... within Epsilon

Twin Cities
ANSYS® User Meeting

September 2013

Contact Analysis

... within Epsilon

Agenda

Part 1: Contact Settings

Part 2: Convergence Issues

Contact Settings

1. Contact Method (Keyopt 12)
2. Formulation
3. Detection at gauss points, nodes, etc.
4. Symmetry
5. FKN, updating stiffness
6. Penetration Tolerance (TOLN)
7. Offsets (CNOFF)
8. Pinball
9. Trim Contact
10. Adhesive
11. Stabilization
12. Predict Impact
13. Contact Tool

1. Contact Method (Keyopt 12)

- **Bonded**
  - Fused at all times
  - AKA `Bonded(always)` Keyopt =5
- **Frictionless, Friction**
  - AKA `Standard` Keyopt = 0
- **No Separation**
  - Frictionless sliding at all times (couples surface in normal direction)
  - Often the conservative case compared to bonded
  - AKA `No Separation(always)` Keyopt = 4
- **Rough** -- has infinite friction Keyopt = 1
- **Forced Frictional**
  - Ignored nodal displacements
  - Models sliding friction (like two spinning disks)

From within WB

1. Contact Method (Keyopt 12)

- **The other 'Bonded'** Keyopt=3
  - Initially inside pinball, or come into contact will stay bonded
- **Bonded (initial contact)**
  - Keyopt =6
  - Those outside pinball are not bonded
- **No Separation (sliding permitted)**
  - Keyopt = 2
  - Sliding only <u>once contact occurs</u>

Available By Snippet Only

2. Formulation

- Penalty Method -- Think in terms of springs
  - Given the load and stiffness (FKN) you can predict the penetration distance
  - Use this if penetration doesn't matter

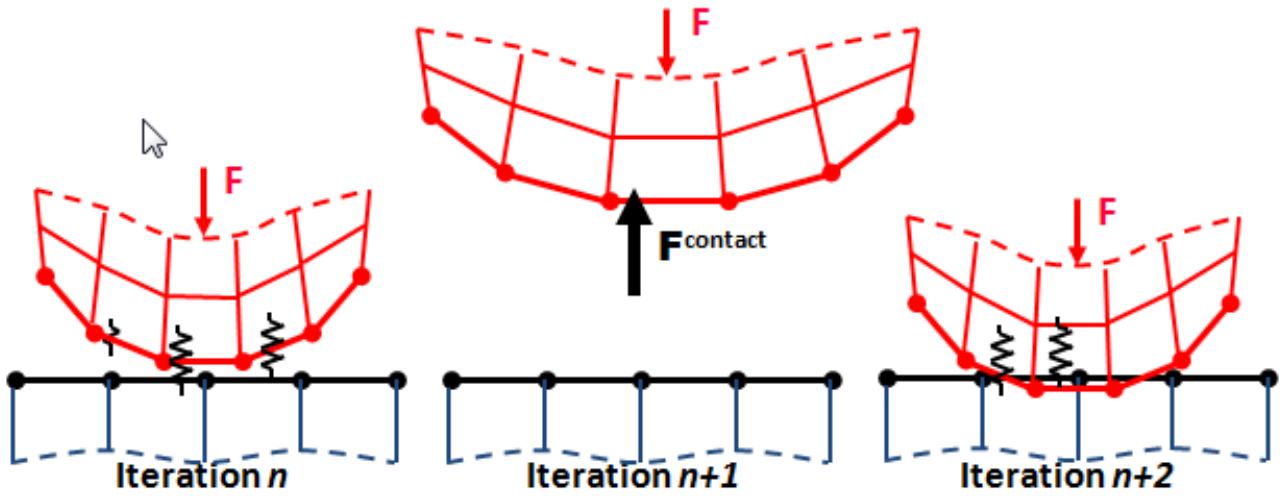
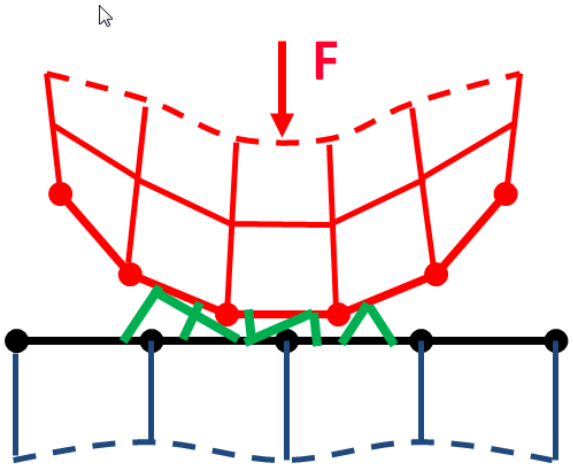


Image from ANSYS inc. training materials.

2. Formulation

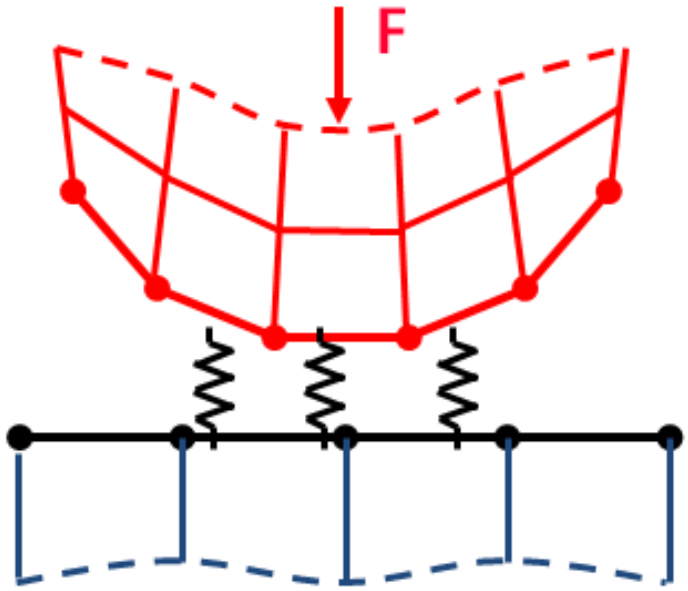
- MPC
  - Full bonded (linear – doesn't separate)
  - Rigid Beams in stead of springs
    - Handled well by solver (better than CERIG)
  - Can slightly stiffen surfaces



- Normal Lagrange
  - Rigid connections -- No stiffness or penetration
  - Difficult to converge
  - Sensitive to discretization (singularities at non-flat interface)
  - Buyer beware…

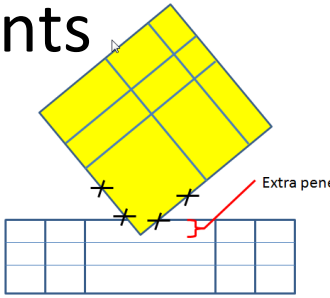
2. Formulation

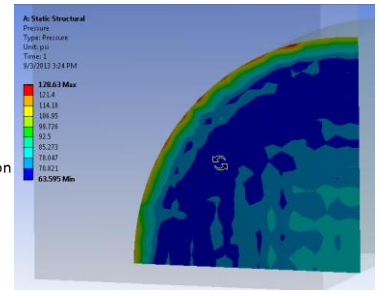
- Augmented Lagrange
  - Like Penalty with intelligence
  - Penetration will be limited internal algorithm
  - Use this if penetration matters



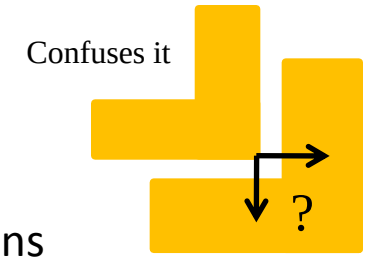
3. Detection Method

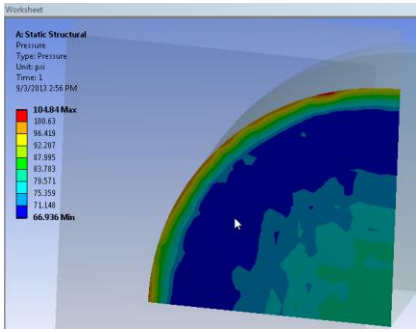
- Contact detection at Gauss Points
  - Default
  - Will have error at corners



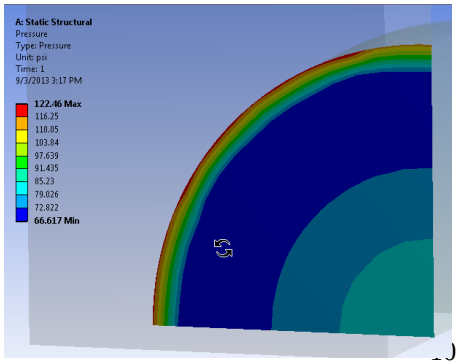


- Contact detection at nodes
  - Smoother pressure plots
  - Longer convergence times (30%?)
  - Unstable for some surfaces combinations
    - Like two nested L-Shapes





- Nodal Projection from contact
  - Latest and greatest

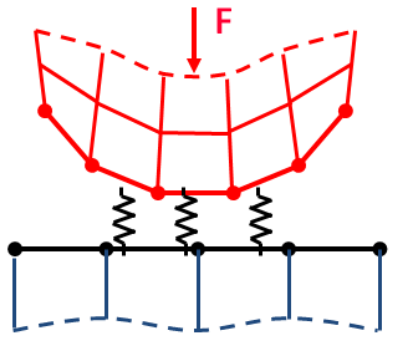


4. Symmetry

- Asymmetric -- user chooses “contact”/”target” surface
  - Fine Mesh, Convex, Softer, Smaller (“Contact)”
  - Coarse Mesh, Concave, Harder, Larger (“Target”)
  - Searching is done from gauss point (or node) toward geometric plane of target element
    - Seeker is the “contact” surface
    - Sought is the “target” surface

Definition	
Type	Frictional
Friction Coefficient	0.1
Scope Mode	Manual
Behavior	Asymmetric
Trim Contact	Program Controlled
Suppressed	No

- Use Symmetry for dissimilar meshes
  - Symmetry paints each surface with both types
    - Two contact “pairs” for each interface
  - Greatly aids convergence
  - Smoother results

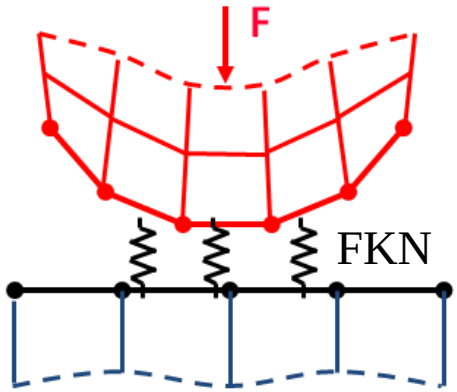


- Symmetry not available for Normal Lagrange
  - And its pointless for MPC
- Symmetry makes post-processing tricky
  - Contact pressure / forces split between contact pairs

5. Stiffness (FKN)

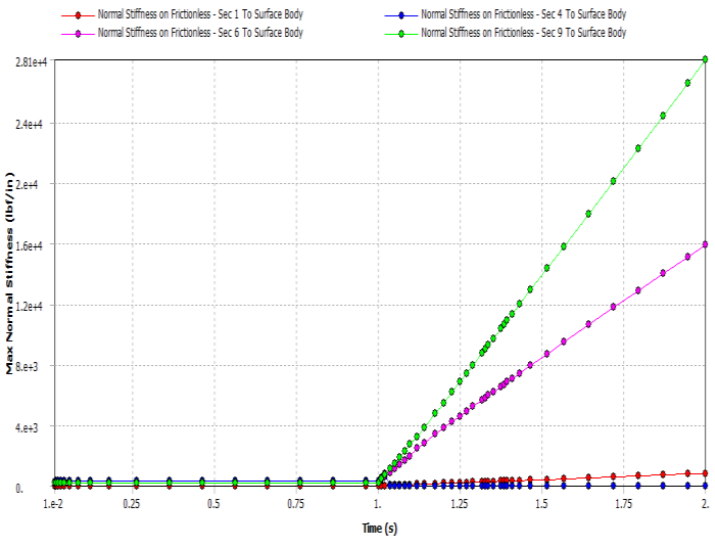
- Stiffness affects convergence, penetration, hot-spots
  - I rarely use the default value FKN=1
- FKN controls spring stiffness
  - Penalty and Augmented Lagrange Method
  - FKN = 0.01 is good starting point if minor penetration is acceptable
    - Check penetration values in post-processing
    - Less than 0.001 usually doesn't by much convergence
    - FKN>10 is difficult to converge
  - Ratio applied to internal spring stiffness calc
    - Printed in output (after FKN ratio is applied)
    - Uses material modulus, element depth and area
  - Make sure its updating for stiffness!
  - Negative value is absolute stiffness value
    - Must use a snippet
  - Divide by 10 for cantilevered beam, membranes, and other flexible structures
    - Convergence driven by component stiffness, note element stiffness

Normal Stiffness	Manual
Normal Stiffness Factor	1.e-002
Update Stiffness	Program Controlled
Stabilization Damping Factor	0.
Pinball Region	Program Controlled
Time Step Controls	None



5. FKN As Variable

- FKN, CNOF, TCC etc can be defined as function of time, temperature, pressure, gap/penetration etc.



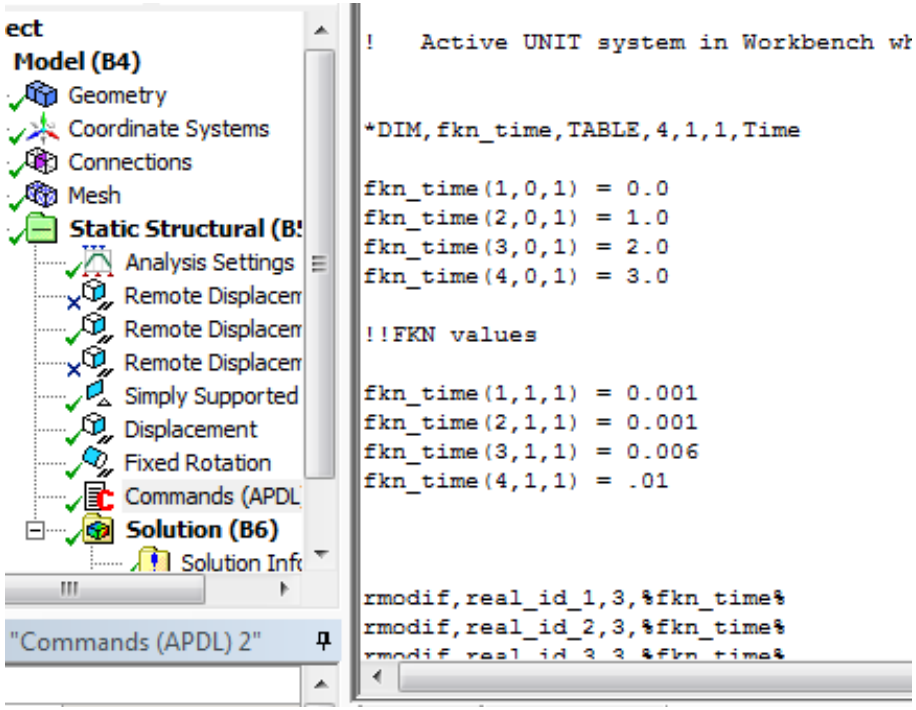


Fig From ANSYS Inc,

6. Penetration Tolerance (TOLN)

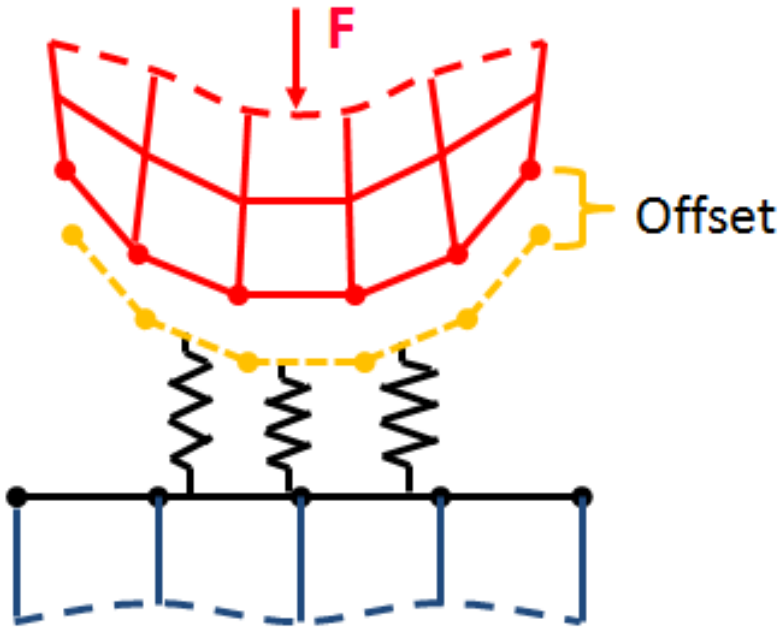
- Set's maximum allowable penetration
  - If exceeded, substep iteration is invalid and another iteration occurs
  - Defaults to 10% element depth
    - That's a lot…
- This is secondary to FKN
- Not for limiting final penetration – that's FKN
  - It's a convergence tool (a red herring imo)
  - Output will complain of contact penetration exceeding tolerance…
  - In my experience over-penetration drops as residual forces drop
- If you have very low FKN (like 0.0001?)
  - Might need to open it up to 20% or more the element depth to keep it from complaining

Advanced	
Formulation	Program Controlled
Detection Method	Program Controlled
Penetration Tolerance	Program Controlled
Elastic Slip Tolerance	Program Controlled
Interface Treatment	Add Offset, No Ramping
Offset	0. mm
Normal Stiffness	Program Controlled
Update Stiffness	Program Controlled
Stabilization Damping Factor	0.
Pinball Region	Program Controlled
Time Step Controls	None

7. Offset (CNOF)

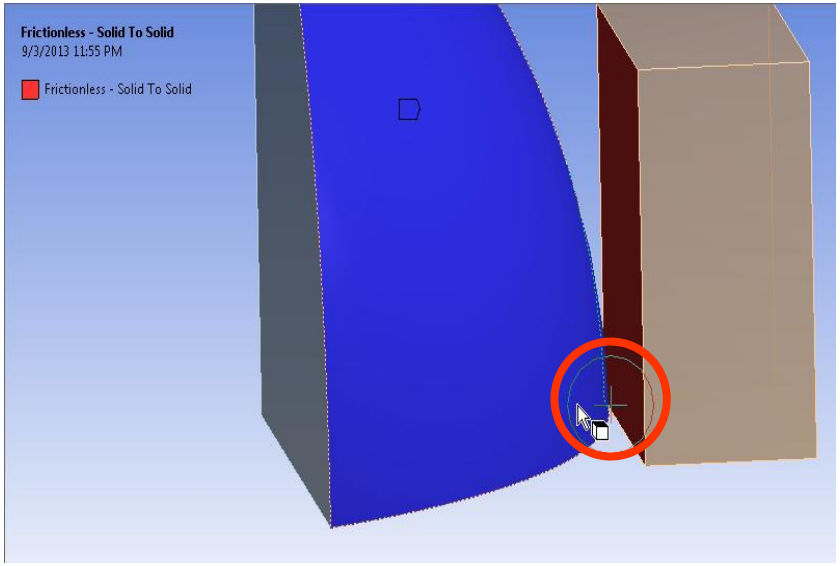
- Moves contact detection by value
  - Offsets the surface numerically
  - Positive value Brings two separated parts closer
  - Alter the press-fit
    - Without updating the CAD geometry
  - Fix sloppy geometry
    - Size it to the gap value
    - Use “Adjust to Touch” (for flat surface)
- Be wary of stepped effects
  - Ramped Effects is scales the offset like a load during the substep

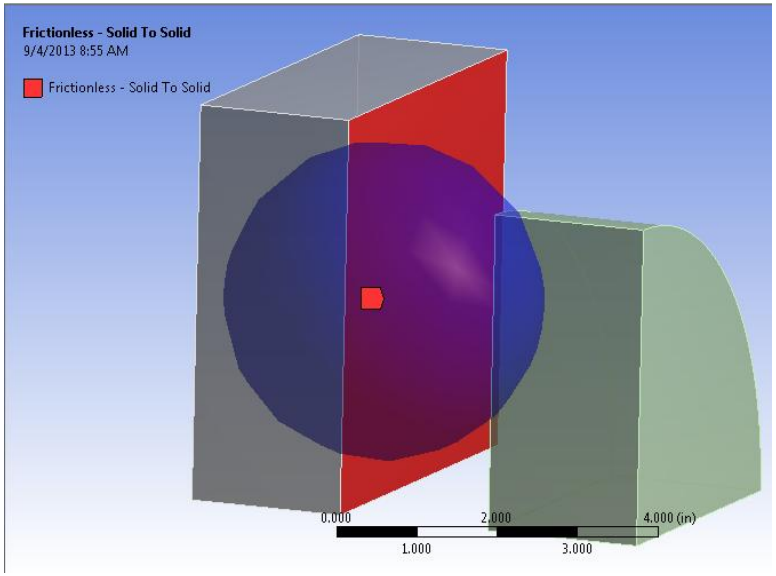
Formulation	Augmented Lagrange
Detection Method	Nodal-Projected Normal From Contact
Penetration Tolerance	Program Controlled
Interface Treatment	Add Offset, Ramped Effects
Offset	0. in



8. Pinball Radius

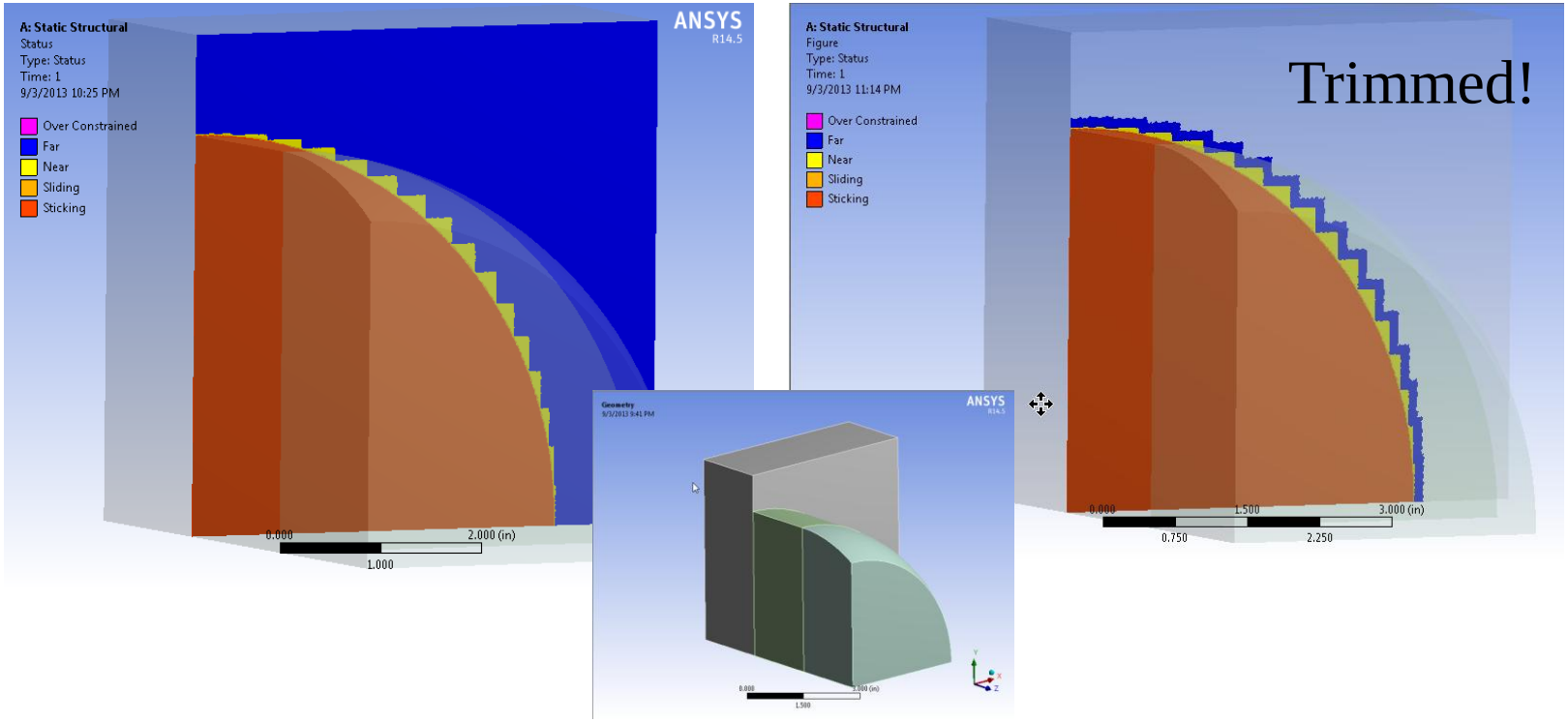
- Contact / Target searching distance
  - Not computationally expensive – crank it up! (1e6?)
  - Can avoid pass-through of contact surfaces (especially with “weak springs” on)
  - This trick only works about 20% of the time





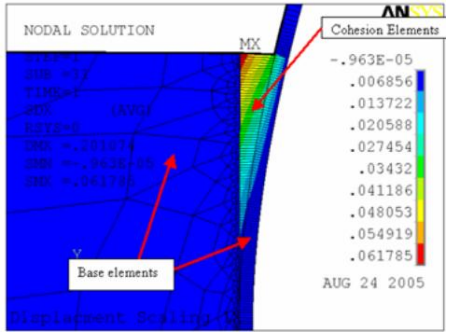
8. Trim Surface

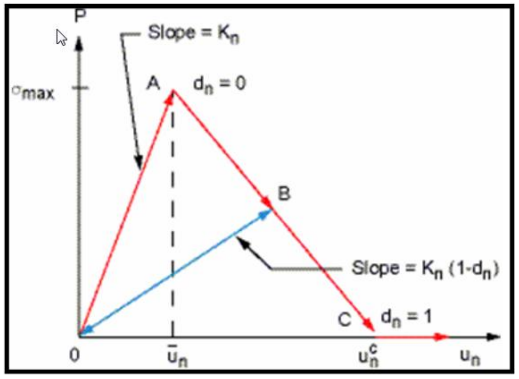
- Contact / Target pair searching
  - Trims element pair using tolerance value
  - Expect 5% to 25% reduction in total solution time



10. Adhesive

- Capable to model bilinear stress/strain curve red line
  - Note that the load reaches a maximum then drops off
    - Numerically unstable – difficult convergence
    - Try LNSRCH (line search)
  - FKN affects the slope! Constants alone do not fully describe it
    - High adhesive stiffness = High FKN = Difficult convergence
  - If you only want it to go up and then fail
    - **Set U_n^C to be less than Ubar$_n$** (controlled via C2 and FKN)
    - Thus it will never reach the second half, weakening portion of red curve…





Constant	Symbol	Meaning
C1	σ_{max}	maximum normal contact stress
C2	U^C_n	contact gap at the completion of debonding
C3	τ_{max}	maximum equivalent tangential contact stress
C4	U^C_t	tangential slip at the completion of debonding
C5	η	artificial damping coefficient
C6	β	flag for tangential slip under compressive normal contact stress

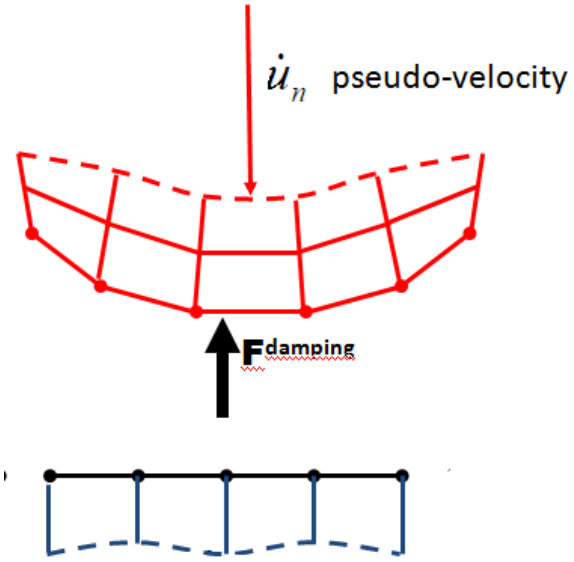
http://www.padtinc.com/blog/wp-content/uploads/oldblog/PADT_TheFocus_56.pdf

11. Stabilization

- Puts dampers on the contact springs
  - Force proportional to pseudo-velocity and %depth into pinball region
  - May need large or small value! 0.05 or 5000?
    - Compare to environmental forces
    - Too high will result in high residuals (element shape errors)!
  - We set FDMN as a scaling factor (see below)
  - Check resulting energy level/error with snippet (etable)

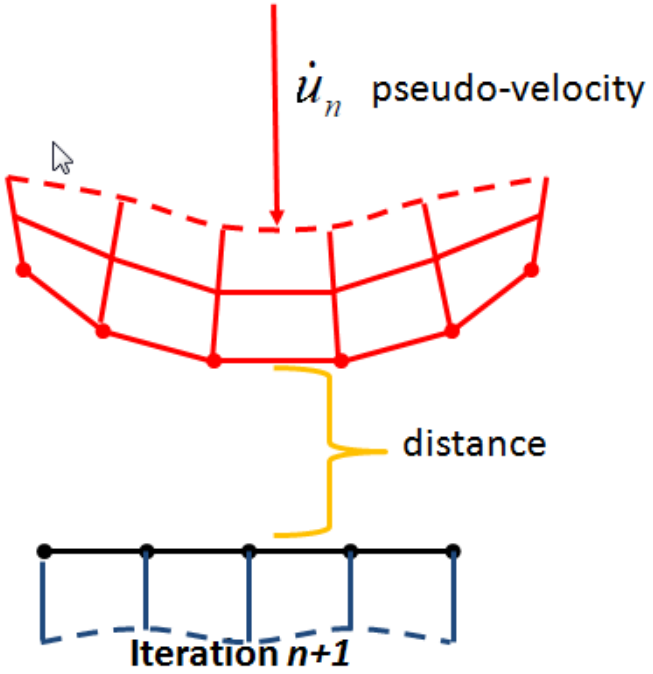
$$\text{Force} = d_n \dot{u}_n$$

$$d_n = \begin{cases} FDMN * (PINB - U_n) / PINB & \text{If } U_n \le U_{pinb} \\ 0 & \text{If } U_n \le 0 \text{ or } U_n \text{ gt } U_{pinb} \end{cases}$$



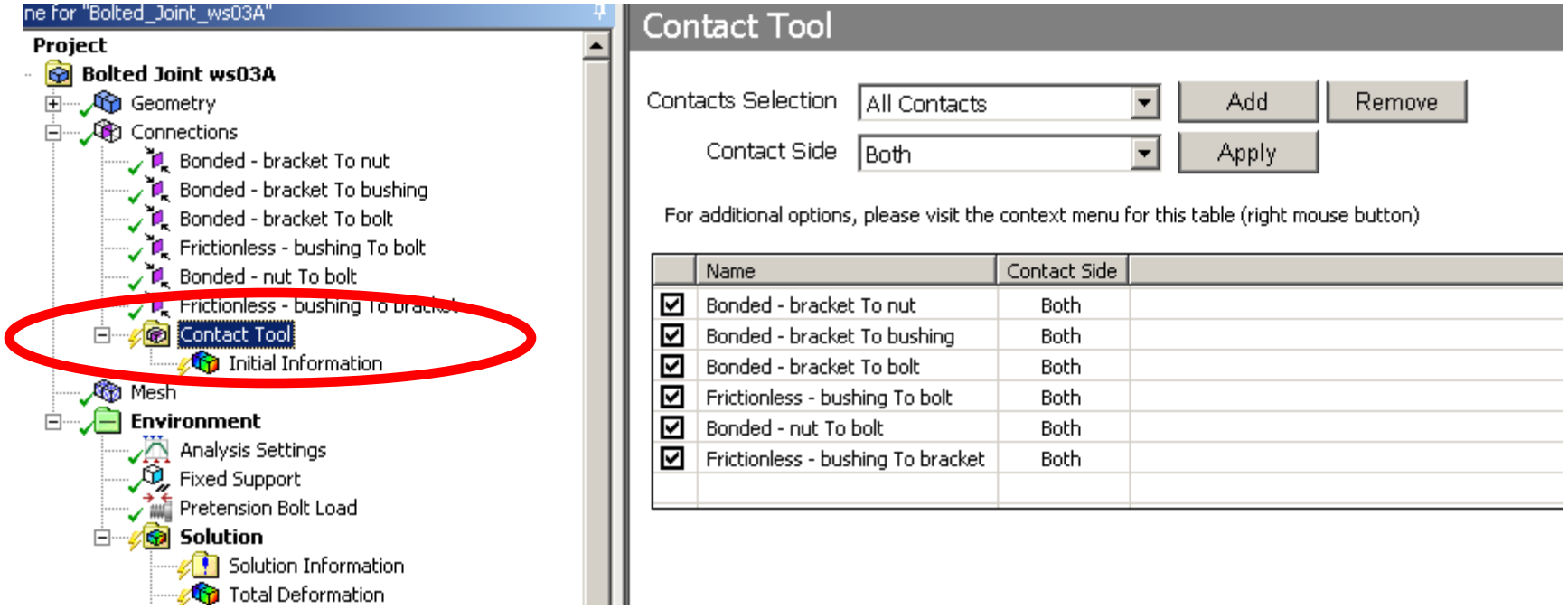
12. Predict Impact

- For force-controlled, or dynamic contact
- Chooses time-step based on rate of closure



13. Contact Tool – Initial Information

- Initial contact information can be scoped to evaluate all regions or specific regions of interest on both contact and/or target sides.



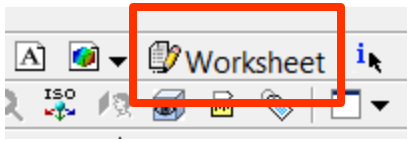
13. Contact Tool – Initial Information

- Use the contact tool to view initial status, gap, pinball and more

Name	Contact Side	Type	Status	Number Contacting	Penetration (mm)	Gap (mm)	Geometric Penetration (mm)	Geometric Gap (mm)	Resulting Pinball (mm)	Real Constant
Bonded - bracket To nut	Contact	Bonded	Closed	16.	0.	0.	1.3643e-012	0.75631	0.9839	5.
Bonded - bracket To nut	Target	Bonded	Inactive	N/A	N/A	N/A	N/A	N/A	N/A	0.
Bonded - bracket To bushing	Contact	Bonded	Inactive	N/A	N/A	N/A	N/A	N/A	N/A	7.
Bonded - bracket To bushing	Target	Bonded	Closed	25.	0.	0.	1.5916e-012	1.819e-012	1.0833	8.
Bonded - bracket To bolt	Contact	Bonded	Inactive	N/A	N/A	N/A	N/A	N/A	N/A	9.
Bonded - bracket To bolt	Target	Bonded	Closed	268.	0.	0.	0.31281	0.30317	0.3291	10.
Frictionless - bushing To bolt	Contact	Frictionless	Near Open	0.	0.	0.13058	0.	N/A	8.582	11.
Frictionless - bushing To bolt	Target	Frictionless	Near Open	0.	0.	0.13006	0.	N/A	3.0728	12.
Bonded - nut To bolt	Contact	Bonded	Closed	49.	0.	0.	0.5	0.	0.7012	13.
Bonded - nut To bolt	Target	Bonded	Inactive	N/A	N/A	N/A	N/A	N/A	N/A	14.
Frictionless - bushing To bracket	Contact	Frictionless	Near Open	0.	0.	1.5	0.	N/A	8.663	15.
Frictionless - bushing To bracket	Target	Frictionless	Inactive	N/A	N/A	N/A	N/A	N/A	N/A	0.

13. Contact Tool

- Connection Matrix Summarizes joint/contact information
- Exportable as a txt file



Hide Preferences | Refresh

- [x] Contact Information
- [ ] Joint DOF Checker
- [ ] Joint Information
- [x] Connection Matrix
  - [x] Show Upper Diagonal
  - [x] Show Diagonal Marker
  - [ ] Show Unconnected Bodies
  - [ ] Show Suppressed Objects
  - [ ] Bundle Connections

Control Connection Types

- [x] Contact
- [ ] Spot Weld
- [ ] Joint
- [x] Spring
- [x] Beam

Connection Matrix

	PRT0003[40]	PRT0002[45]	PRT0004[56]	PRT0005[59]
PRT0003[40]	----			
PRT0002[45]	Contact Region	----		
PRT0004[56]	Contact Region 2	Contact Region 5	----	
PRT0005[59]	Contact Region 4		Contact Region 6	----

Export txt file

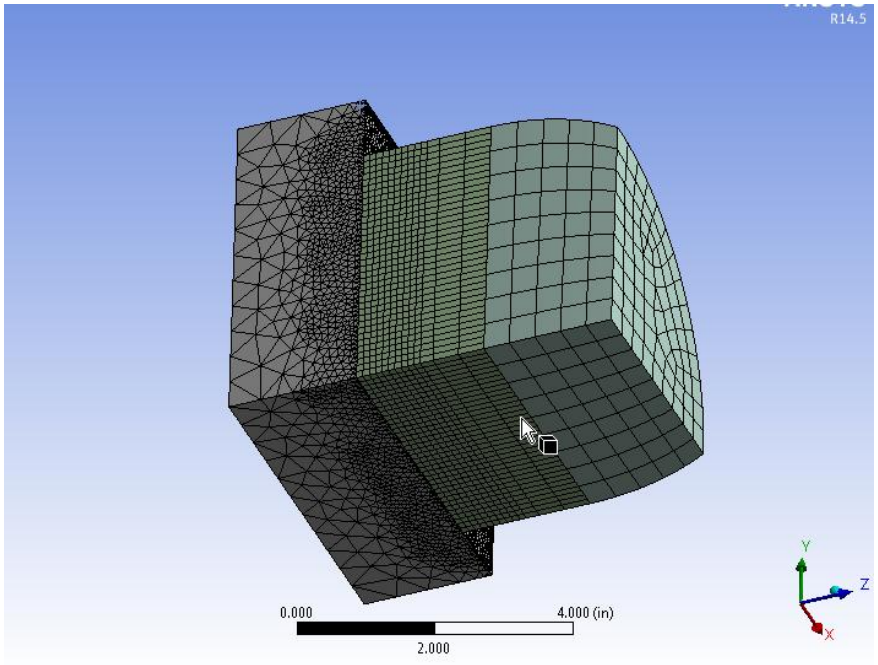
```
1 PRT0003[40]    PRT0002[45]    PRT0004[56]    PRT000
2 PRT0003[40]    ----
3 PRT0002[45]    Contact Region  /  Fixed - PRT0003[40
4 PRT0004[56]    Contact Region 2    Contact Region 5
5 PRT0005[59]    Contact Region 4          Contact Regi
```

Legend:

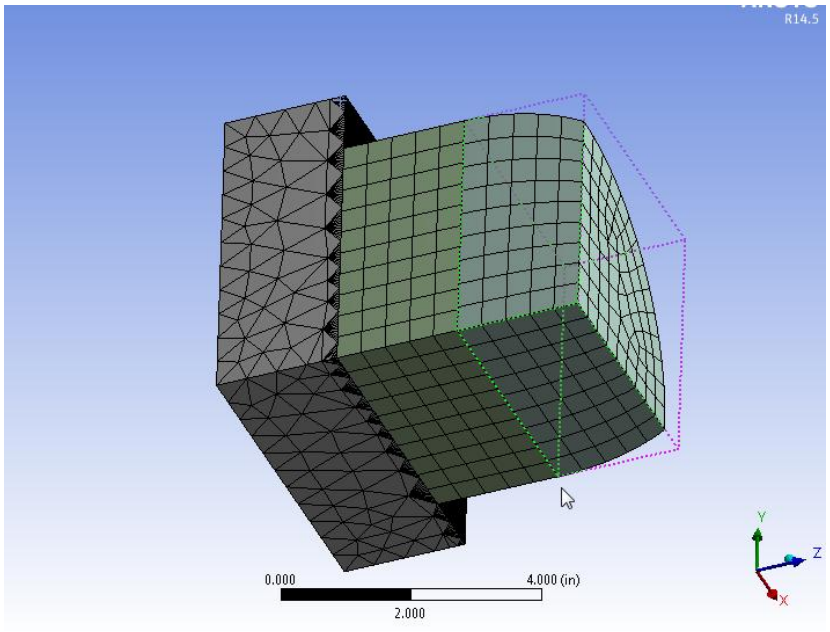
Contact | Spot Weld | Joint | Mesh Connection | Spring | Beam | Multiple Connection Types | Suppressed

Bonus Info

- Use Contact Sizing for sub-surface mesh control
  - Then suppress the contact surface if its not a real contact
  - Element size transitions very slowly!



Contact Sizing



Normal Surface Sizing

Part 2: Convergence

- **See our previous meeting on convergence topic**
- Reading the output
  - Graphs
  - Lines
  - NR Residuals
- DOF Exceeded
- Contact Penetration
- Contact Status/Chattering
- Shape Formulation
- Residuals

Reading the Output

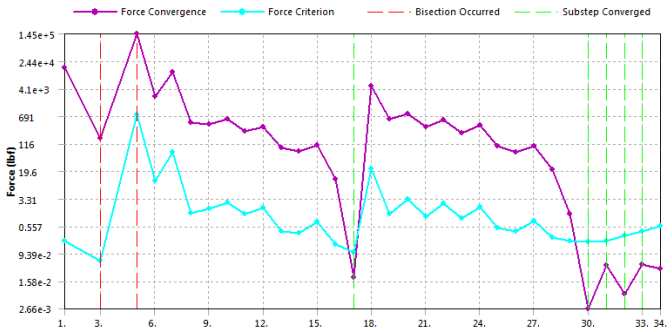
- Must read the output file!
  - Text describes convergence problems
  - Read it… it will begin to make sense!
    - Or send it to me and I'll translate

```
FORCE CONVERGENCE VALUE  =  86.98     CRITERION=  7.365
EQUIL ITER   7 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.1830E-03
 LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC = -0.1830E-03
 3D CONTACT ELEMENTS:  425 CONTACT POINTS HAVE TOO MUCH PENETRATION
 FORCE CONVERGENCE VALUE  =  107.8     CRITERION=  8.576
EQUIL ITER   8 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.2239E-03
 LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC = -0.2239E-03
 3D CONTACT ELEMENTS:  408 CONTACT POINTS HAVE TOO MUCH PENETRATION


     R E S T A R T   I N F O R M A T I O N

REASON FOR TERMINATION. . . . . .DOF LIMIT EXCEEDED
RESTART BY RE-RUNNING THE ANALYSIS

ALL CURRENT ANSYS DATA WRITTEN TO FILE NAME= file.db
 FOR POSSIBLE RESUME FROM THIS POINT



*** ERROR ***                    CP =    1254.288   TIME= 00:24:08
One or more elements have become highly distorted.  Excessive
distortion of elements is usually a symptom indicating the need for
corrective action elsewhere.  Try incrementing the load more slowly
(increase the number of substeps or decrease the time step size).  You
```

- Understand the Residuals Graph
  - This plots the NR residuals (error)
  - Abort non-converging runs
  - If it can't converge in 25-100 iterations

    it ain't gonna (usually)
  - If it can't converge at 1% (time =0.01)

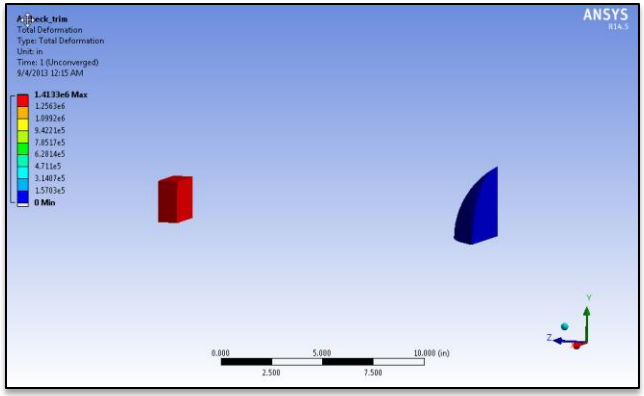
    it ain't gonna (usually)



DOF Limit Exceeded

- Parts flew away into space
  - Contact passed through each other?
  - Contact didn't see each other?
  - Contact slid off one side?
- Try this
  - Weak springs
  - Huge Pinball
  - Contact stabilization
  - Adjust to touch
  - Automatic Bisection / Predict for impact

```
R E S T A R T   I N F O R M A T I O N

REASON FOR TERMINATION. . . . . .DOF LIMIT EXCEEDED
RESTART BY RE-RUNNING THE ANALYSIS

ALL CURRENT ANSYS DATA WRITTEN TO FILE NAME= file.db
 FOR POSSIBLE RESUME FROM THIS POINT
```



Contact Penetration

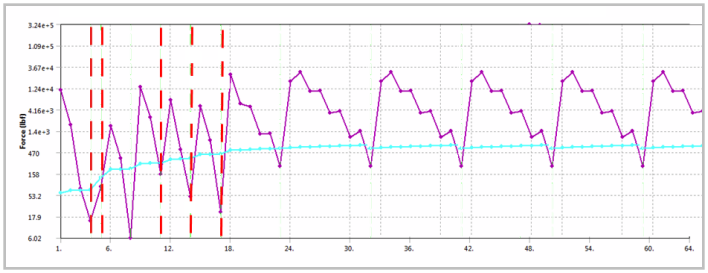
- Too much penetration
  - Exceeded penetration tolerance value (TOLN)
- Try this
  - Live with it (just increase TOLN)
  - Increase FKN
  - Refine the Mesh
  - Switch to Symmetric contact (or flip contact/target surface)

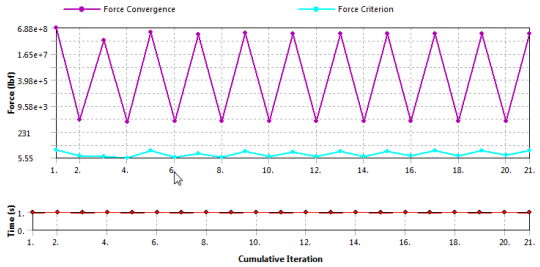
```
3D CONTACT ELEMENTS:  462 CONTACT POINTS HAVE TOO MUCH PENETRATION
     FORCE CONVERGENCE VALUE  =  152.7      CRITERION=  6.609
    EQUIL ITER   4 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC=  0.1249E-03
     LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC =  0.1249E-03
```

Contact Chattering

- Contact Status Keeps Changing
  - Chattering (cycling of contact status in loop)
  - Often visible as NR residual pattern
- Try this
  - Reduce FKN (if penetration allows it)
  - Reduce time step size
  - Switch to Symmetric contact (or flip contact/target surface)
  - Refine the Mesh
  - Contact Stabilization
  - Change anything (numerical instability hole)

*** NOTE *** CP= 0.000 TIME= 00:00:00
6 contact points have abrupt change in contact status.





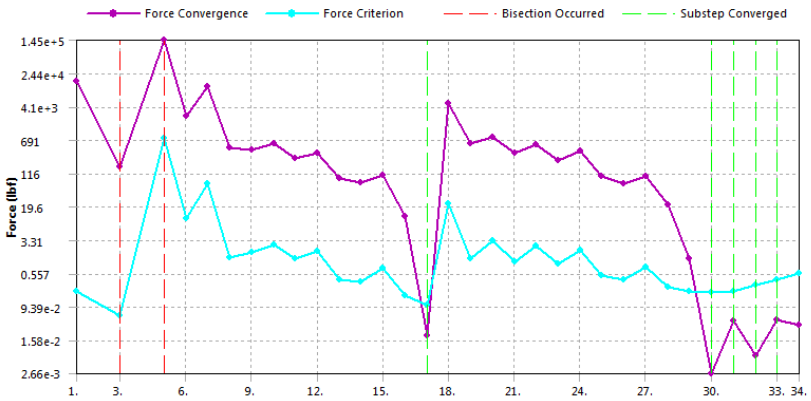
Element Shape Errors

- Element Distortion Errors
  - Excessive forces are distorting elements
  - Often a corner / singularity situation
- Try this
  - Switch to detection at Gauss Points or to Line/Edge contact
  - Switch to Symmetric or flip contact/target designation
  - Refine the Mesh
  - Reduce FKN (if penetration allows it)
  - Reduce time-step
  - Use Mixed U-P formulation for underlying elements

*** ERROR *** CP = 1254.288 TIME= 00:24:08
One or more elements have become highly distorted. Excessive distortion of elements is usually a symptom indicating the need for corrective action elsewhere.

Residual Convergence

- A good problem to have!
  - Means everything is working right
  - Try simplifying to problem region only
    - Faster testing
- Try this
  - Reduce FKN (if penetration allows it)
  - Update FKN stiffness “aggressive”
  - Reduce time-step
  - Refine Mesh
  - Symmetric Contact
  - Post-process partial results
    - Units problem?



Actual output

Conclusions

- Think in terms of springs
  - Decrease FKN
- Avoid force-controlled problems
- Post-process unconverged results for clues
- Get advice! ANSYS contact is an art-form…
  - A small support contract with Epsilon goes a long way
  - My two hours effort could save you a week (and increase accuracy)
  - I can help for free too (to make the case to your bean-counters)