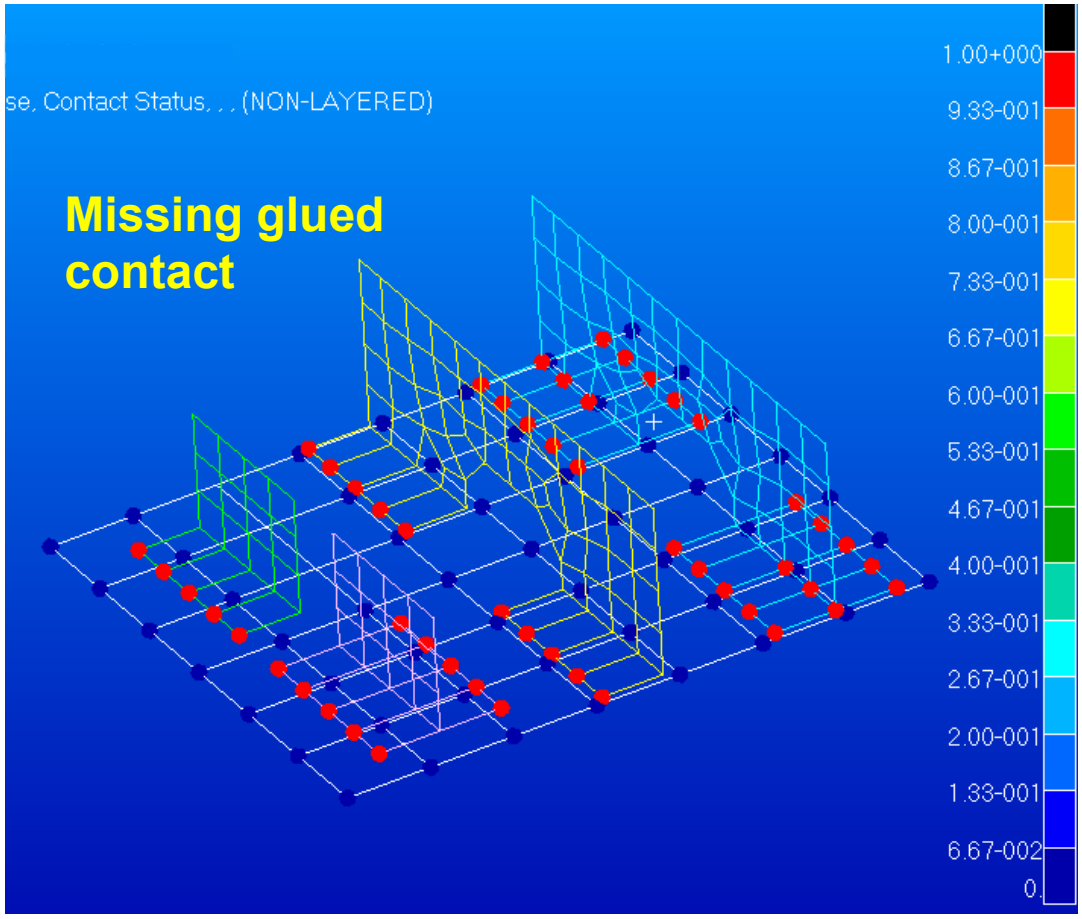
CASE STUDY 4: ANGLE AND TEE CLIPS

- **Plot contact status**



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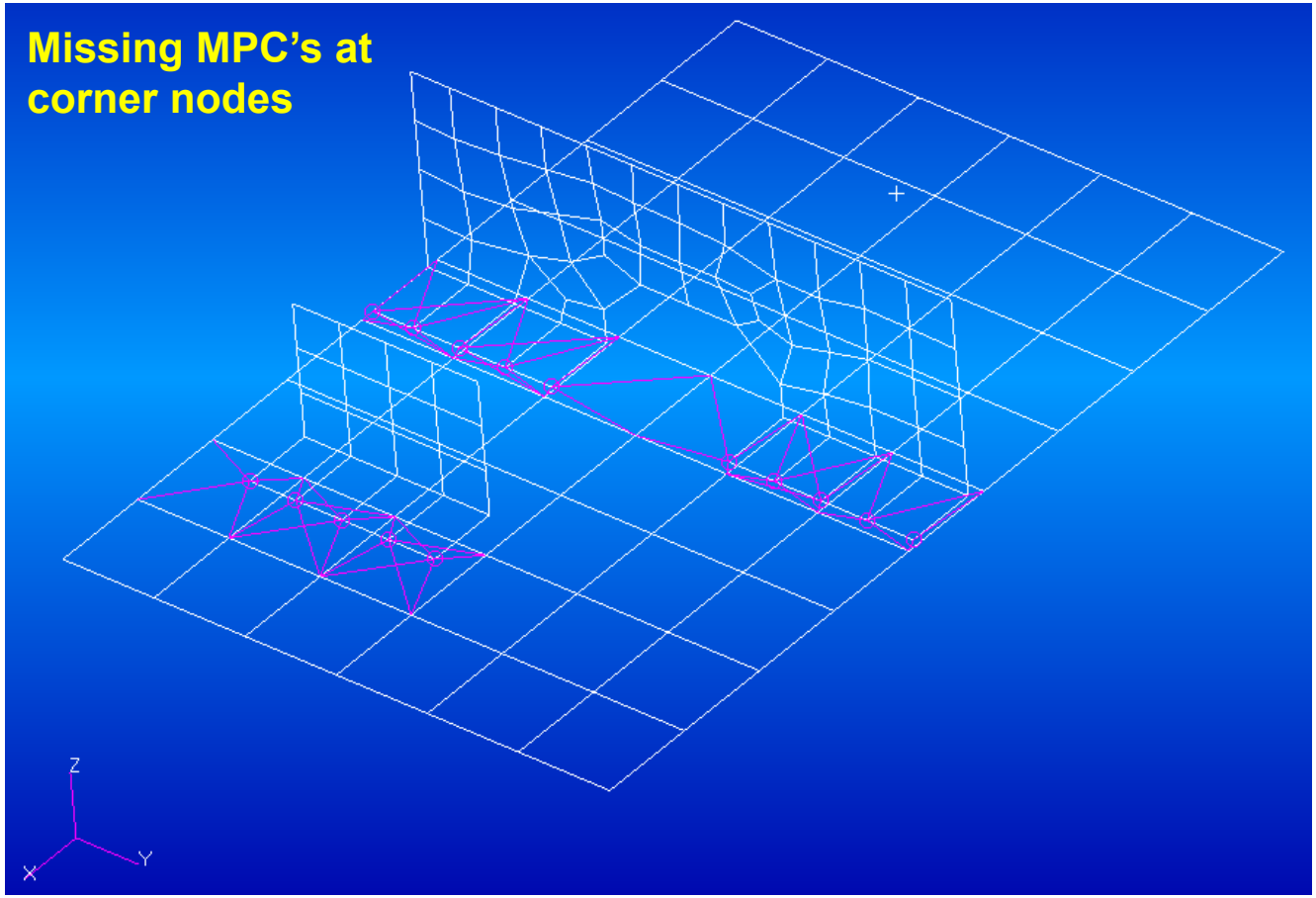
CASE STUDY 4: ANGLE AND TEE CLIPS

- **Plot MPC equations for angle clips**



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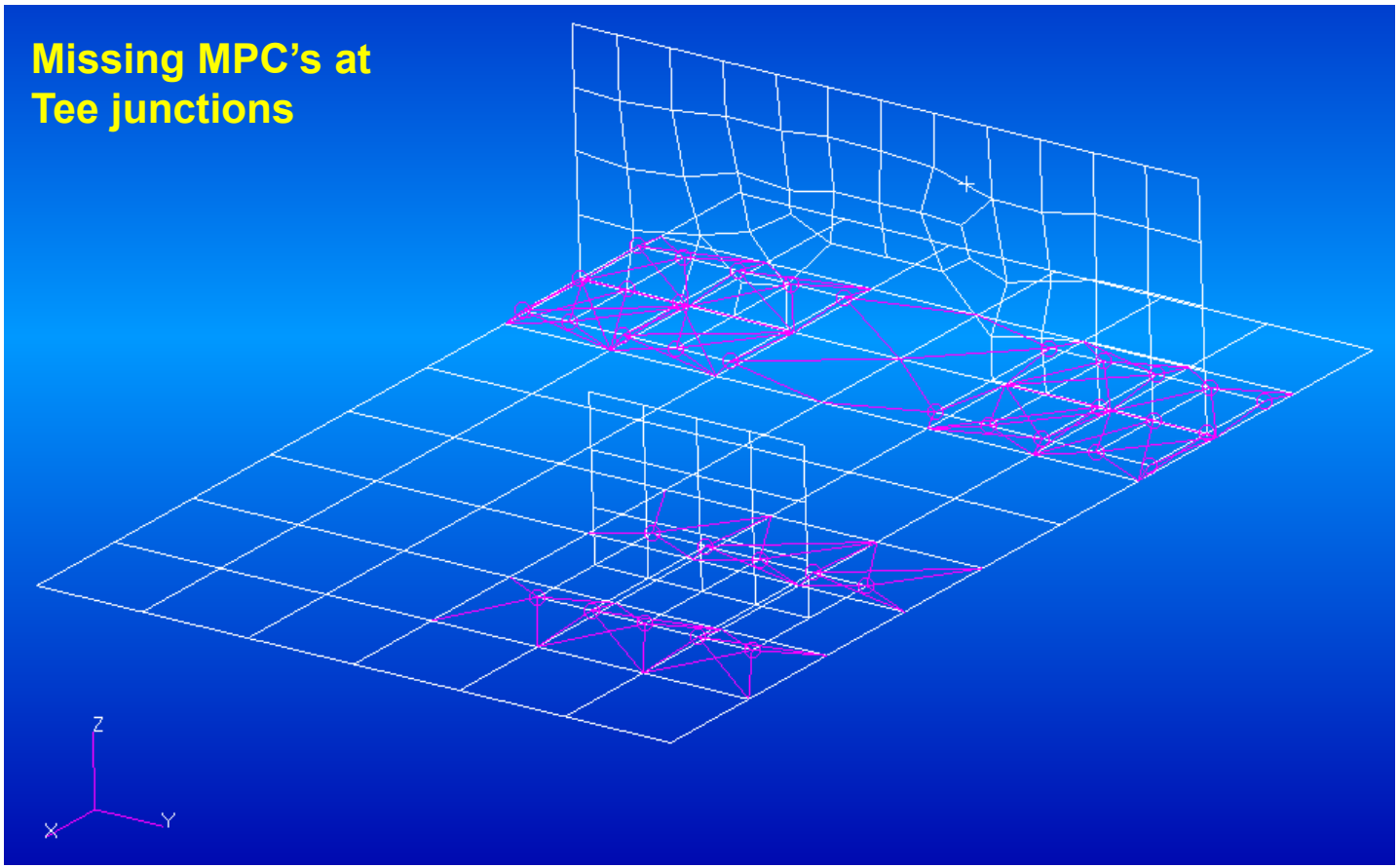
CASE STUDY 4: ANGLE AND TEE CLIPS

- **Plot MPC equations for the clips**



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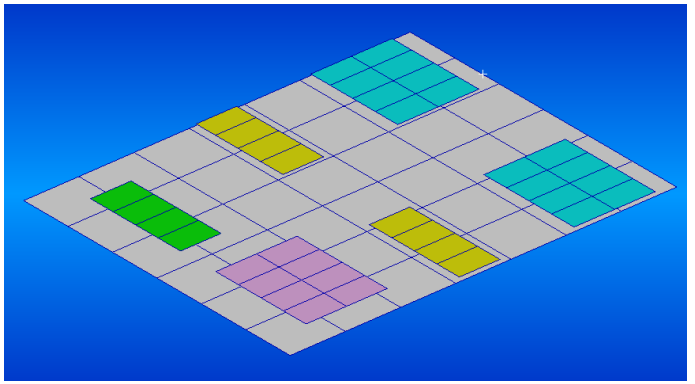
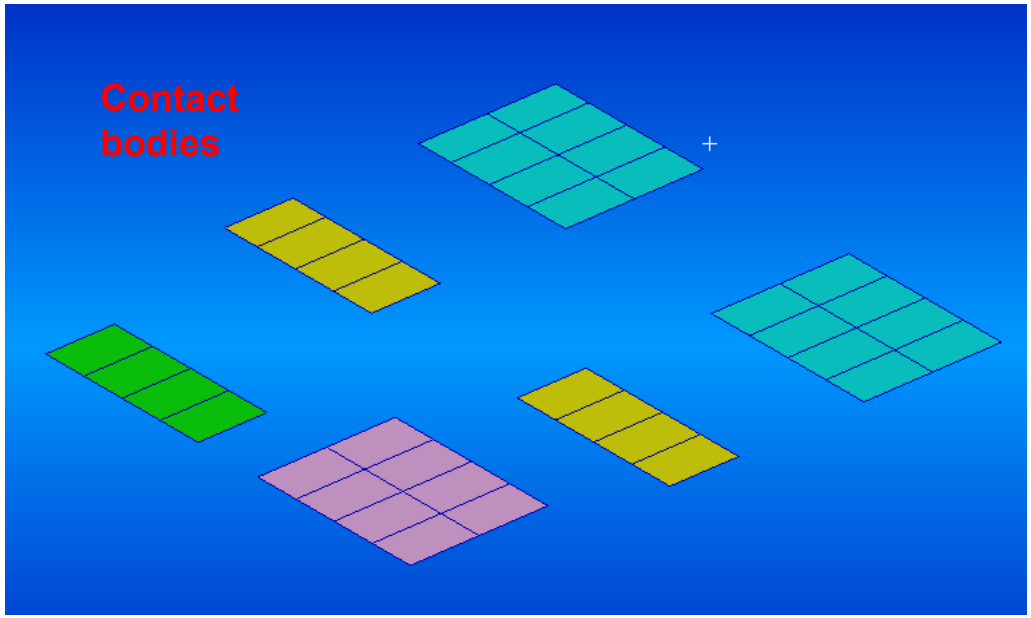
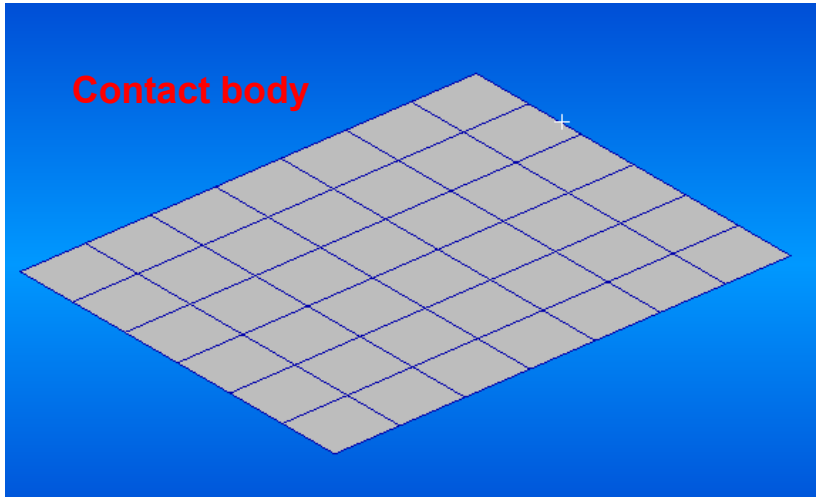
CASE STUDY 4: ANGLE AND TEE CLIPS

- **Redefine contact bodies**







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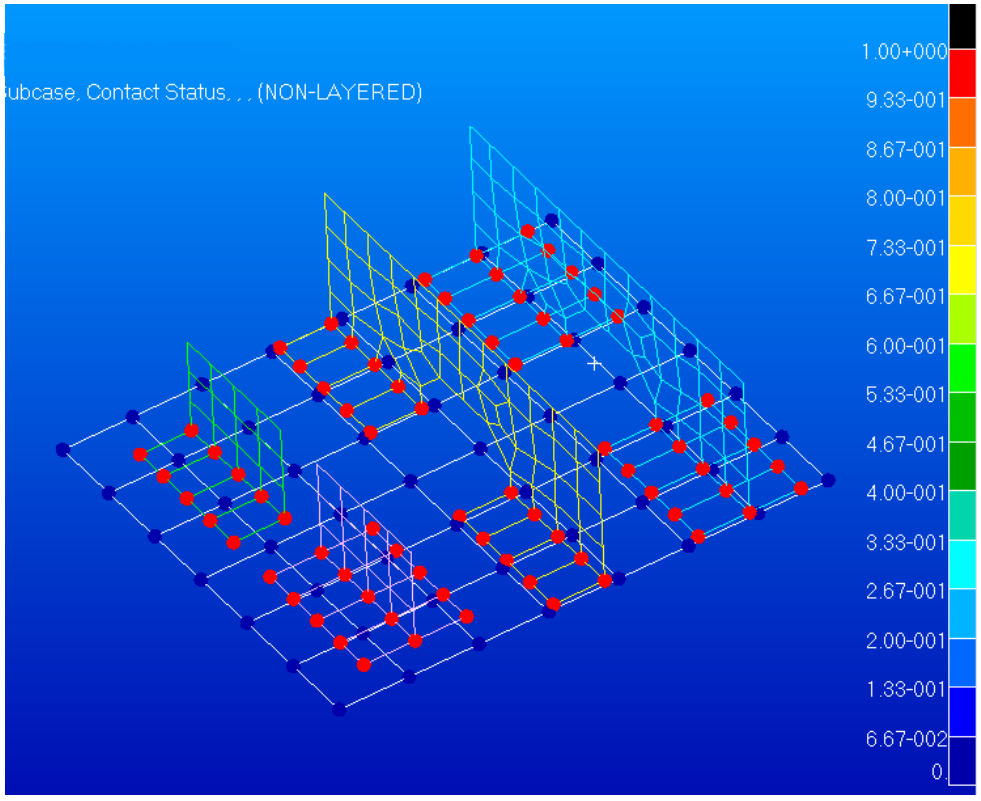
CASE STUDY 4: ANGLE AND TEE CLIPS

- **Redefined contact bodies**
  - Plot contact status
  - All corner and junction nodes are now glued



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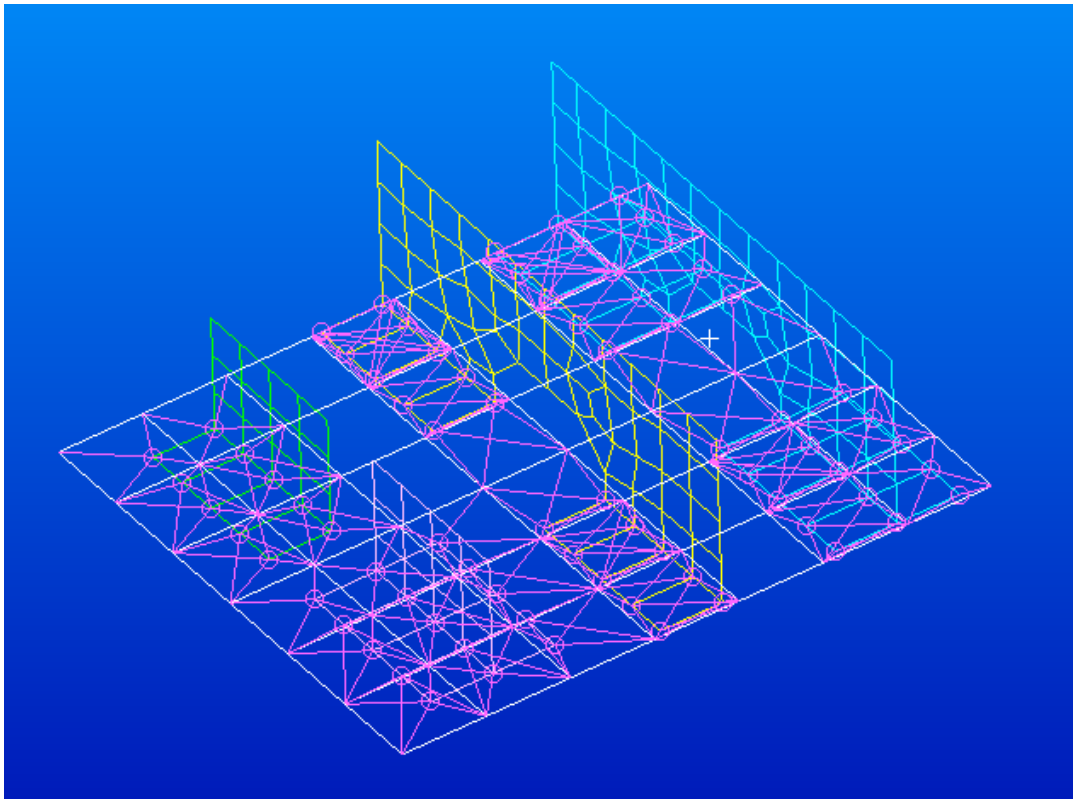
CASE STUDY 4: ANGLE AND TEE CLIPS

- **Redefined contact bodies**
  - Plot MPC equations
  - All corner and junction nodes are now glued



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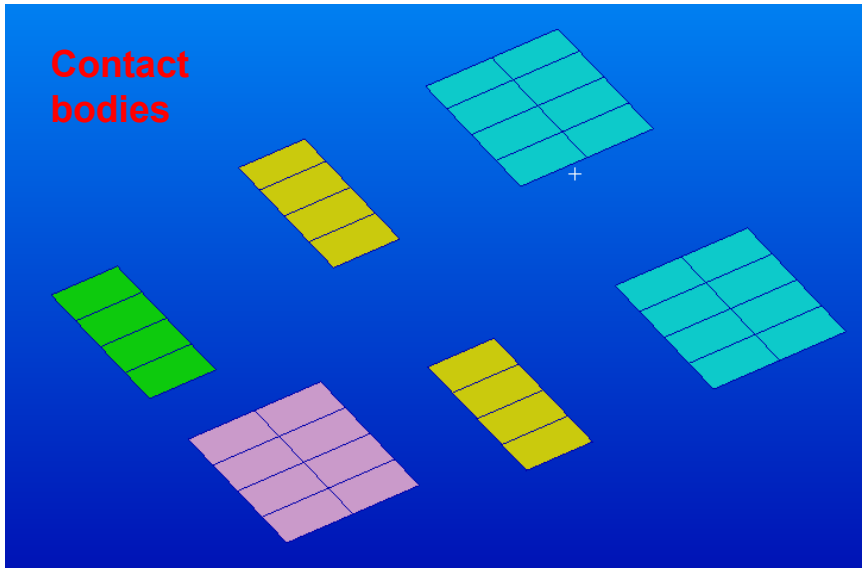
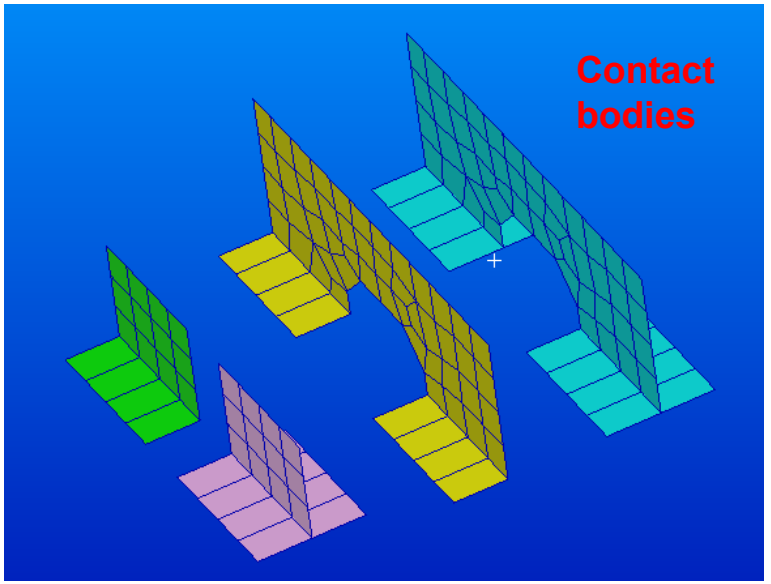
CASE STUDY 4: ANGLE AND TEE CLIPS

- **Recommended practice**

Recommend



Avoid



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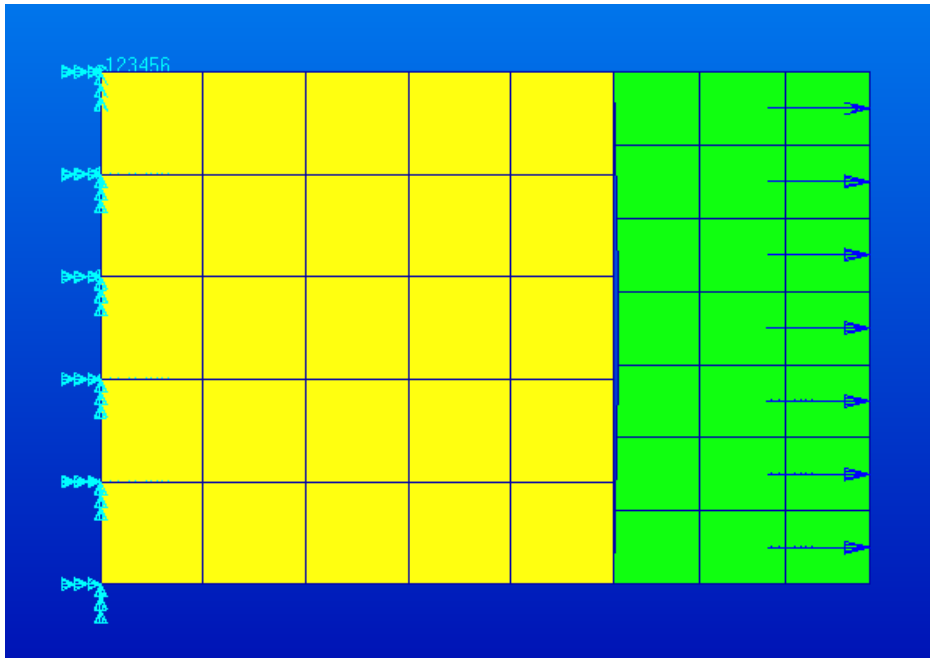
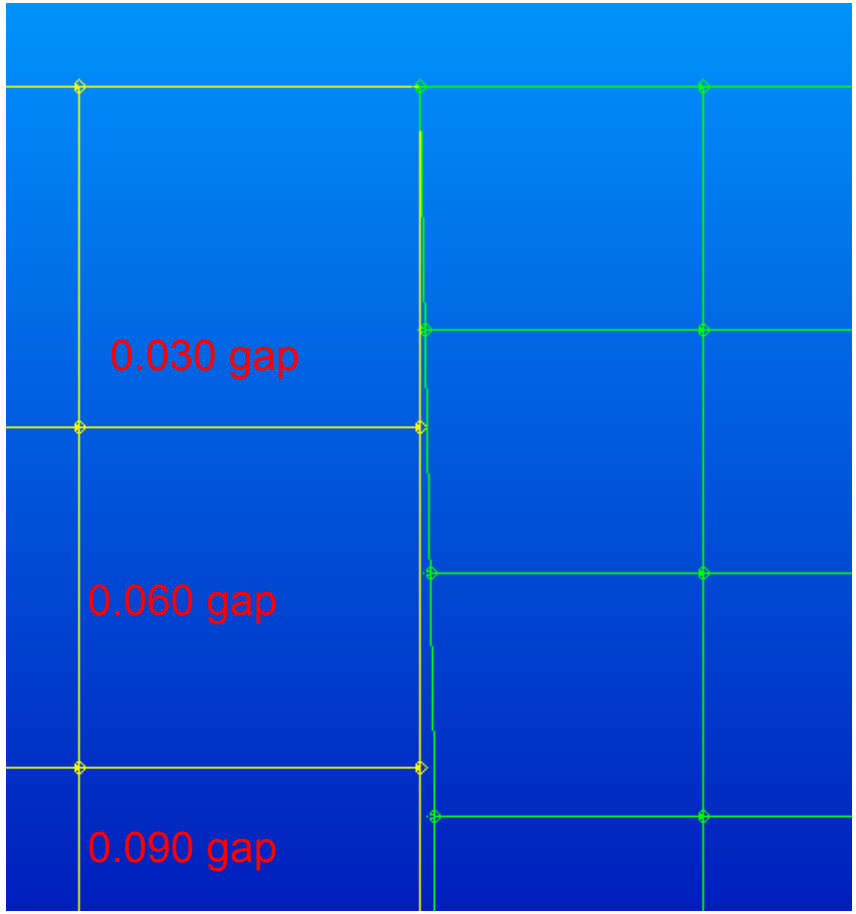
CASE STUDY 5: SHELL EDGE-TO-EDGE GLUED CONTACT WITH IN-PLANE GAP

- **Two shell bodies lie in the same plan**
- **An in-plane gap exists**





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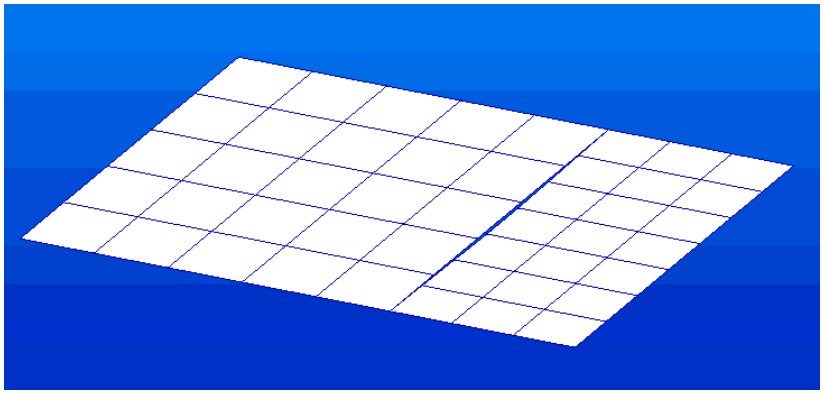
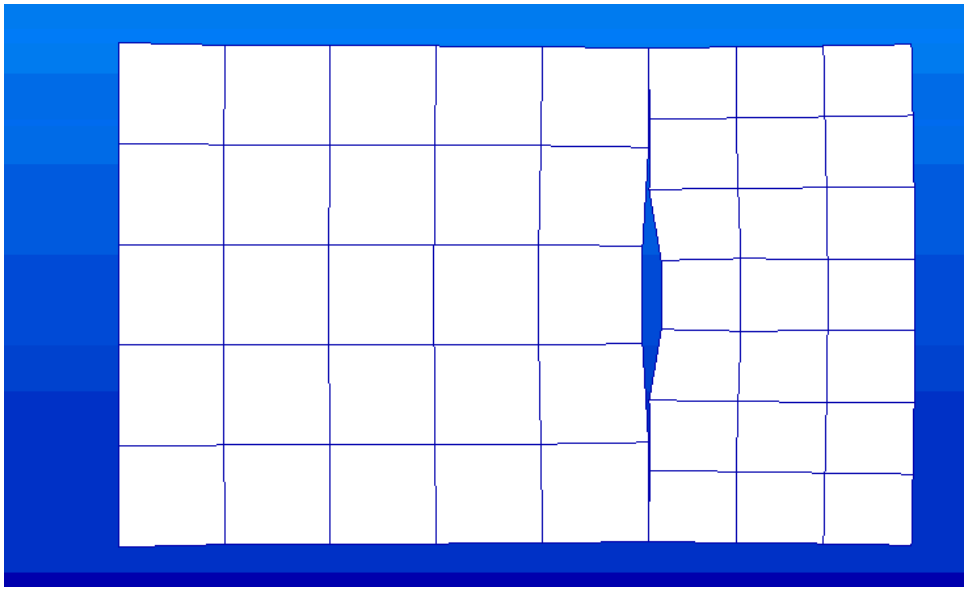
CASE STUDY 5: SHELL EDGE-TO-EDGE GLUED CONTACT WITH IN-PLANE GAP

- Glued the two plates as in Case Study 4
- Plot the deformed shape
- The plate edges are partially glued





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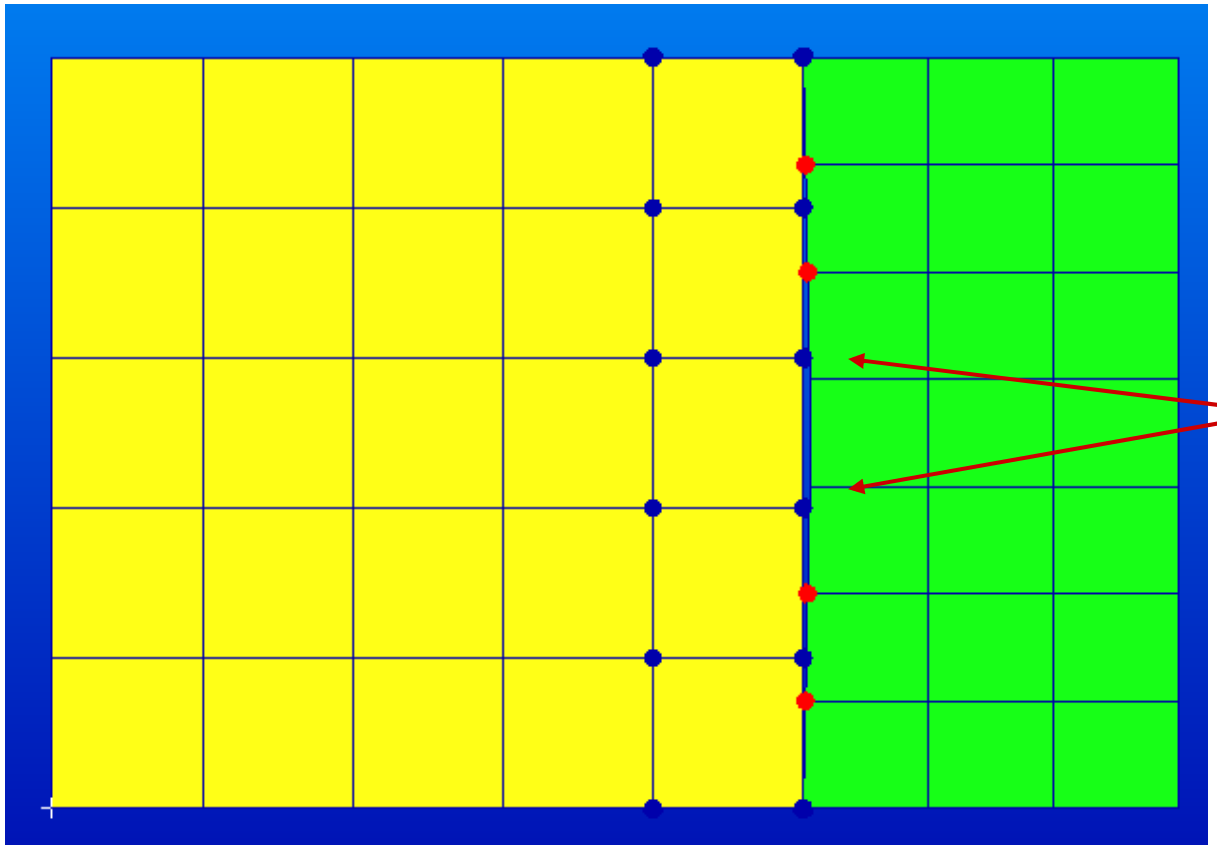
CASE STUDY 5: SHELL EDGE-TO-EDGE GLUED CONTACT WITH IN-PLANE GAP

- **Plot the contact status**
  - 2 nodes did not get glued



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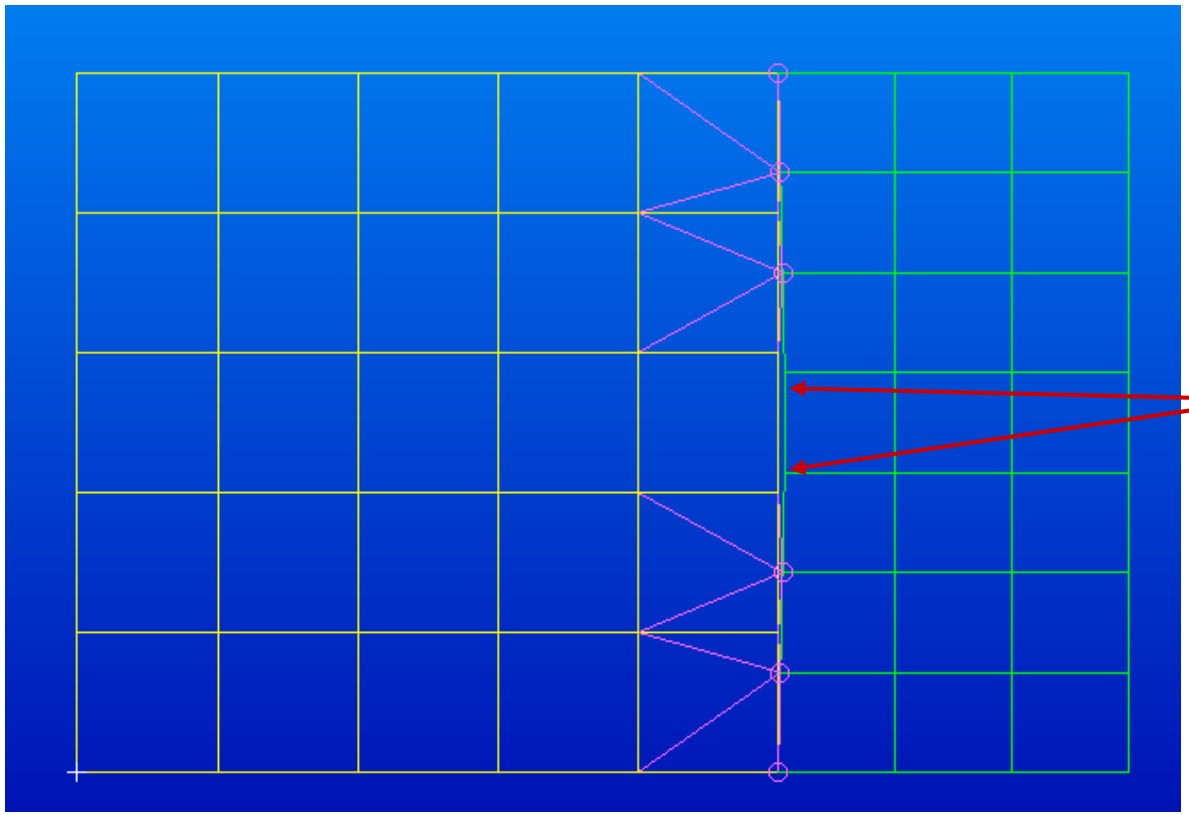
CASE STUDY 5: SHELL EDGE-TO-EDGE GLUED CONTACT WITH IN-PLANE GAP

- **Plot the MPC equations**
  - 2 nodes did not get glued



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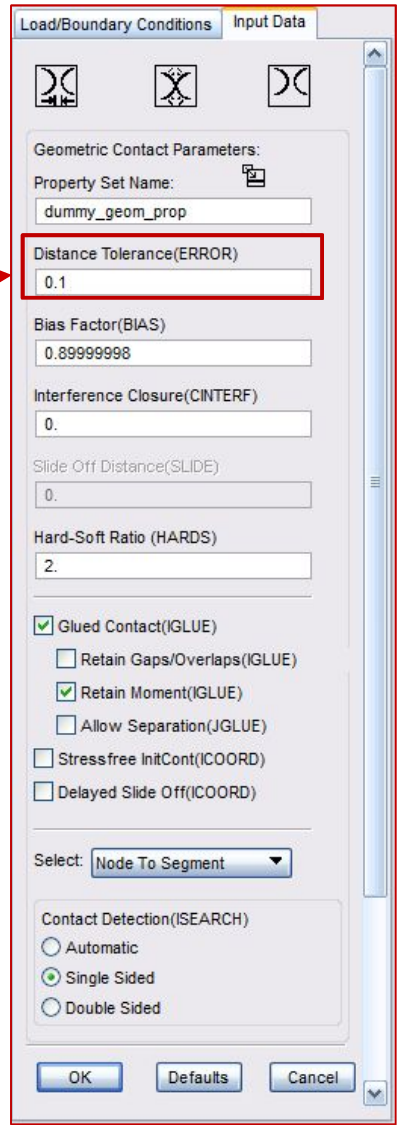
CASE STUDY 5: SHELL EDGE-TO-EDGE GLUED CONTACT WITH IN-PLANE GAP

- **Examine the default contact tolerance**
  - The default value is 0.0625
  - The largest in-plane gap is 0.090
  - Let's increase the contact tolerance to 0.100



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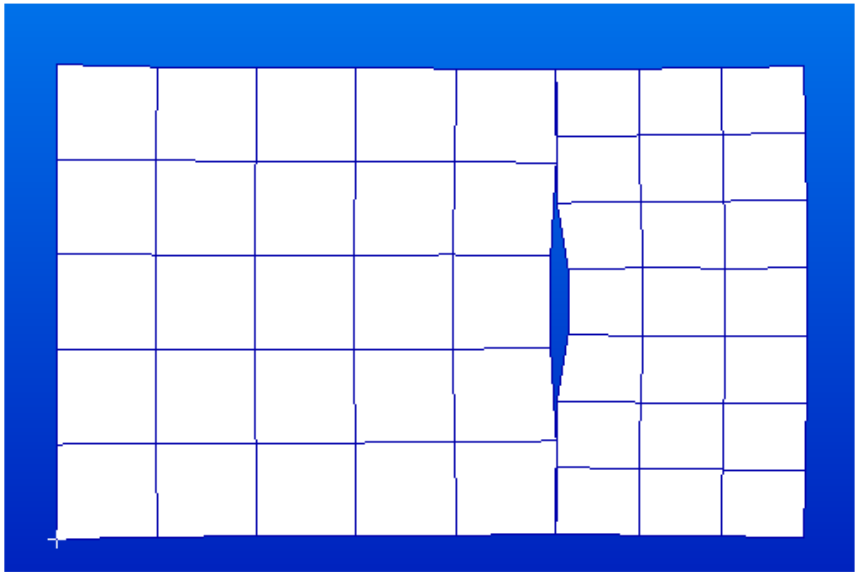
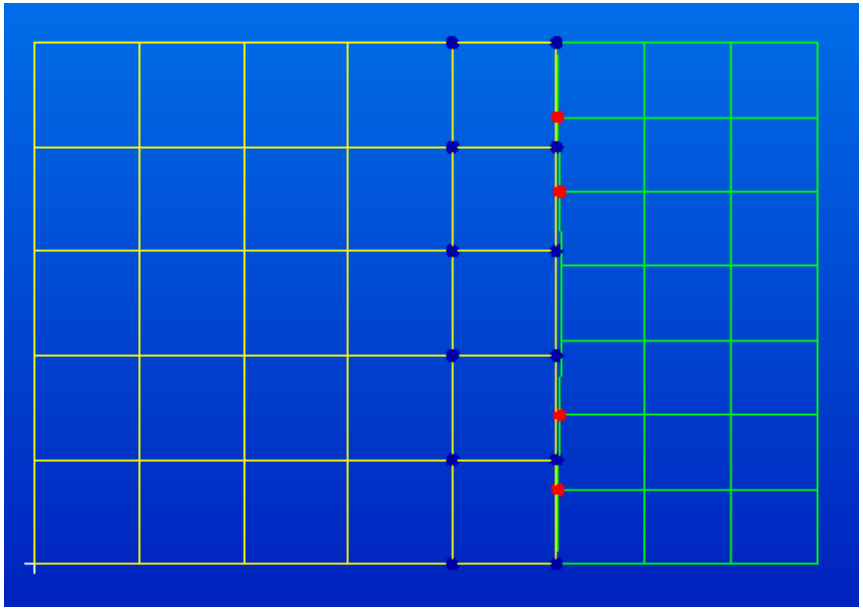
CASE STUDY 5: SHELL EDGE-TO-EDGE GLUED CONTACT WITH IN-PLANE GAP

- **Analysis results for contact tolerance of 0.100**
  - Same results as before. No improvement.





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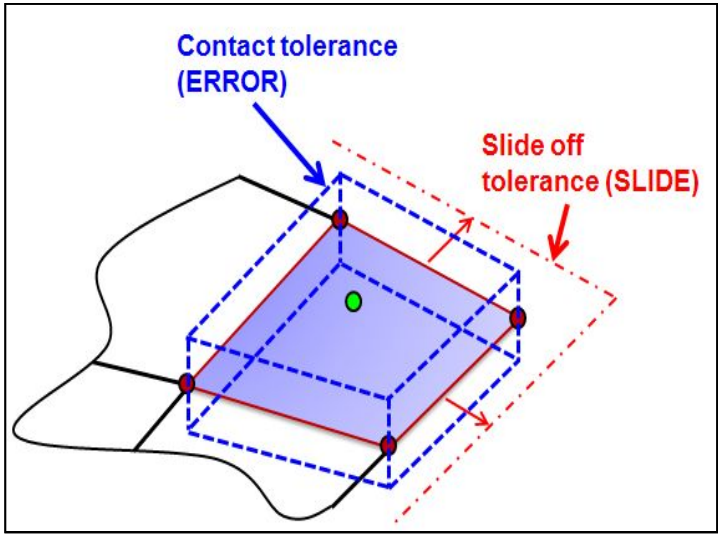
CASE STUDY 5: SHELL EDGE-TO-EDGE GLUED CONTACT WITH IN-PLANE GAP

- **How to handle in-plane gaps**
  - The contact tolerance (ERROR) is measured normal to the Master element face. That's why increasing this value did not help bridging across the in-plane gap.
  - The delayed slide off tolerance (SLIDE) can be used to bridge the in-plane gap
    - By default, this slide off tolerance is equal to the default contact tolerance. It extends the Master element edge by this amount.
    - If this default tolerance is not enough, then the user can set a specific slide off tolerance by
      - » Set ICOORD=2 to activate the SLIDE parameter
      - » and set SLIDE to the desired value



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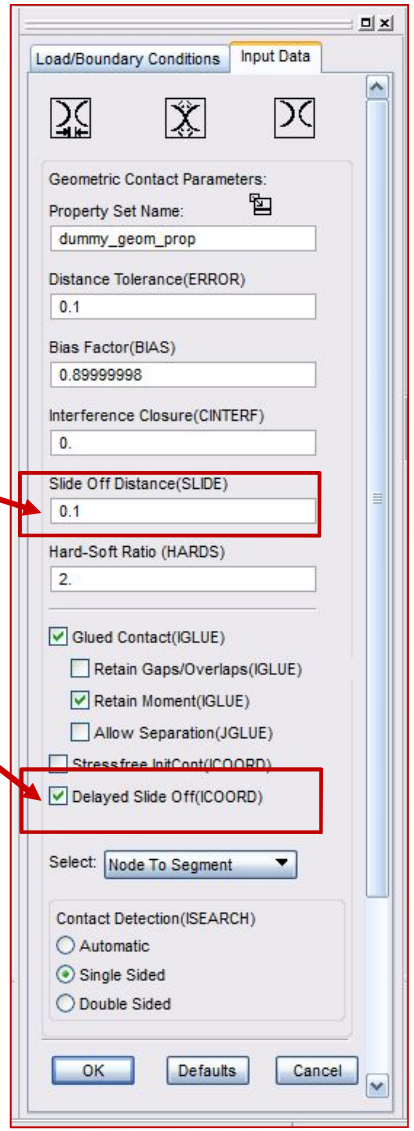
CASE STUDY 5: SHELL EDGE-TO-EDGE GLUED CONTACT WITH IN-PLANE GAP

- **How to handle in-plane gaps**
  - Set ICOORD=2
  - Set SLIDE=0.100



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CASE STUDY 5: SHELL EDGE-TO-EDGE GLUED CONTACT WITH IN-PLANE GAP

- **What the MSC Nastran entries looks like**

```
$ Direct Text Input for Bulk Data
PARAM    POST    0
PARAM   PRTMAXIM YES
BCPARA   0       NLGLUE  0
NLPARM   1                                                       NO
BCTABL1  0       8003
BCONECT  8003    3001            2       1
BCONPRG  3001            COPTS   1061    ERROR  .1       ICOORD  2
         IGLUE   3       ISEARCH 1       SLIDE  .1
BCTABL1  1       8003
$ Nodes of the Entire Model
GRID     1               0.      0.      0.
GRID*    2                               .200000002980232 0.
*        0.
GRID*    3                               .400000005960465 0.
*        0.
```


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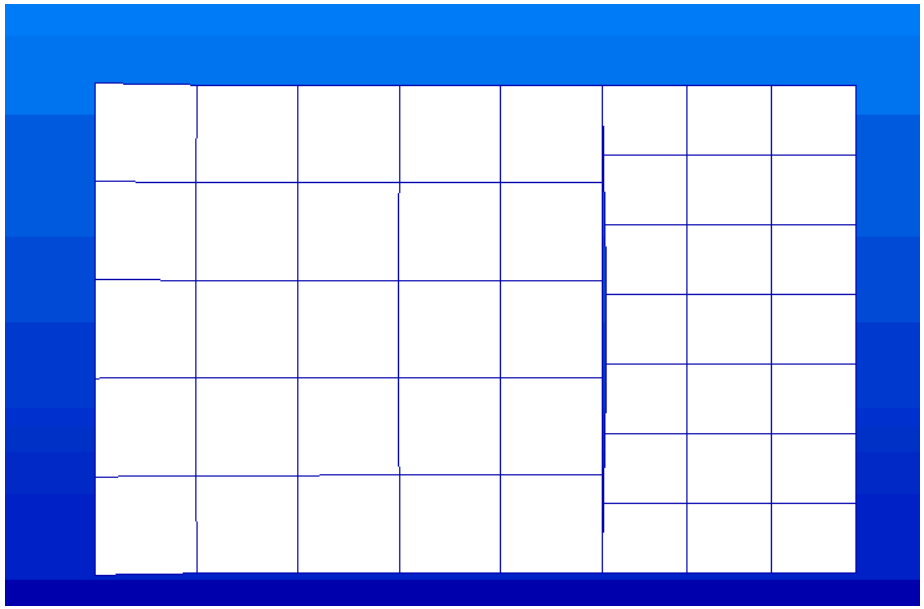
CASE STUDY 5: SHELL EDGE-TO-EDGE GLUED CONTACT WITH IN-PLANE GAP

- **Analysis results for new ICOORD and SLIDE settings**
  - Deformed shape plot shows that both plates appear to be fully connected



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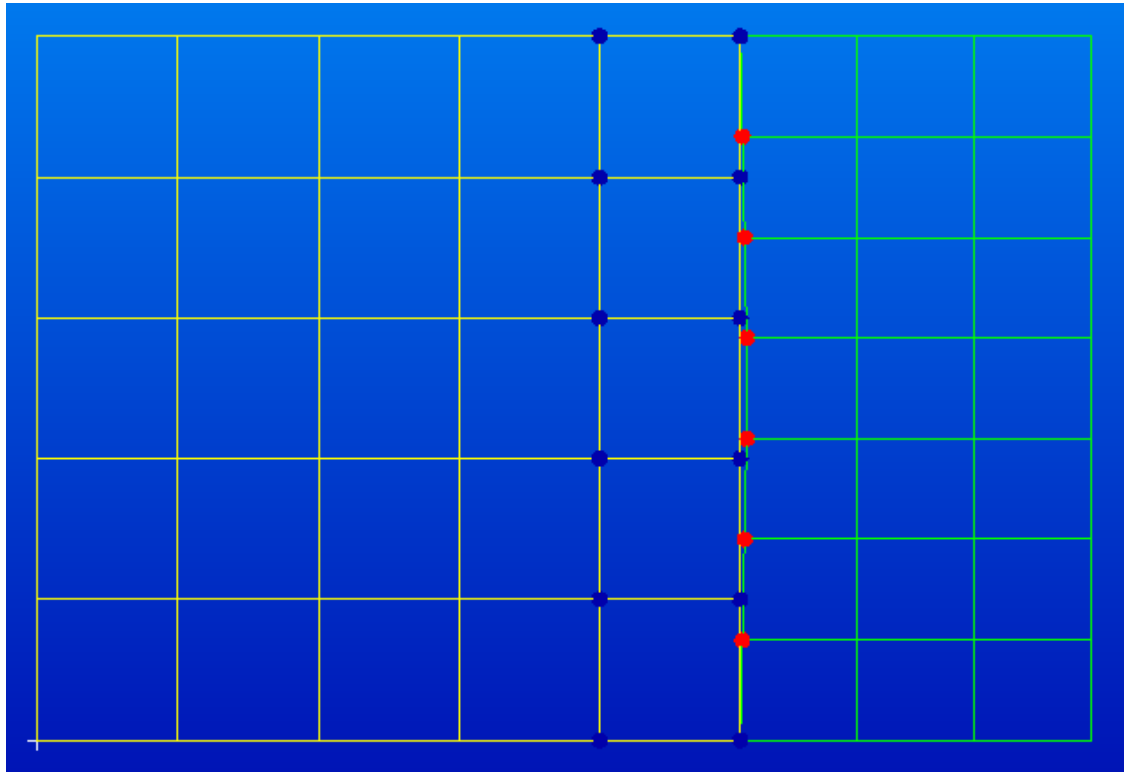
CASE STUDY 5: SHELL EDGE-TO-EDGE GLUED CONTACT WITH IN-PLANE GAP

- **Analysis results for new ICOORD and SLIDE settings**
  - Plot contact status
  - All nodes are connected



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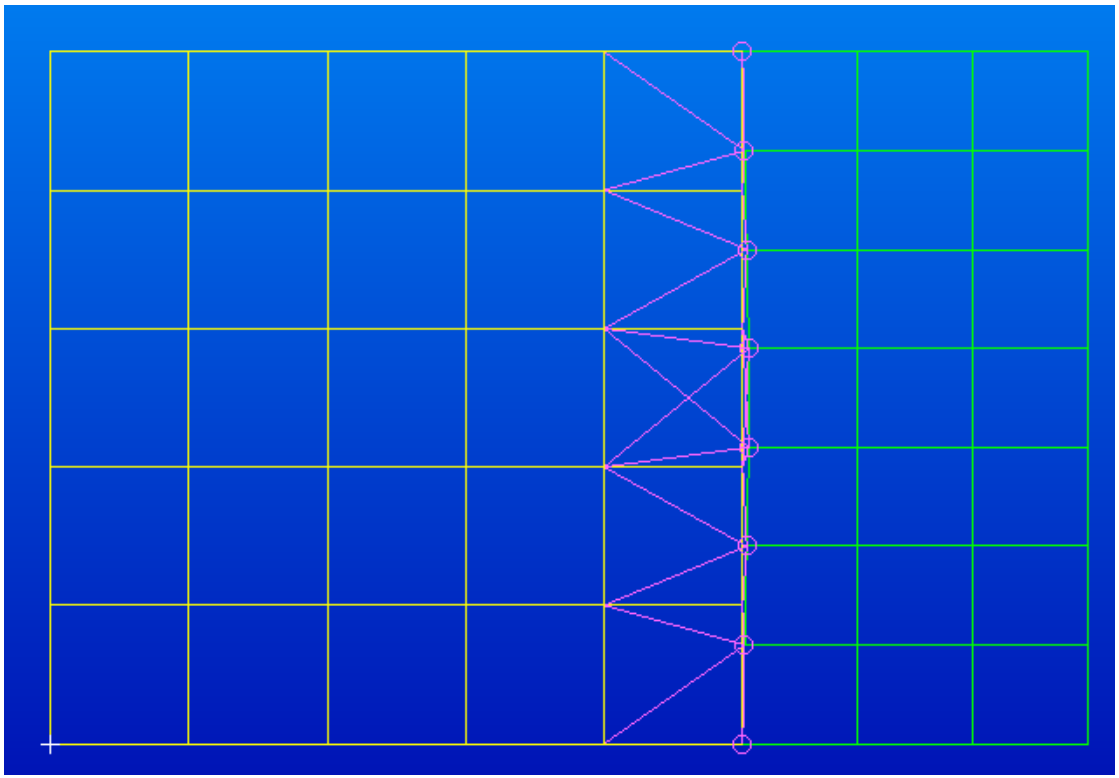
CASE STUDY 5: SHELL EDGE-TO-EDGE GLUED CONTACT WITH IN-PLANE GAP

- **Analysis results for new ICOORD and SLIDE settings**
  - Plot MPC equations
  - All nodes are connected



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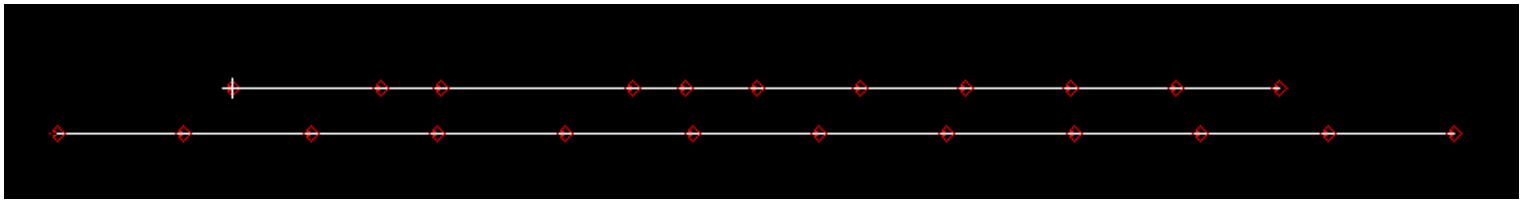
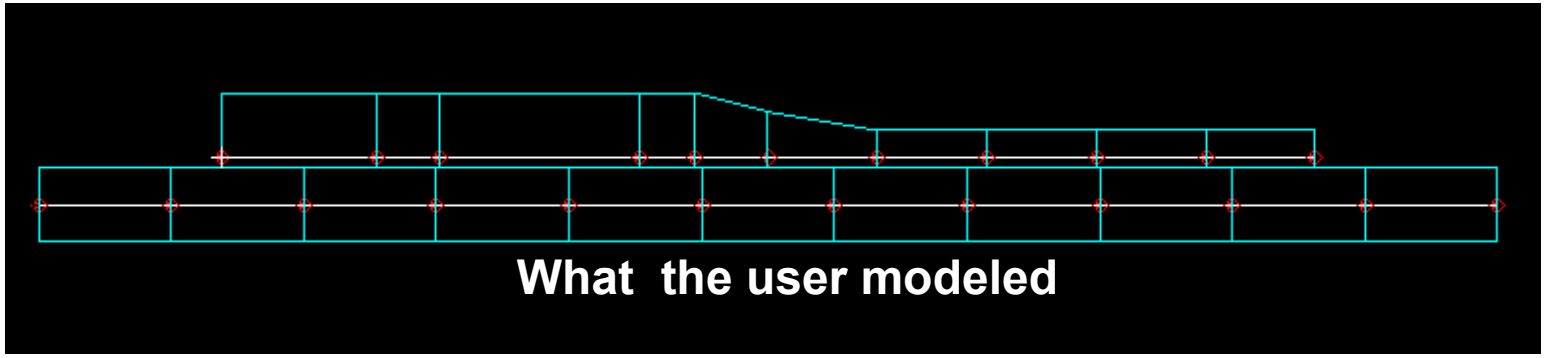
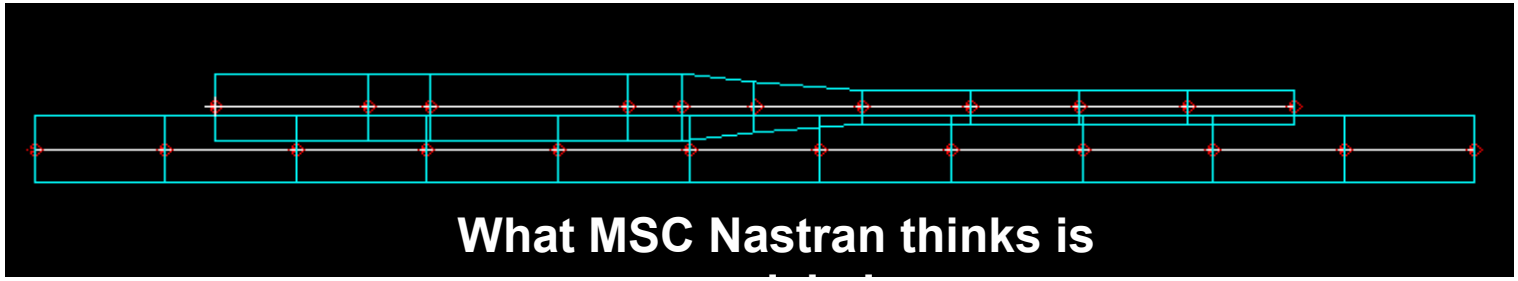
CURRENT LIMITATIONS

- **Composite Layup Offset**
  - MSC Nastran currently does not look at the Z0 definition in PCOMP and PCOMPG when doing contact search
  - It assumes the layup is centered about the grid plane







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APPENDIX D

SHELL TOUCHING CONTACT CASE STUDIES

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SHELL CONTACT ANALYSIS EXAMPLES

- **Shell Contact Analysis can be explained well by reviewing a series of Case studies**
- **The following examples of Shell contact are included in this Appendix**
  - Case Study 1 – Shell Face-to-Face Touching Contact
  - Case Study 2 – Curved Shell Face-to-Face Touching Contact

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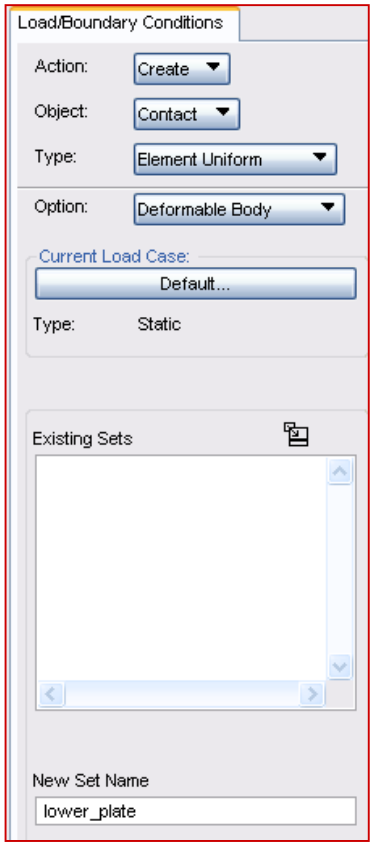
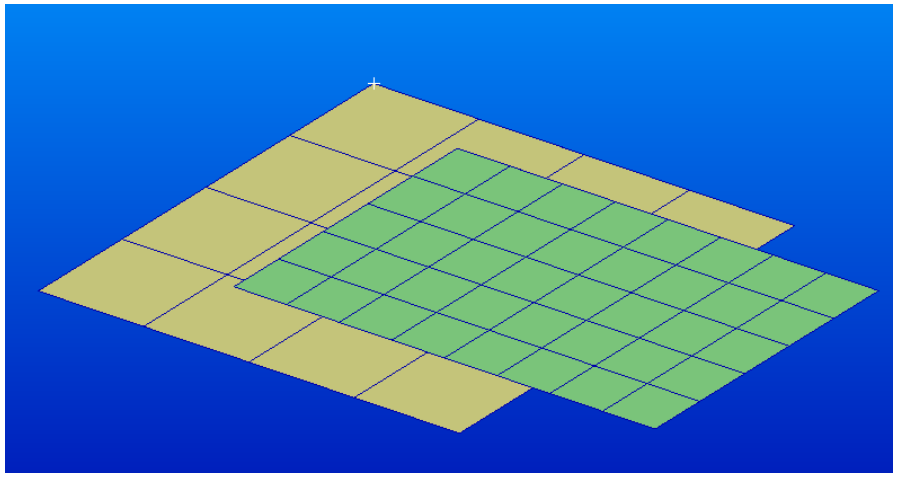
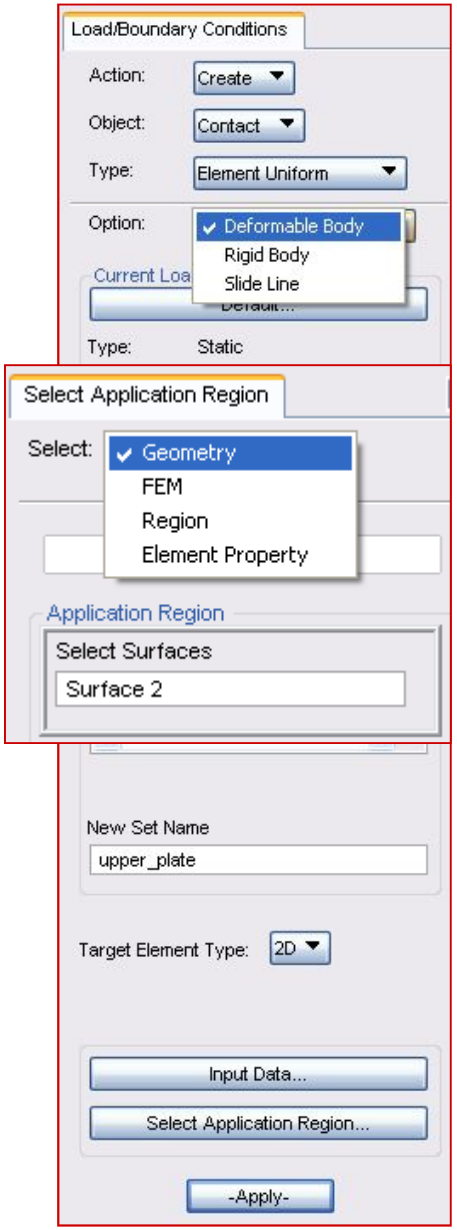
CASE STUDY 1: SHELL FACE-TO-FACE TOUCHING CONTACT

- **First define the contact bodies**







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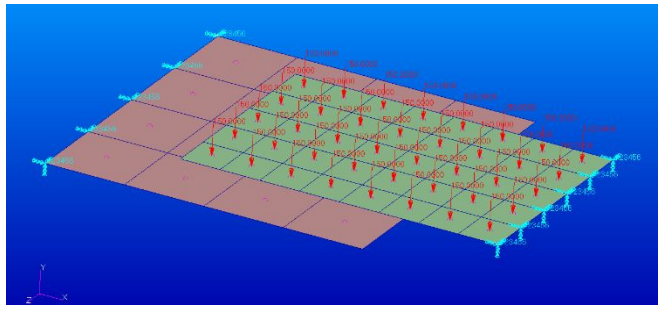
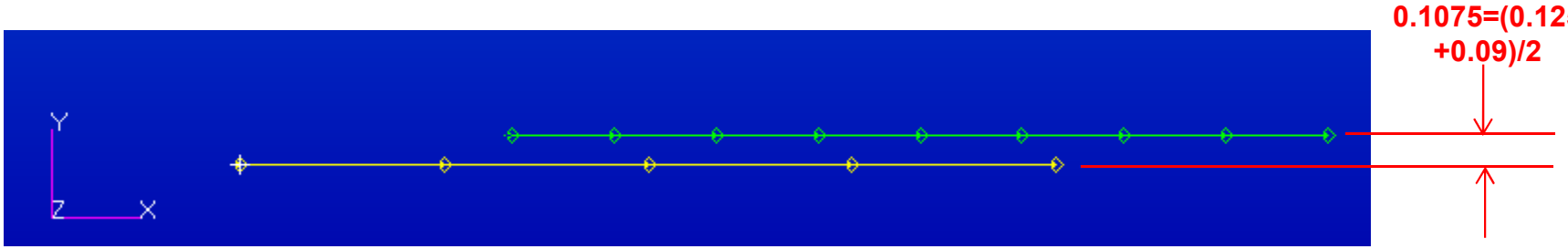
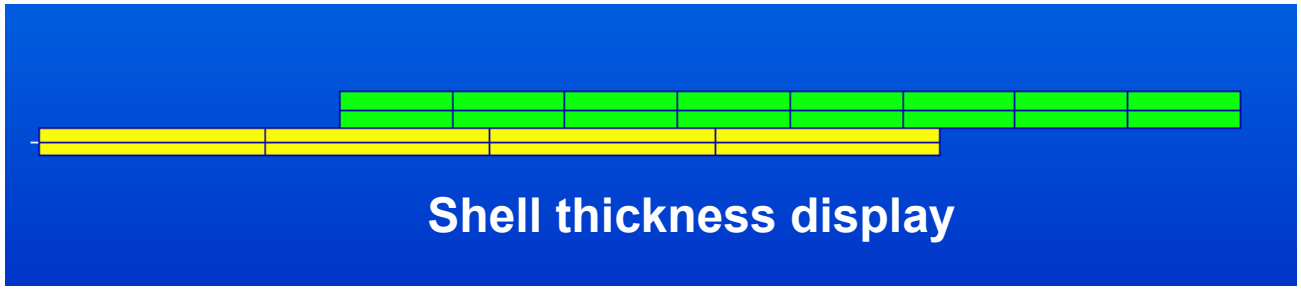
CASE STUDY 1: SHELL FACE-TO-FACE TOUCHING CONTACT

- **The contact bodies are located at (t1+t2)/2 apart**
  - Upper plate is 0.125 thick
  - Lower plate is 0.090 thick







Patran: Utilities\Display\Display Shell Thickness

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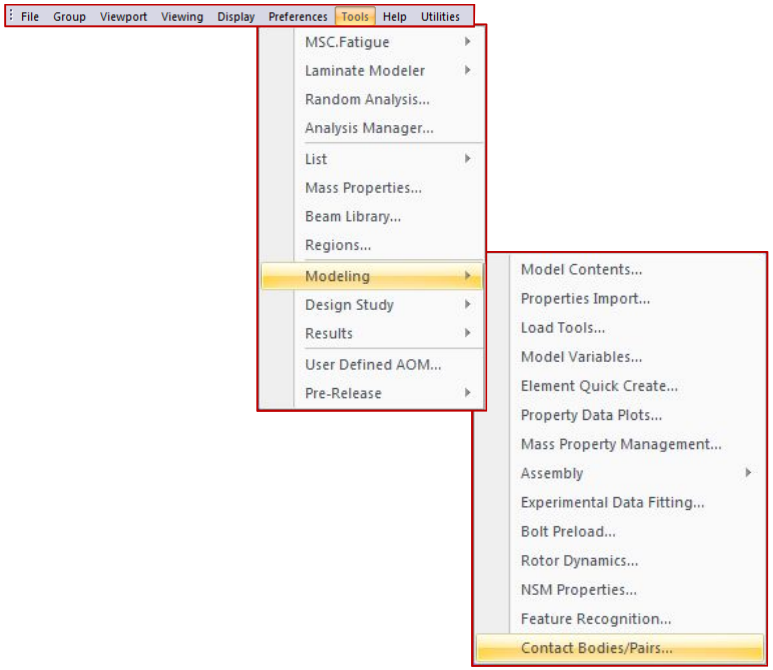
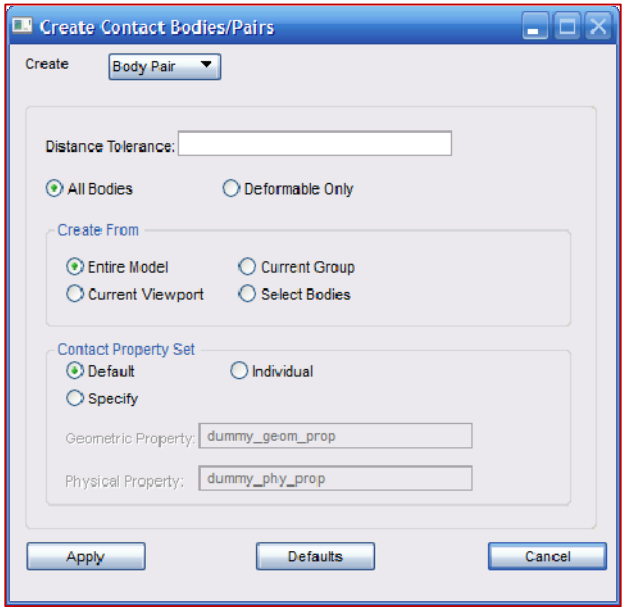
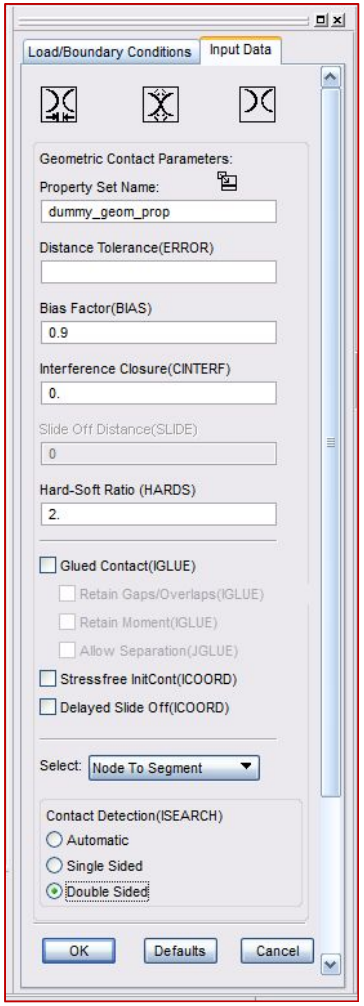
CASE STUDY 1: SHELL FACE-TO-FACE TOUCHING CONTACT

- **Next define the contact Pair: Tools>Modeling>Contact Bodies/Pair**







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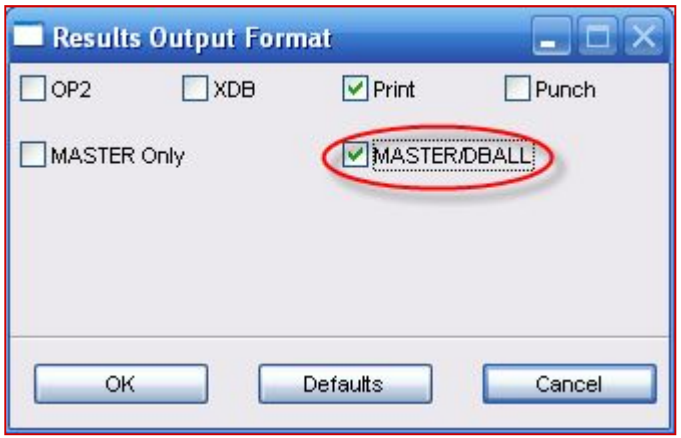
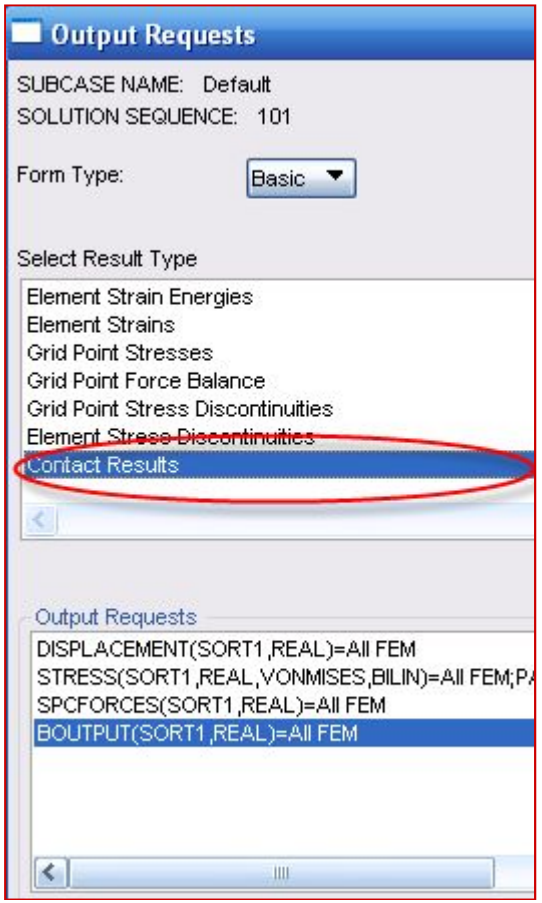
CASE STUDY 1: SHELL FACE-TO-FACE TOUCHING CONTACT

- **Plotting the Contact Status**
  - First request for Contact Status as an output quantity
  - Next specify MASTER/DBALL as results output format (contact results are not available in the XDB format)





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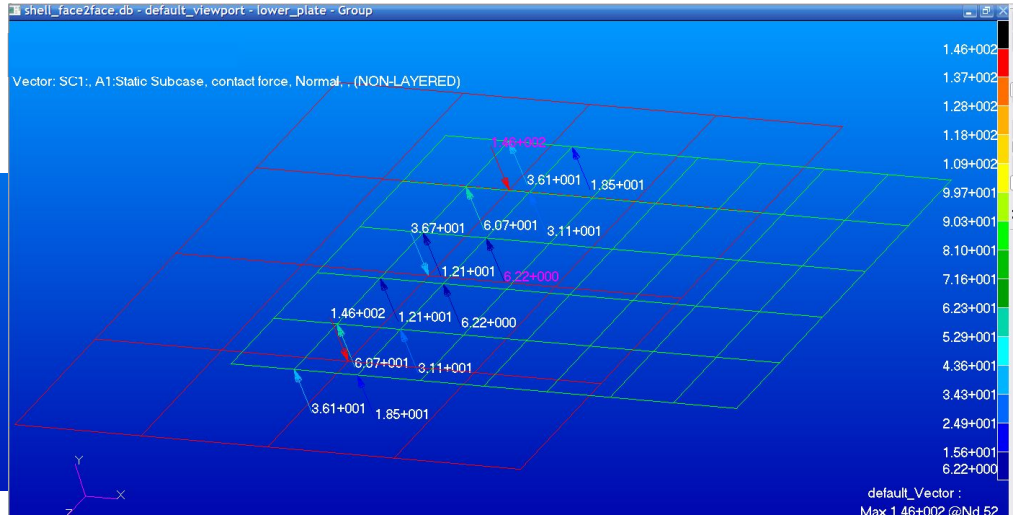
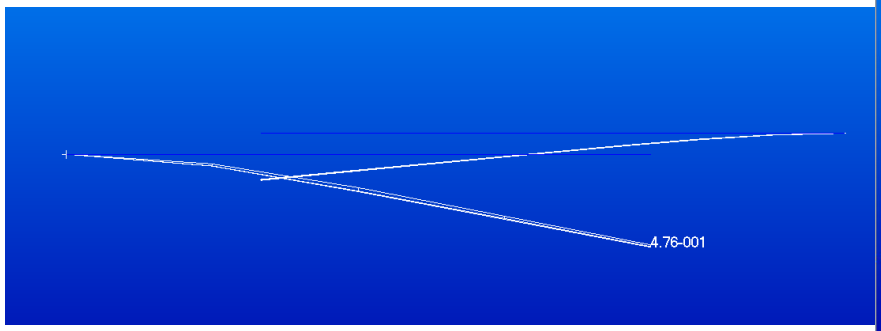
CASE STUDY 1: SHELL FACE-TO-FACE TOUCHING CONTACT

- **Run a linear static analysis**
  - Attach MASTER/DBALL (contact results are not available in the XDB format)
  - Plot the deformed shape in true scale
    - Penetration happens!
  - Plot normal contact force marker

Normal contact force





Deformation

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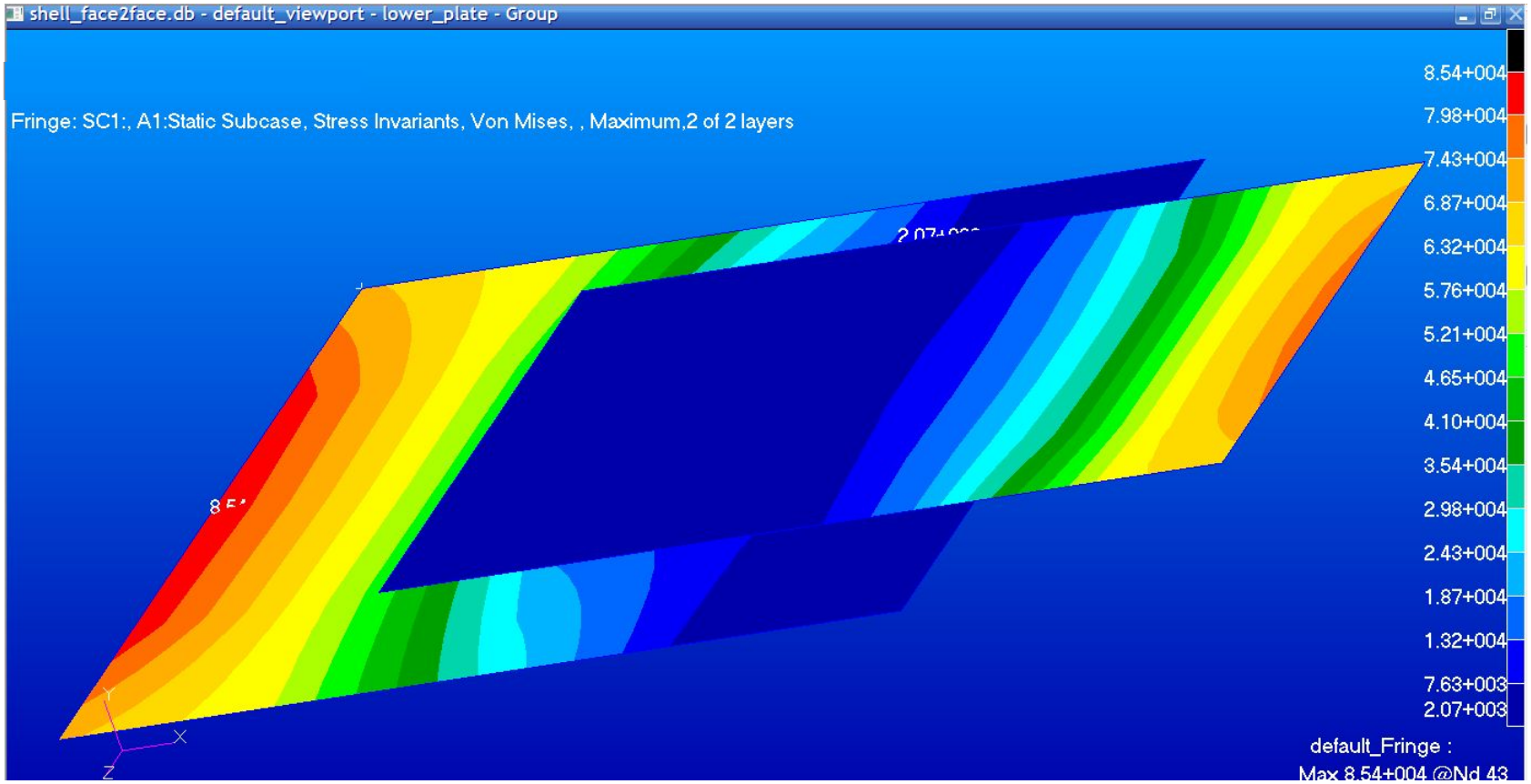
CASE STUDY 1: SHELL FACE-TO-FACE TOUCHING CONTACT

- **von Mises stress result**



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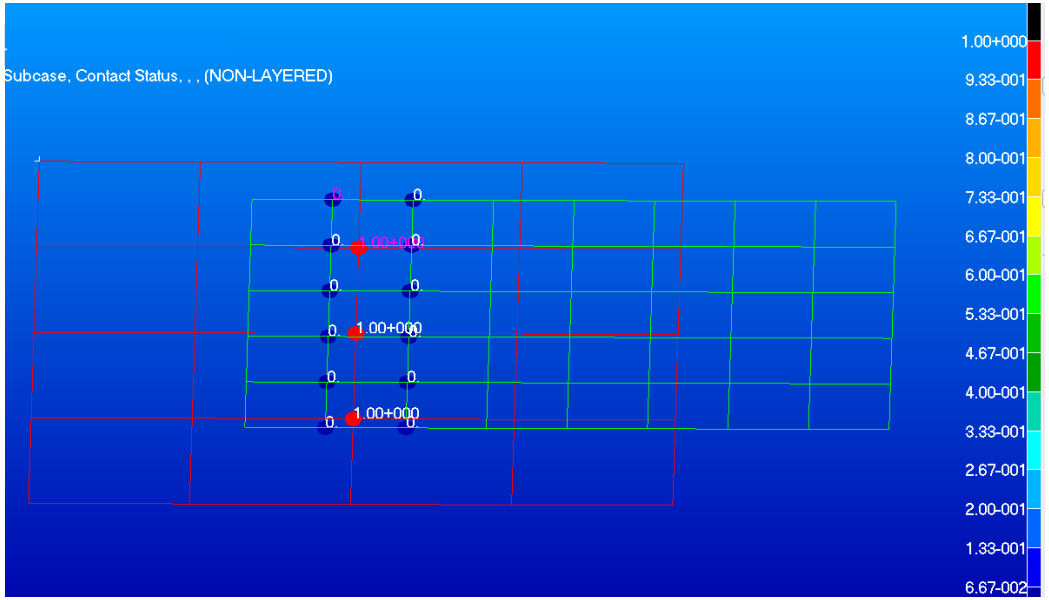
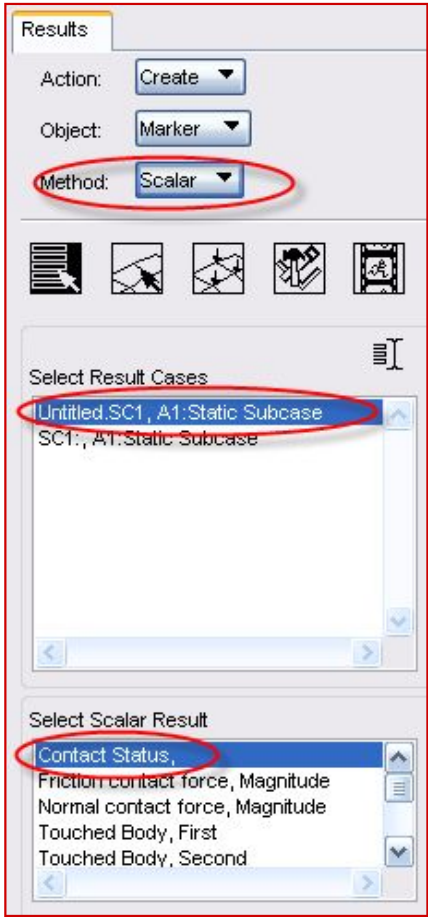
CASE STUDY 1: SHELL FACE-TO-FACE TOUCHING CONTACT

- **Plotting the Contact Status**
  - 0 indicates a touched node (master): nodes on the segment
    - Memory aid: 0 for a patch
  - 1 indicates a touching node (slave)





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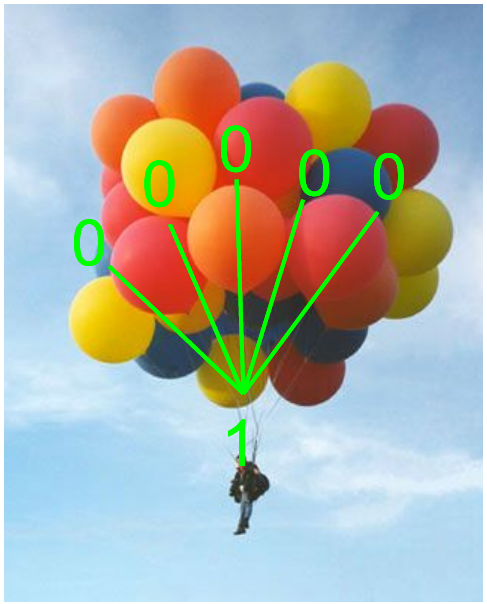
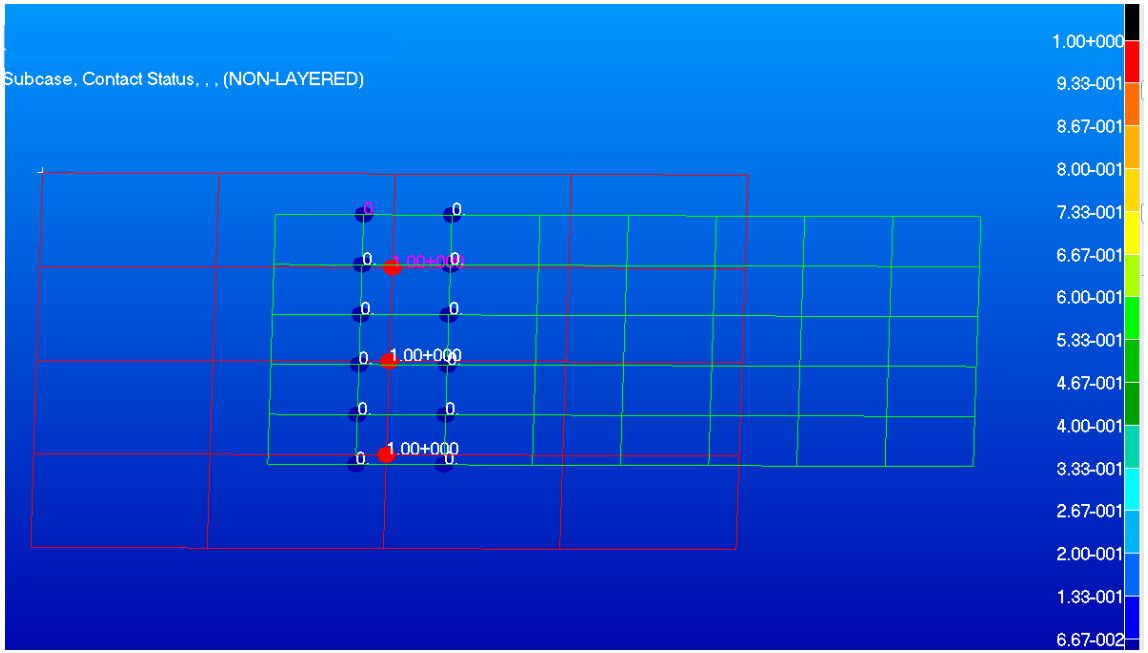
CASE STUDY 1: FIRST RUN PLOT THE CONTACT STATUS

- **Contact status shows 0's and 1's**
  - 0 indicates a touched node (master)
  - 1 indicates a touching node (slave)





Memory aid

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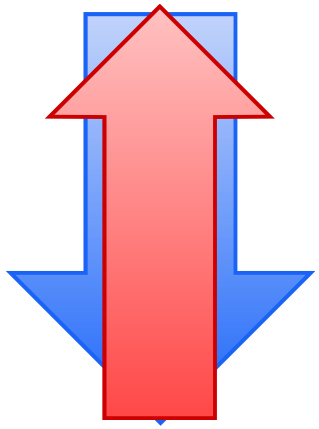
CASE STUDY 1: CONTACT SEARCH OPTIONS

- **The MSC Nastran default option for contact search order (ISEARCH=0) was used.**
  - First Pass: MSC Nastran first searches from each node on the lower-ID body toward elements on the higher-ID body.
  - Second Pass: MSC Nastran next searches from each node on the higher-ID body toward elements on the lower-ID body.
    - The new contact node-face pairs do not conflict with those already created during the first pass)



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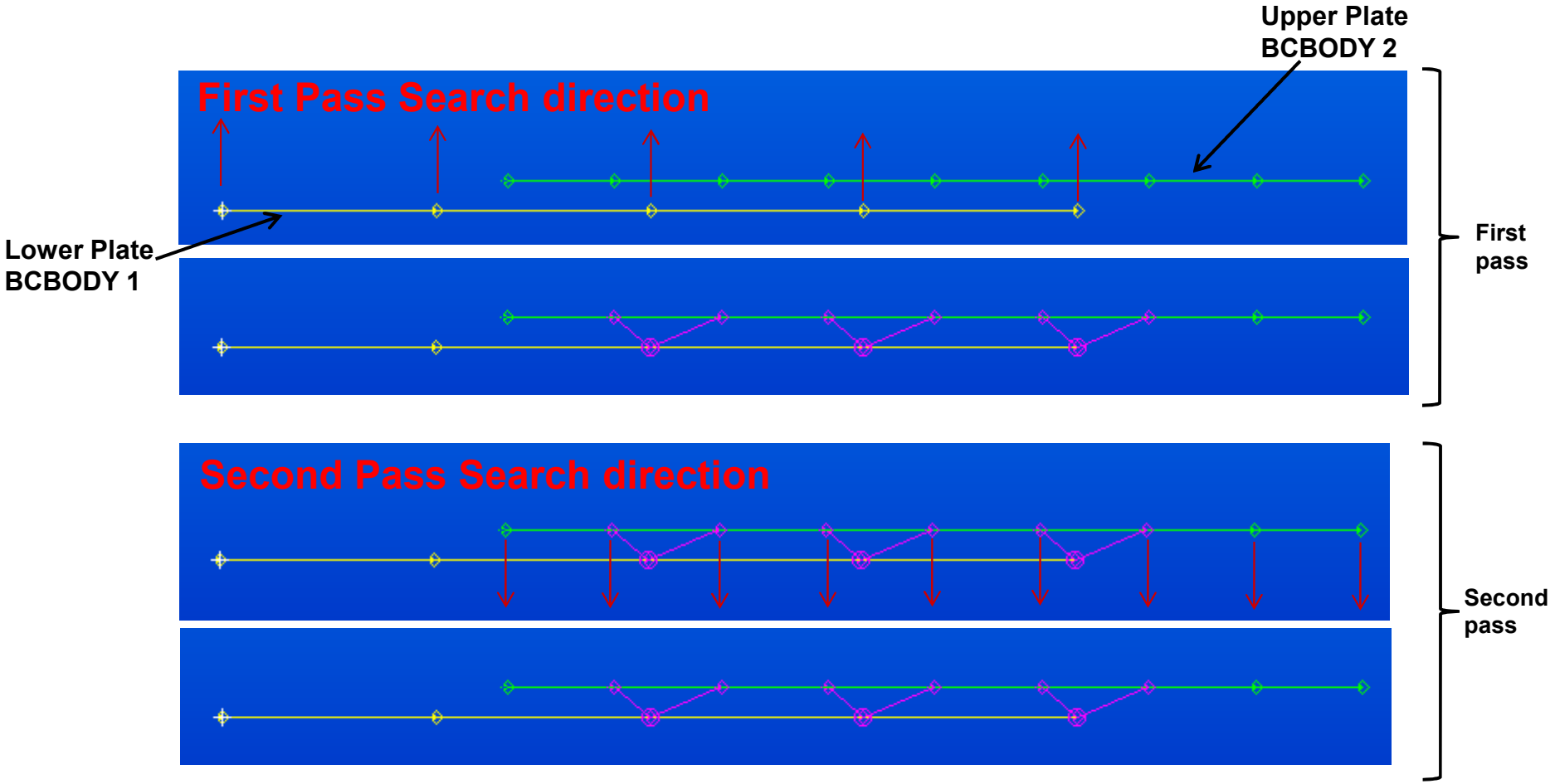
CASE STUDY 1: HOW ISEARCH WORKS

- **The default option for contact search order (ISEARCH=0)**



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CASE STUDY 1: CHANGE SEARCH ORDER TO ISEARCH=1

- **Would a different contact search order option produce a better touching joint?**
- **Try ISEARCH=1**
  - The user defines one body as Slave and one body as Master
  - The search order is from Slave to Master
  - Selecting the finer-mesh body as Slave in general produces a better touching contact.
    - Select the upper plate (finer mesh) as the Slave.
    - Select the lower plate (coarser mesh) as the Master

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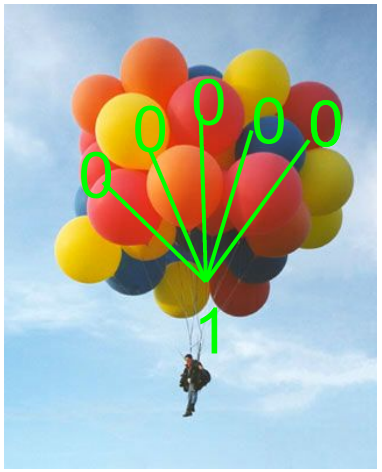
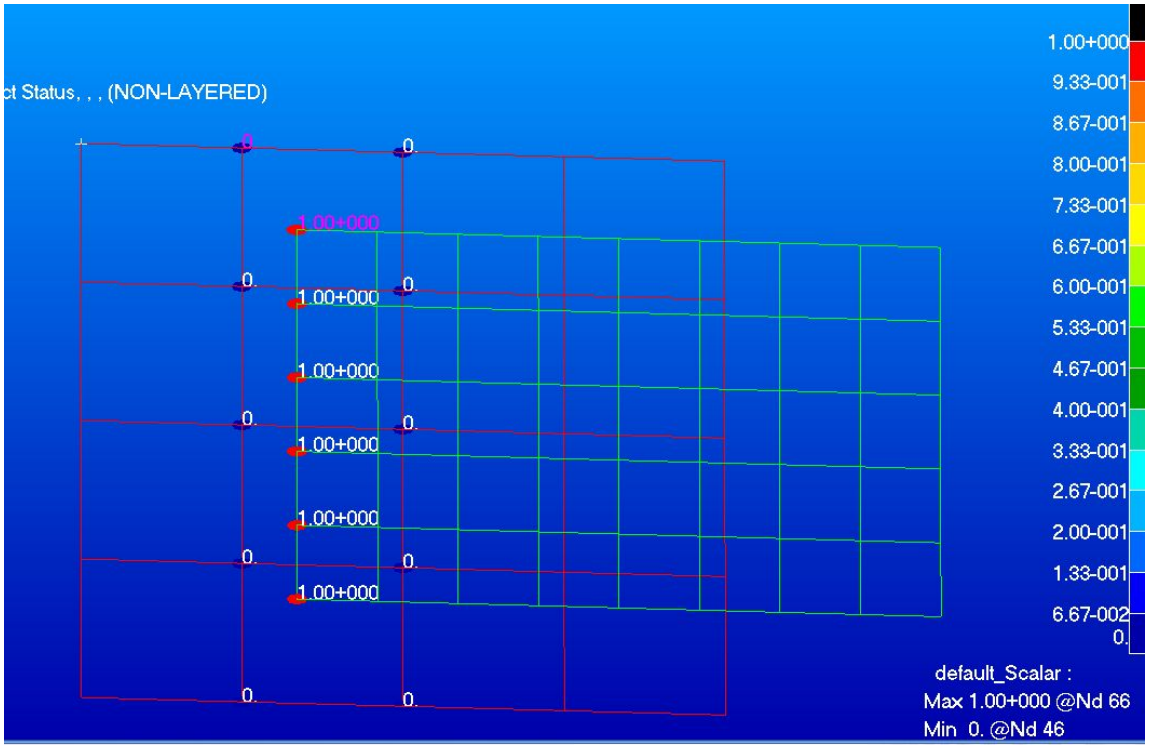
CASE STUDY 1: SECOND RUN PLOT THE CONTACT STATUS FOR ISEARCH=1



- **Plotting the Contact Status**
  - 0 indicates a touched node (master)
  - 1 indicates a touching node (slave)



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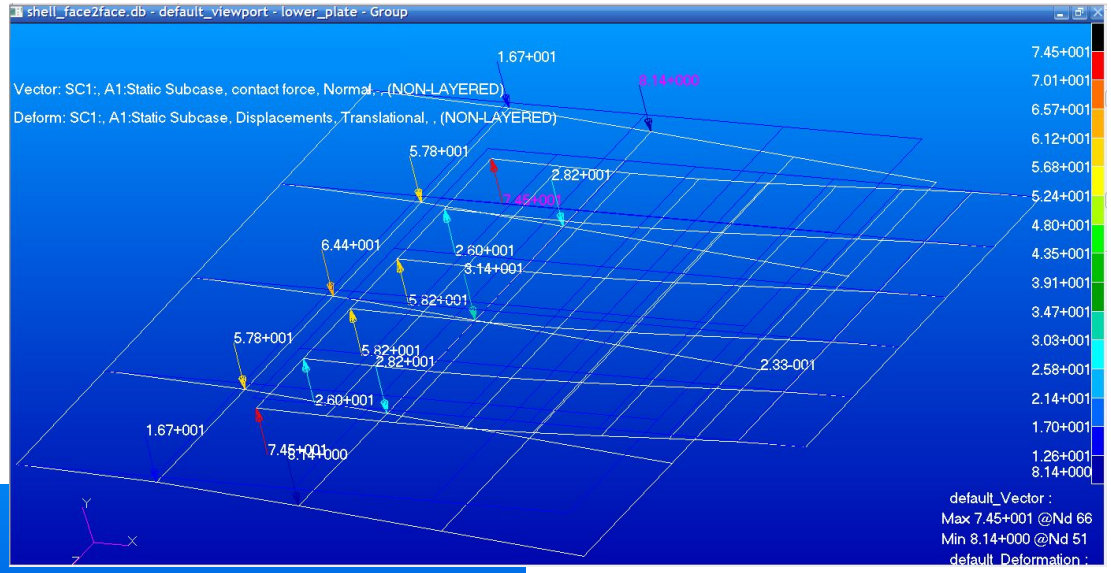
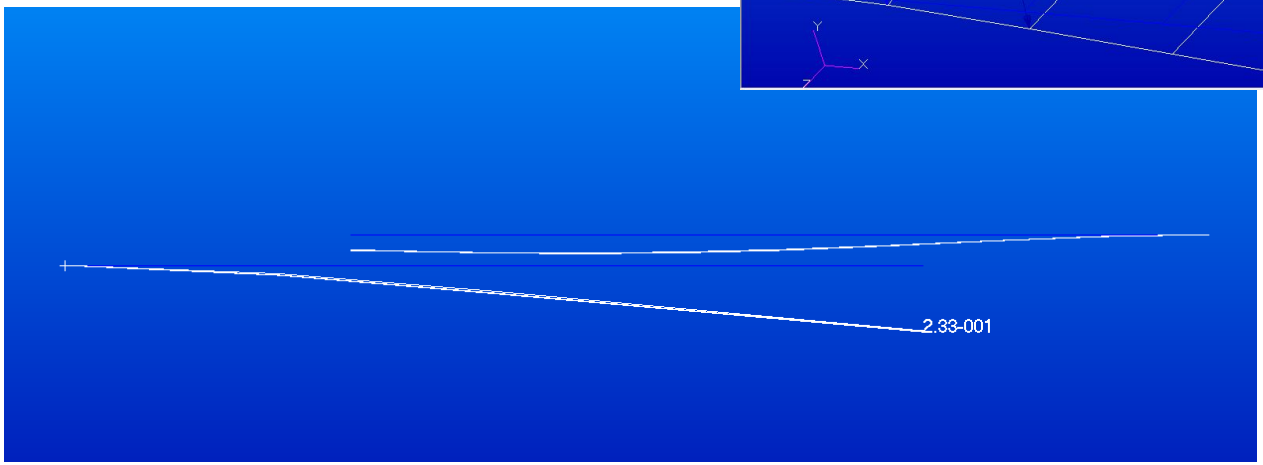
CASE STUDY 1: SECOND RUN DEFORMATION AND NORMAL CONTACT FORCE FOR ISEARCH =1



Normal Contact Force



Deformation

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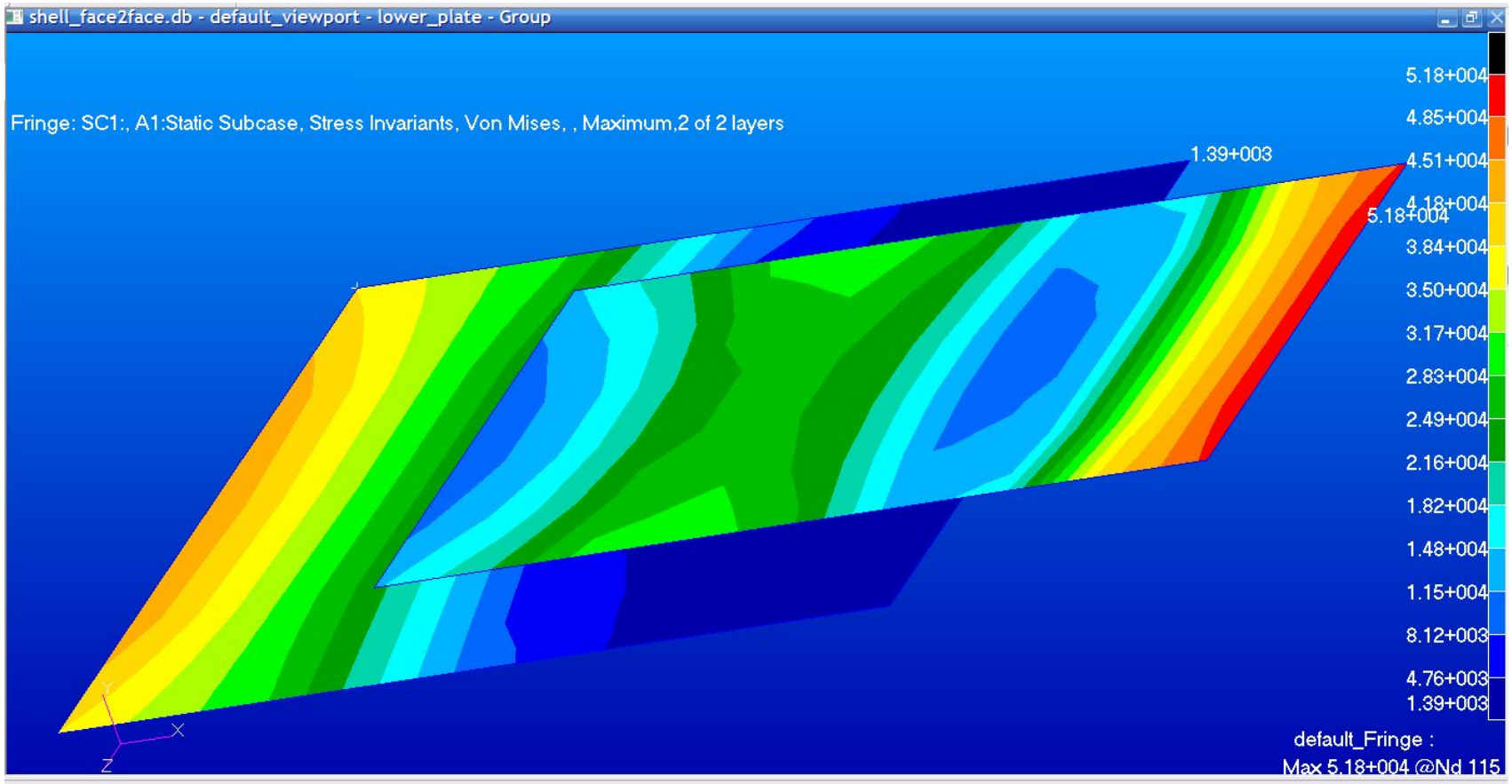
CASE STUDY 1: SECOND RUN VON MISES STRESS FOR ISEARCH=1



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CASE STUDY 1: CHANGE SEARCH ORDER TO ISEARCH=2

- **MSC Nastran can select the Slave and Master bodies for you automatically based on element edge size and thickness**
- **This is done with ISEARCH=2**
  - The contact tolerance for each body is computed
  - The contact tolerance is equal to 1/20 of the smallest element edge for any element in a contact body or 1/4 of the thickness of any shell element in a contact body, whichever is smaller.
  - Search order is from the body with the smaller contact tolerance to the body with the larger contact tolerance.
  - This option is currently not recommended for shell contact bodies because the thickness criterion may result in the coarser mesh body being selected as the Slave.

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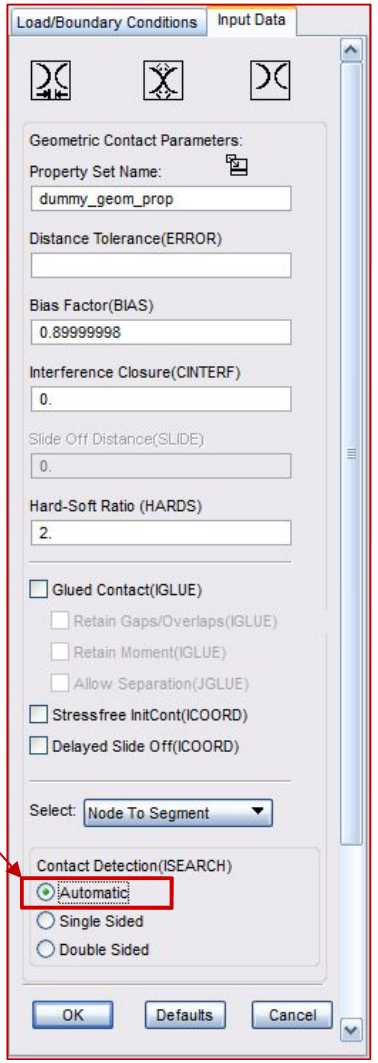
CASE STUDY 1: CHANGE SEARCH ORDER TO ISEARCH=2

- **Set the contact search order**
  - Select Automatic in Patran form



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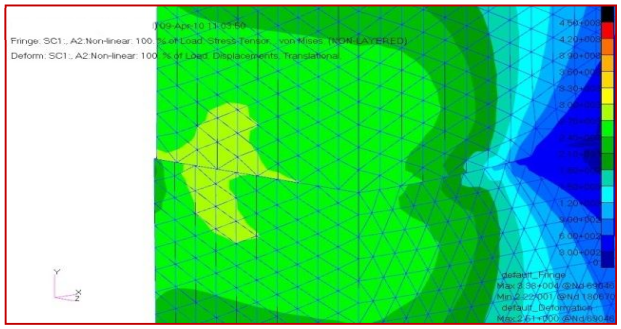
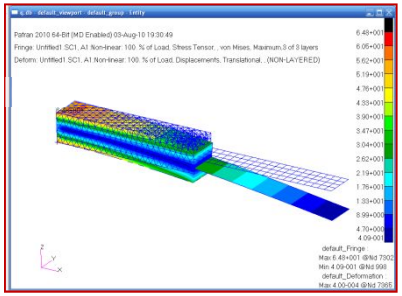
CASE STUDY 1: SEGMENT-TO-SEGMENT CONTACT

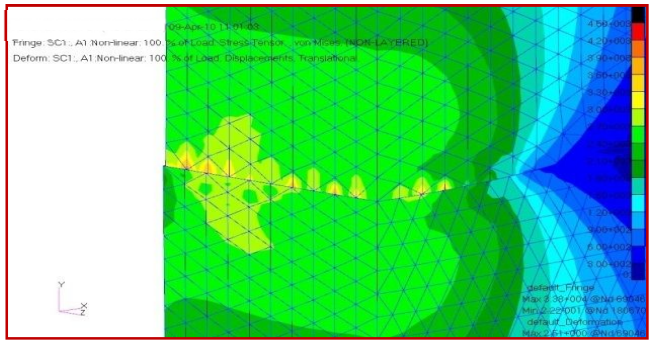
- **Segment–to–segment contact**
  - Improved accuracy providing a better stress continuity in the contact region.
- **How did you do it before?**
  - Node to Segment



Segment to Segment

Full Bending Continuity – glued contact





Node to Segment

- **Why is it better?**
  - Improved Accuracy
  - Full shell thickness “footprint”
  - Shell can connect on both sides (not dependent on MPC dependency limitations)
  - Fewer contact parameters compared to the node-to-segment algorithm (automatic moment-carrying glue on shell/solid connections)
  - Don’t need to worry about Master/Slave selection

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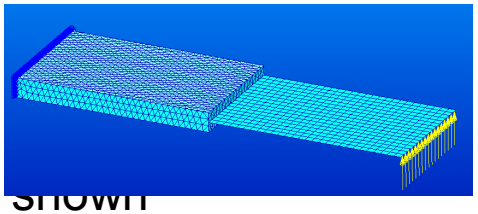
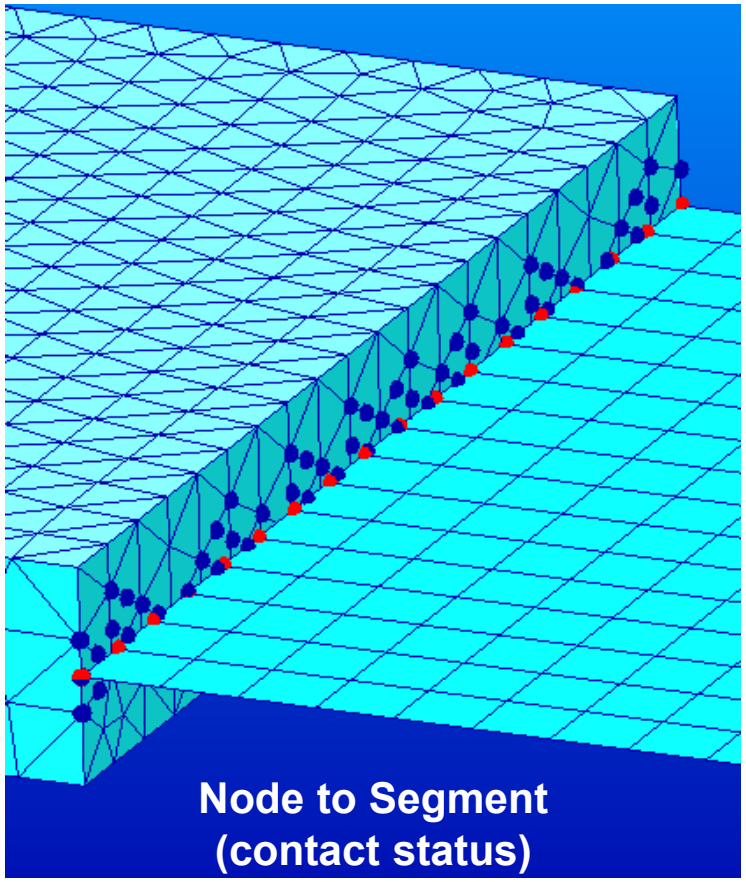
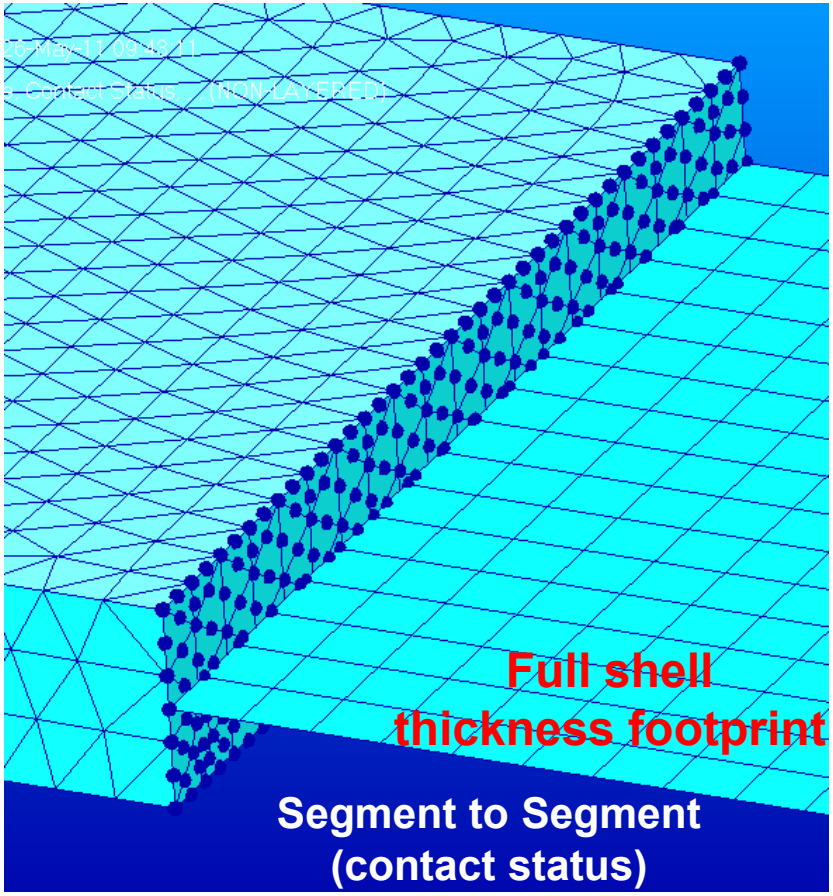
CASE STUDY 1: SEGMENT-TO-SEGMENT CONTACT



- **Better shell edge to solid face glued contact**
  - Shell and solid bodies have equal thickness in example shown
  - Shell contact footprint is equal to shell thickness for segment-to-segment contact





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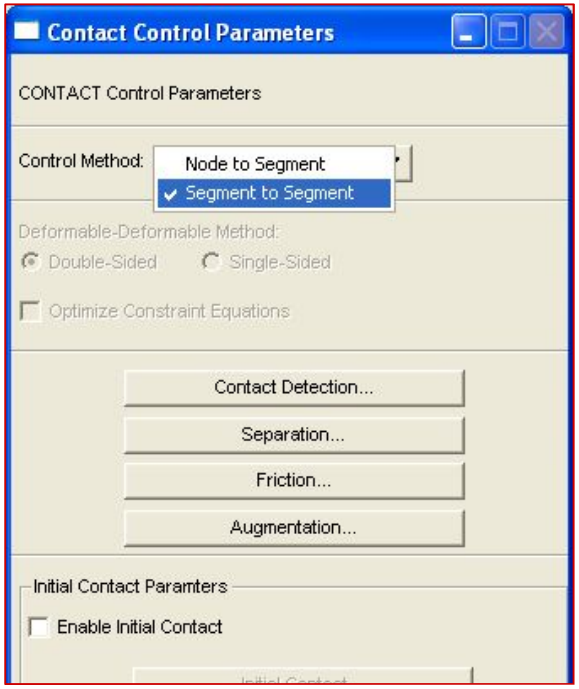
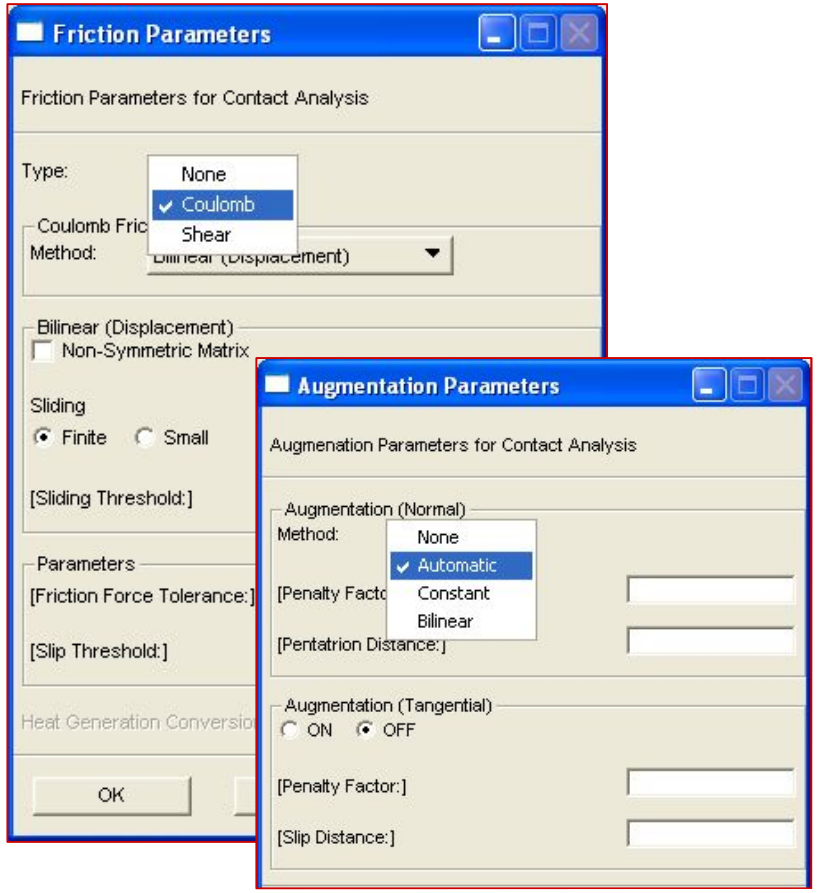
CASE STUDY 1: SEGMENT-TO-SEGMENT CONTACT SUPPORT

- **Supports the segment-to-segment contact: Analysis\Solution Type\Contact Parameters**
  - Friction parameters
  - Augmentation parameters





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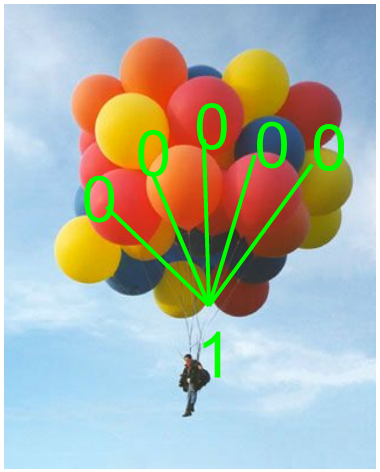
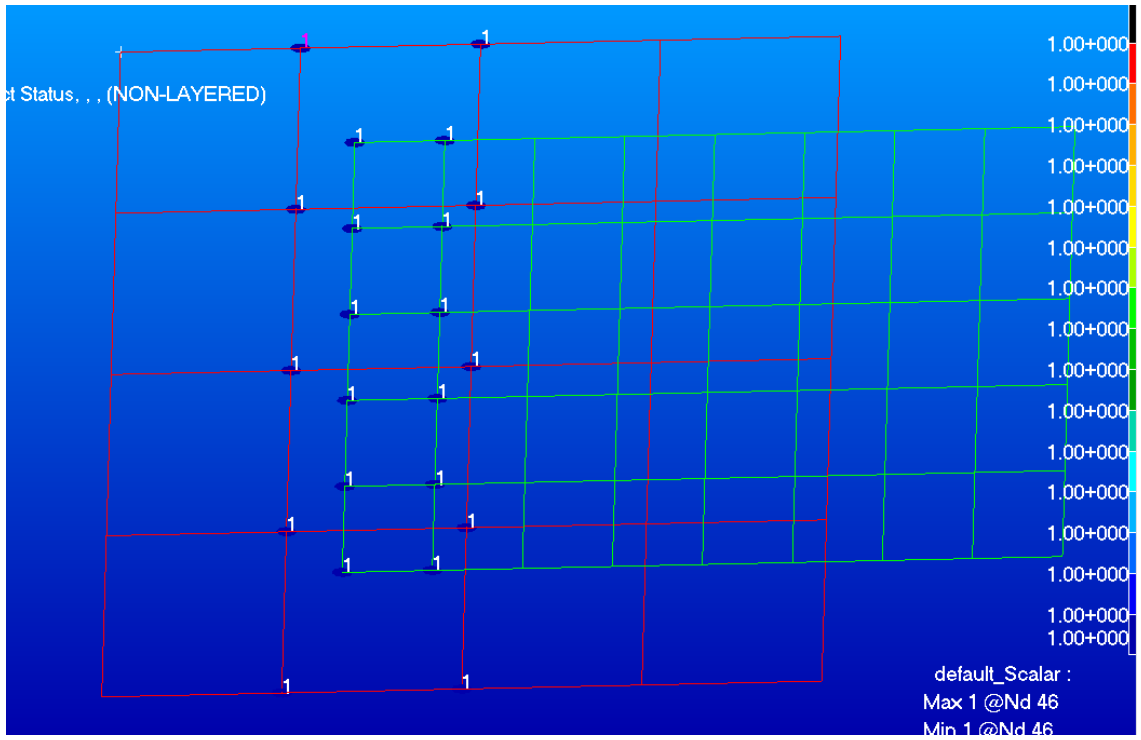
CASE STUDY 1: THIRD RUN PLOT THE CONTACT STATUS FOR SEGMENT-TO-SEGMENT CONTACT

- **Plotting the Contact Status**
  - 0 indicates a touched node (master)
  - 1 indicates a touching node (slave)
  - All the nodes have 1: no slave/master concept





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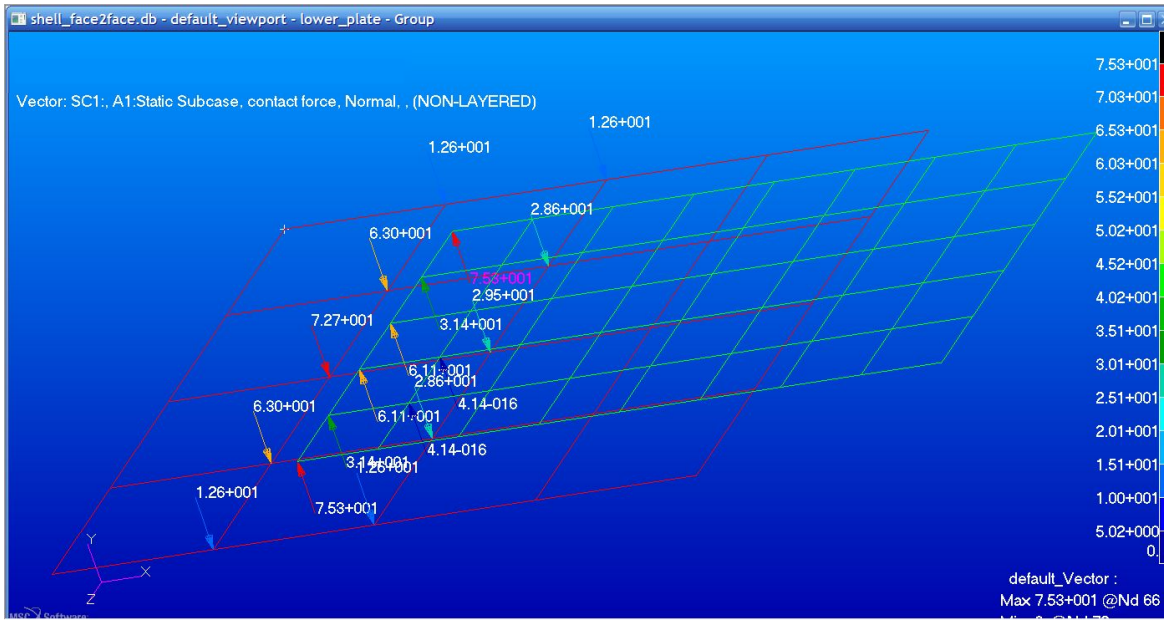
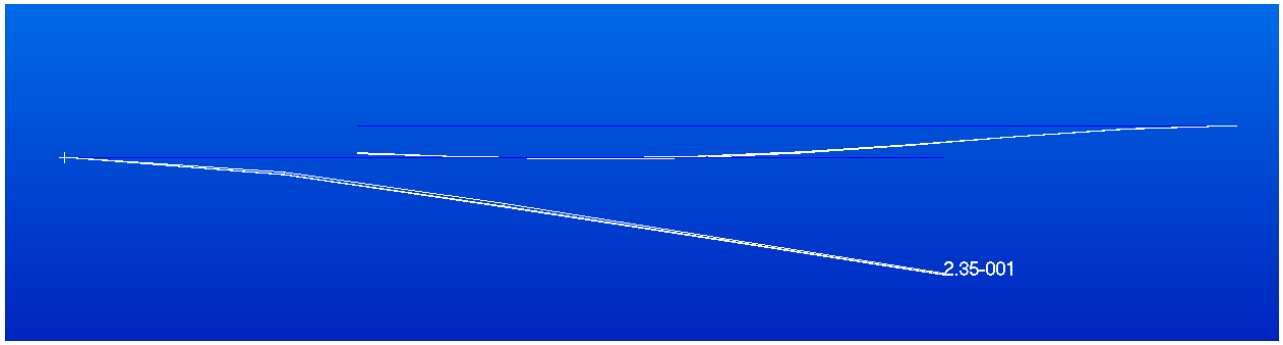
CASE STUDY 1: THIRD RUN DEFORMATION AND NORMAL CONTACT FORCE FOR SEGMENT-TO-SEGMENT CONTACT



Normal Contact Force



Deformation

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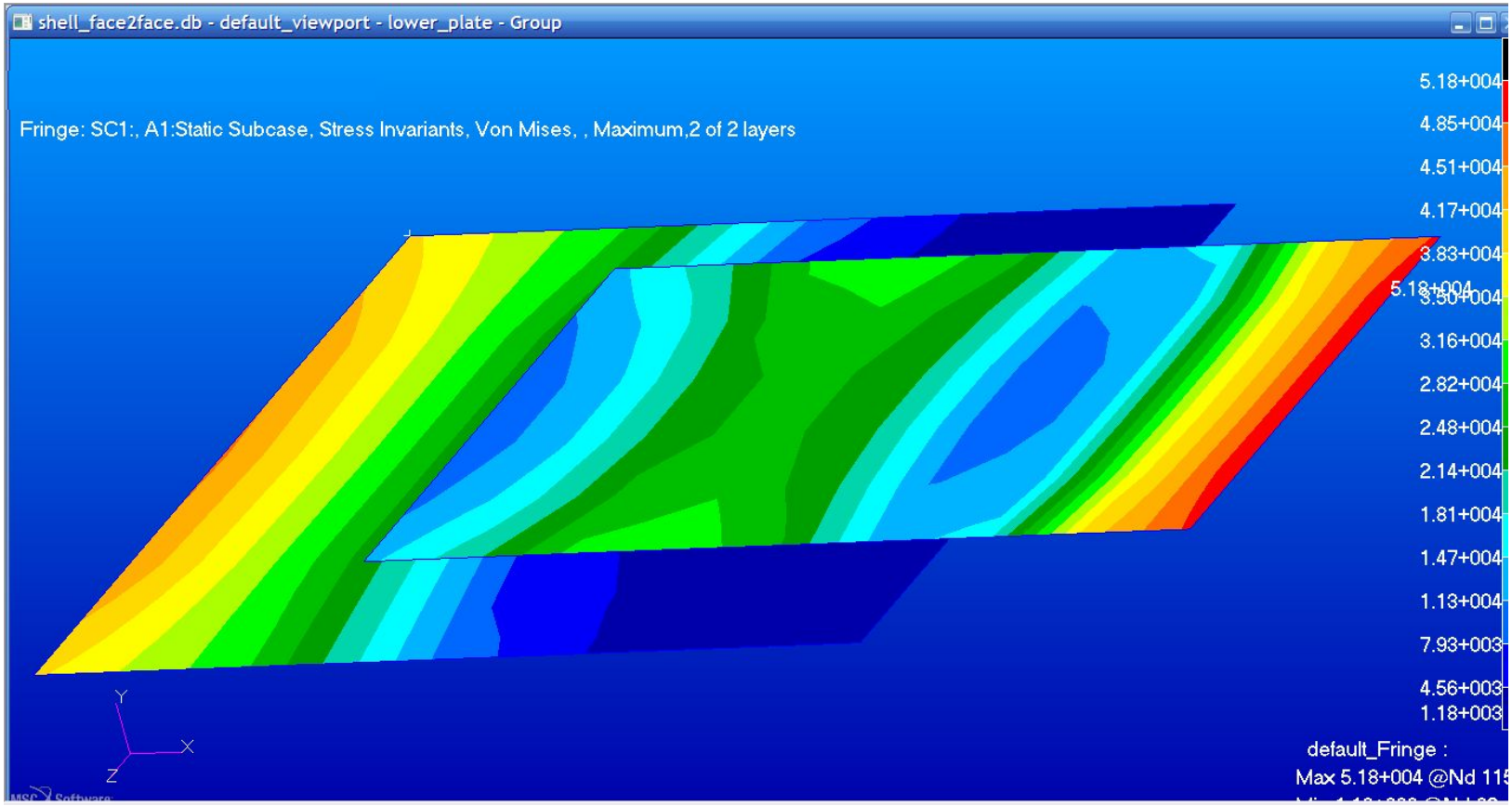
CASE STUDY 1: THIRD RUN VON MISES STREES FOR SEGMENT-TO-SEGMENT CONTACT



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CASE STUDY 1: SHELL FACE-TO-FACE TOUCHING CONTACT

- **Result Comparison**

	Node-to-Segment ISEARCH=0	Node-to-Segment ISEARCH=1	Segment-to-Segment ISEARCH=0/1
Maximum Displacement	0.476	0.233	0.235
Maximum von Mises Stress	8.54e4	5.18e4	5.18e4
Maximum Contact Force	146	74.5	75.3

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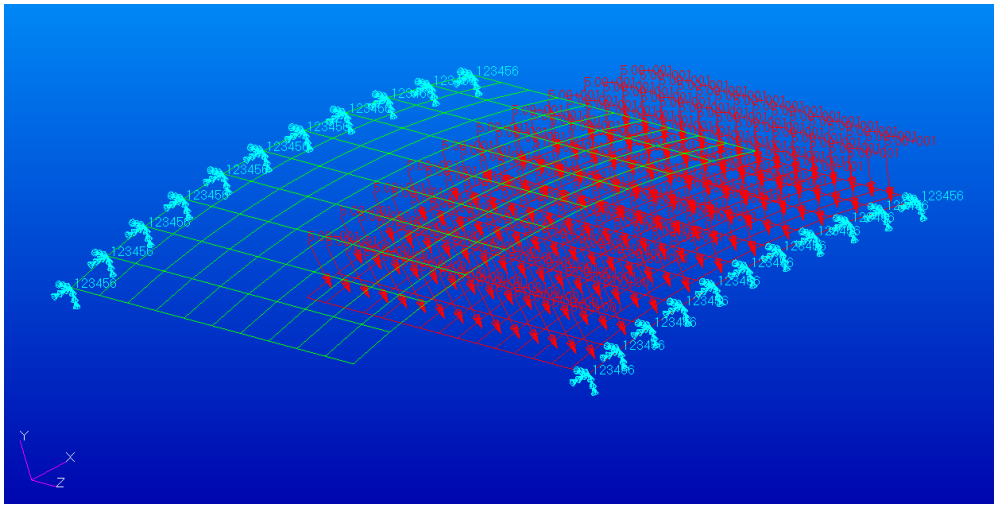
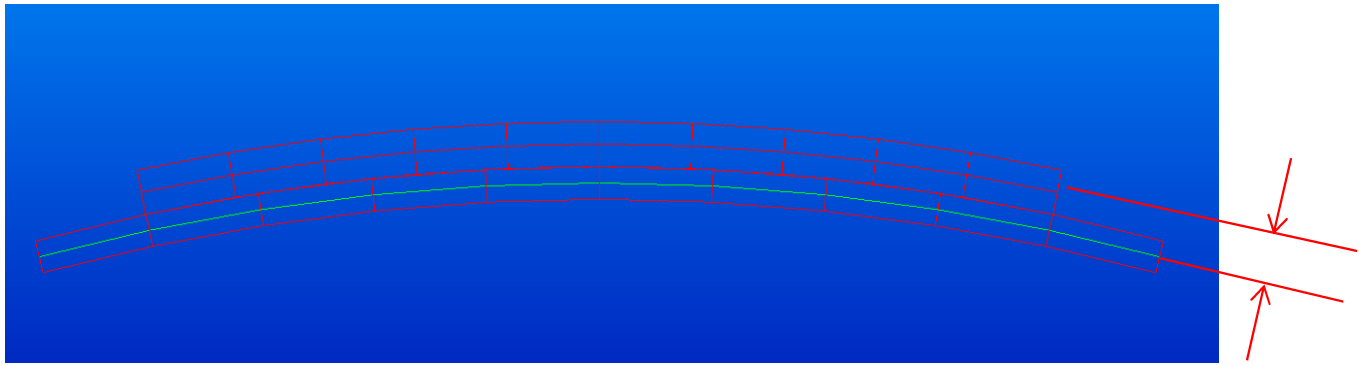
CASE STUDY 2: CURVED SHELL FACE-TO-FACE TOUCHING CONTACT

- **The curved contact bodies have radius difference of (t1+t2)/2**
  - Upper plate is 0.125 thick
  - Lower plate is 0.090 thick





0.1075=(0.125+0.09)/2

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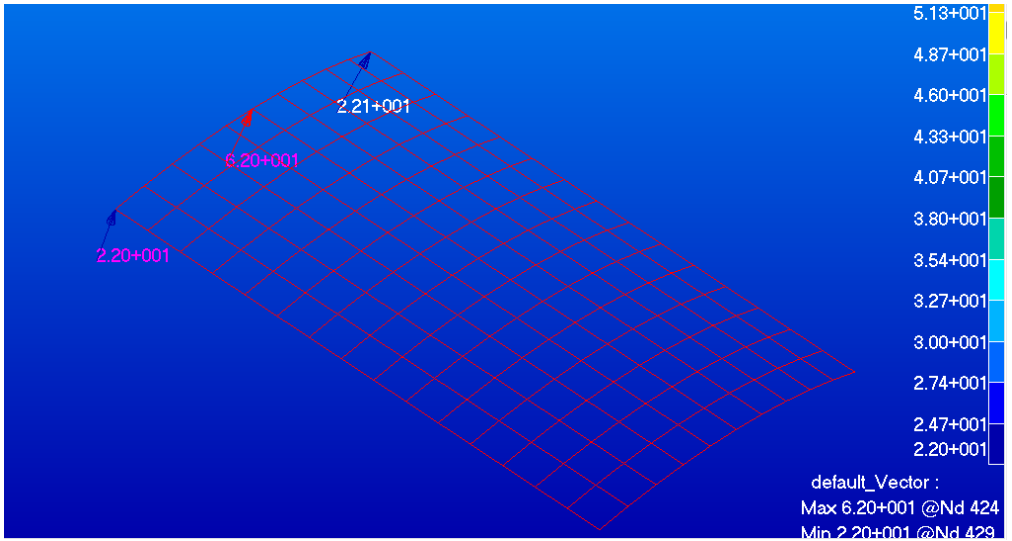
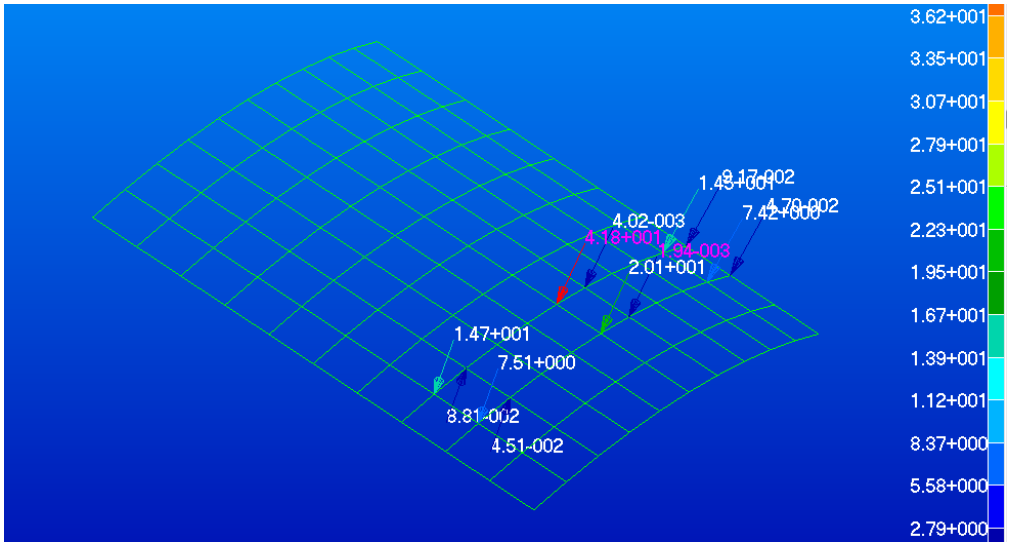
CASE STUDY 2: FIRST RUN CURVED SHELL FACE-TO-FACE TOUCHING CONTACT

- **Using default settings and ISEARCH=1**
  - Normal contact force

Upper shell:
Few touching nodes detected!



Lower shell



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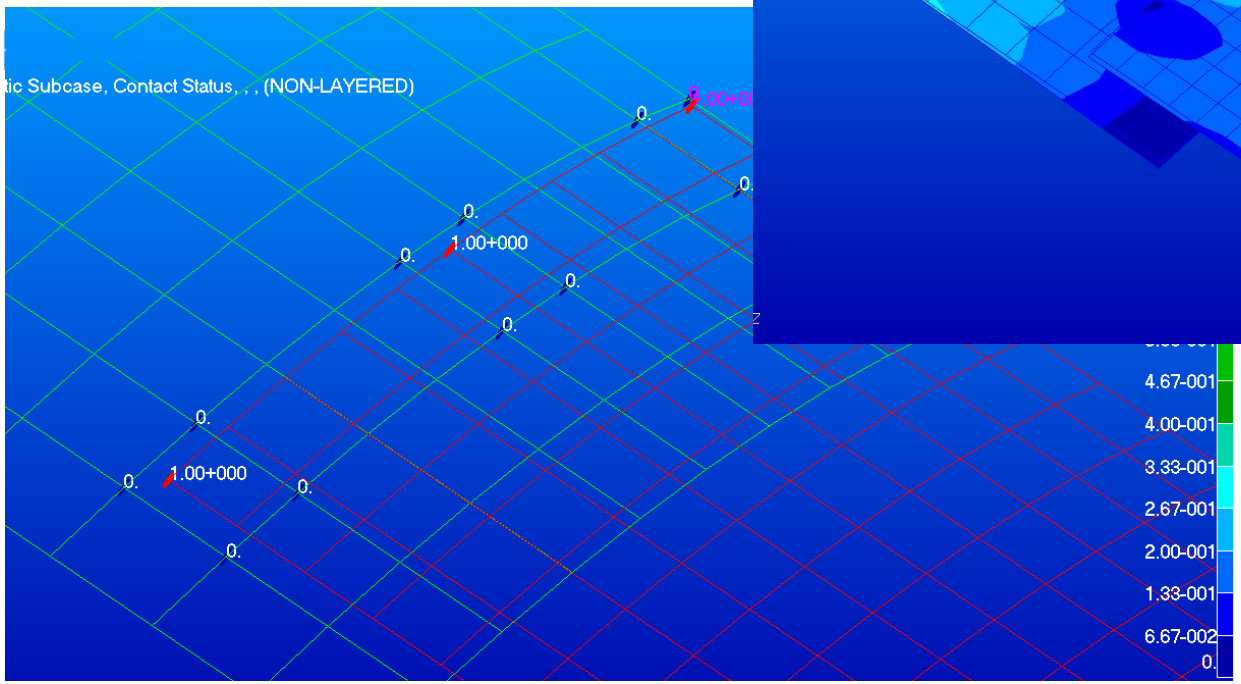
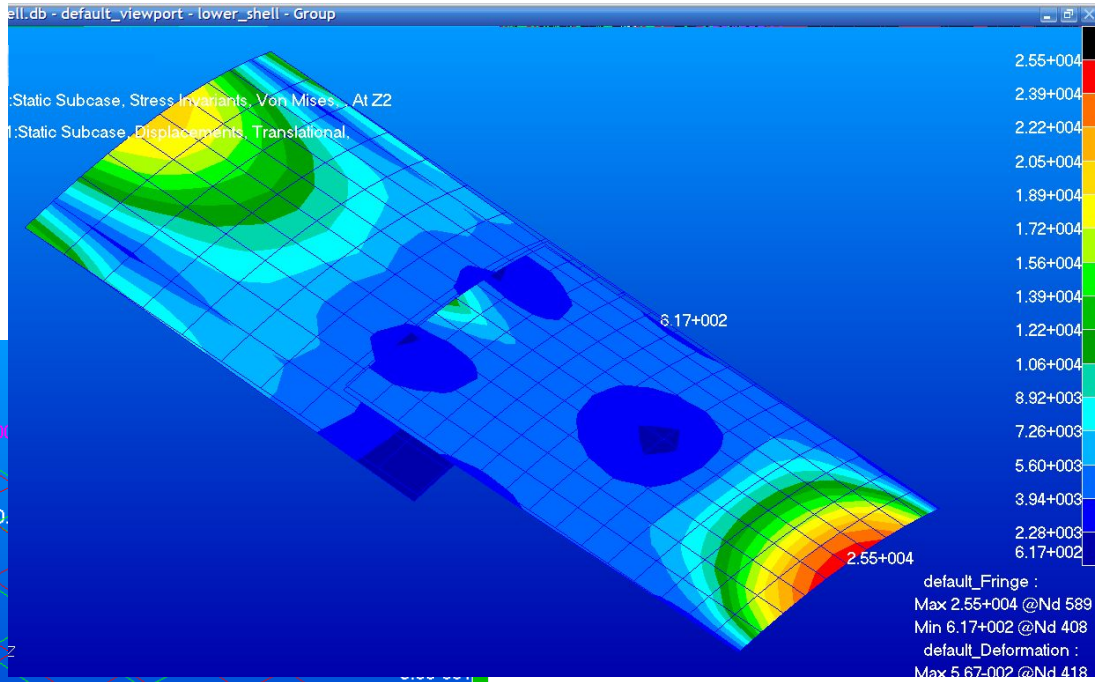
CASE STUDY 2: FIRST RUN CURVED SHELL FACE-TO-FACE TOUCHING CONTACT

- **Using default settings and ISEARCH=1**
  - Deformation and von Mises stress
  - Contact Status





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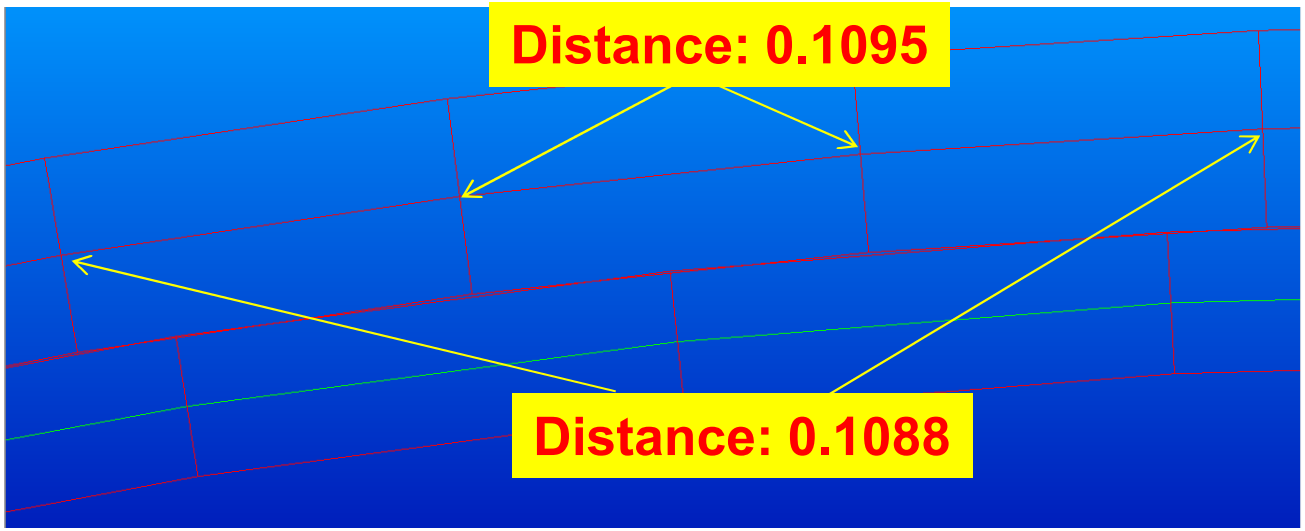
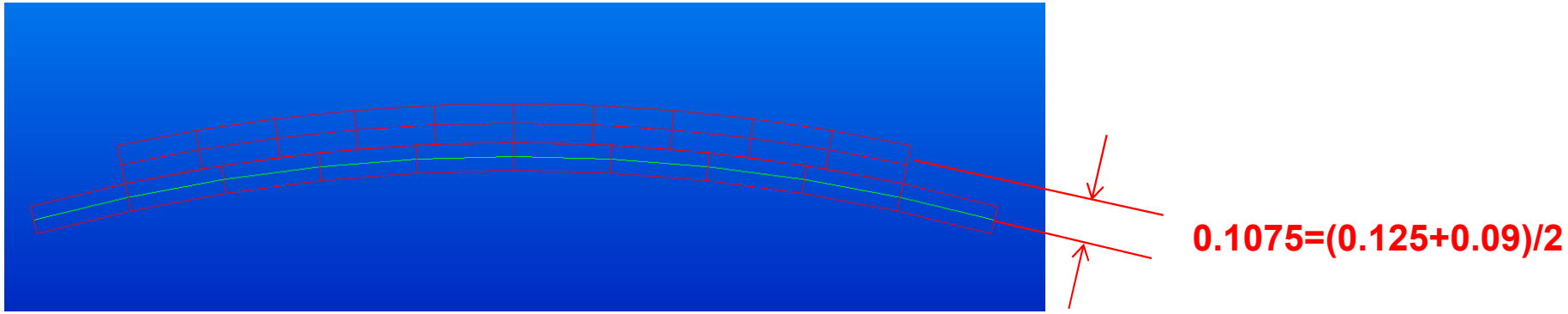
CASE STUDY 2: FIRST RUN CURVED SHELL FACE-TO-FACE TOUCHING CONTACT

- **Distance between upper nodes and lower element faces**
  - Biggest gap: 0.1095 - 0.1075 = 0.002





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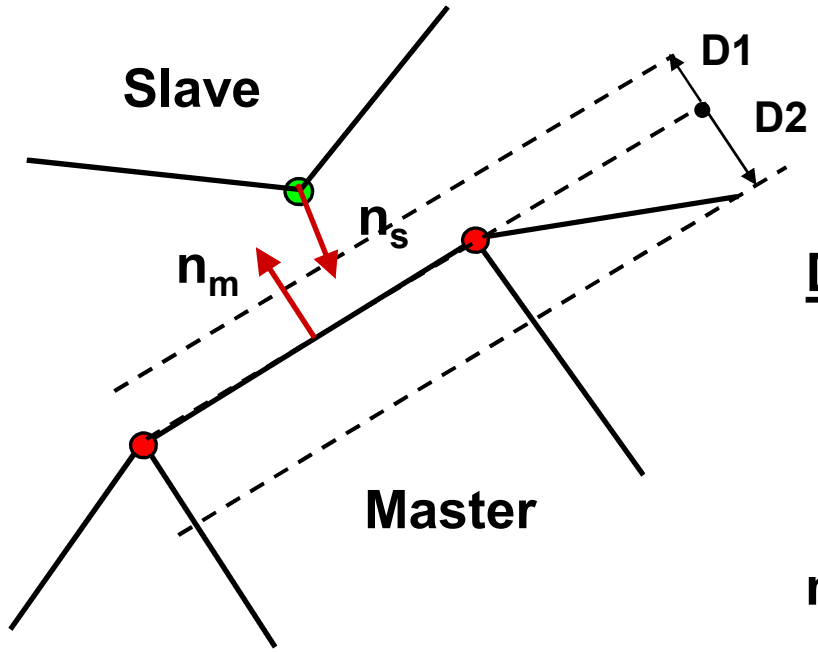
CASE STUDY 2: FIRST RUN CURVED SHELL FACE-TO-FACE TOUCHING CONTACT

- **What is contact tolerance?**
  - Contact tolerance is measured normal to the Master contact body as shown below
  - When there are gaps and overlaps between a contact body pair, a slave node is considered in touch with the master surface if it falls within this contact tolerance zone.



Default BIAS: 0.9 for touching contact; 0.0 for glued contact

Distance Tolerances

D1=(1 – BIAS)xERROR

D2=(1 + BIAS)xERROR

n – contact normals

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CASE STUDY 2: FIRST RUN CURVED SHELL FACE-TO-FACE TOUCHING CONTACT

- **What is the default contact tolerance value?**
  - The default Contact Tolerance is equal to 1/20 of the smallest element edge for any element in any contact body or 1/4 of the thickness of any shell element in any contact body, whichever is the smallest.
  - Important – MSC Nastran searches thru **all** the contact bodies in the model for this smallest value.

```
            contact tolerances per contact body:
             body_id body_name                contact_tolerance     element_id  outside_nodes  outside_patches
                   1 body_1                        1.50000E-02       321 edge            121              240
                   2 body_2                        1.00000E-02       461 edge            176              350

            relative displacement below which sticking is simulated :  6.48920E-04


            average edge length of all contact body segments:          0.00000E+00
1    MSC.NASTRAN JOB CREATED ON 09-JUL-12 AT 16:02:55                        JULY  10, 2012  MSC.NASTRAN 11/25/11

0                                                                                                          SUBCASE

     ********************************************
     Values used during contact : contact tolerance                        (ERROR)
          Default Value =   0.1000000E-01
     ********************************************
      Body ID       1 Defor        2 Defor
     ---------------------------------------------
     1 Defor             N/A         0.2500000E-01
     ---------------------------------------------
     2 Defor          0.2500000E-01     N/A
     ********************************************
```

"edge": element edge length
"prop": shell element thickness

Default ERROR= 0.01

Obtained with Case Control Section command: **NLOPRM NLDBG=N3DMED**

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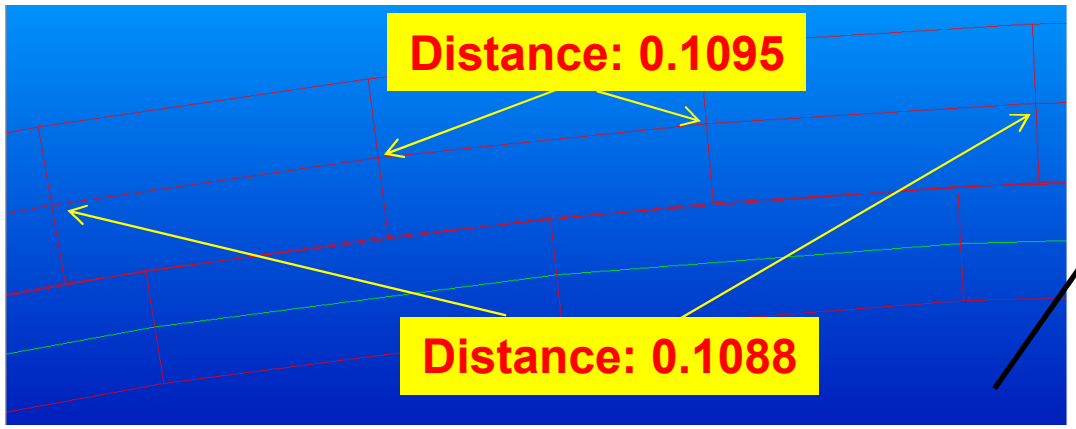
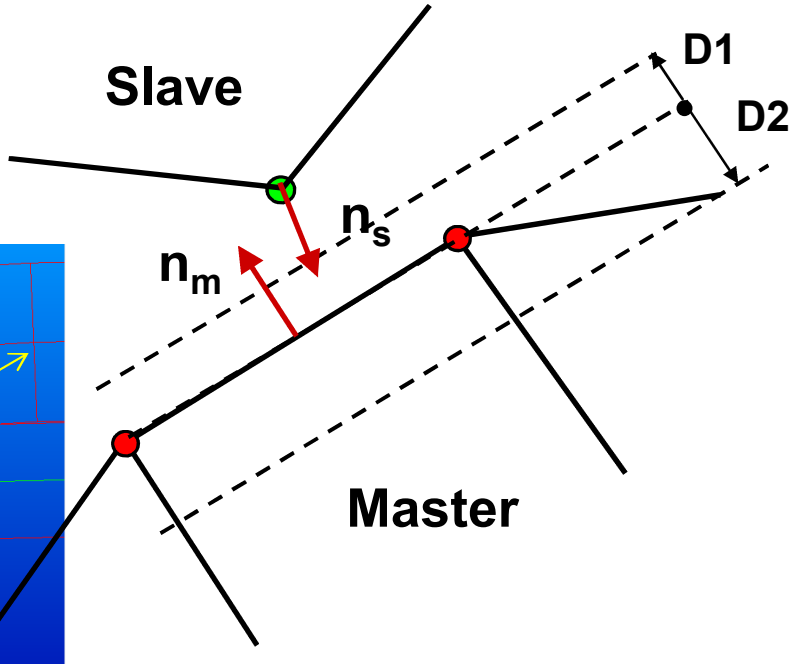
CASE STUDY 2: FIRST RUN CURVED SHELL FACE-TO-FACE TOUCHING CONTACT

- **Default contact tolerance value for this example**
  - BIAS=0.9, ERROR=0.01
  - D1=(1-BIAS)*ERROR=0.001 < 0.002
  - D2=(1+BIAS)*ERROR=0.019
  - If ERROR=0.025, D1=0.0025>0.002

Biggest gap: 0.1095 - 0.1075 = 0.002





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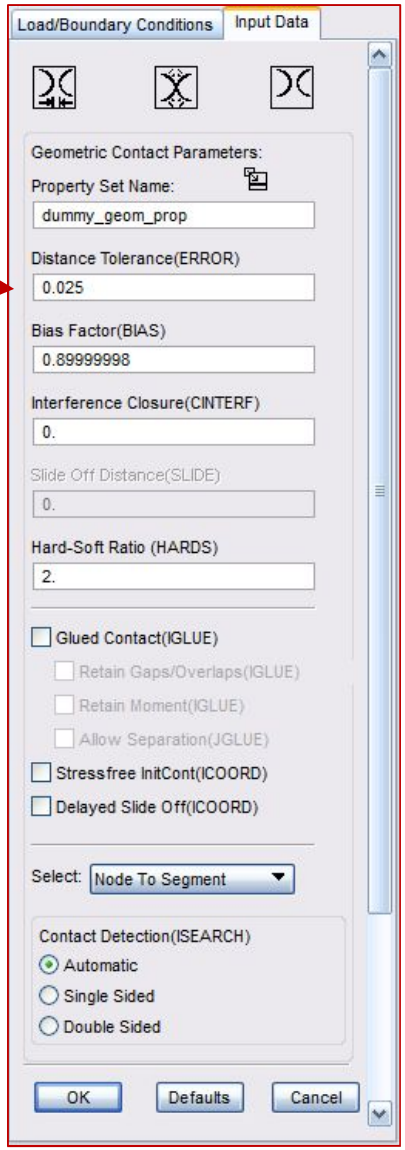
CASE STUDY 2: FIRST RUN CURVED SHELL FACE-TO-FACE TOUCHING CONTACT

- **Adjust the contact tolerance**
  - Change the contact tolerance to 0.025 so it is larger than the largest gap



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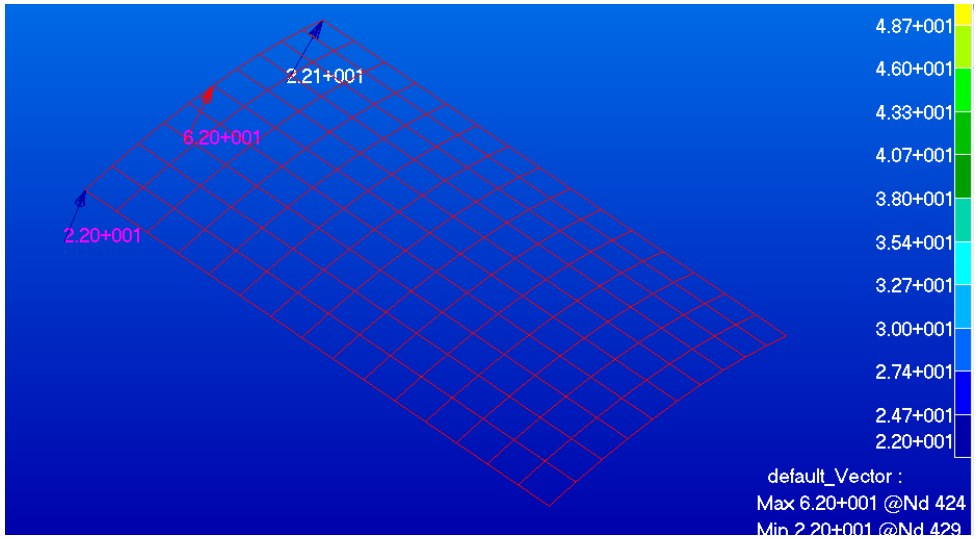
CASE STUDY 2: SECOND RUN CURVED SHELL FACE-TO-FACE TOUCHING CONTACT

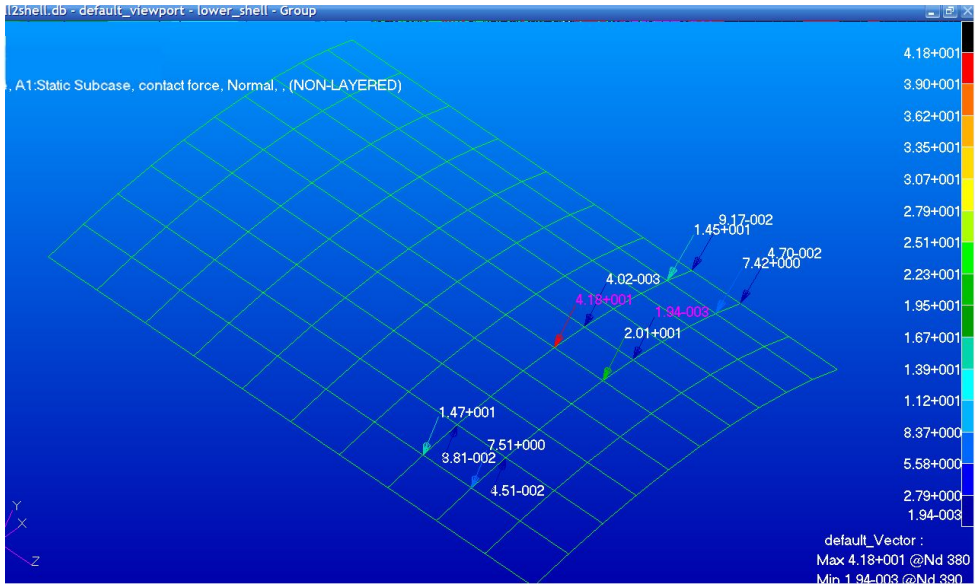
- **Using ERROR=0.025 and ISEARCH=1**
  - Normal contact force

Upper shell:

Few touching nodes detected;
No improvements!



Lower Shell



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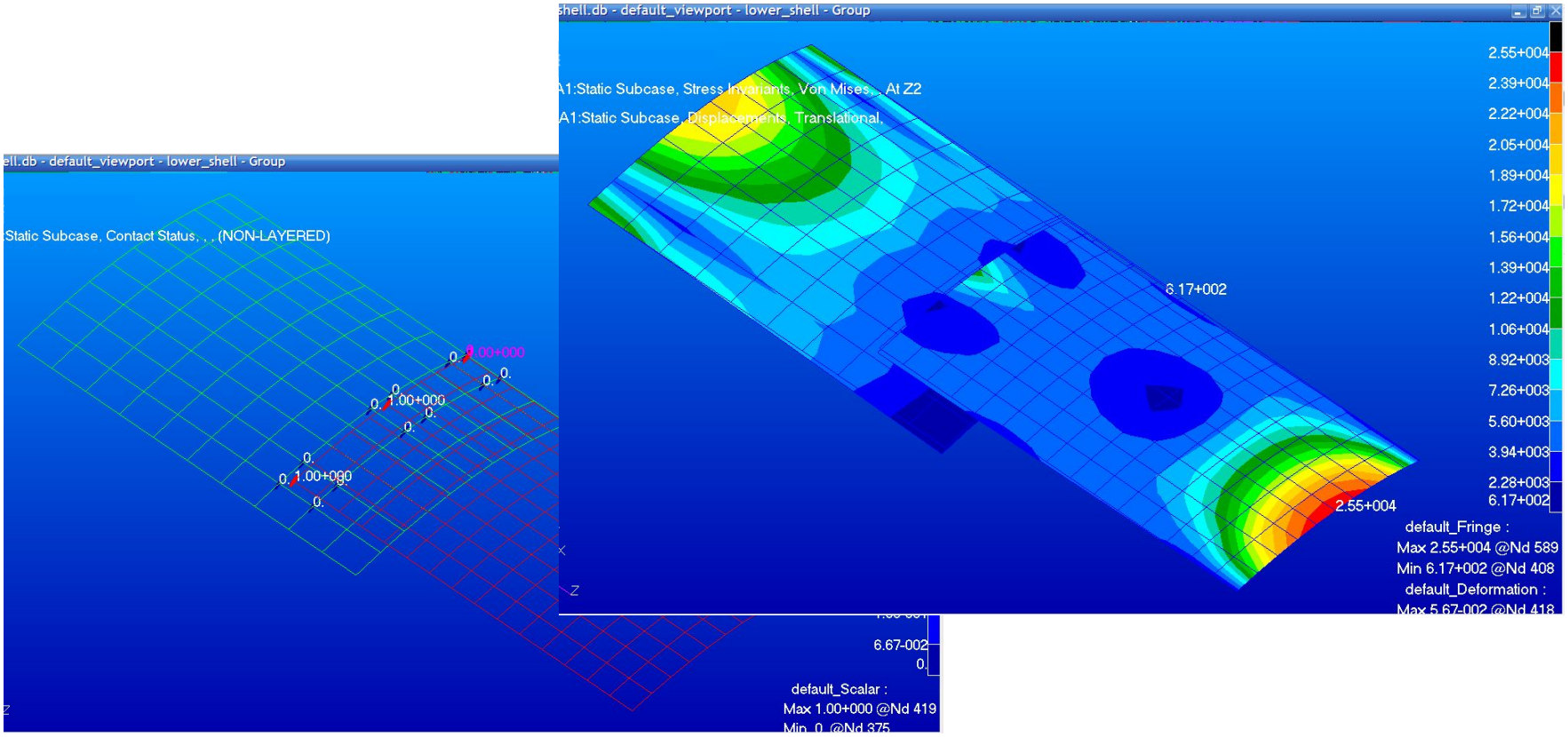
CASE STUDY 2: FIRST RUN CURVED SHELL FACE-TO-FACE TOUCHING CONTACT

- **Using ERROR=0.025 and ISEARCH=1**
  - Deformation and Von Mises stress
  - Contact status



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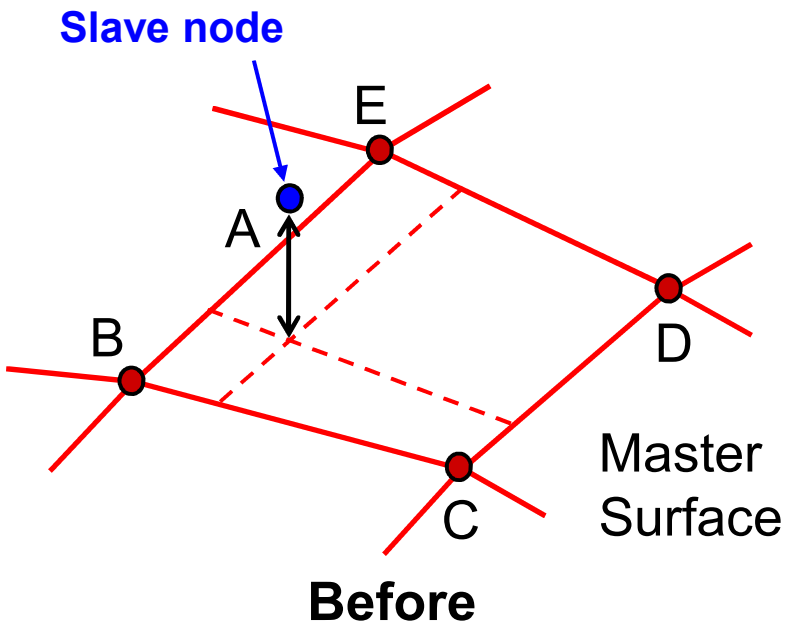
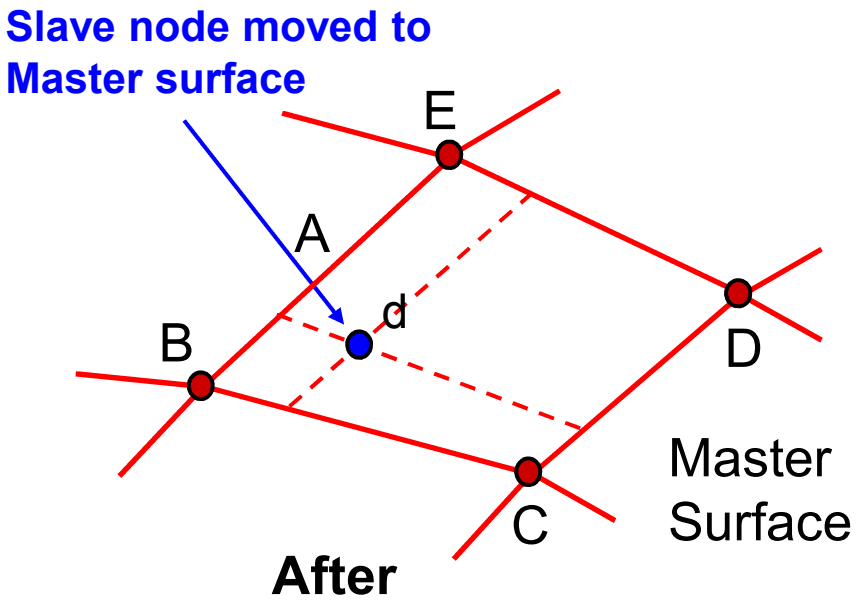
CASE STUDY 2: CURVED SHELL FACE-TO-FACE TOUCHING CONTACT

- **Stress-free initial contact**
  - Set **ICOORD=1**
  - MSC Nastran modifies the coordinates of the nodes in contact to close the gaps and overlaps between the two bodies





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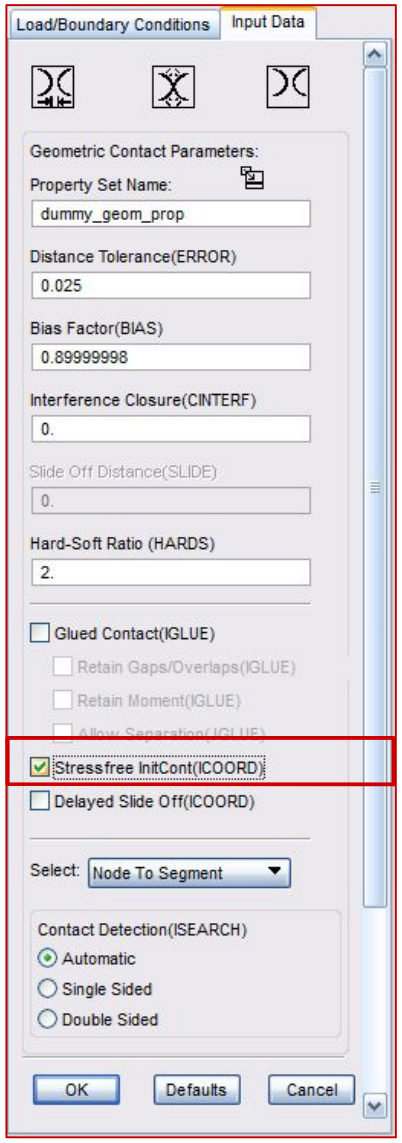
CASE STUDY 2: CURVED SHELL FACE-TO-FACE TOUCHING CONTACT

- **Stress-free initial contact**
  - Set ICOORD=1



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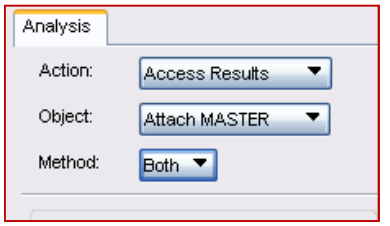
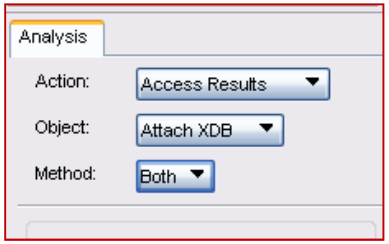
CASE STUDY 2: CURVED SHELL FACE-TO-FACE TOUCHING CONTACT

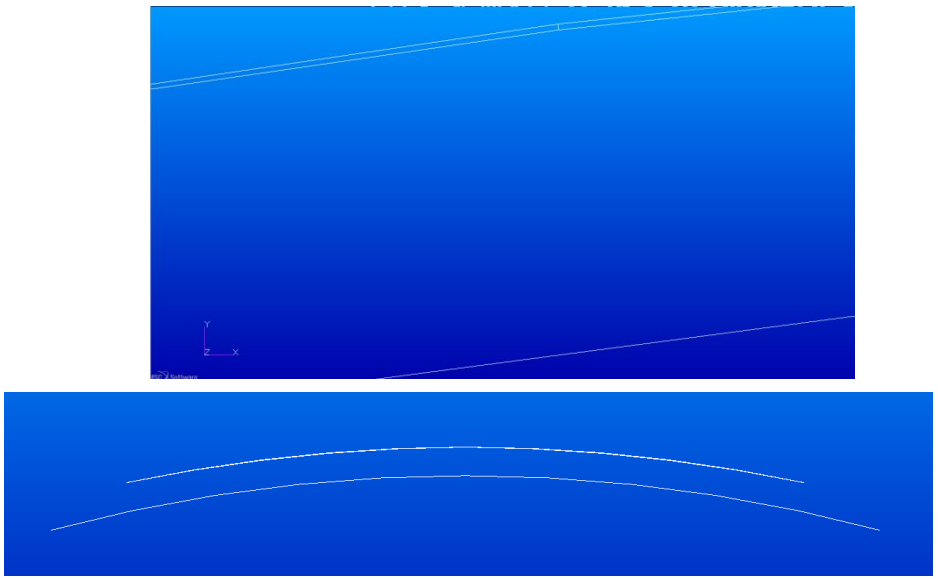
- **Visualize nodal coordinate adjustments due to ICOORD=1**
  - Patran currently does not account for the stress-free initial coordinate adjustments in deformed shape plots
  - But it does show it in the model when you attach both the model and results.



or



Before adjustments



After adjustments

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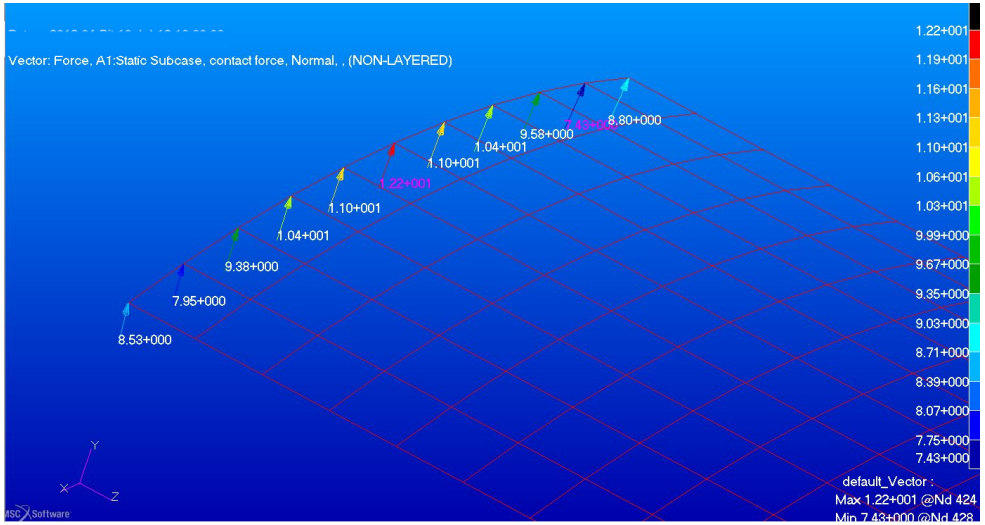
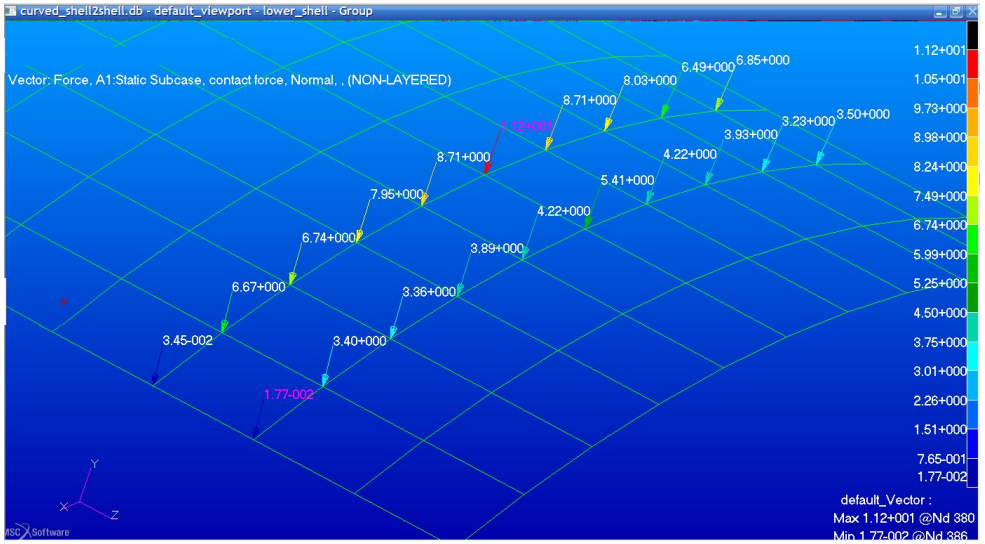
CASE STUDY 2: THIRD RUN CURVED SHELL FACE-TO-FACE TOUCHING CONTACT

- **Using ERROR=0.025, ISEARCH=1 and ICOORD=1**
  - Normal contact force

Upper shell:All edge nodes have contact force



Lower shell



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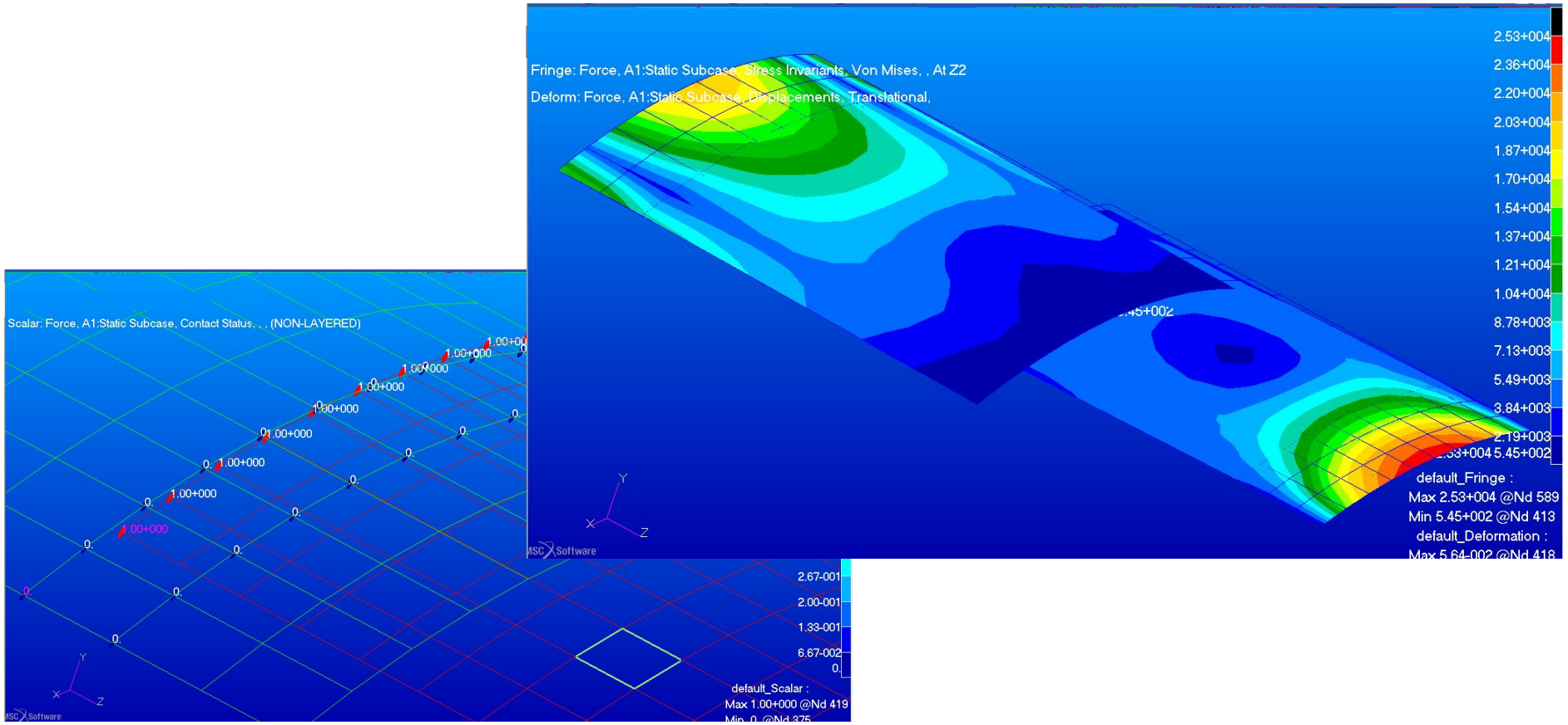
CASE STUDY 2: THIRD RUN CURVED SHELL FACE-TO-FACE TOUCHING CONTACT

- **Using ERROR=0.025, ISEARCH=1 and ICOORD=1**
  - Deformation and Von Mises stress
  - Contact status



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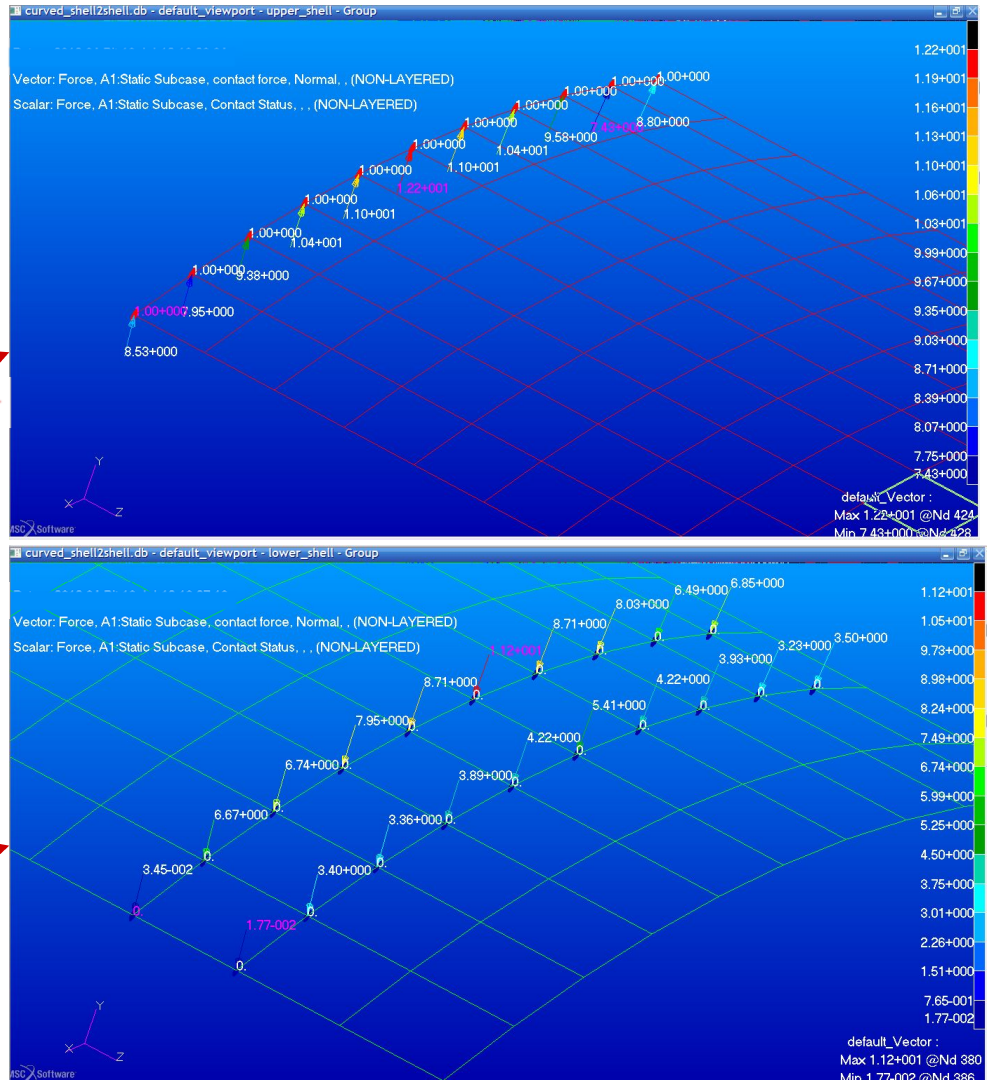
CASE STUDY 2: FOURTH RUN CURVED SHELL FACE-TO-FACE TOUCHING CONTACT

- **Segment-to-Segment contact**
- **Using ERROR=0.025, ISEARCH=0 and ICOORD=1**
  - Normal contact force

Upper shell:

All edge nodes have contact force

Lower shell



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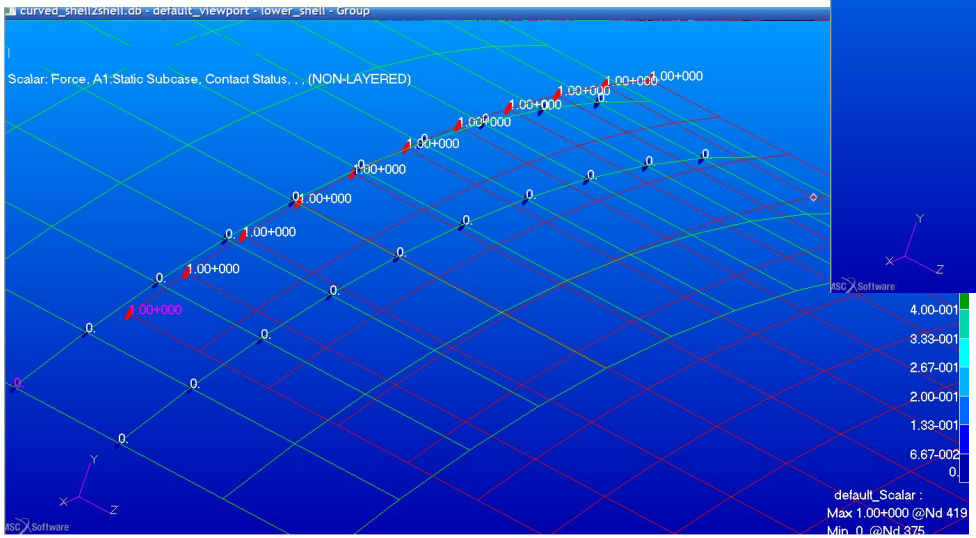
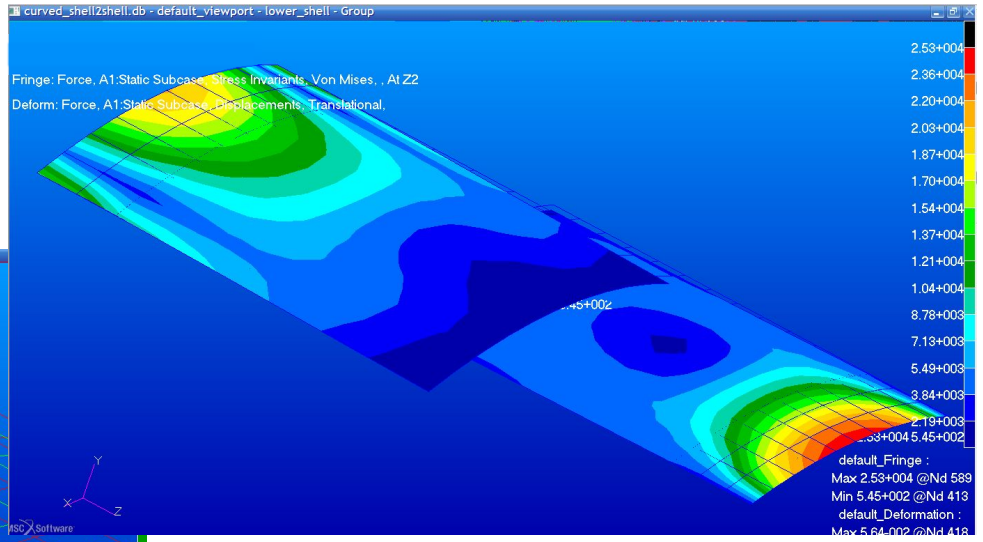
CASE STUDY 2: THIRD RUN CURVED SHELL FACE-TO-FACE TOUCHING CONTACT

- **Segment-to-Segment contact**
- **Using ERROR=0.025, ISEARCH=0 and ICOORD=1**
  - Deformation and Von Mises stress
  - Contact status





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CASE STUDY 2: CURVED SHELL FACE-TO-FACE TOUCHING CONTACT

- **Result Comparison**

	Node-to-Segment: ISEARCH=1	Node-to-Segment: ISEARCH=1; ERROR=0.025	Node-to-Segment: ISEARCH=1; ERROR=0.025; ICOORD=1	Segment-to-Segment: ISEARCH=0/1; ERROR=0.025; ICOORD=1
Maximum Displacement	0.0567	0.0567	0.0564	0.0564
Maximum Von Mises Stress	2.55e4	2.55e4	2.53e4	2.53e4
Maximum Contact Force	62	62	12.2	12.2

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SUMMARY

- **For Node-to-Segment contacts**
  - Use slave to master contact, single search, with
    - The softer body as slave, e.g., rubber should be SLAVE and steel should be master
    - The finer meshed body as slave
    - Or use ISEARCH=2 for automatic selection, but be careful about shell element structures
  - A rigid body must be master.
  - Patran generates contact body ID according to contact body names
    - Define slave contact bodies with “lower” names, master bodies with “higher” names, and rigid bodies with “highest” names.
- **Segment-to-Segment contact**
  - No need to care about slave/master bodies; will discard ISEARCH option.
  - Other options has similar effects to Segment-to-Segment contact as Node-to-Segment contact.
- **Curved shell-to-shell touching contact**
  - May need to change tolerance setting ERROR
  - Stress-free initial contact needs to be activated, i.e. ICOORD=1
  - When ICOORD=1, always check the modified initial model

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