
Task 6 - Safety Review and Licensing On the Job Training on Stress Analysis

F.M. with Finite Element analysis - Wall Elliptical crack, Sub-Clad semielliptical crack and Elastic-Plastic calculation of the J parameter (ANSYS Workbench/ Apdl)

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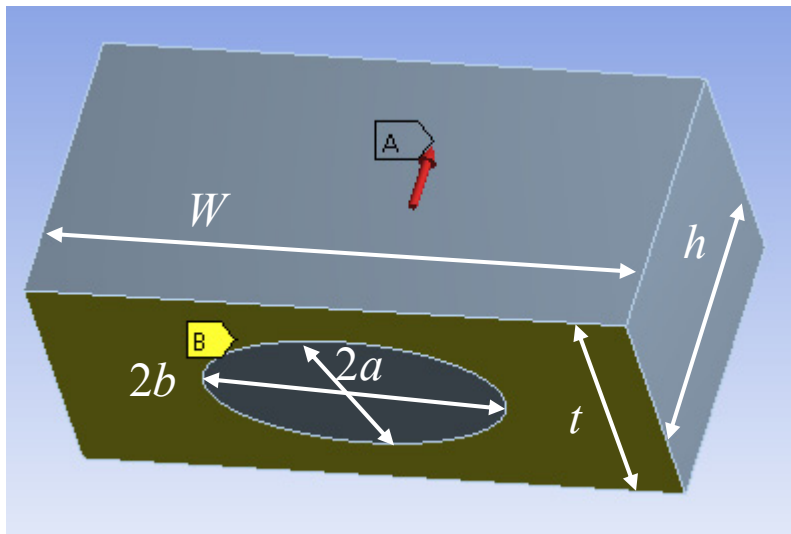
Pisa (Italy)
June 15 – July 14, 2015

Content

- Calculation example of a wall subsurface Elliptical crack
- The effect of the cladding properties on a semielliptical sub-clad surface crack, ANSYS Workbench
- J parameter calculation with ANSYS Workbench with Elastic-Plastic material

Definition of the problem

Half model (symmetry), with an elliptical shape crack



$$t = 25 \text{ mm}$$

$$W = 60 \text{ mm}$$

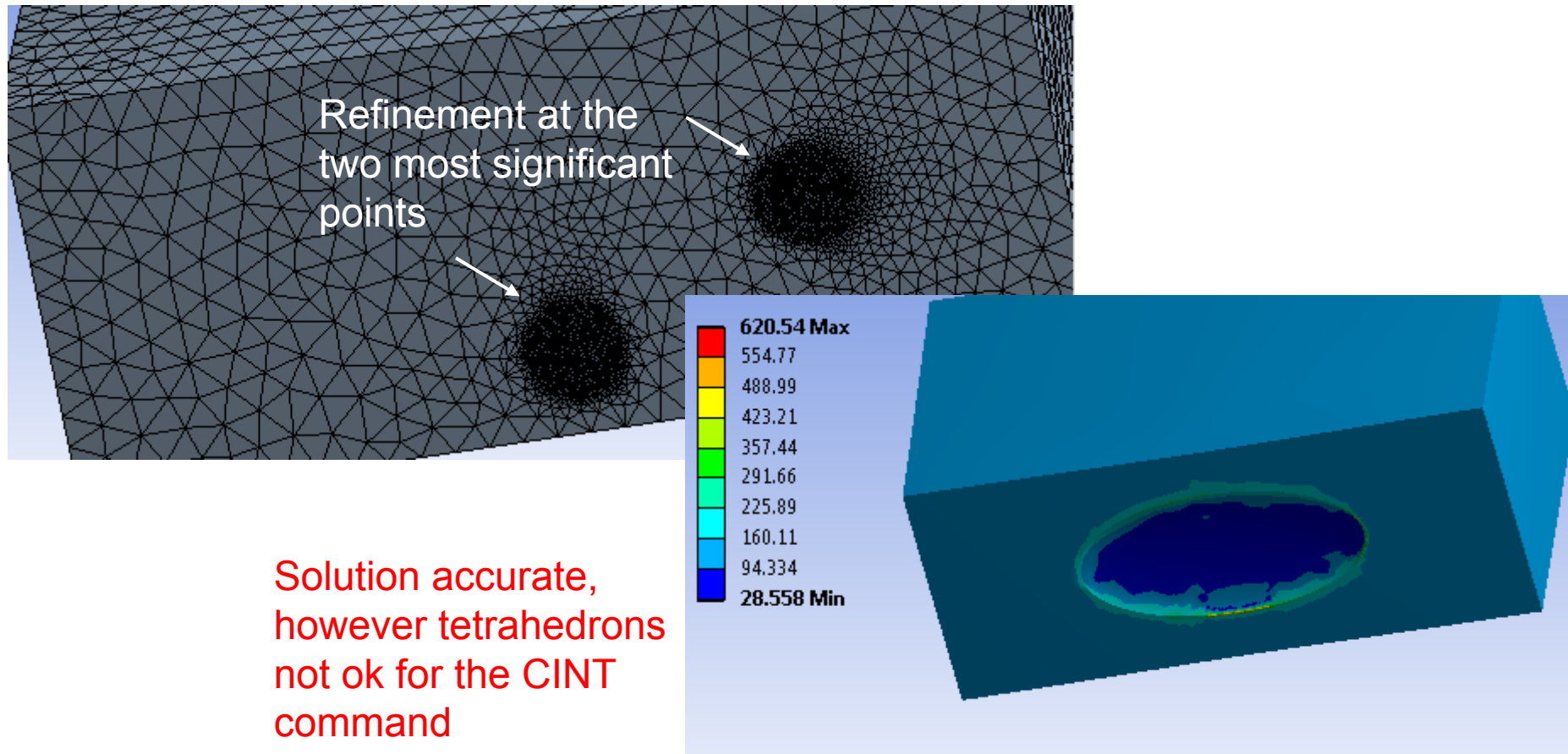
$$h = 30 \text{ mm}$$

$$2a = 15 \text{ mm}$$

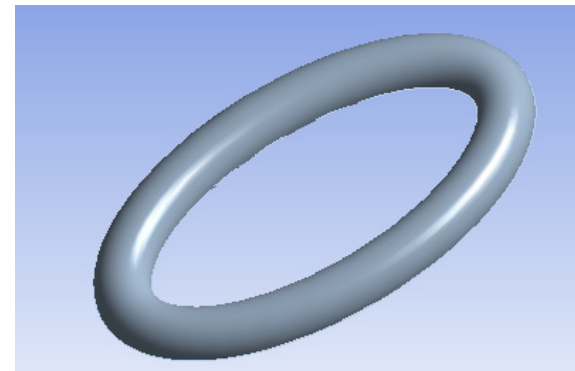
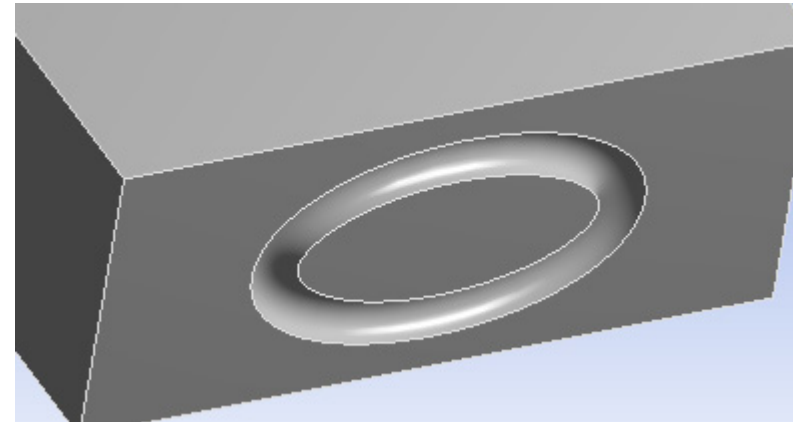
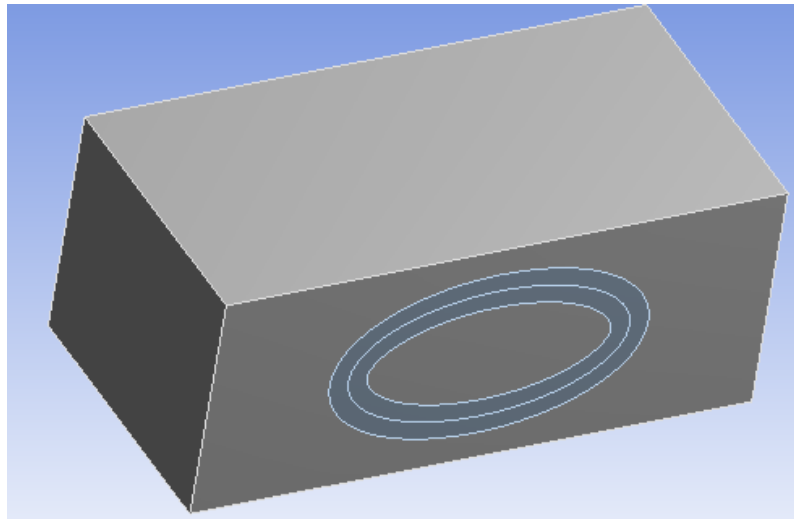
$$2b = 30 \text{ mm}$$

$$\sigma_0 = 100 \text{ MPa}$$

Solution with Tetrahedrons mesh

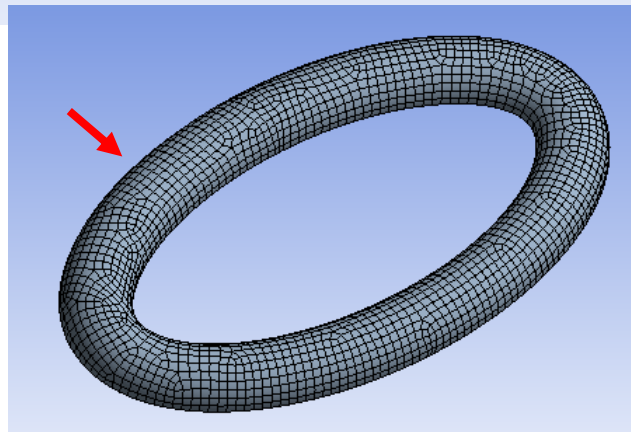
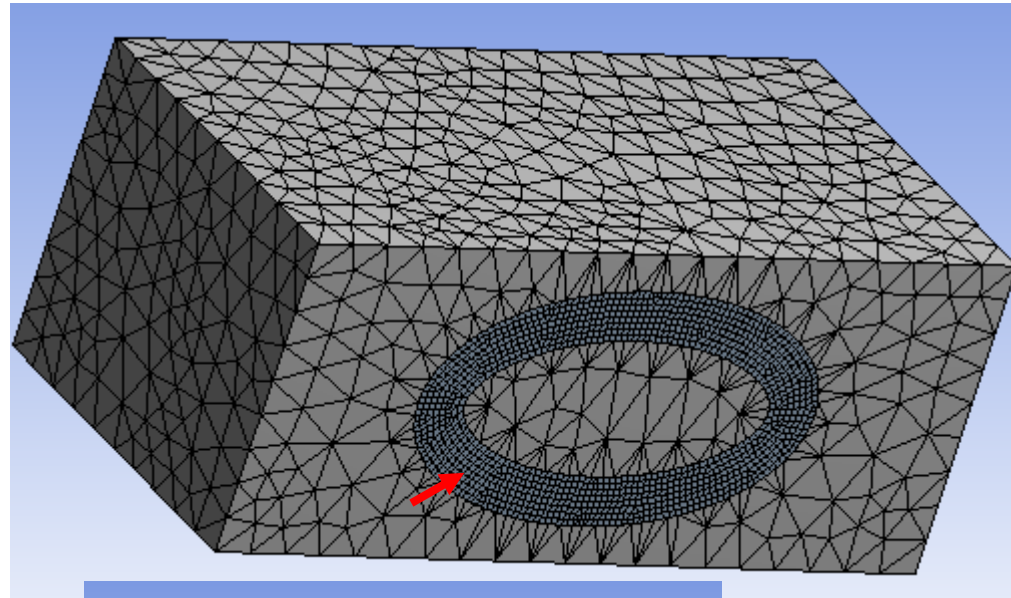
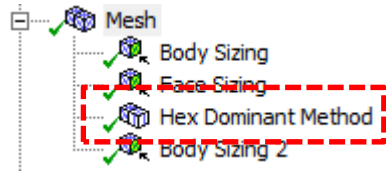


Solution with Hexahedrons mesh



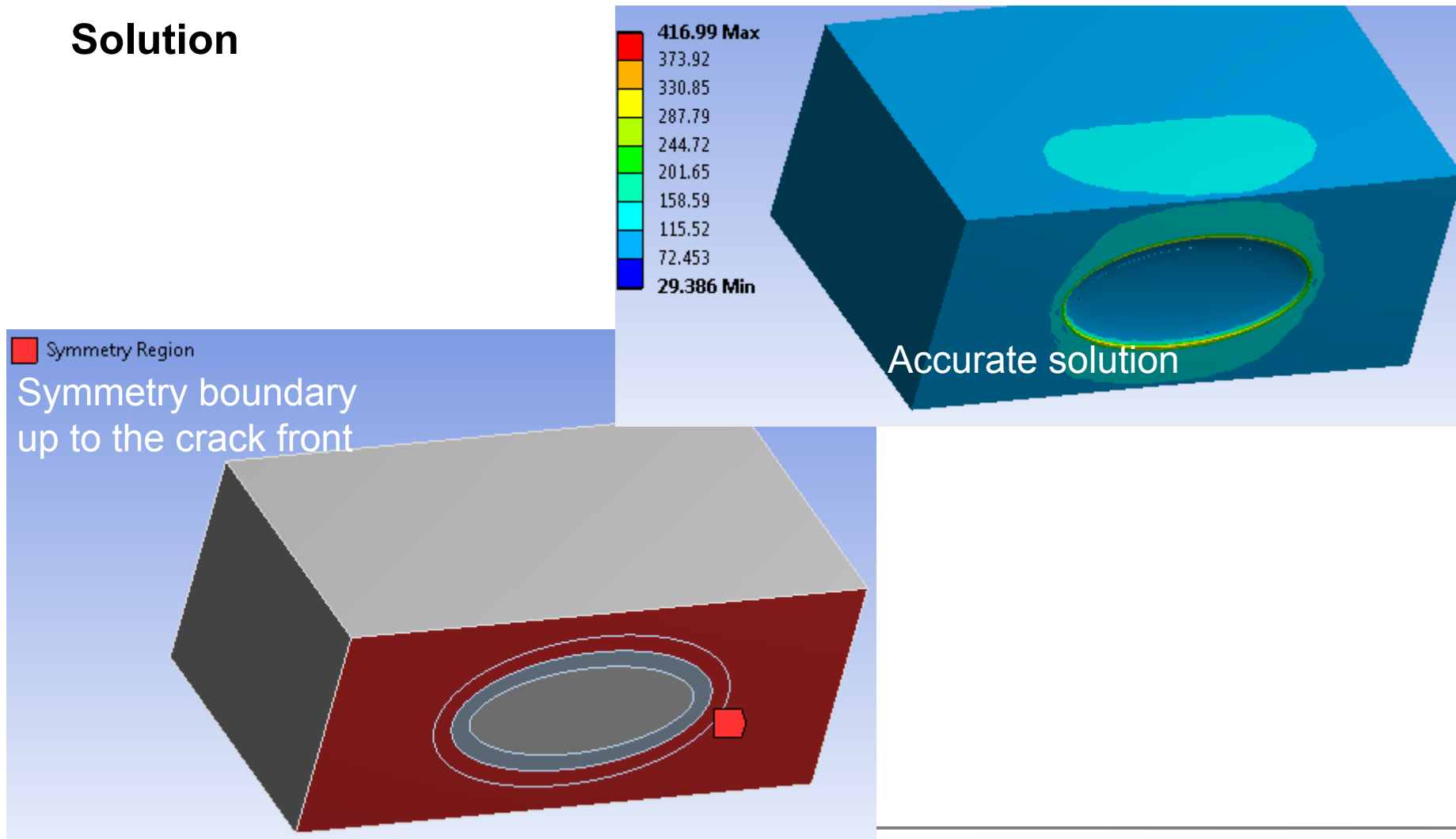
The model is divided into solids for keep Hexahedrons mesh near the crack front

Mesh options



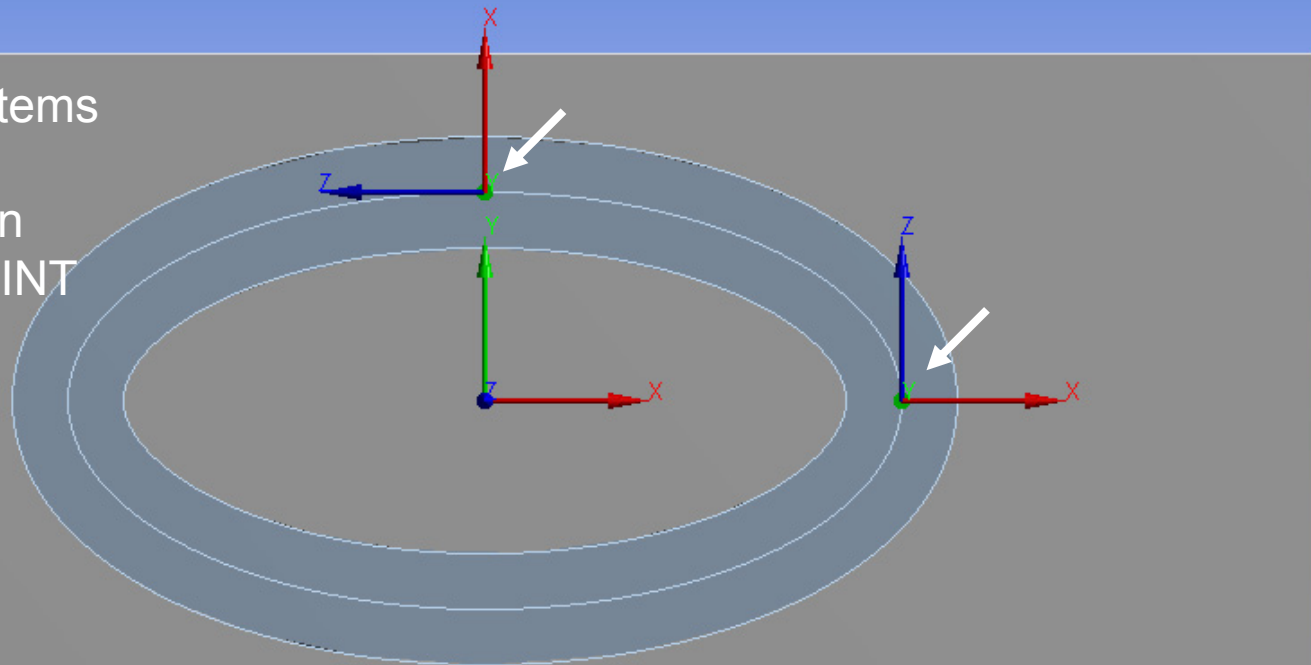
The Hex dominant option works with this toroid shape

Solution

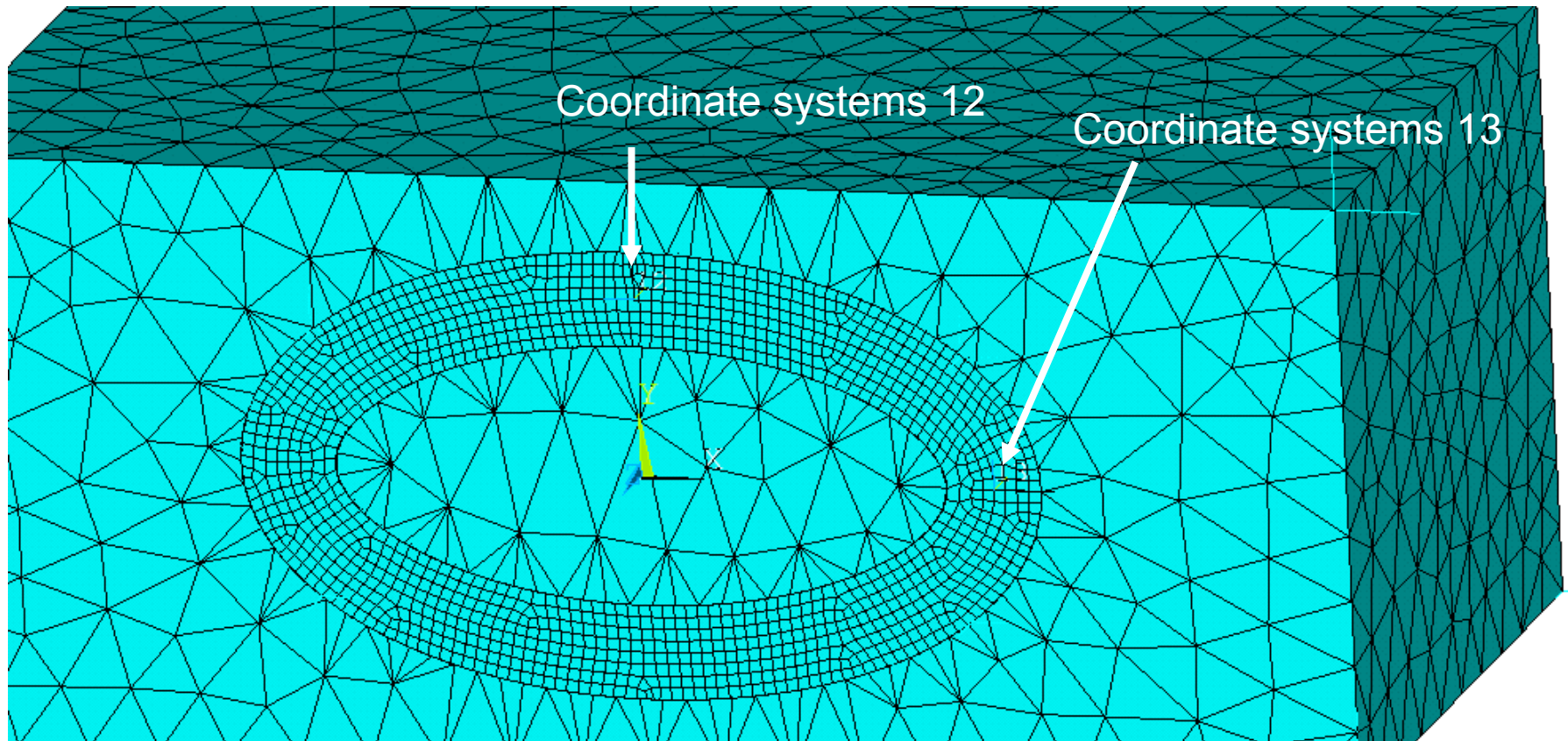


CINT,SIFS calculation

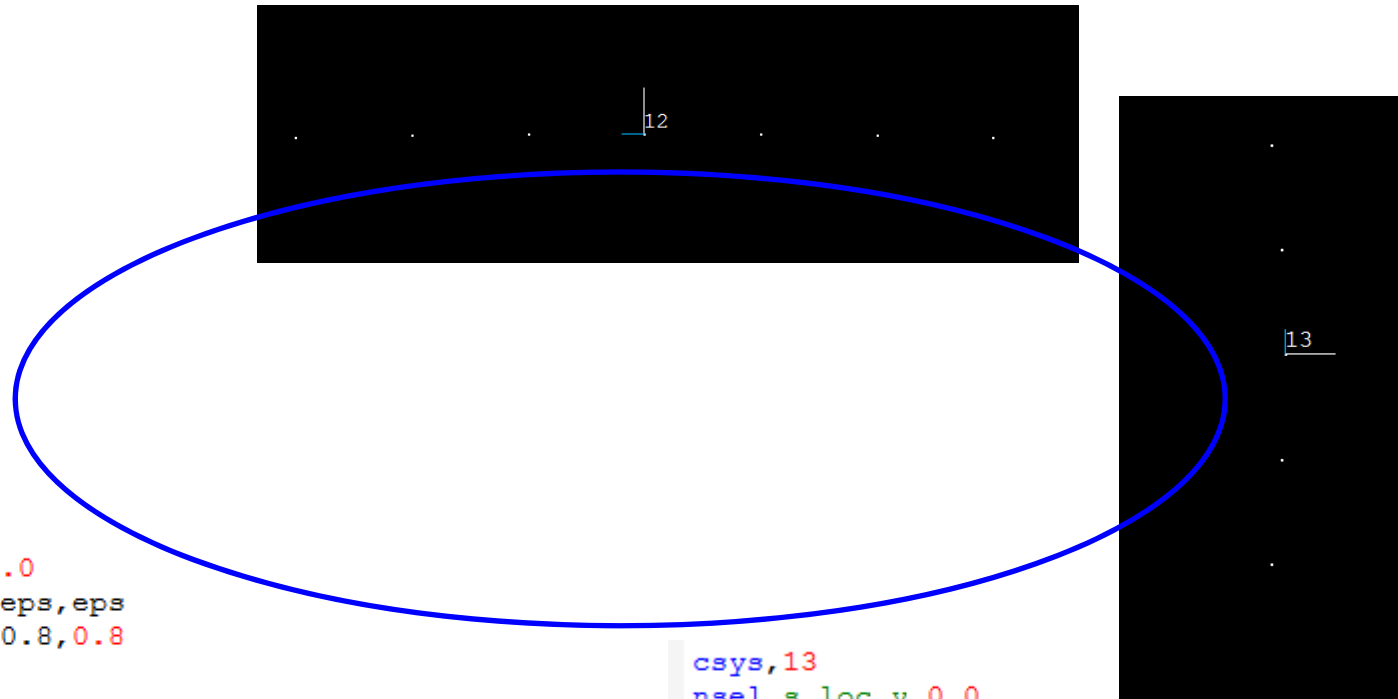
Coordinate systems introduced in Workbench then useful for the CINT calculation in ANSYS Apdl



CINT,SIFS calculation



CINT,SIFS calculation



```
eps = 0.05  
  
csys,12  
nsel,s,loc,y,0.0  
nsel,r,loc,x,-eps,eps  
nsel,r,loc,z,-0.8,0.8  
esel,s,type,,4  
nsle,u  
cm,CRACK_TIP_NODE_CM_2,node  
alls
```

```
csys,13  
nsel,s,loc,y,0.0  
nsel,r,loc,x,-eps,eps  
nsel,r,loc,z,-0.8,0.8  
esel,s,type,,4  
nsle,u  
cm,CRACK_TIP_NODE_CM_3,node  
alls
```

CINT,SIFS calculation

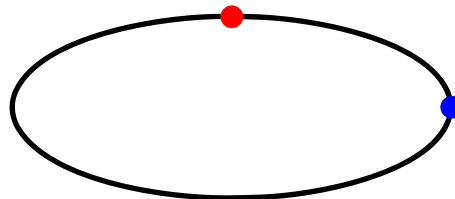
- Unreliable values at the boundary of the crack front
- Outer contours interact with the boundary of the toroid volume

```

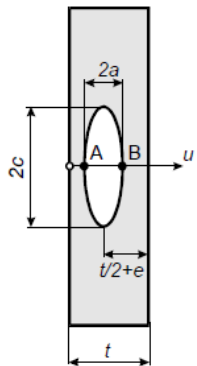
**** POST1 K1      RESULT LISTING ****
CrackID = 2
Crack Front Node = 34031
Contour Values = 860.07    916.60    917.34    918.17
Contour Values = 581.79    140.21
Crack Front Node = 56983
Contour Values = 432.25    462.39    465.40    464.97
Contour Values = 192.43    -146.09
Crack Front Node = 33957
Contour Values = 430.06    467.49    466.95    466.95
Contour Values = 268.89    91.450
Crack Front Node = 56982
Contour Values = 428.18    474.41    474.87    474.71
Contour Values = 266.43    -115.45
Crack Front Node = 33987
Contour Values = 412.64    437.41    435.06    435.29
Contour Values = 247.05    16.339
Crack Front Node = 57050
Contour Values = 401.55    513.81    515.19    515.76
Contour Values = 325.95    -22.894
Crack Front Node = 34048
Contour Values = 815.59    891.08    891.28    891.38
Contour Values = 513.49    32.073
    
```

```

**** POST1 K1      RESULT LISTING ****
CrackID = 3
Crack Front Node = 34062
Contour Values = 556.27    601.00    603.87    603.26
Contour Values = 430.28    -43.602
Crack Front Node = 57188
Contour Values = 283.87    306.75    306.72    307.51
Contour Values = 188.02    -128.93
Crack Front Node = 34075
Contour Values = 287.74    310.59    310.85    309.35
Contour Values = 205.25    13.022
Crack Front Node = 57208
Contour Values = 287.48    310.62    309.15    307.90
Contour Values = 103.74    -80.828
Crack Front Node = 34076
Contour Values = 566.23    616.15    617.52    617.81
Contour Values = 362.80    -30.772
    
```



Results verification through handbook



$$t = 25 \text{ mm}$$

$$h = 30 \text{ mm}$$

$$2a = 15 \text{ mm}$$

$$2c = 30 \text{ mm}$$

$$\sigma_0 = 100 \text{ MPa}$$

$$e/t = 0$$

$$c/a = 2$$

$$2a/t = 0.6$$

$c/a = 1$						
$2a/t$	$e/t = 0$		$e/t = 0.15$		$e/t = 0.3$	
	f_m^A	f_b^A	f_m^A	f_b^A	f_m^A	f_b^A
0	0.638	0.000	0.638	0.191	0.638	0.383
0.2	0.649	0.087	0.659	0.286	0.694	0.509
0.4	0.681	0.182	0.725	0.411	-	-
0.6	0.739	0.296	0.870	0.609	-	-
$c/a = 2$						
$2a/t$	$e/t = 0$		$e/t = 0.15$		$e/t = 0.3$	
	f_m^A	f_b^A	f_m^A	f_b^A	f_m^A	f_b^A
0	0.824	0.000	0.824	0.247	0.824	0.494
0.2	0.844	0.098	0.862	0.359	0.932	0.668
0.4	0.901	0.210	0.987	0.526	-	-
0.6	1.014	0.355	1.332	0.866	-	-

$$K_I = f_m^A \sigma_0 \sqrt{\pi a} = 492 \text{ MPa} \sqrt{\text{mm}}$$

$$K_I (\text{ANSYS Wb, 3D}) = 475 \text{ MPa} \sqrt{\text{mm}}$$

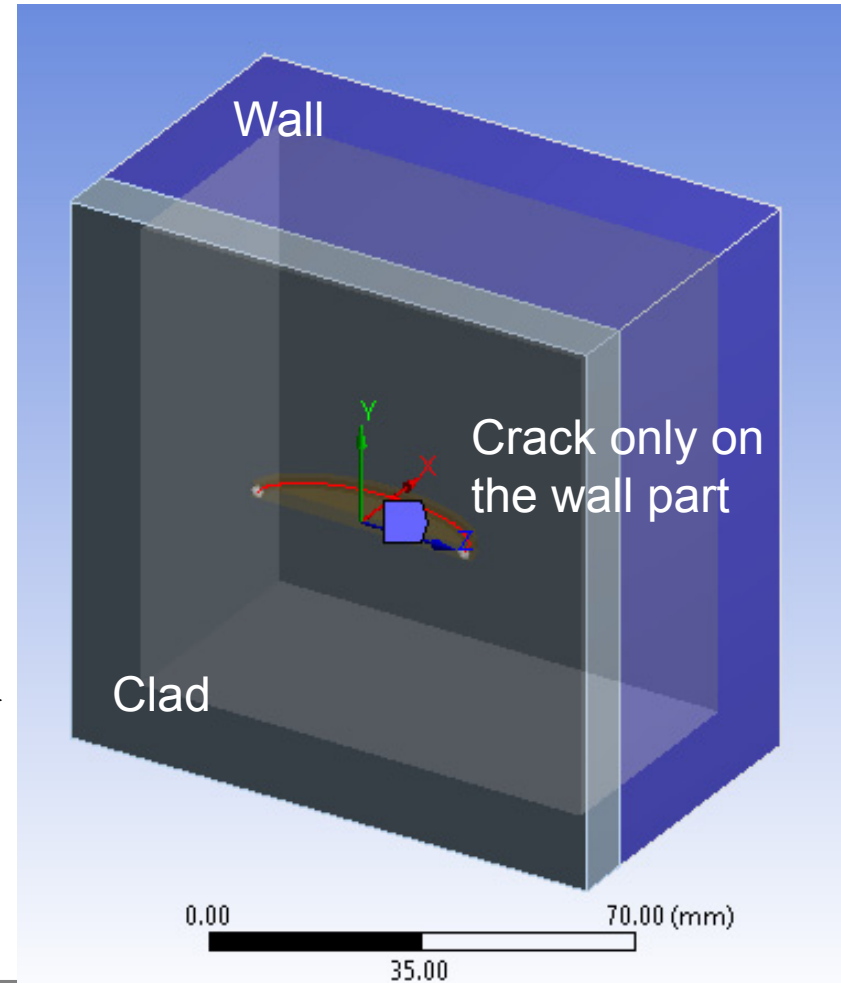
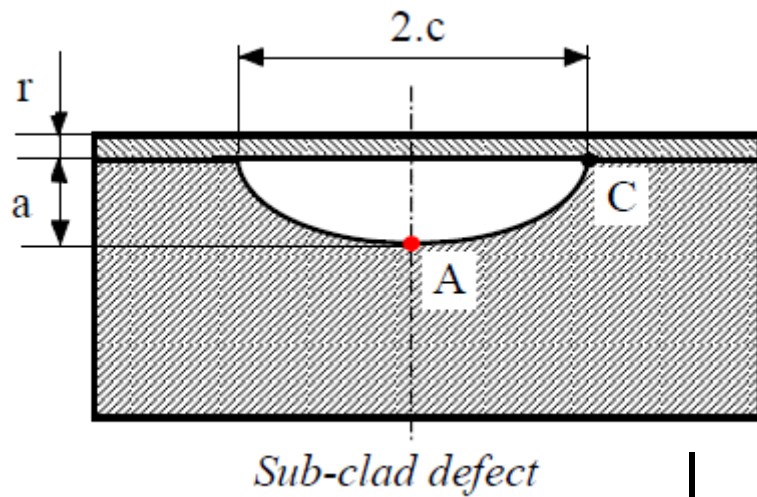
Ok! possible effect of the limited width

Content

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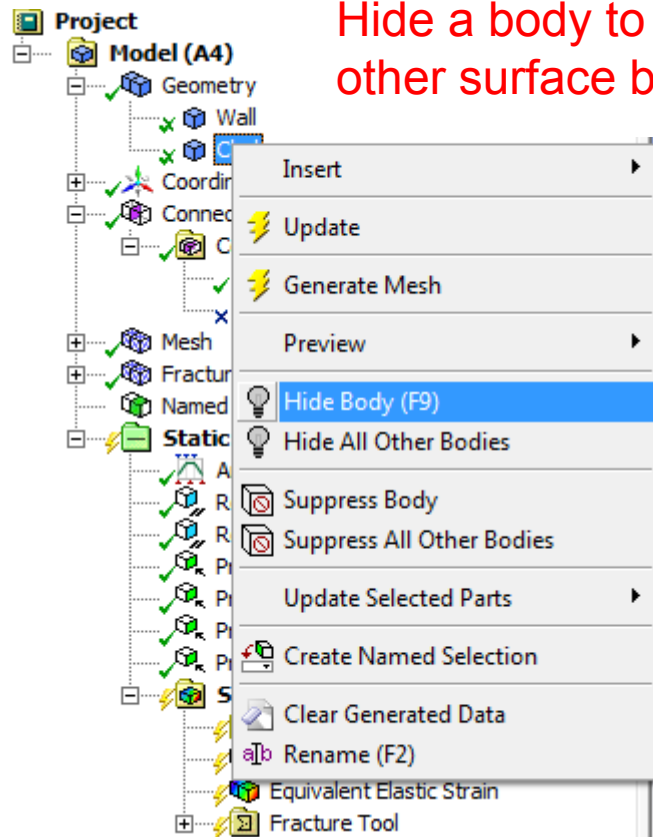
Sub-clad surface semielliptical crack

The model

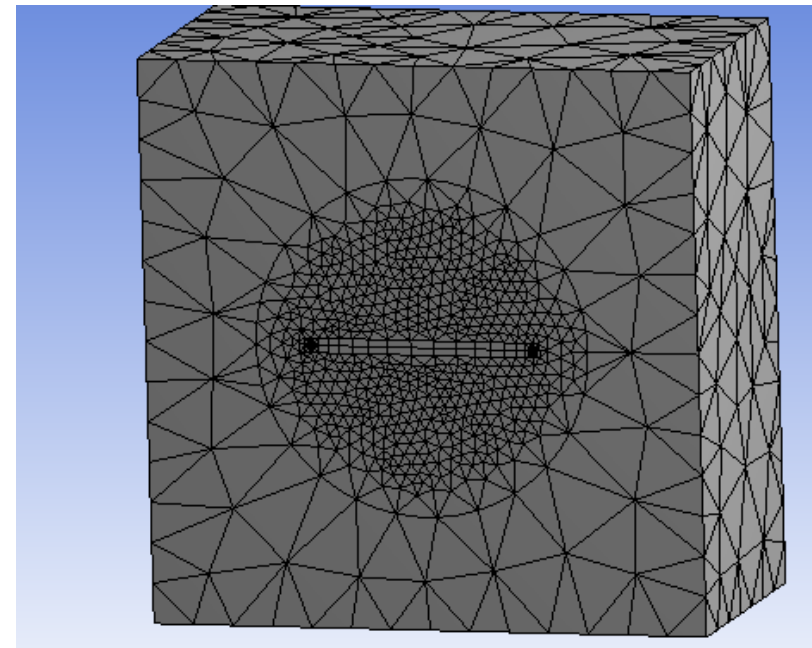
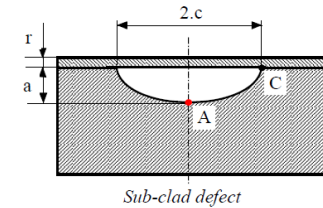


Sub-clad surface semielliptical crack

The model



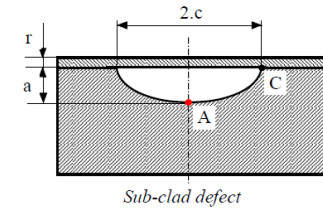
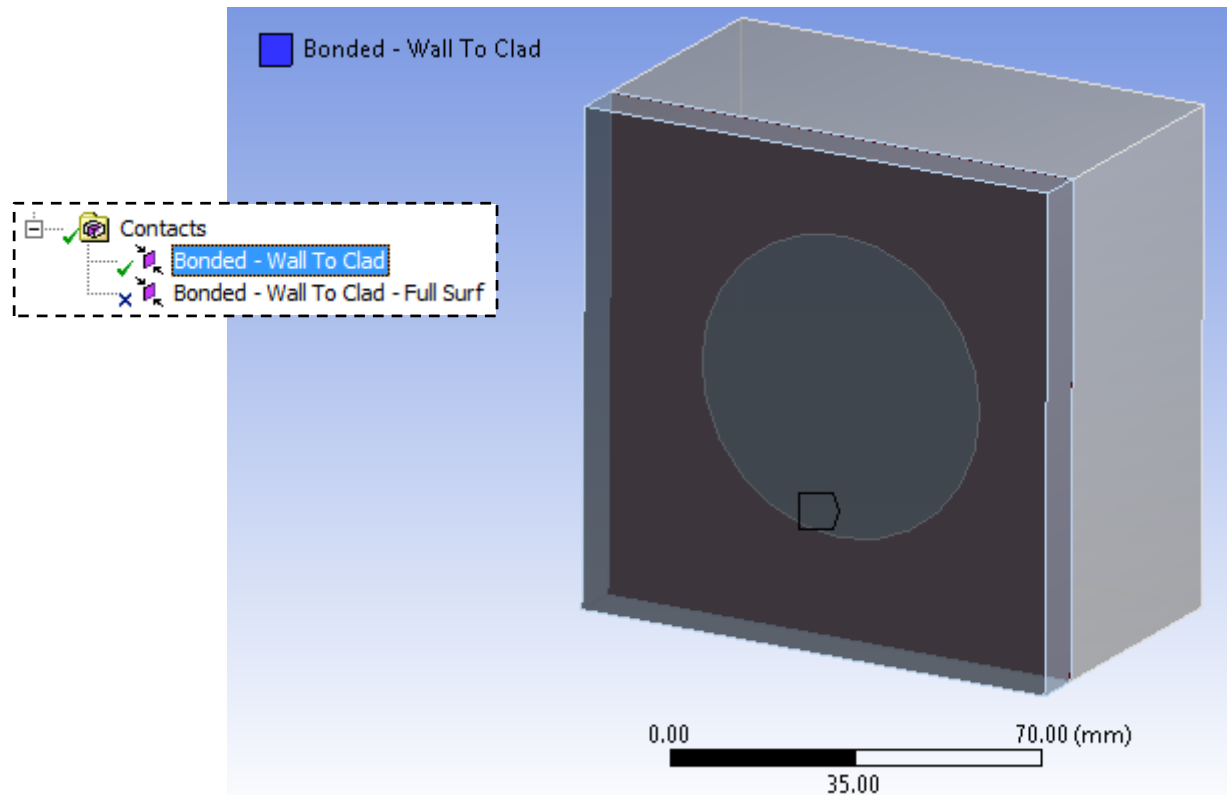
Hide a body to pick any other surface behind



Create the surface semielliptical crack through the usual steps

Sub-clad surface semielliptical crack

The model



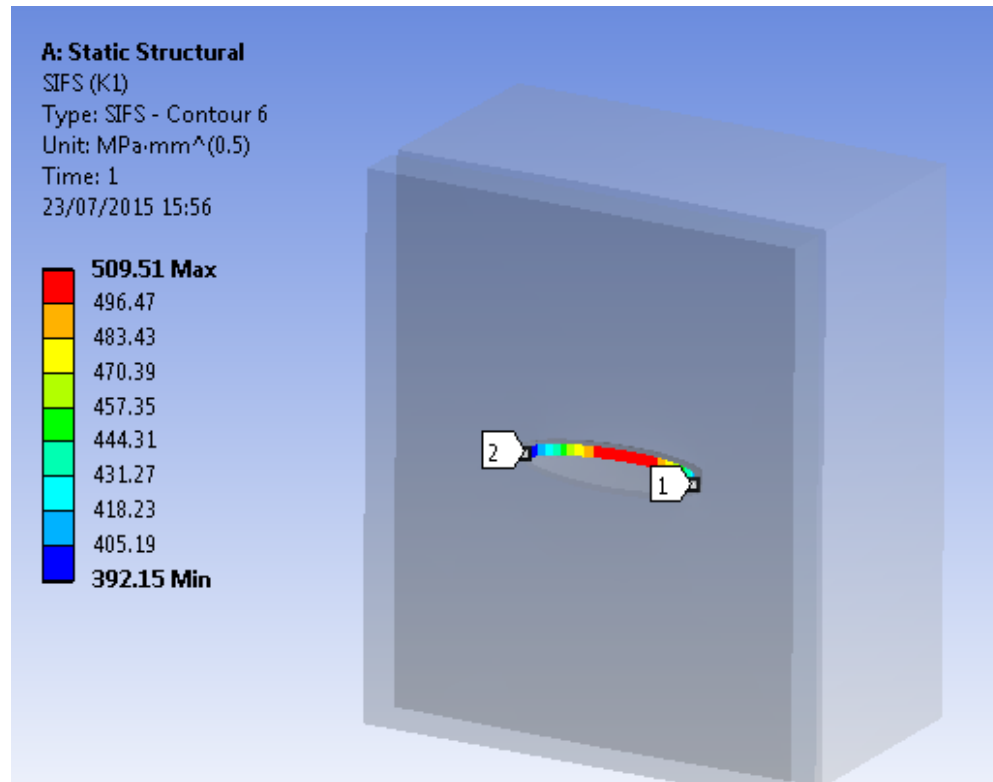
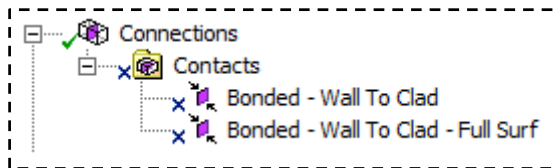
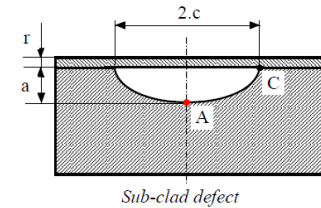
The attachment between the wall and the clad cannot be continuous across the entire surface

A circle can give a dimension of the discontinuity between the two parts

Sub-clad surface semielliptical crack

SIF results

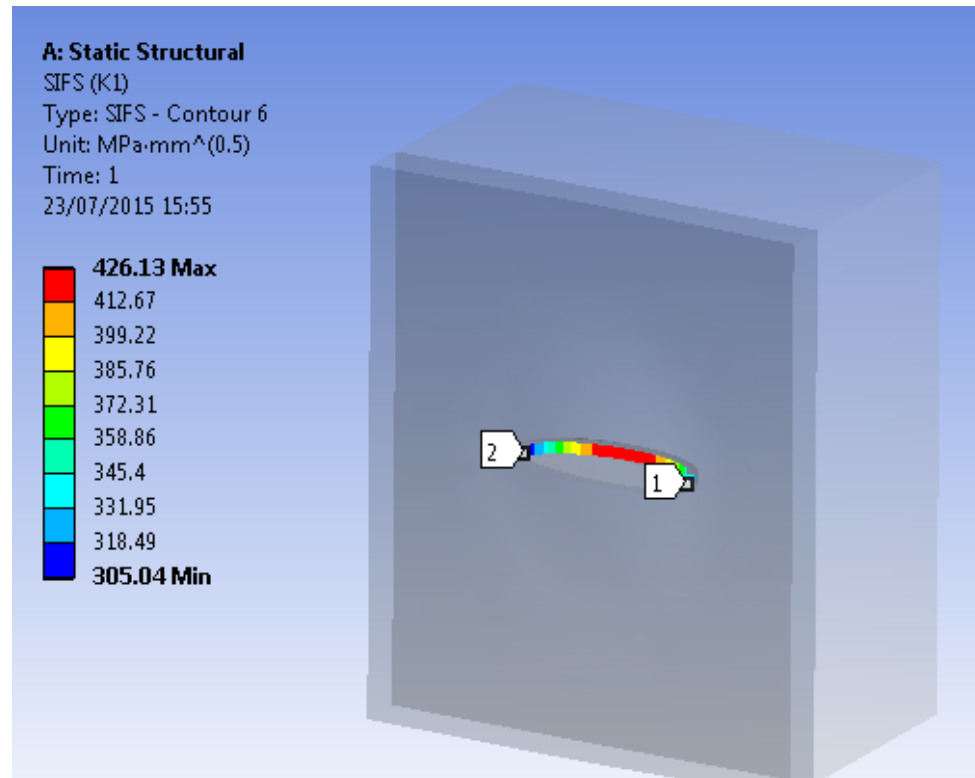
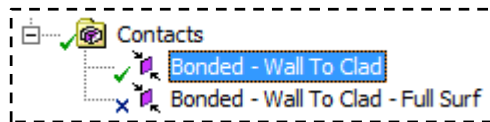
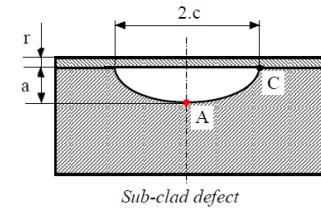
First result can be obtained without any connection between the two parts



Sub-clad surface semielliptical crack

SIF results

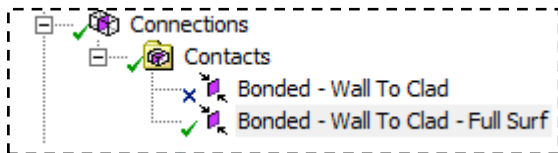
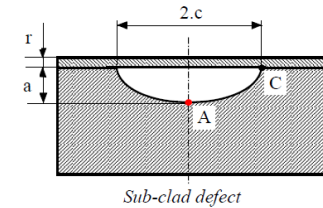
Then calculation is repeated with connection outside the circle



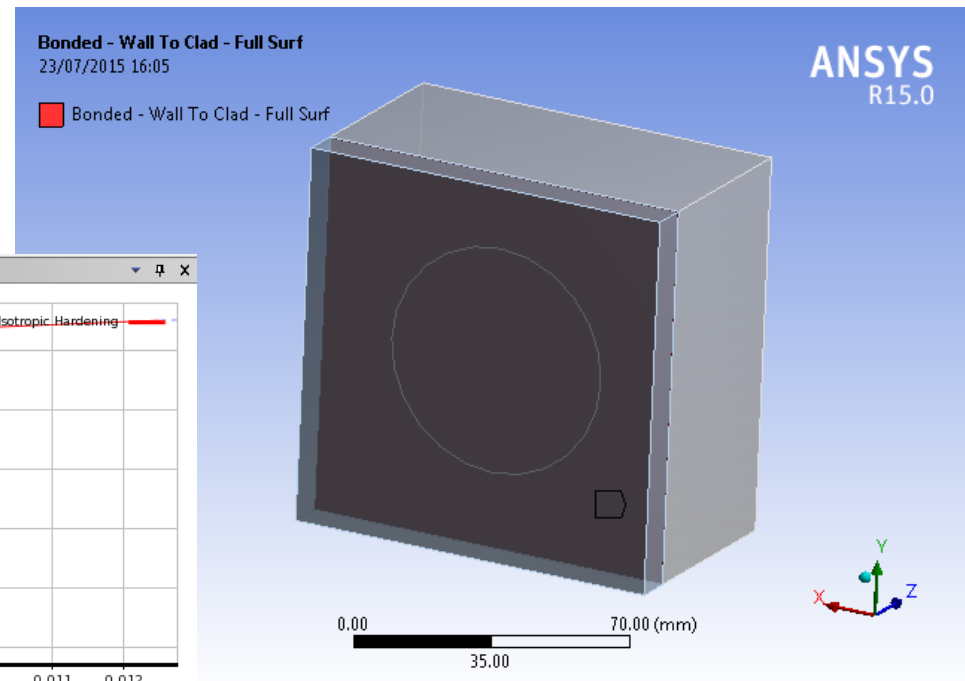
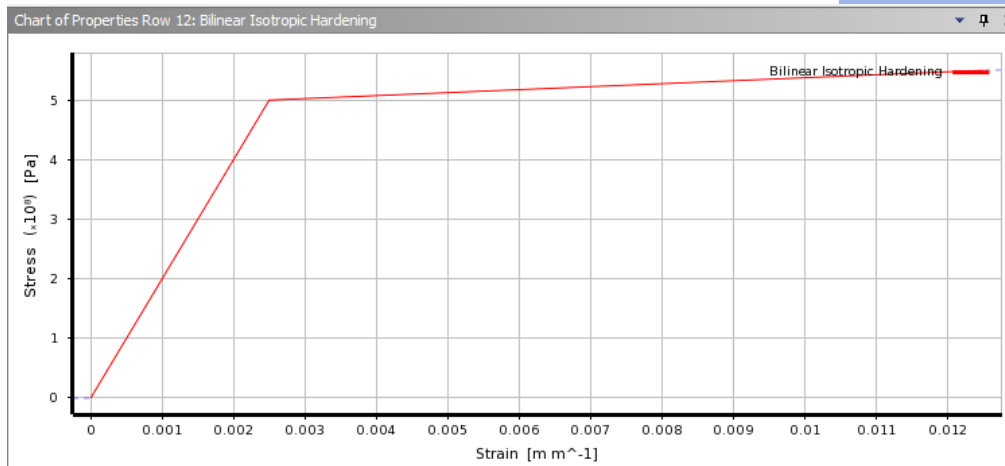
Sub-clad surface semielliptical crack

SIF results

Finally the full surface connection can be activated, after imposing plastic properties of the clad



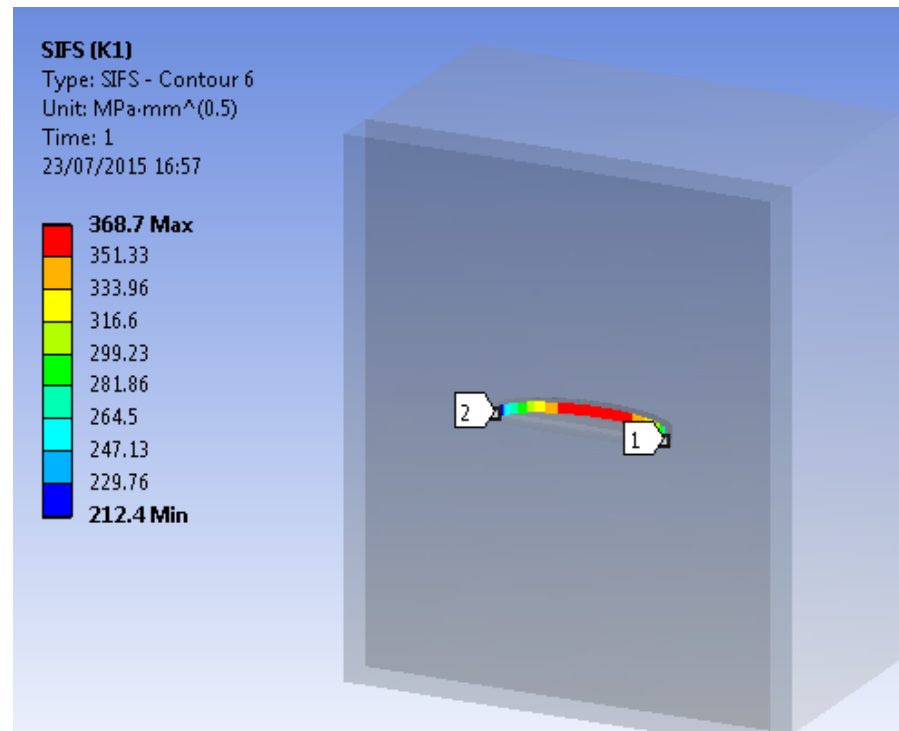
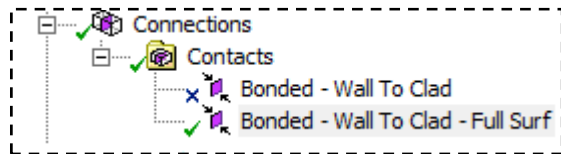
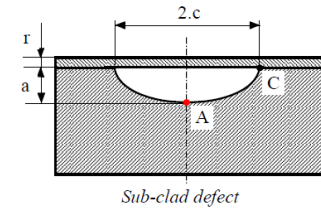
Clad Elastic-Plastic properties



Sub-clad surface semielliptical crack

SIF results

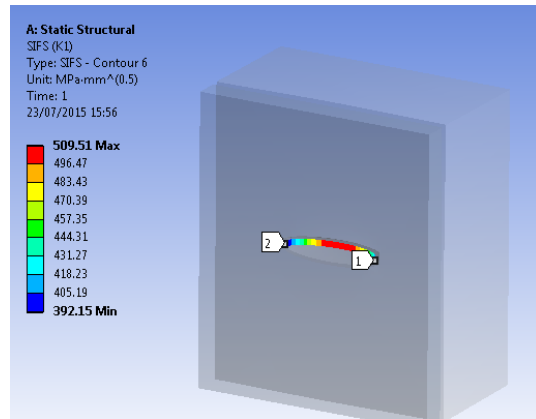
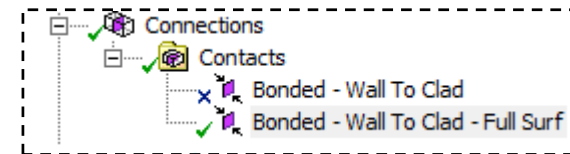
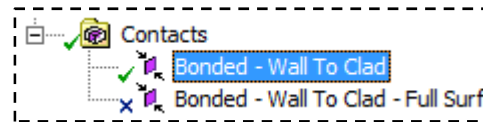
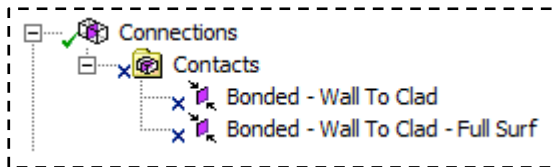
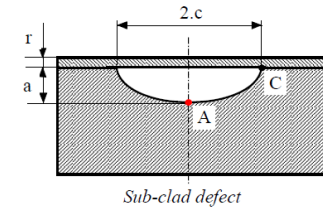
Finally the full surface connection can be activated, after imposing plastic properties of the clad



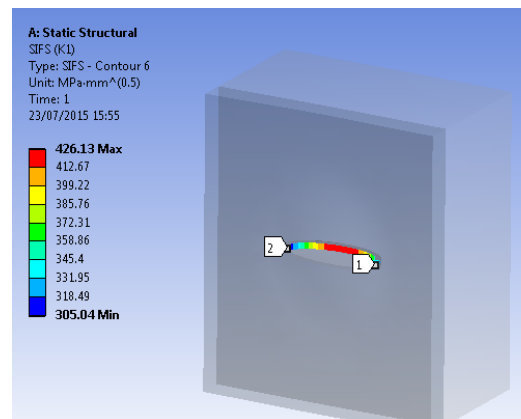
Sub-clad surface semielliptical crack

SIF result comparison

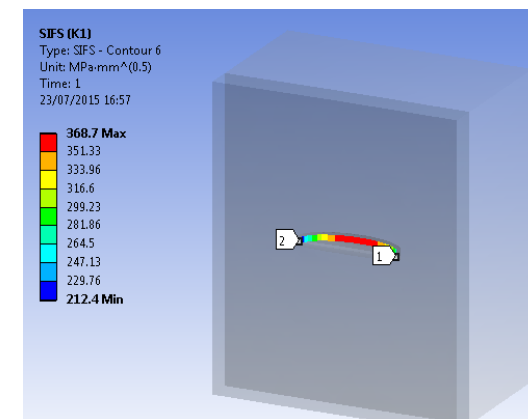
Which one is the most realistic result?



$$K_I = 510 \text{ MPa}\sqrt{\text{mm}}$$



$$K_I = 426 \text{ MPa}\sqrt{\text{mm}}$$



$$K_I = 369 \text{ MPa}\sqrt{\text{mm}}$$

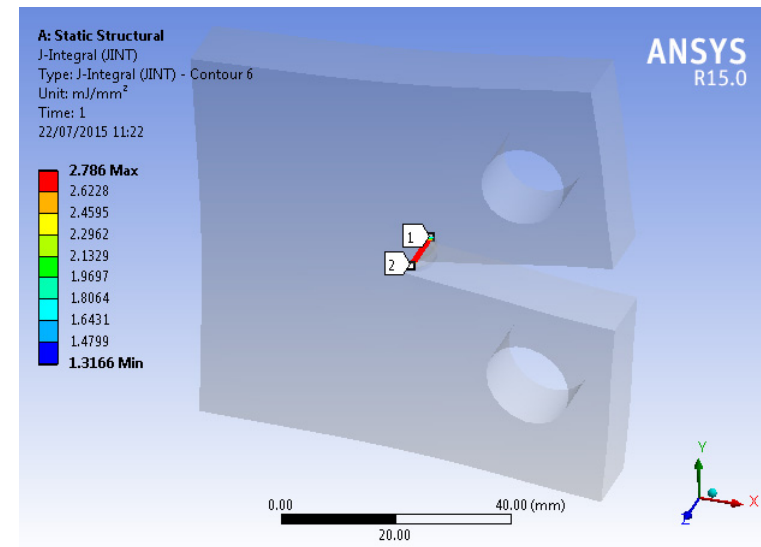
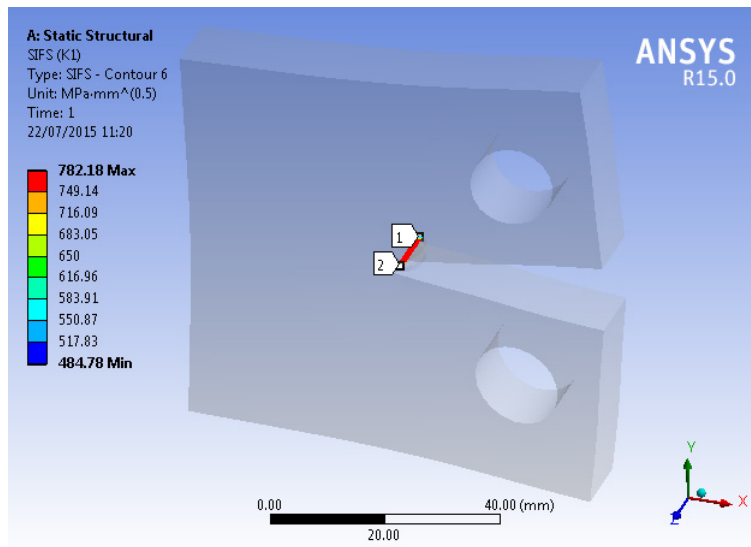
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CT specimen example

J parameter as an option of the Wb automatic Crack tool

Elastic calculation – Relation between K_I and J



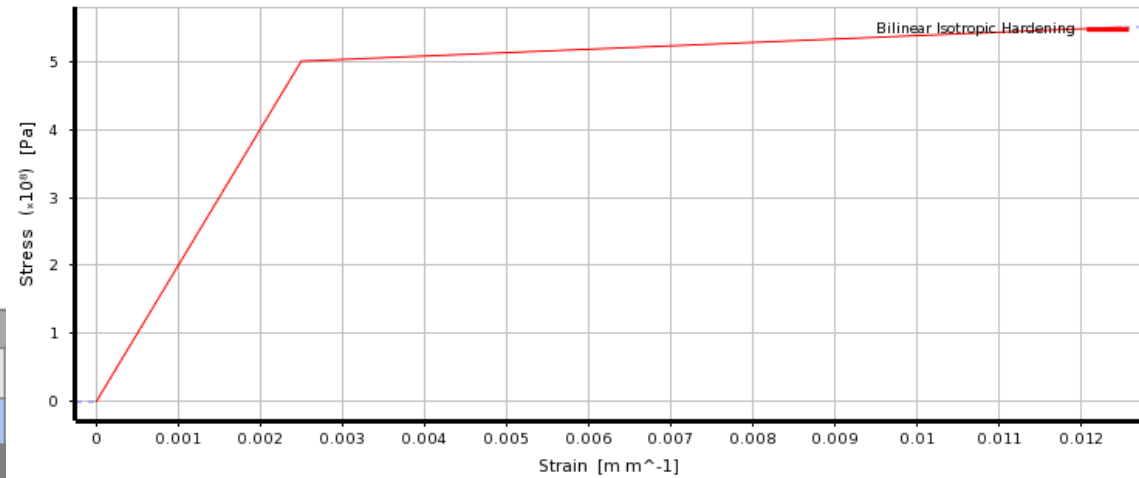
$$K_I(\text{ANSYS}) = 782 \text{ MPa} \sqrt{\text{mm}} \quad J(\text{ANSYS}) = 2.786 \text{ mJ/mm}^2$$

Conversion, validation: $E = 200\,000 \text{ MPa}$, $\nu = 0.3$

$$J = \frac{K_I^2}{E'} = 2.782 \text{ mJ/mm}^2 \quad \text{OK!}$$

CT specimen example

Elastic-Plastic steel, *Bilinear Isotropic Hardening*



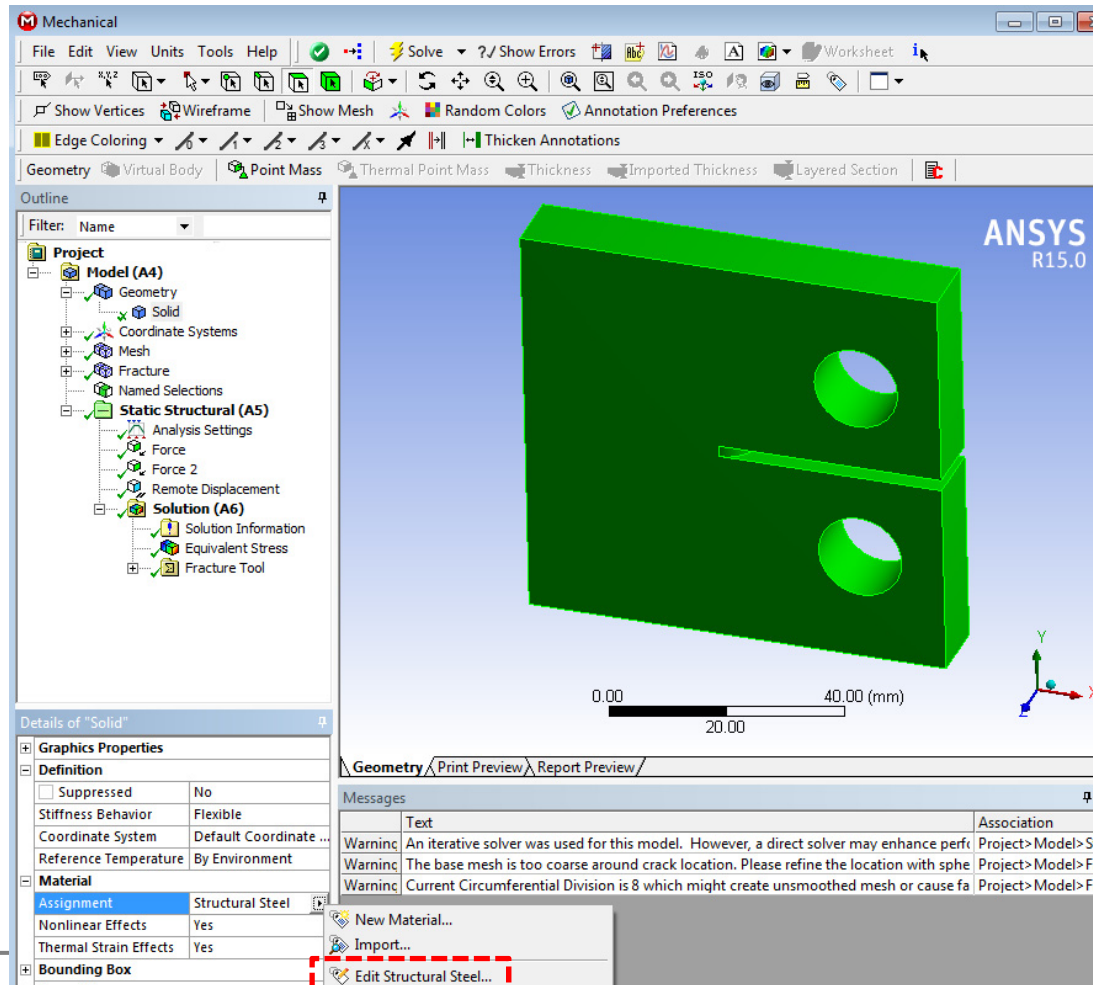
Outline of Schematic A2: Engineering Data			
	A	B	
1	Contents of Engineering Data		
2	Material		
3	Structural Steel	<input type="checkbox"/>	General_Materials.
4	Structural Steel - ElasticPlastic	<input type="checkbox"/>	General_Materials.
*	Click here to add a new material		

12	Bilinear Isotropic Hardening		
13	Yield Strength	500	MPa
14	Tangent Modulus	5000	MPa



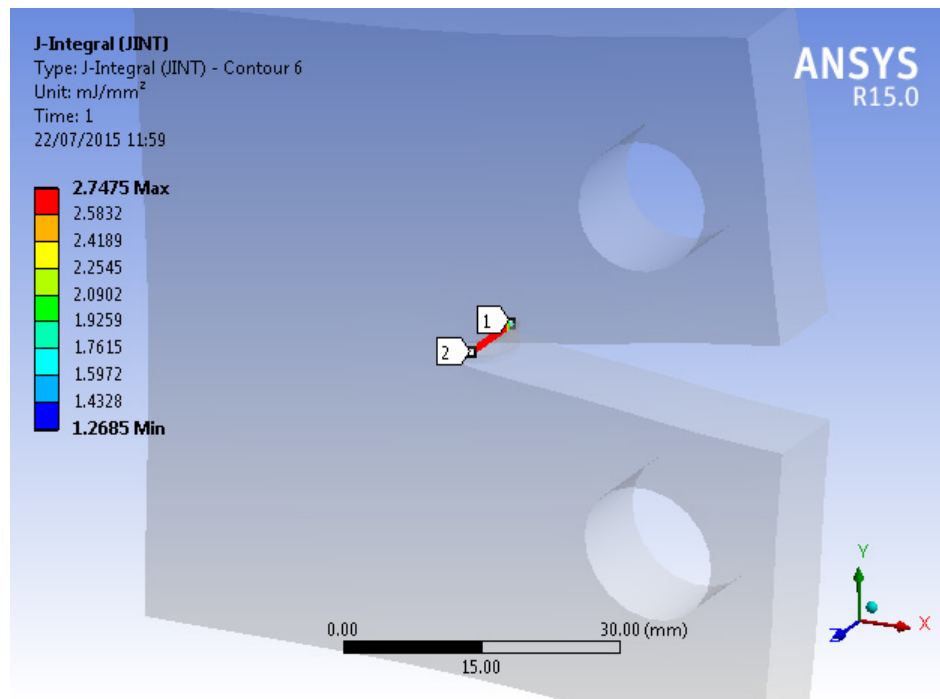
CT specimen example

Elastic-Plastic steel, *Bilinear Isotropic Hardening*



CT specimen example

Elastic-Plastic steel, *Bilinear Isotropic Hardening*



Same load P , Elastic-Plastic material:

$$J(\text{ANSYS}) = 2.748 \text{ mJ/mm}^2$$

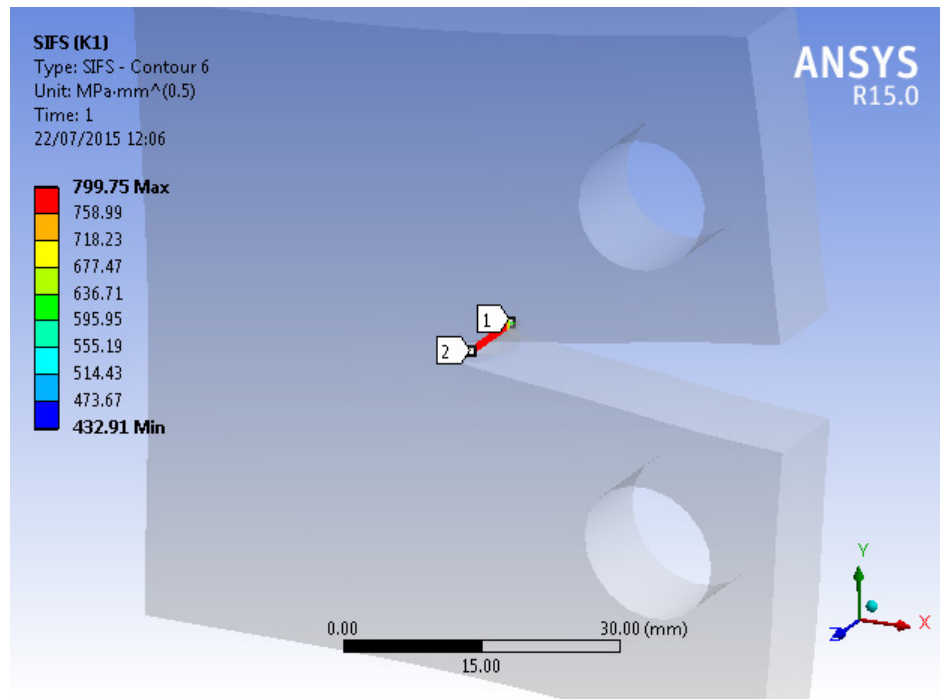
Previous (just Elastic):

$$J(\text{ANSYS}) = 2.786 \text{ mJ/mm}^2$$

$$\Delta\% = -1.4\%$$

CT specimen example

Elastic-Plastic steel, *Bilinear Isotropic Hardening*



Same load P , Elastic-Plastic material:

$K_{I(II,III)}$ is also calculated,

though theoretically not available

(just the output of CINT, SIFS command)

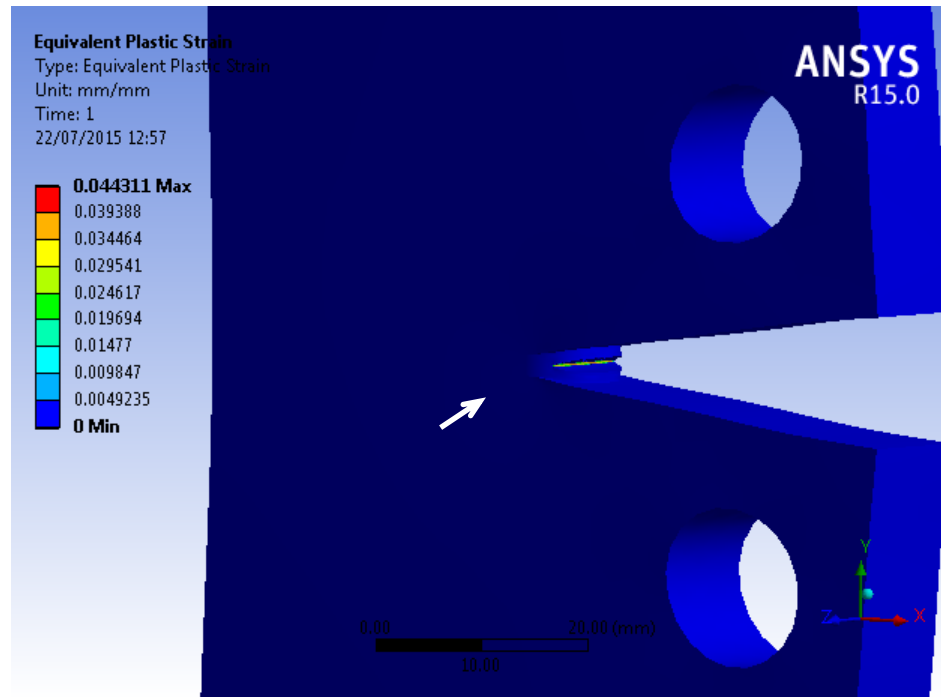
$$K_I(\text{ANSYS}) = 800 \text{ MPa}\sqrt{\text{mm}}$$

Previous (just Elastic):

$$K_I(\text{ANSYS}) = 782 \text{ MPa}\sqrt{\text{mm}}$$

$$\Delta\% = 2.3\%$$

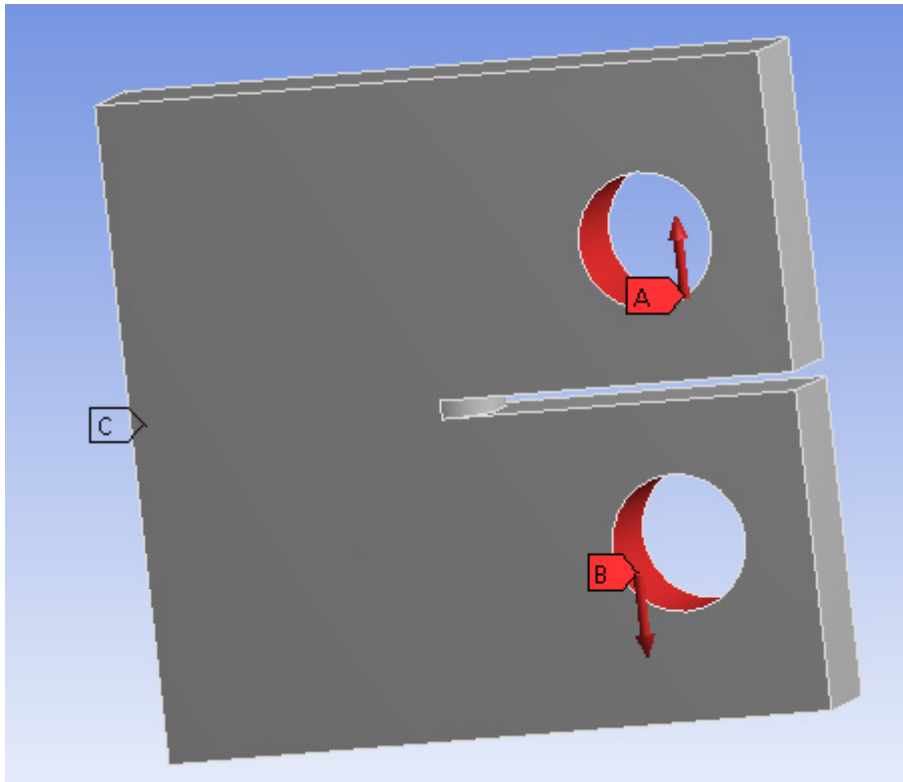
Small Scale Yielding



K_I and J similar values,
with respect to the
previous just elastic calculation,
due to the very small
plastic region

CT specimen example

Increasing load – Multiple time step simulation



Details of "Analysis Settings"	
<input type="checkbox"/> Step Controls	
Number Of Steps	4.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled

Tabular Data					
	Steps	Time [s]	<input checked="" type="checkbox"/> X [N]	<input checked="" type="checkbox"/> Y [N]	<input checked="" type="checkbox"/> Z [N]
1	1	0.	0.	0.	0.
2	1	1.	0.	10000	0.
3	2	2.	0.	20000	0.
4	3	3.	0.	30000	0.
5	4	4.	0.	40000	0.
*					

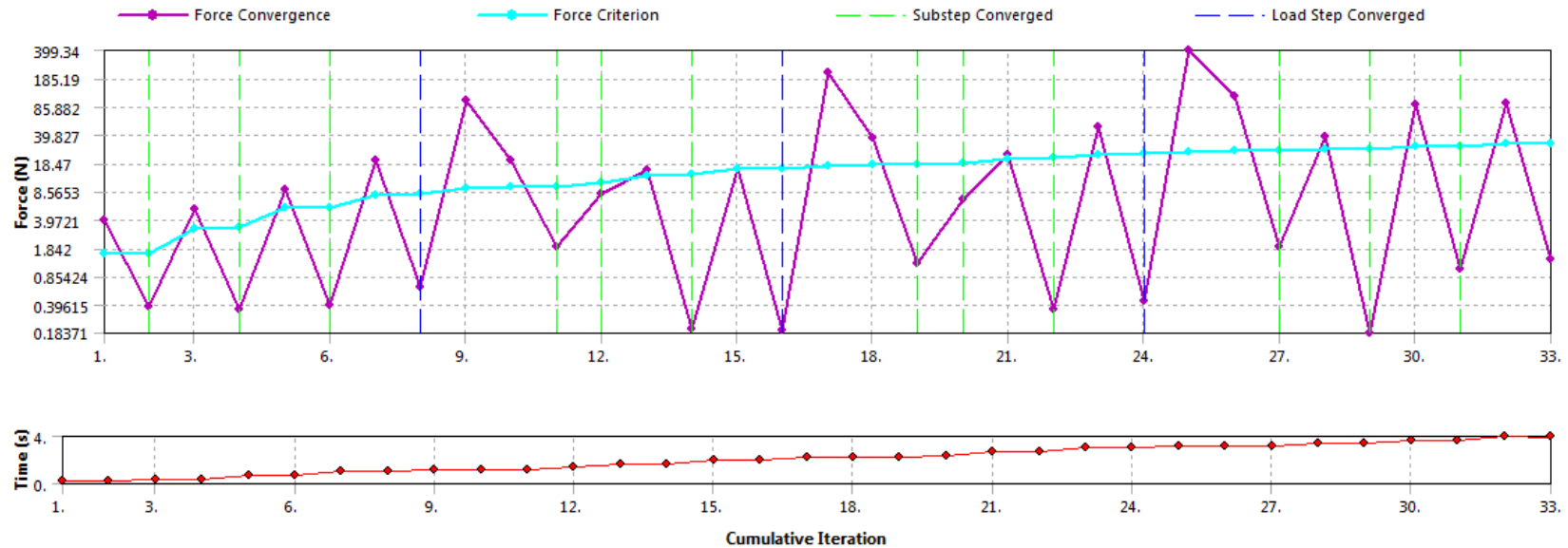
CT specimen example

Increasing load – Multiple time step simulation

Non linear analysis – iterative solution

Tabular Data					
	Steps	Time [s]	✓ X [N]	✓ Y [N]	✓ Z [N]
1	1	0.	0.	0.	0.
2	1	1.	0.	10000	0.
3	2	2.	0.	20000	0.
4	3	3.	0.	30000	0.
5	4	4.	0.	40000	0.
*					

Force Convergence



CT specimen example

Increasing load – Multiple time step simulation

Increasingly discrepancy of K_I with respect to J

Elastic-Plastic, ANSYS Workbench							
S _Y , MPa	B, mm						
500	12						
P, kN	K _I , MPa mm ^{0.5}	J, mJ/mm ²	K _I , from J	Delta %	B _{min} for Pl. Strain		
10	800	2.748	777	-2.9	6.0	=>	Pl. Strain
20	1969	11.25	1572	-25.2	24.7	=>	Pl. Stress
30	3712	27.32	2450	-51.5	60.0	=>	Pl. Stress
40	6269	56.85	3535	-77.4	124.9	=>	Pl. Stress

↑
Unreliable
↑
Reliable
↑
Equivalence

CT specimen example

Increasing load – Multiple time step simulation

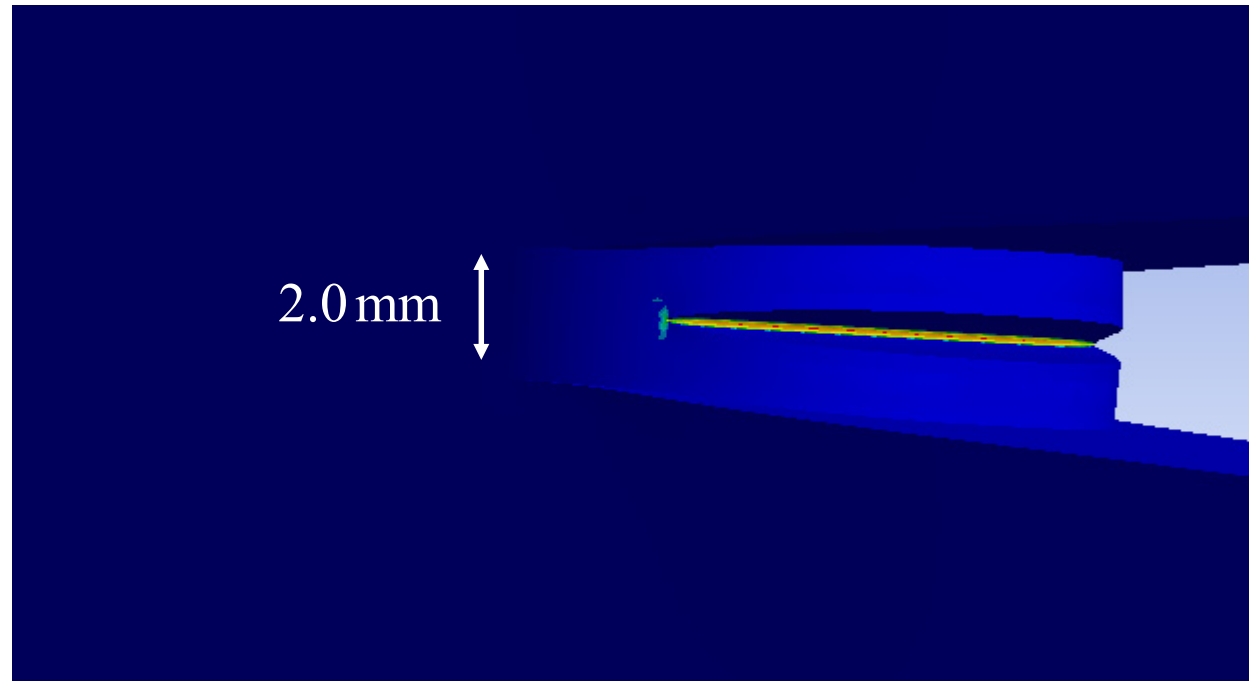
Plastic region size

$$P = 10 \text{ kN} \quad B = 12 \text{ mm}$$

$$B_{\min} = 2.5 \left(\frac{K_I}{S_Y} \right)^2 = 6.0 \text{ mm}$$

→ Plane strain

$$r_p = \frac{1}{3\pi} \left(\frac{K_I}{S_Y} \right)^2 = 0.26 \text{ mm}$$



CT specimen example

Increasing load – Multiple time step simulation

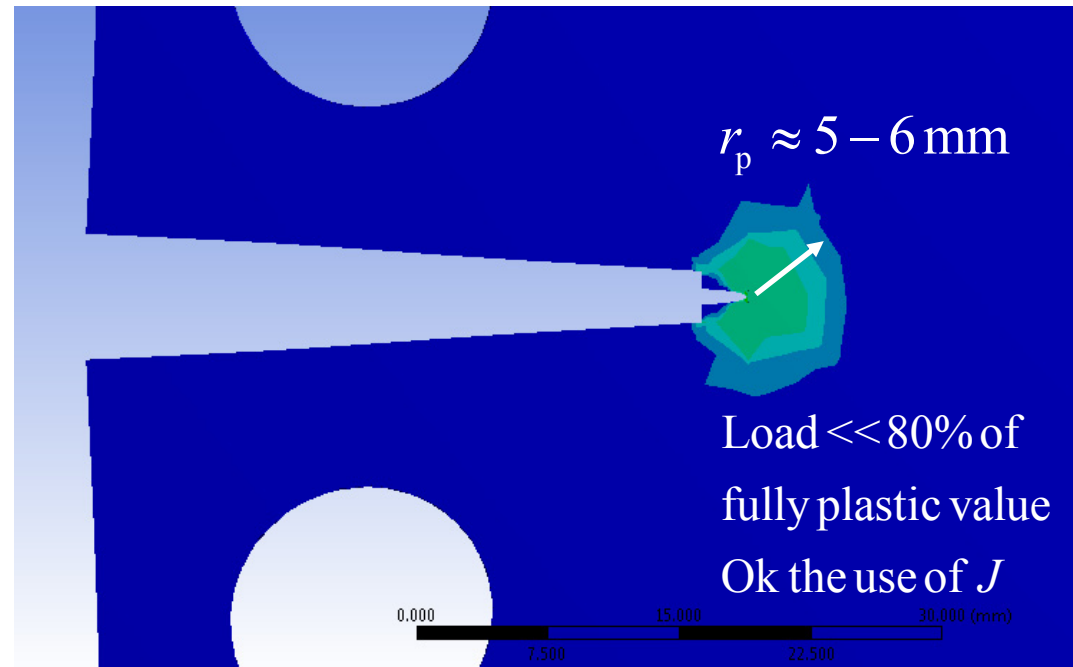
Plastic region size

$$P = 40 \text{ kN} \quad B = 12 \text{ mm}$$

$$B_{\min} = 2.5 \left(\frac{K_I}{S_Y} \right)^2 = 124.9 \text{ mm}$$

→ **Plane stress**

$$r_p = \frac{1}{\pi} \left(\frac{K_I}{S_Y} \right)^2 = 15.9 \text{ mm}$$



LEFM validity for Pl. Stress **not** satisfied:

$$a = 30 \text{ mm} < \frac{4}{\pi} \left(\frac{K_I}{S_Y} \right)^2 = 57.9 \text{ mm}$$