

Troubleshooting convergence problems in LS-DYNA implicit



```
*** Error 60004 (IMP+4)
*****
*                                     *
*      - FATAL ERROR -              *
*                                     *
* Nonlinear solver failed to find equilibrium.
*                                     *
*****
```

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Today's goal

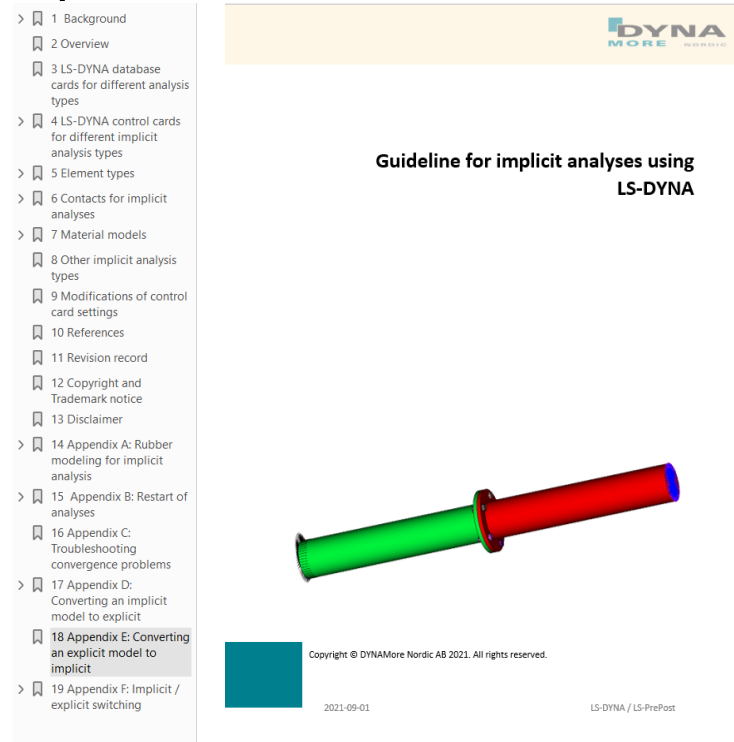
- To give the audience:
 - Information of common causes for failed convergence.
 - Show where to find convergence related information.
 - Explain how to interpret some of the information output by LS-DYNA.
- To exemplify remedies for some common convergence issues.

Overview

- The basics
 - Implicit set-up
 - LS-DYNA
- Troubleshooting tips
 - General
 - Contacts
 - Examples
 - Control card modifications
 - Interpreting convergence history output
- D3hsp View

Implicit set-up in LS-DYNA

- In order to help the user getting started with Implicit analyses in LS-DYNA, the Guideline to implicit analysis was developed.



- The focus of the “Guidelines for implicit analyses” is how to set up the analysis as such, and to guide in choice of elements, contacts, material models etc. Also provide a suggested starting point for control cards settings.
 - Latest release: September 2021.

Basic implicit set-up in LS-DYNA

- LS-DYNA is a versatile multi-physics solver. Many different analysis types are possible. But many settings are left to the user ...
 - Control cards, telling LS-DYNA how to solve the task
 - Element formulations (many different formulations available)
 - Contact definitions (many different formulations and options to chose from)
 - Material models (over 250 to chose from)
- Based on the Guideline for implicit analyses, this may (in many cases) be greatly simplified. The objective of the Guideline is to reduce the time it takes to make these choices, so that the time can be spent on solving the actual task.
- The Guideline for implicit analyses is available for download from the Client Area of project.dynamore.se
- The **Appendix P** of the LS-DYNA keyword manual (R9.0 and later) also provides some recommendations, background and motivation to implicit control card settings.

Suggested control card settings from the Guideline

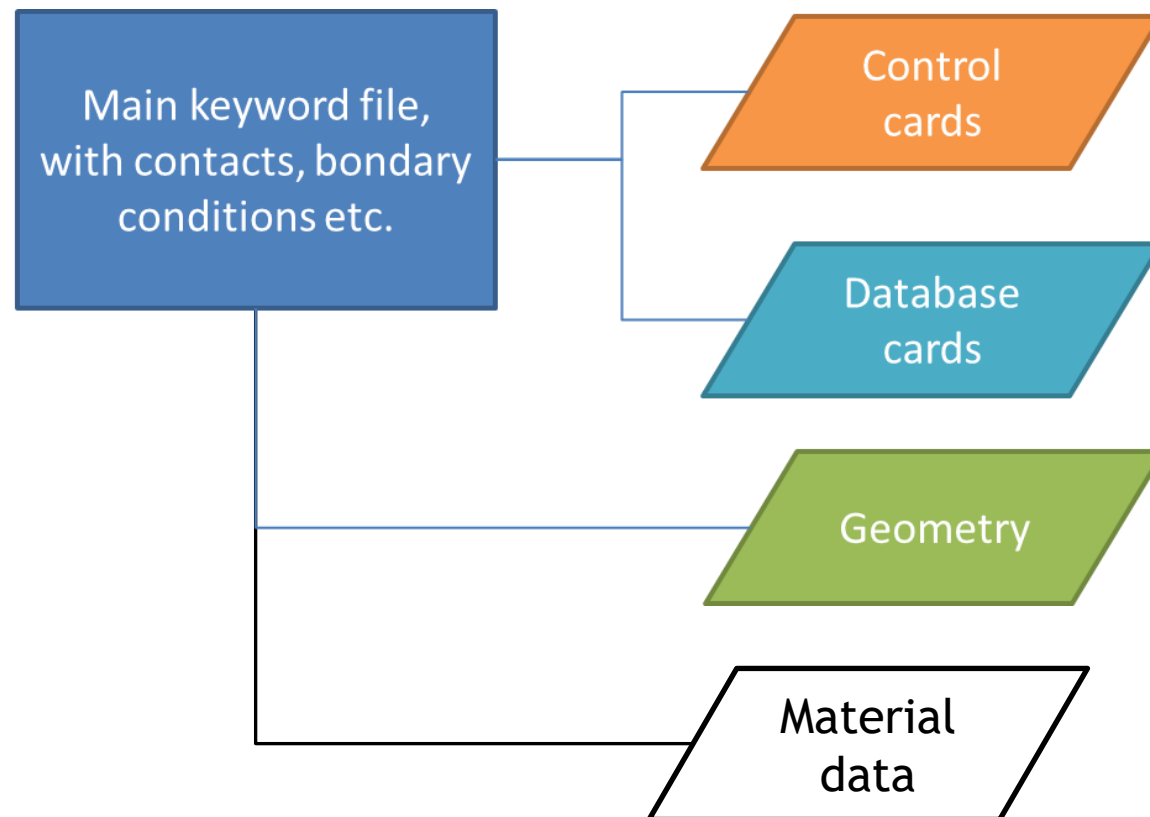
- Identify analysis type and select control card include file
 - In many cases, `*CONTROL_TERMINATION` is the only required additional control card
 - Note! LS-DYNA implicit is always either purely non-linear or purely linear!
- Use an include file structure! Then the control card include files from the Guideline package can be used directly.

	Include files		Add keywords: (*)
Analysis type	control_cards_...	database_cards_...	*CONTROL_IMPLICIT_...
Linear static	linear.key	static.key	
Non-linear static	nonlin.key	static.key	
Linear buckling		(1)static.key	BUCKLE
Non-linear postbuckling	arc.key	static.key	
Eigenfrequency analysis		(1)static.key	EIGENVALUE
Linear transient modal dynamics	linear.key	dynamic.key	MODAL_DYNAMIC
Frequency domain analyses ⁽²⁾	linear.key		
Non-linear implicit dynamics	nonlin.key	dynamic.key	DYNAMICS

Notes: (*) `*CONTROL_TERMINATION` must always be added. (1) Can be part of both linear and non-linear analysis. (2) Frequency response functions, steady state dynamics etc.

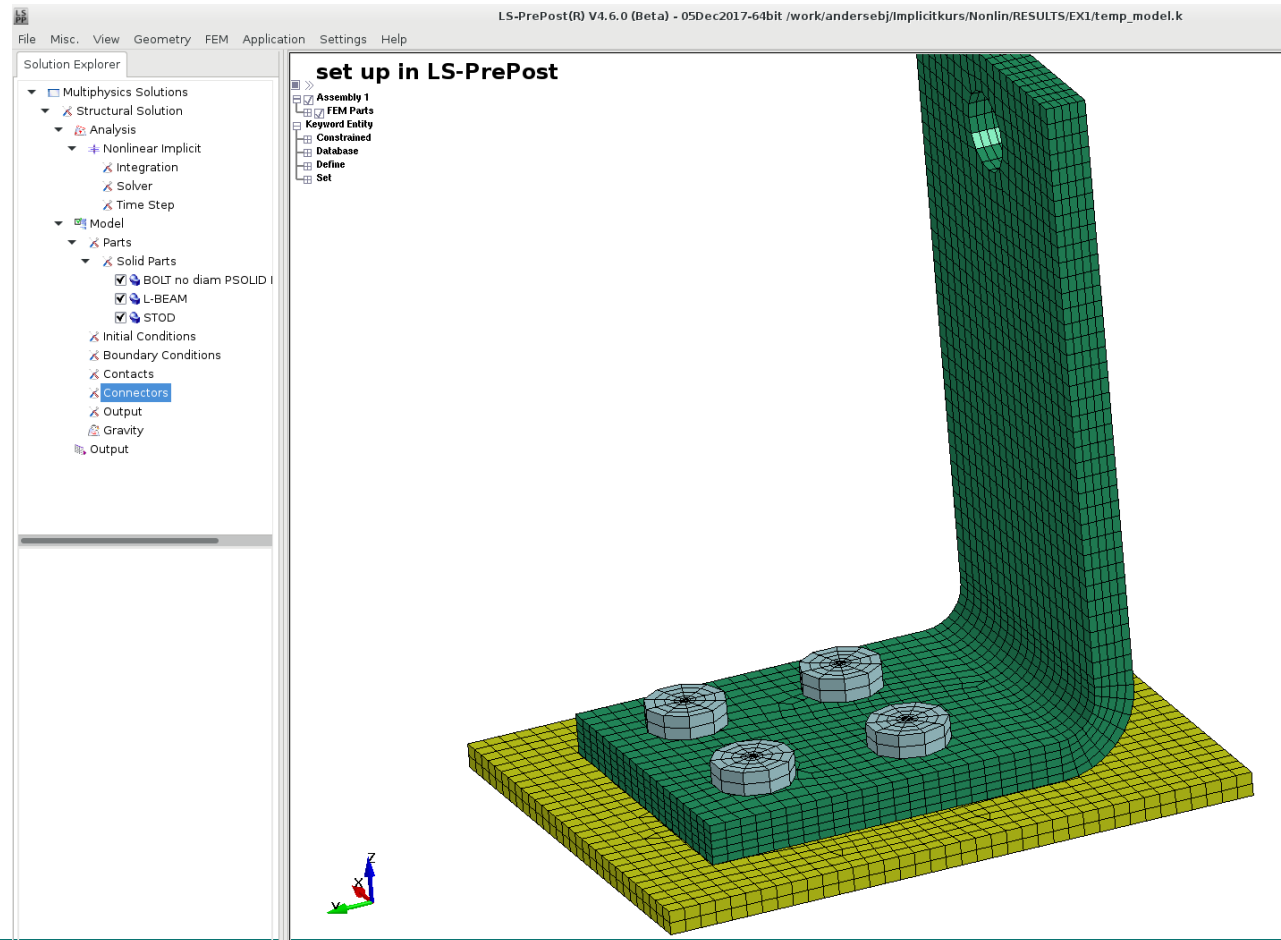
Implicit set-up in LS-DYNA - Control cards

- Identify analysis type and select appropriate control card include file.
 - In many cases, `*CONTROL_TERMINATION` is the only required additional control card.
- Use an include file structure! Then the control card include files can be used directly.



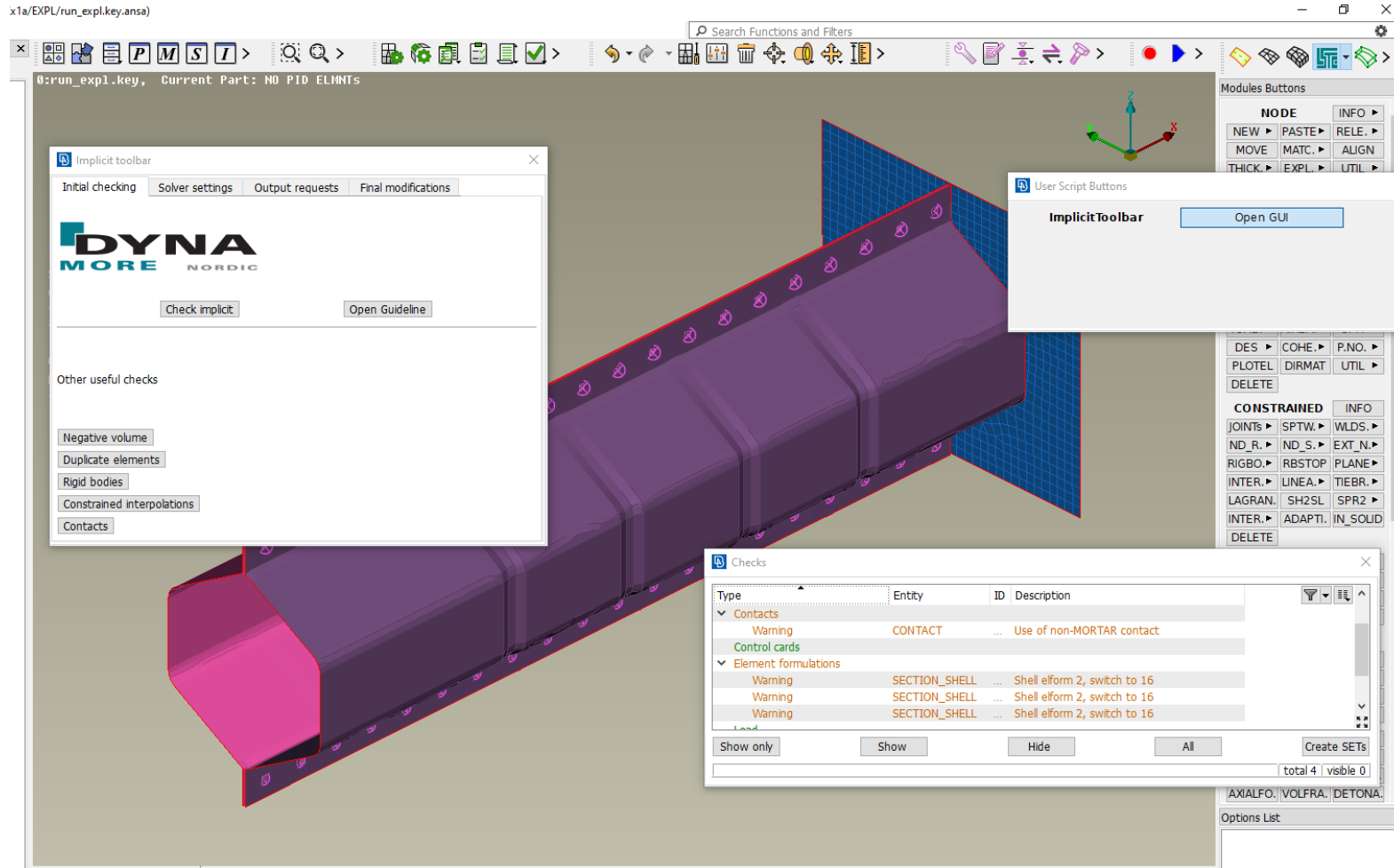
Pre-processing: LS-PrePost Solution Explorer

- The Solution Explorer, a GUI dedicated for implicit set up is available in LS-PrePost from v4.7



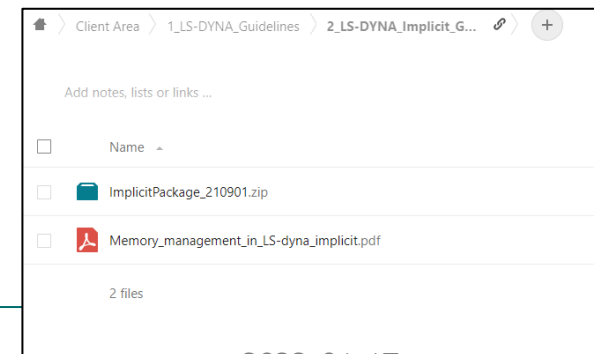
Pre-processing: ANSA Implicit toolbar

■ Help with model check and set-up



LS-DYNA for implicit analyses

- Double precision is required for implicit analyses.
- For performance reasons we recommend mpp-LS-DYNA or hybrid-LS-DYNA
- Some implicit features are only supported in smp, for example
 - `*CONTROL_IMPLICIT_MODAL_DYNAMIC`
- Also - 2d analyses are often run in smp
- Memory management
 - Try to run in-core.
 - Static memory assignment is controlled by command-line arguments `memory` and `memory2` when submitting a job. Details may differ due to your local installation.
 - Specified in Words or Mega Words. One Word in double precision is normally 8 bytes.
 - R10 and earlier: use only `memory=Xm`, and set X high enough so that matrix factorization can be performed in-core
 - From R11 dynamic memory handling is used
 - For more details, see new documentation at the Client Area



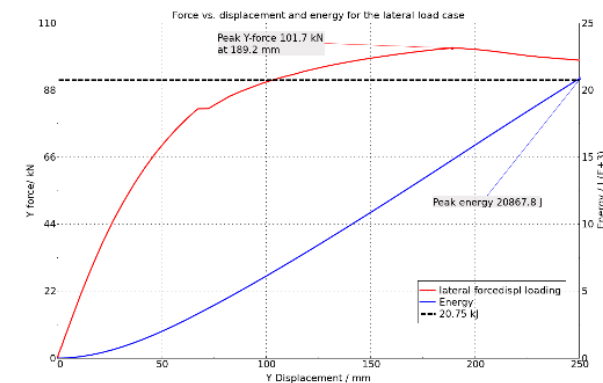
TROUBLESHOOTING TIPS

- WHERE TO FIND INFORMATION

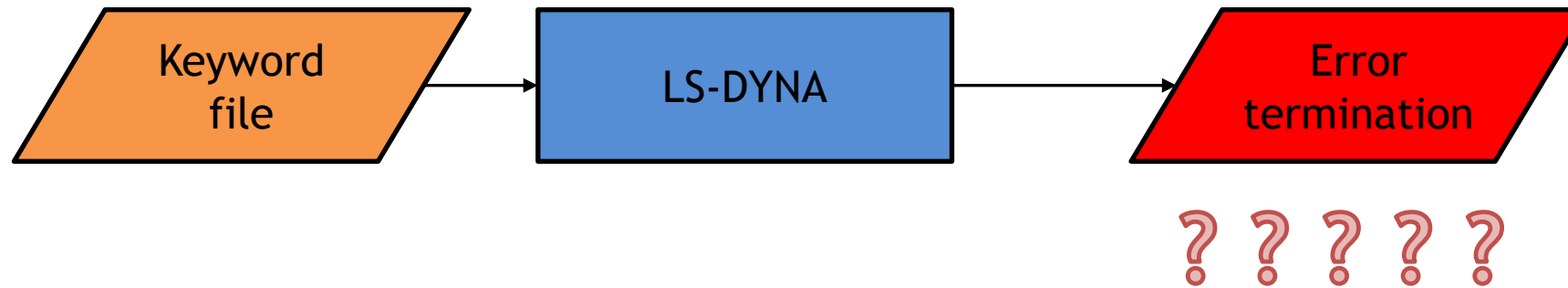
Troubleshooting convergence problems

- Does following the previous recommendations mean that your solution will allways converge? - **No!**
 - Still parameters that needs to be defined by the user
 - Model convergence is dependent on problem physics
 - Even presumed small model-/setting-changes may cause a change in problem physics
 - Model status-changes (contacts) will introduce discontinuity in the model residual -> more difficult to converge.
 - Important to know
 - What do you want to do?
 - Which results are of interest?
 - Try to predict model behavior from start to finish!
-
- Using tips and recommendation up to, and including, this slide will get you the a very good starting point!

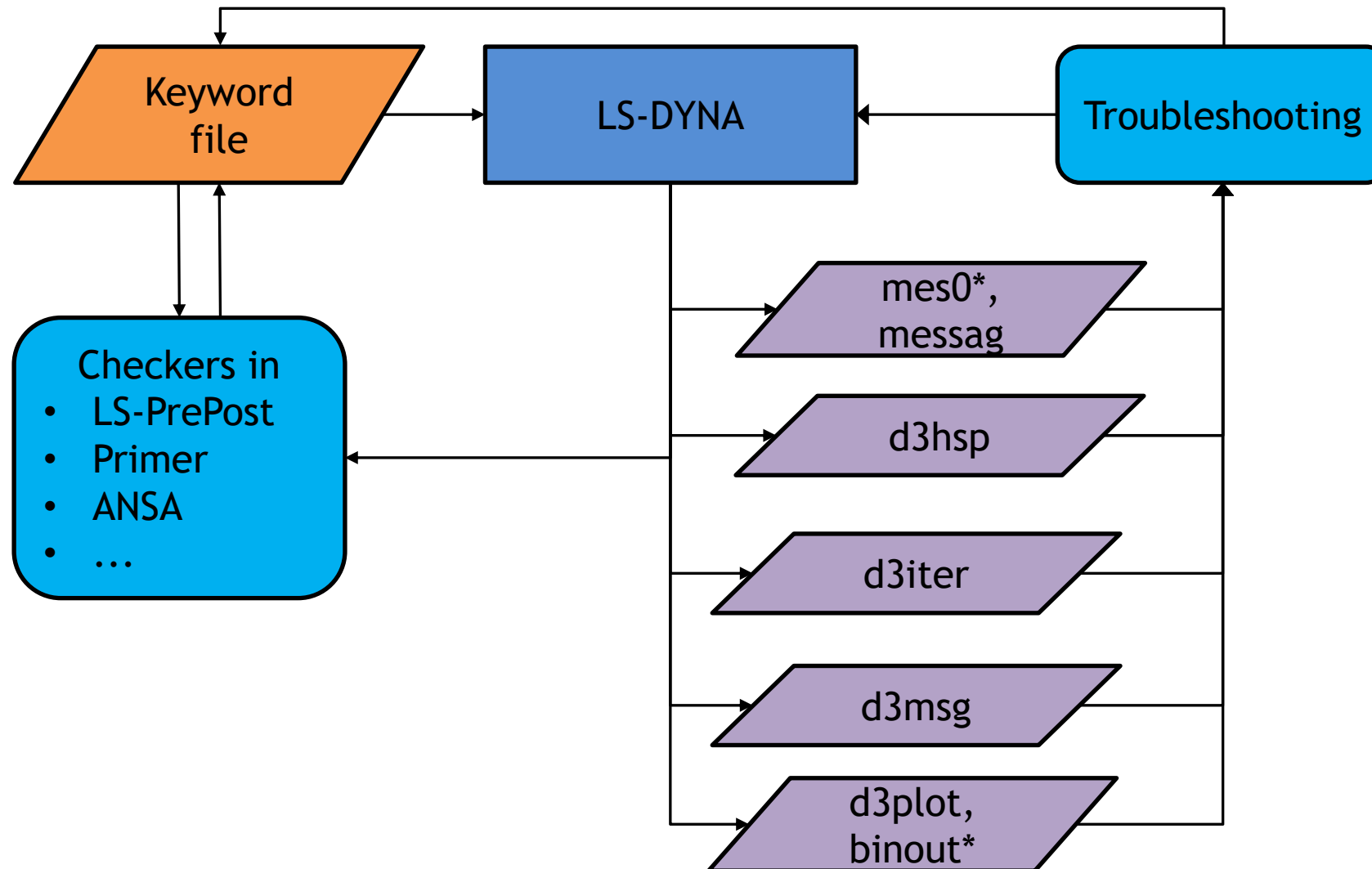
Troubleshooting convergence problems



Troubleshooting convergence problems



Troubleshooting convergence problems



Troubleshooting convergence problems

- Where to find useful information for troubleshooting a LS-DYNA simulation:
- d3hsp (text file)
 - Model information, contact settings, element formulations etc. - Check that you got what you intended
 - Failed element information / element quality
 - Errors and warnings
 - Implicit iteration information, convergence history
- mes00* (text files / one per MPI thread)
 - Errors and warnings
 - Mortar contact information (penetrations, active segments etc.)
 - Failed element information / element quality
 - Extended iteration information, including line search
- d3msg - summary of errors and warnings in d3hsp and mes0*
- d3iter (binary file, like d3plot)
 - Open in LS-PrePost
 - Deformed configuration after each iteration
- d3plot, binout0*
 - Track solution progress

TROUBLESHOOTING TIPS

- GENERAL SUGGESTIONS AND TIPS

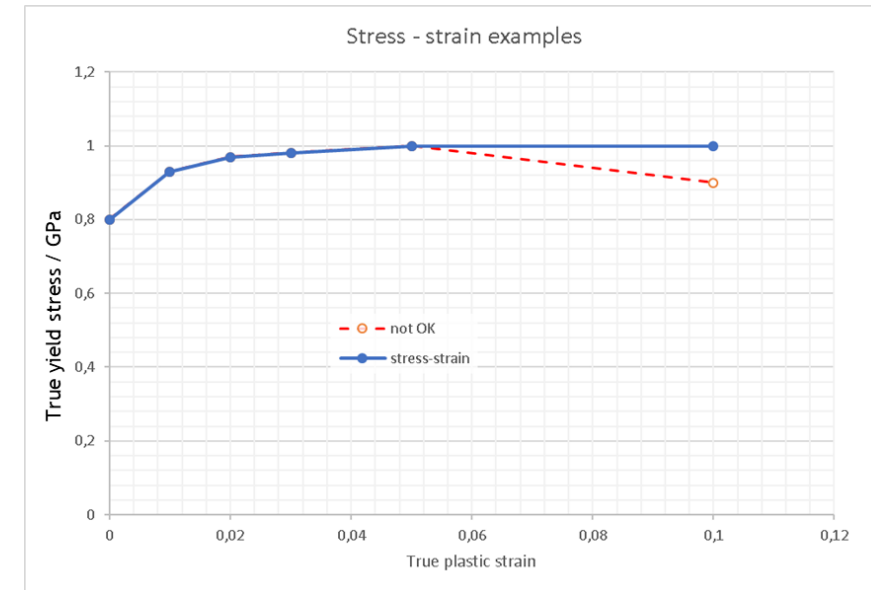
Troubleshooting convergence problems

- Start out with the suggested control card settings of the Guideline package
- Check the model integrity
 - Element quality, element types, un-intended cracks in the mesh, element connectivity (beams attached directly to solids by common node(s)) etc. Also beware of element connectivity when coupling *ELEMENT_BEAM elform 6 to other elements.
 - Many pre-processors have built-in tools for model checking
- Check model connectivity
 - Perform eigenvalue analysis - *CONTROL_IMPLICIT_EIGENVALUE
 - In ANSA: Check > Connectivity > Detect unconnected assemblies
- Avoid the use of release conditions on
 - Constrained nodal rigid bodies (use joints instead)
 - Also, if possible, on beam elements (use joints or trusses instead)
- Check that consistent units are used (for materials, loadings, accelerations, time etc.)
- Use a moderate (not too small) initial time step.
 - The automatic time step control can only decrease time step size upon RETRY.
- Check material models

Troubleshooting convergence problems

■ Check material models

- Avoid use of `*MAT_ELASTIC` for rubbers (at least for finite deformations)
- Use `MAT_24` instead of `MAT_3` with `BETA = 1` for isotropic hardening
- For non-linear elastic springs, try replace `*ELEMENT_BEAM` elform 6 and `*MAT_67` with `*ELEMENT_DISCRETE` and `*MAT_S04`.
- Check last segment of hardening curve! Since LS-DYNA will extrapolate, negative last segment slope is not recommended.
- For `*MAT_FABRIC`, use `FORM = -14`, and set `ECOAT`, `T_COAT`. Also use elform 9 (membrane formulation) on `*SECTION_SHELL`



- Do not involve parts with `*MAT_NULL` in contacts.
- Note! Some material models may not be currently supported in implicit.

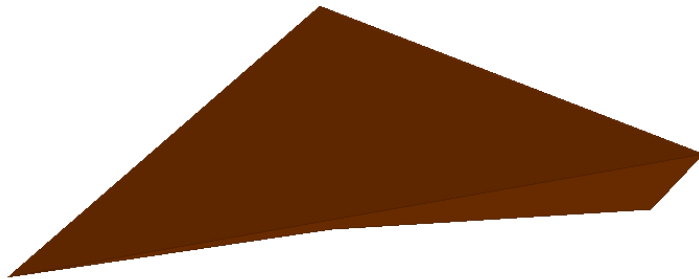
TROUBLESHOOTING TIPS

- MODEL INTEGRITY

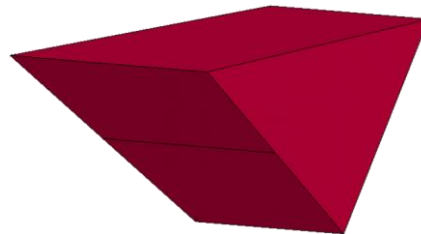
Troubleshooting convergence problems

■ First step - basic model quality checking ...

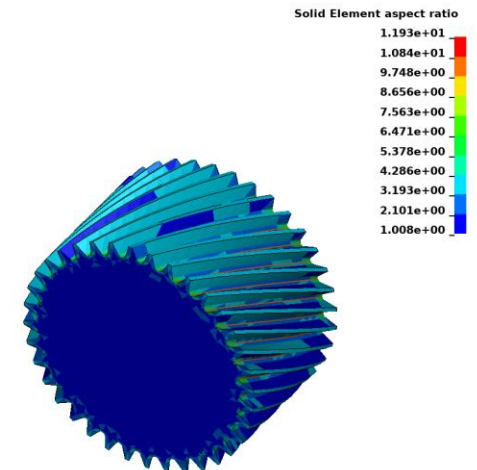
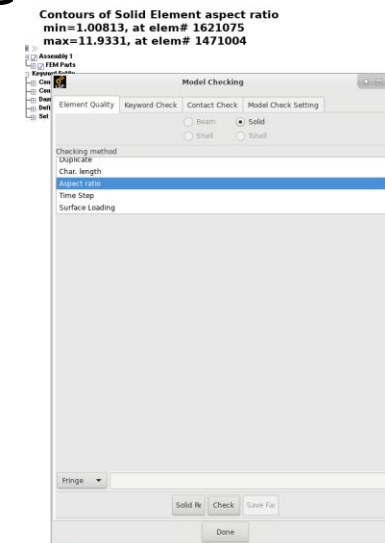
- Check mesh quality, avoid “4-noded trias” poorly shaped “pentas”
- Negative / small volume for 2nd order tets
- Poor aspect ratio of elements
- Unintended cracks in the mesh / Check DupNodes in LS-PrePost, “red cons” in ANSA
- Avoid CNRBs with common nodes / Check rigid dependency in ANSA
- Avoid CNRB:s with release conditions / DRFLAG, RRFLAG



Almost flat tet-10



Degenerated hex



TROUBLESHOOTING TIPS

- CONTACTS

Troubleshooting convergence problems

- Check tie contacts. Ensure that the intended slave nodes are tied (not too many, not too few) Inspect d3hsp/mes0* files to confirm check results from pre-processors.
 - ANSA: Check > Contacts > Contacts from solver, input the d3hsp - file. Untied nodes will be highlighted in the model.
 - Define a slave node set if full control is desired
 - Check for mesh distortion due to nodal projections *** Warning 41240 (SOL+1240)
 - Use minimum number of tied contacts, due to risk of over-occupying master segments and consequential failure of following tied contacts
- When using constraint-based tied contact, nodes subjected to other constraints (*CONSTRAINED_NODAL_RIGID_BODY, *BOUNDARY_SPC, ...) can not be tied. One remedy may be to set IPBACK > 0 on Optional Card E of the *CONTACT_TIED_ - definition. By this, LS-DYNA will automatically create a penalty-based tied contact for nodes that are subjected to other constraints.

Troubleshooting convergence problems

- Use the MORTAR contacts for implicit
 - Contact definition based on parts or part sets
 - Use the softer part as slave
- Check (and correct) unintended initial penetrations in contacts.
 - The default *IGNORE* = 2 can handle initial penetrations within reasonable limits
 - Use *IGNORE* = 3 or 4 of the Mortar contacts to handle press-fit (or alternatively *CONTACT_SURFACE_TO_SURFACE_INTERFERENCE_ID).
- Modify penalty stiffness of contacts.
 - Increase stiffness if penetrations gets “too big” or warning is issued - the Mortar contacts will print penetration messages, and based on this information the user can judge what is acceptable in terms of relative or absolute penetration distance.
 - Reduced stiffness may give smoother contact force transitions which is beneficial for convergence.

Mortar Contact - initial penetrations

- Inspect the mes00* - files and check for penetration messages once the simulation gets started.

- For example:

```
*** Warning      521 number of initial penetrations detected
```

```
Contact sliding interface      151
```

```
Number of contact pairs      80179
```

```
Maximum penetration is  0.1686677E-17 between  
elements      515944 and      493946 on this processor
```

```
Maximum relative penetration is  0.6337536E+00 % between  
elements      515944 and      493946 on this processor
```

```
BEGIN implicit dynamics step      1 t= 1.0000E-02      02/04/20 21:15:17
```

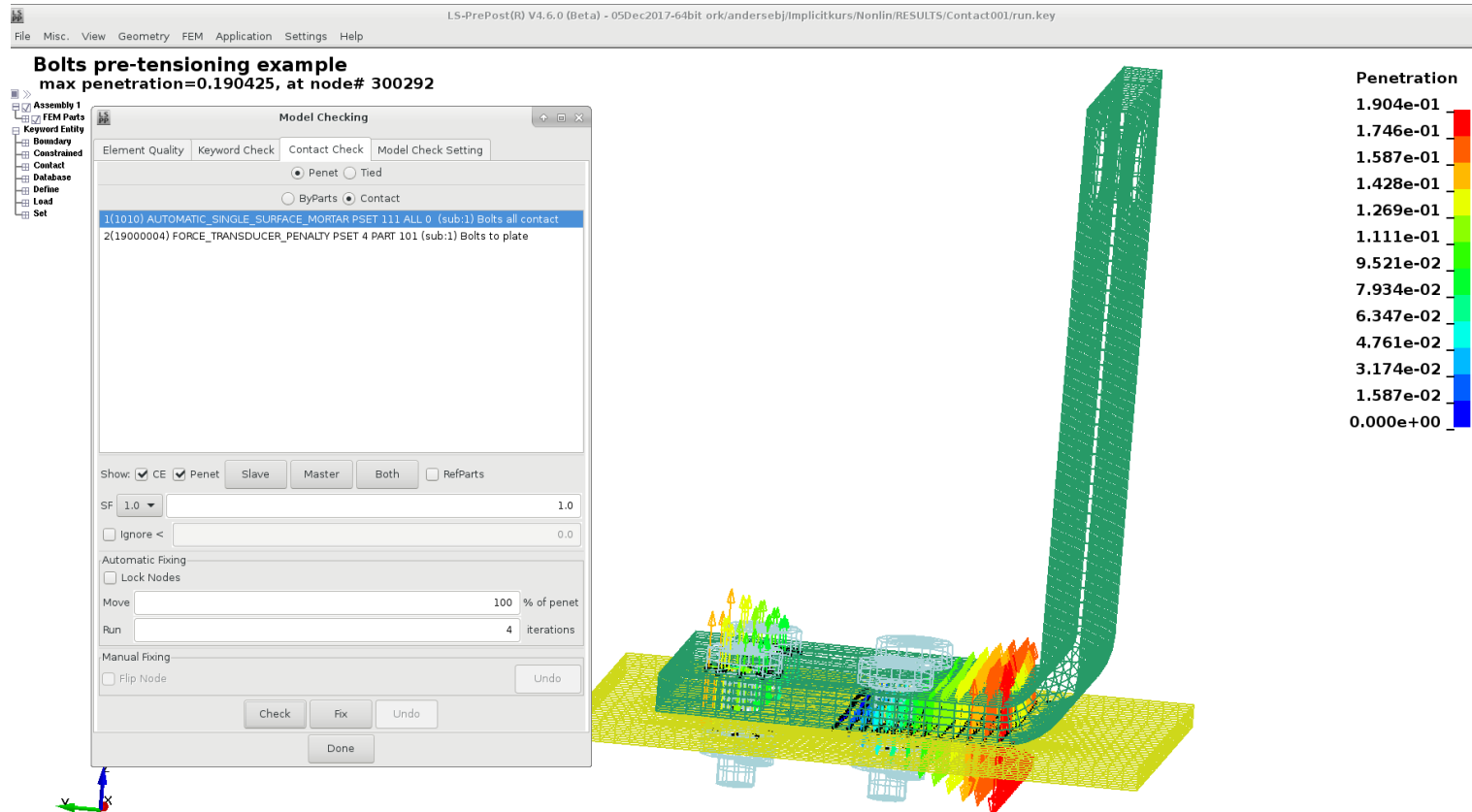
```
=====
```

- Set MINFO=1 on *CONTROL_OUTPUT

- Number of contact pairs
 - Maximum penetration, absolute and relative, and elements where this penetration occurs
 - Warning for initial penetrations and if contact is about to release

Mortar Contact - initial penetrations

- Check (and correct) unintended initial penetrations in contacts.



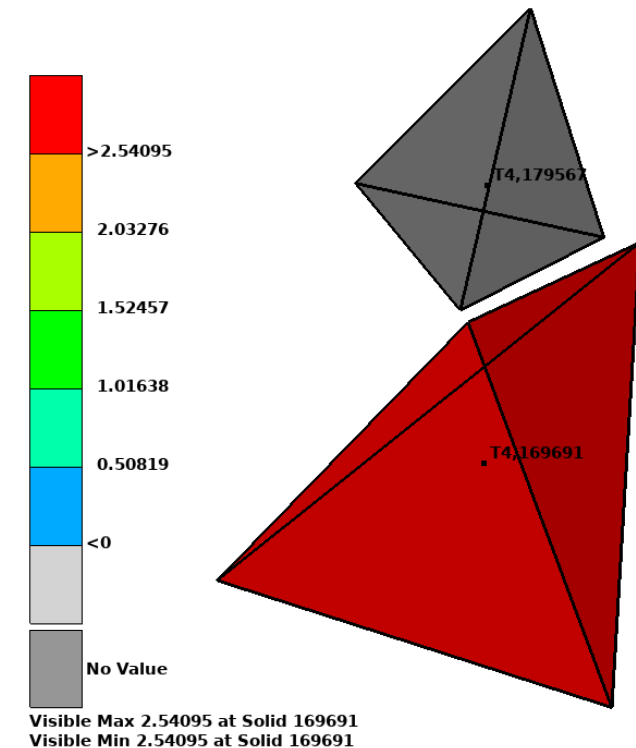
In LS-PrePost: Application>Model Checking>Contact Check

Mortar Contact - spurious penetrations

- In some cases, typically with coarse solid (tet) mesh of surfaces close to each other, the default search depth of the Mortar contact may be too large.
- This can typically be noted by that spurious penetrations are reported in the mes0* - files.
- In these cases, either
 - Give a reasonable search depth using PENMAX,
 - and/or change mesh size on the surfaces
 - If a mortar single-surface contact is used, try set ignore = -2

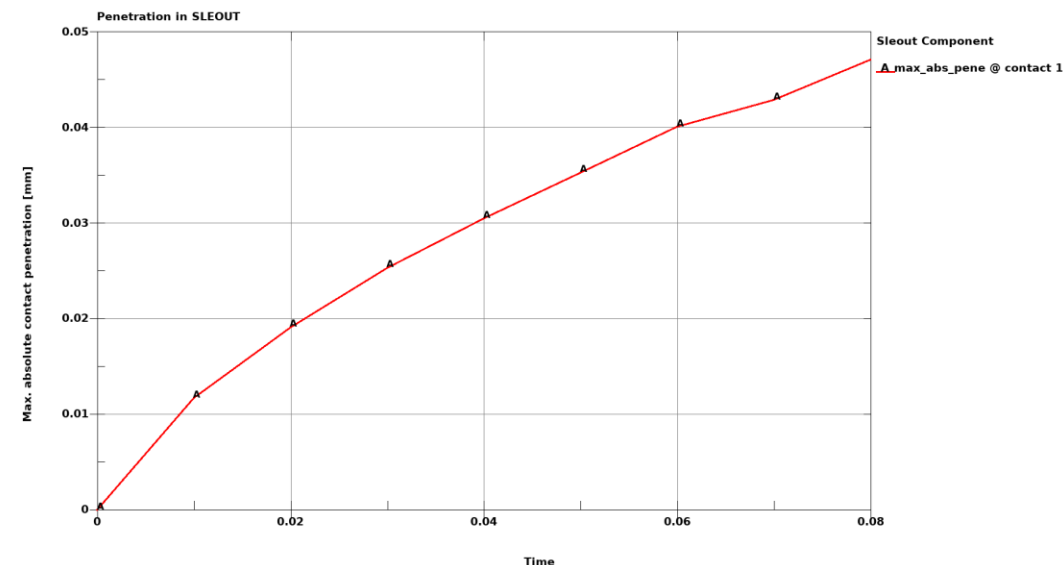
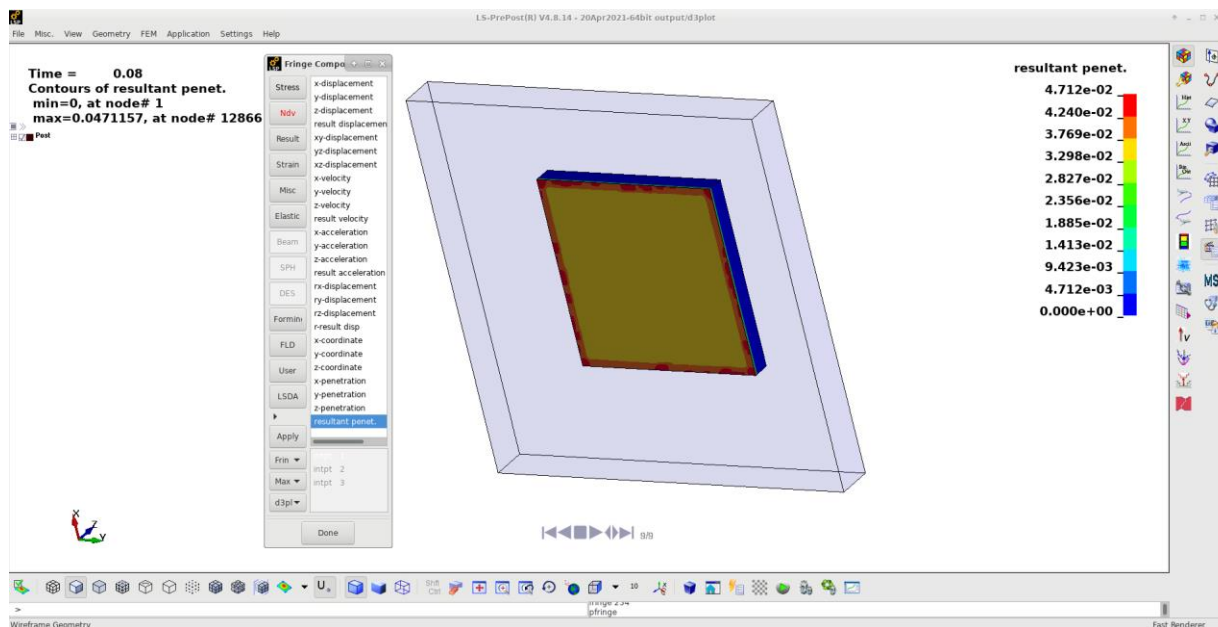
Face of solid element 169691 is penetrating
face of solid element 179567 by 0.2540949E+01

Face of solid element 169691 is penetrating
edge of solid element 179567 by 0.2512578E+01



Mortar Contact - tracking penetrations

- Inspect the mes00* - files and check for absolute and relative penetration as the simulation progresses.
- Output penetrations from MORTAR-contact to D3PLOT and SLEOUT
 - Set `PENOUT > 0` on `*CONTROL_OUTPUT`
 - Also shows initial penetrations!



Mortar Contact - tracking penetrations

■ Using Mortar contact output in the mes0XXX - files

The image shows two columns of text representing LS-DYNA output. Red arrows point from labels to specific parts of the output:

- Number of pairs:** Points to the 'Number of contact pairs' values (16209, 11932, 0, 776, 981, 62, 24).
- Warnings!:** Points to the '*** Warning Penetration is close to maximum before release' messages.
- Penetrations:** Points to the 'Maximum relative penetration' values (0.1005474E+03 %, 0.1001476E+03 %, 0.3886436E+00, 0.7772871E+02 %).

Output text (left column):

```
Contact sliding interface      1
Number of contact pairs      16209

Maximum penetration is 0.5027372E+00 between
elements 219492 and 94935 on this processor

Maximum relative penetration is 0.1005474E+03 % between
elements 219492 and 94935 on this processor
*** Warning Penetration is close to maximum before release

Contact sliding interface      2
Number of contact pairs      11932

Maximum penetration is 0.5007380E+00 and occurs
on some other processor

Maximum relative penetration is 0.1001476E+03 % and occurs
on some other processor
*** Warning Penetration is close to maximum before release

Contact sliding interface      3
Number of contact pairs      0

Contact sliding interface      4
Number of contact pairs      776

Maximum penetration is 0.3886436E+00 between
elements 205048 and 224238 on this processor

Maximum relative penetration is 0.7772871E+02 % between
elements 205048 and 224238 on this processor
```

Output text (right column):

```
Contact sliding interface      5
Number of contact pairs      981

Maximum penetration is 0.3835662E+00 and occurs
on some other processor

Maximum relative penetration is 0.7671323E+02 % and occurs
on some other processor

Contact sliding interface      7
Number of contact pairs      62

Maximum penetration is 0.1375767E+00 and occurs
on some other processor

Maximum relative penetration is 0.2751534E+02 % and occurs
on some other processor

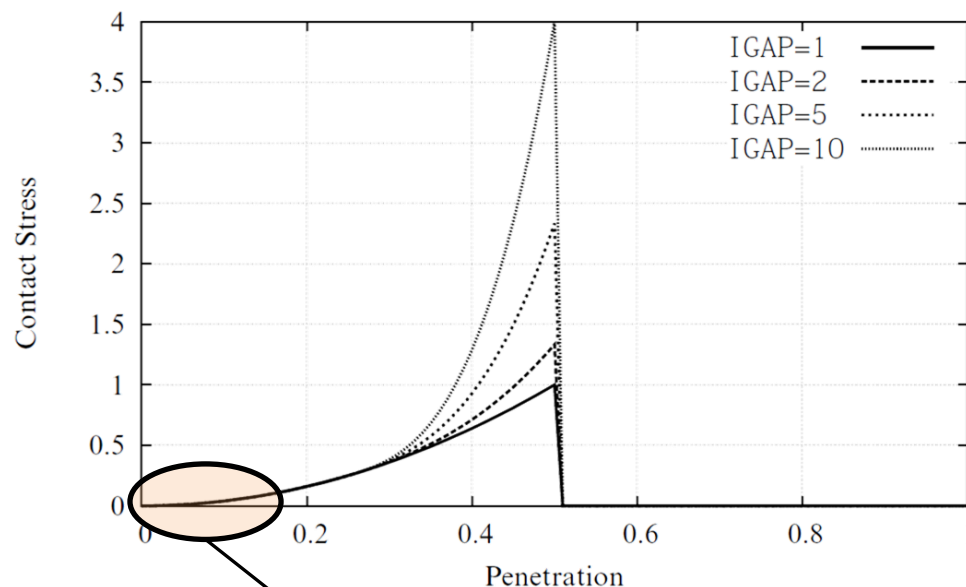
Contact sliding interface      8
Number of contact pairs      24

Maximum penetration is 0.5608894E-01 and occurs
on some other processor

Maximum relative penetration is 0.1121779E+02 % and occurs
on some other processor
```

- Set MINFO=1 on *CONTROL_OUTPUT
- Number of contact pairs
- Maximum penetration, absolute and relative, and elements where this penetration occurs
- Warning if contact is about to release

Mortar Contact - Dealing with locally high penetrations



$$\sigma_n = \alpha \beta_s \beta_m \varepsilon K_s f \left(\frac{d}{\varepsilon d_c^s} \right),$$

α = stiffness scaling factor (**SFS*****SLSFAC**)

K_s = stiffness modulus of *slave* segment

$\varepsilon = 0.03$

d_c^s = characteristic length of *slave* segment

β_s = stiffness scale factor of slave

β_m

= stiffness scale factor of master segment

- Depicts contact stress as function of relative penetration
- Relative penetration 0.5 is maximum (wrt to some characteristic size)
- **IGAP>1** can be used to increase stiffness for large penetrations, or to deal with large contact pressures, ***f* goes from parabolic to cubic at 0.25**
- d_c^s is the shell thickness or element size for solids (overridden by **PENMAX**)
- Better for convergence in general compared to increasing **SFS**

TROUBLESHOOTING TIPS

- RIGID BODY MODES & THE D3ITER-DATABASE

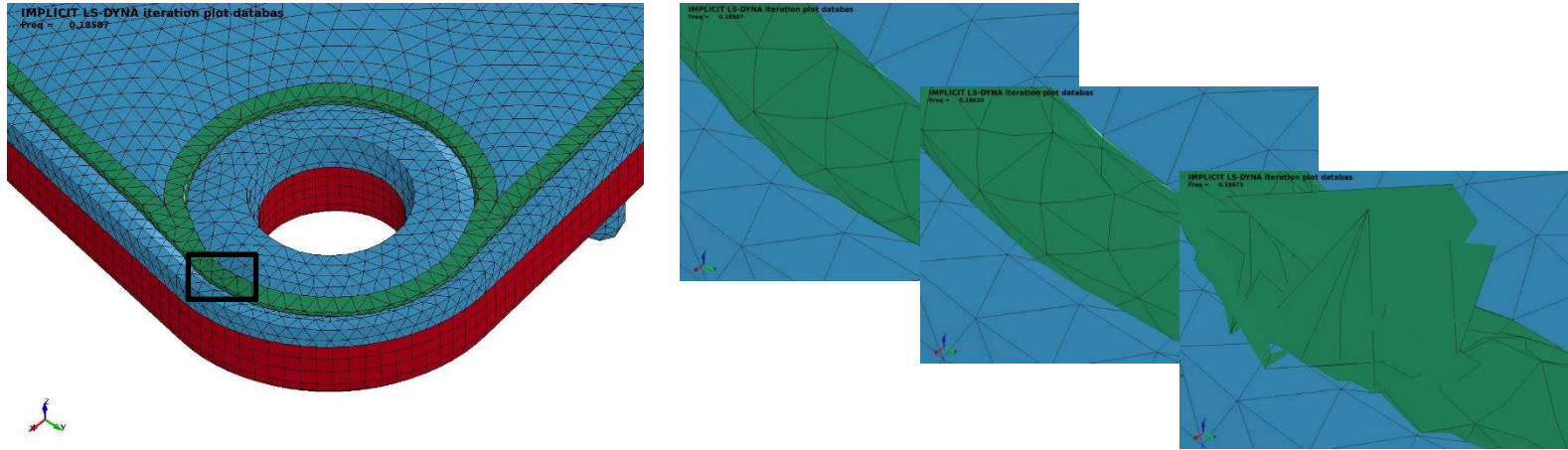
Troubleshooting convergence problems

- Negative eigenvalue warnings are most likely due to rigid body modes or elements that gets severely distorted (for example rubber) during deformation.

```
*** Warning 60124 (IMP+124)  
      XX negative eigenvalues detected
```

- Check for rigid body modes by eigenvalue analysis (*CONTROL_IMPLICIT_EIGENVALUE)
 - Also look in the d3iter - file
 - Use implicit dynamics (*CONTROL_IMPLICIT_DYNAMICS) or in some cases inertia relief to properly handle rigid body modes. Beware of time scale (ms, s)
-
- Use the d3iter - file! Looking at the non-converged states can give a lot of information, if for example loose parts in the structure are “flying away”. Scale up the displacement, or fringe plot it, in order to identify areas where large changes in displacement take place.
 - Set *RESPLT* = 1 on Card 4 of *DATABASE_EXTENT_BINARY to be able to fringe plot the residual in the d3iter - files. This can pinpoint where in the model convergence is the hardest.

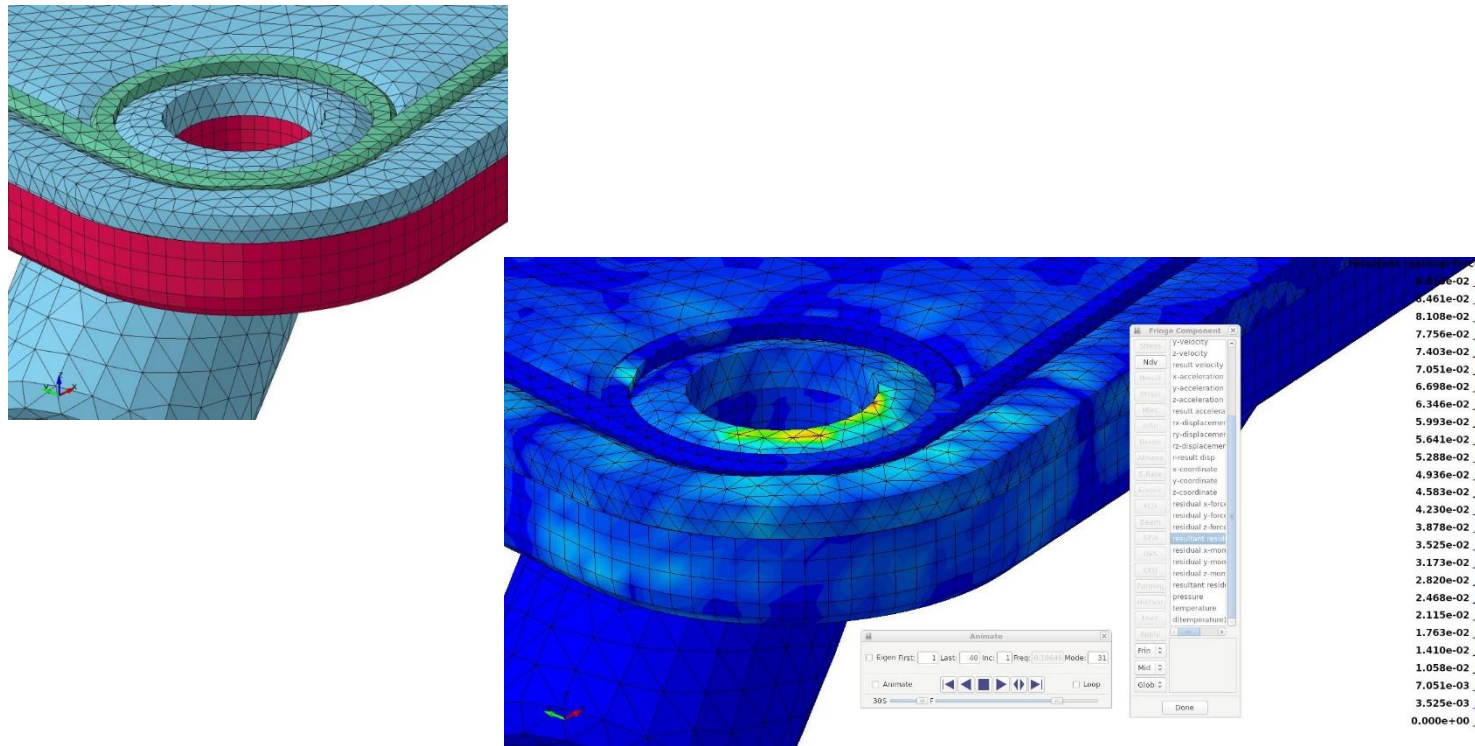
Troubleshooting convergence problems - the D3ITER database



- Allows to visualize geometry of Newton iterates
 - deformed geometry each nonlinear iteration (use displacement scale factor!)
 - possible to fringe residual norms (**RESPLT** on **DATABASE_EXTENT_BINARY**)
 - good for debugging convergence problems
 - can be specified on **CONTROL_IMPLICIT_SOLUTION**, **D3ITCTL** governs how many time steps iteration database is stored
- Too much sliding and no self contact of rubber
- Introduce contact and friction

Troubleshooting convergence problems - the D3ITER database

- In LS-PrePost, fringe residual forces
- Narrows in on critical regions
- Often in connection with contact



Troubleshooting convergence problems

- Negative eigenvalue warnings are most likely due to rigid body modes or elements that gets severely distorted (for example rubber) during deformation.

IMPLICIT LS-DYNA iteration plot databas

Time = 0.002004

*CONTROL_IMPLICIT_DYNAMICS

\$	IMASS	GAMMA	BETA				IRATE
	1	0.6	0.38	0.0	0.4	0.70	1

Elapsed time 46 seconds for 197 cycles using 4 MPP procs
(0 hour 0 minute 46 seconds)

N o r m a l	t e r m i n a t i o n	01/30/18 15:12:42
197 t	2.0000E+00 dt 1.00E-01 flush i/o buffers	01/30/18 15:12:42



DIVERGENCE (increasing translational residual norm) detected:
current norm 2.022E+04 exceeds prior maximum 1.980E+04

Troubleshooting convergence problems

■ Check model connectivity

- For example, is the list of tie slave parts complete?
- Look for AUTOSPC warnings in the d3hsp - file.

```
*** Warning 60055 (IMP+55)
*****
*
*           - WARNING -
*
*           6 Unconstrained degrees of freedom have
* been detected and removed from this IMPLICIT model.
*
*****
```

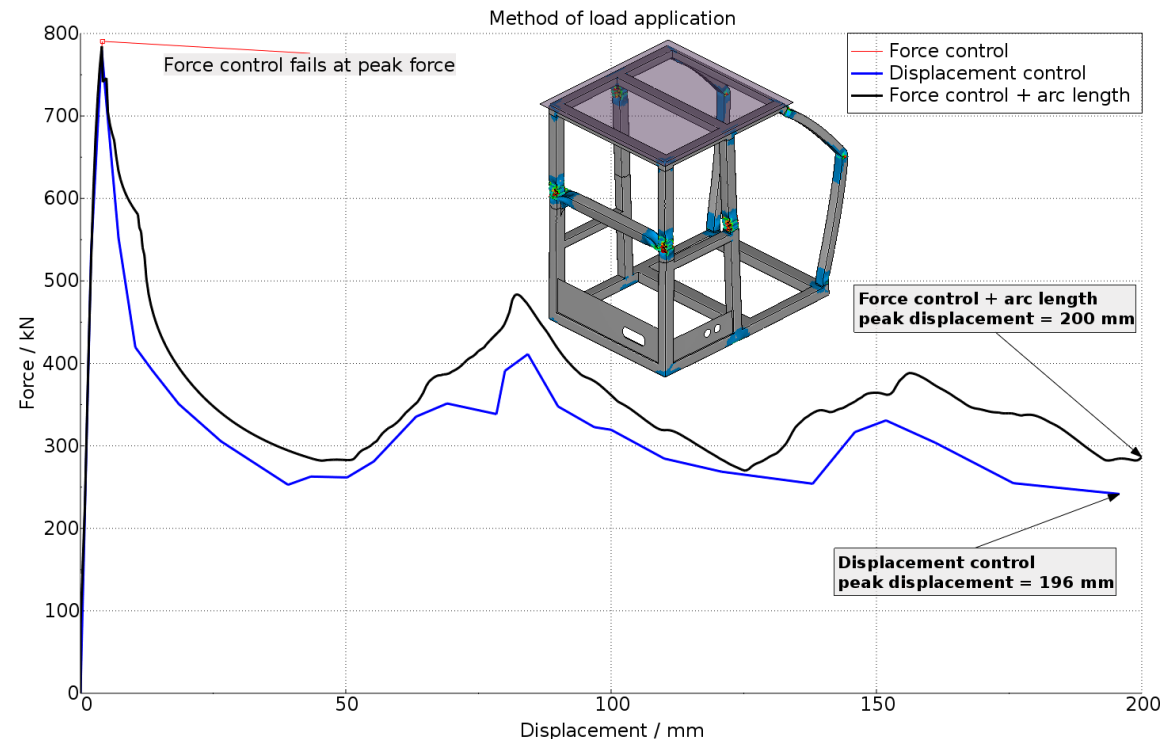
Set *LPRINT* = 3 on *CONTROL_IMPLICIT_SOLVER to get a list of all nodes (or rigid parts) subjected to AUTOSPC:s

TROUBLESHOOTING TIPS

- PROBLEM PHYSICS

Troubleshooting convergence problems

- Is the physical problem in fact unstable? Will collapse / buckling / bifurcation occur?
 - Try switching from load control to displacement control
 - Try using the arc-length solver (`control_cards_arc.key` of the Guideline package)
 - Turn on dynamics
 - Use implicit → Explicit switching



Troubleshooting convergence problems

- For (dynamic) simulations with (very) small time steps, for example 1.E-4, modify the *DTMIN* settings of `*CONTROL_TERMINATION` and `*CONTROL_IMPLICIT_AUTO` (to for example 1.E-6) This allows the implicit solver to re-try step with a smaller time step if convergence fails.
- Switching to full-Newton is in general efficient for highly non-linear problems
 - Set `ILIMIT=1` and increase `MAXREF` (to 30 - 100) on `*CONTROL_IMPLICIT_SOLUTION`
- Activating the non-symmetrical equation solver (set `LCPAK = 3` on `*CONTROL_IMPLICIT_SOLVER`) may help in some cases, such as follower loads, or “snap-through” deformation, or situations with “high” friction



TROUBLESHOOTING TIPS

- SOLVER ITERATION INFORMATION

Troubleshooting convergence problems

■ Convergence Diagnostics in the mes0XXX - files

Not converged Not active Converged

NLPRINT>0

```
Iteration: 20 displacement energy
----- **trans** rot trans rot
norm ratio 6.439e-01 n/a 1.452e-05 n/a
current norm 1.393e-01 5.894e-04 2.972e-02 1.775e-07
initial norm 2.907e+00 6.828e-02 1.125e+01 4.882e-04
absolute tol 3.162e-08 3.162e-07 1.000e-11 1.000e-11
max norm 5.598e-03 2.879e-05 -8.623e-04 1.679e-08
node/RB ID 993675 n 14731 n 1014243 n 24 n
direction dY rY dY rY
```

residual	
trans	rot
n/a	n/a
1.438e+00	2.642e-02
2.357e+01	1.544e-03
3.162e-06	3.162e-06
1.318e-01	1.980e-03
1020027 n	376 n
dZ	rZ

NLPRINT=3

```
BFGS step computed
Initial translational energy = 2.9474754e-02
Initial total energy = 2.9474754e-02
Initial residual norm = 1.4380817e+00

Evaluated residual for full step
Current translational energy = -1.3217790e-01
Current total energy = -1.3217790e-01
Current residual norm = 3.8502288e+00

...

Evaluated residual for step size 1.8203621e-01
Current translational energy = -6.3229873e-07
Current total energy = 4.8911119e-08
Current residual norm = 1.4009738e+00

Line search converged in 2 iterations
```

Norms separated into translational and rotational parts, NLNORM can be used to combine

If the current norm goes below -ABSTOL, then convergence is detected, converged states can be used to deduce good value for ABSTOL

Line search should converge within ~10 iterations

Troubleshooting convergence problems

■ Convergence Diagnostics in the mes0XXX - files

dctol

ectol

NLPRINT>0

```
Iteration: 28
----- **trans**
norm ratio 6.439e-03 n/a 1.452e-05 n/a
current norm 1.393e-01 5.894e-04 2.972e-02 1.775e-07 1.438e+00 2.642e-02
initial norm 2.907e+00 6.828e-02 1.125e+01 4.882e-04 2.357e+01 1.544e-03
absolute tol 3.162e-08 3.162e-07 1.000e-11 1.000e-11 3.162e-06 3.162e-06
max norm 5.598e-03 2.879e-05 -8.623e-04 1.679e-08 1.318e-01 1.980e-03
node/RB ID 993675 n 14731 n 1014243 n 24 n 1020027 n 376 n
direction dY rY dY rY dZ rZ
```

NLPRINT=3

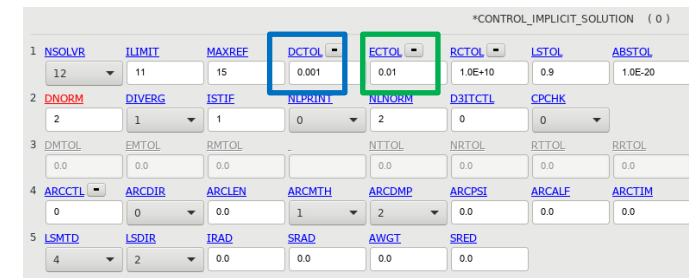
```
BFGS step computed
Initial translational energy = 2.9474754e-02
Initial total energy = 2.9474754e-02
Initial residual norm = 1.4380817e+00

Evaluated residual for full step
Current translational energy = -1.3217790e-01
Current total energy = -1.3217790e-01
Current residual norm = 3.8502288e+00

...

Evaluated residual for step size 1.8203621e-01
Current translational energy = -6.3229873e-07
Current total energy = 4.8911119e-08
Current residual norm = 1.4009738e+00

Line search converged in 2 iterations
```



Norms separated into translational and rotational parts, NLNORM can be used to combine

If the current norm goes below -ABSTOL, then convergence is detected, converged states can be used to deduce good value for ABSTOL

Line search should converge within ~10 iterations

Troubleshooting convergence problems

- Observe convergence progress of displacement & energy norms (view `d3hsp` and `mes0XXX`-files)
- If displacement and energy norms decreases slowly
 - Switch to Full Newton method (`ILIMIT=1` and `MAXREF=30-100`)
 - Check for incorrect material or contact properties
 - Increase step size if “nothing” happens
- If convergence progress is “erratic” (displacement norm jump up and down between iterations)
 - Decrease contact penalty stiffness scale factor 10x (monitor penetrations)
 - Decrease step size or tolerance levels, the problem may lie in previously poorly converged states, check residual norms

Troubleshooting convergence problems - Understanding NLPRINT=3

- Beginning of an implicit iteration displays either one of
 - *Linear step computed*
 - Displayed at beginning of entire implicit step, corresponds to the first Newton iteration
 - *Newton step computed*
 - Displayed if a full stiffness reformation has been performed
 - *BFGS step computed*
 - Displayed if a rank-2 update (BFGS) has been performed
- This is then followed by reference/initial values of some important quantities
 - *(Initial translational energy* = translational force times translational displacement increment, not so important)
 - *Initial total energy* = force time displacement increment, used as reference in line search and convergence checks
 - *Initial residual norm* = norm of residual force, used as reference in convergence checks
 - Various max norms, dealt with specifically in later slides
- Then line search starts

Iteration:	1	displacement		energy		residual	
-----		**trans**	rot	**trans**	rot	trans	rot
	norm ratio	1.000E+00	n/a	1.000E+00	n/a	n/a	n/a
	current norm	2.009E+00	0.000E+00	3.392E+05	0.000E+00	4.224E+06	0.000E+00
	initial norm	2.009E+00	0.000E+00	3.392E+05	0.000E+00	1.700E+07	0.000E+00
-----		trans	rot	trans	rot	trans	rot
	nodal max	2.000E-02	0.000E+00	-2.625E+01	0.000E+00	5.264E+03	0.000E+00
	at node ID	16248	n/a	14266	n/a	9964	n/a
BFGS step computed							
Initial translational energy =		7.4772587E+04					
Initial total energy =		7.4772587E+04					
Initial residual norm =		4.2238635E+06					
Translational nodes norm =		4.2238635E+06					
Translational nodes max =		5.2641063E+03 at node					9964

Troubleshooting convergence problems - Understanding NLPRINT=3

- Line search starts with an attempt to perform a full step
 - Displays "*Evaluated residual for full step*"
- Quantities evaluated at full step is shown
 - (*Current translational energy* = translational force times translational displacement increment, not so important)
 - *Current total energy* = current force time displacement increment
 - *Current residual norm* = norm of residual force
 - Various max norms
- Line search is checked, either
 - *Line search is skipped* is displayed, meaning that energy and/or force for the full step is ok, or
 - Line search commences
- Skipping line search is generally promising, this means that the predicted step is in a sense a good one

*CONTROL_IMPLICIT_SOLUTION (0)

1	NSOLVR	ILIMIT	MAXREF	DCTOL	ECTOL	RCTOL	LSTOL	ABSTOL
	12	11	15	0.001	0.01	1.0E+10	0.9	1.0E-20
2	DNORM	DIVERG	ISTIF	NLPRINT	NLNORM	D3ITCTL	CPCHK	
	2	1	1	0	2	0	0	
3	DMTOL	EMTOL	RMTOL	NTTOL	NRTOL	RTTOL	BBTOL	
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
4	ARCCTL	ARCDIR	ARCLEN	ARCMT	ARCDMP	ARCPSI	ARCALE	ARCTIM
	0	0	0.0	1	2	0.0	0.0	0.0
5	LSMTD	LSDIR	IRAD	SRAD	AWGT	SRED		
	4	2	0.0	0.0	0.0	0.0		

```
Evaluated residual for full step
Current translational energy = -4.2237075E+04
Current total energy        = -4.2237075E+04
Current residual norm       = 4.2238635E+06
Translational nodes norm    = 4.2238635E+06
Translational nodes max     = 5.2641063E+03 at node 9964

Line search is skipped
```

Troubleshooting convergence problems - Understanding NLPRINT=3

- If line search is needed then two force evaluations are performed at different step sizes
 - Each one displays "*Evaluated residual for step size...*"
 - The reason for two is due to the line search algorithm
- For each evaluation, again the following is displayed
 - (*Current translational energy* = translational force times translational displacement increment, not so important)
 - *Current total energy* = current force time displacement increment
 - *Current residual norm* = norm of residual force
 - Various max norms
- Line search convergence is checked, either
 - "*Line search converged in ... Iterations*" is displayed, meaning that energy and/or force for the full step is ok, or
 - "*Line search continues*" is displayed, meaning that line search continues
- If line search converges then the following is displayed
 - *Max relative step* = Accumulated step relative to start of implicit step, this needs to be reaching 1 to fulfill all nonzero prescribed boundary conditions

```
Evaluated residual for step size 2.7611841E-01
Current translational energy = -1.3532158E+03
Current total energy        = -1.3532158E+03
Current residual norm       = 1.0947320E+06
Translational nodes norm    = 1.0947320E+06
Translational nodes max     = 6.0539289E+02 at node 15332

Line search converged in 2 iterations
Max relative step          = 1.0000000E+00
```

Troubleshooting convergence problems - Understanding NLPRINT=3

- Line search should converge preferably in ~10 iterations with a reasonable step size
 - Difficult steps may require more, but this shouldn't happen all the time
 - The last step size shown prior to convergence is the step chosen
 - If this is small, a full stiffness reformation is incurred with according message displayed
- The case with many iterations required, or even worse, the case when *Line search did not converge* is shown will be treated in later slides
- If line search does not converge, this is a bad thing as this means that LS-DYNA requires 100(!) iterations or more to obtain line search convergence
 - May indicate a bug in implicit feature

```
Evaluated residual for step size 2.8337593E-01
Current translational energy = -2.8173909E+03
Current total energy = -2.8173909E+03
Current residual norm = 1.1409147E+06
Translational nodes norm = 1.1409147E+06
Translational nodes max = 6.2132008E+02 at node 15332

Line search continues
Max relative step = 1.0000000E+00
Lower bound = 0.0000000E+00
Upper bound = 2.8337593E-01

Evaluated residual for step size 1.4168796E-01
Current translational energy = 3.0820215E+04
Current total energy = 3.0820215E+04
Current residual norm = 2.3205575E+06
Translational nodes norm = 2.3205575E+06
Translational nodes max = 2.5046377E+03 at node 8014

Evaluated residual for step size 2.7611841E-01
Current translational energy = -1.3532158E+03
Current total energy = -1.3532158E+03
Current residual norm = 1.0947320E+06
Translational nodes norm = 1.0947320E+06
Translational nodes max = 6.0539289E+02 at node 15332

Line search converged in 2 iterations
Max relative step = 1.0000000E+00
```

Troubleshooting convergence problems - Understanding NLPRINT=3

- If line search continues, the *Line search continues* message is followed by
 - *Max relative step* = Accumulated step relative to start of implicit step, this needs to be reaching 1 to fulfill all prescribed nonzero boundary conditions
 - *Lower bound* = lower bound of step size for current line search
 - *Upper bound* = upper bound of step size for current line search
- The step to be sought is located between the lower and upper bounds
- On line search convergence, lower and upper bound should preferably not be close
 - Indicates a reasonable step
 - If close, this may mean that the residual force as function of step size is highly nonlinear, or even discontinuous (see overview of line search)

```
Evaluated residual for step size 2.8337593E-01
Current translational energy = -2.8173909E+03
Current total energy = -2.8173909E+03
Current residual norm = 1.1409147E+06
Translational nodes norm = 1.1409147E+06
Translational nodes max = 6.2132008E+02 at node 15332

Line search continues
Max relative step = 1.0000000E+00
Lower bound = 0.0000000E+00
Upper bound = 2.8337593E-01

Evaluated residual for step size 1.4168796E-01
Current translational energy = 3.0820215E+04
Current total energy = 3.0820215E+04
Current residual norm = 2.3205575E+06
Translational nodes norm = 2.3205575E+06
Translational nodes max = 2.5046377E+03 at node 8014

Evaluated residual for step size 2.7611841E-01
Current translational energy = -1.3532158E+03
Current total energy = -1.3532158E+03
Current residual norm = 1.0947320E+06
Translational nodes norm = 1.0947320E+06
Translational nodes max = 6.0539289E+02 at node 15332

Line search converged in 2 iterations
Max relative step = 1.0000000E+00
```

Troubleshooting convergence problems - Understanding NLPRINT=3

- If many line search iterations are needed, or if interval between lower and upper bound is small, then examine line search history
 - Is residual norm "continuous"? If not, this may indicate a problem
- Source to such an event may lie in the max norms displayed for each force evaluation
 - *Translational/rotational nodes/rigid body norm* = Norm of translational/rotational forces in nodes/rigid bodies
 - Node or part ID is displayed
- Is a node or part continuously repeated?
 - Examine this in d3iter database, or model, and deduce what feature might affect this
 - This should also be viewable in the residual force fringe

Iteration: 167	displacement		energy		residual	
-----	**trans**	rot	trans	rot	trans	rot
norm ratio	7.887E-02	n/a	7.143E-04	n/a	n/a	n/a
current norm	1.422E-01	0.000E+00	2.423E+02	0.000E+00	6.795E+04	0.000E+00
initial norm	1.803E+00	0.000E+00	3.392E+05	0.000E+00	9.245E+04	0.000E+00
-----	trans	rot	trans	rot	trans	rot
nodal max	3.707E-02	0.000E+00	-8.424E+01	0.000E+00	1.368E+03	0.000E+00
at node ID	<u>10231</u>	n/a	10231	n/a	3469	n/a

→

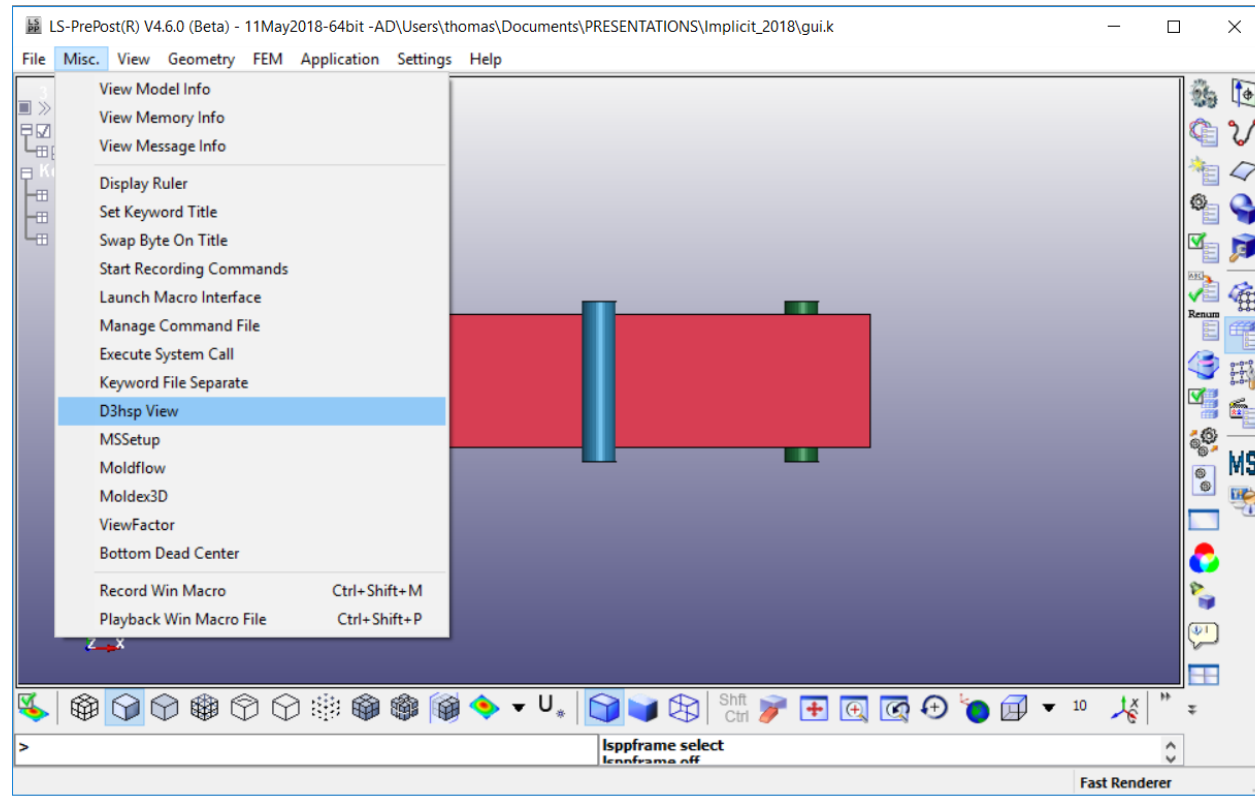
Iteration: 168	displacement		energy		residual	
-----	**trans**	rot	trans	rot	trans	rot
norm ratio	7.964E-02	n/a	7.353E-04	n/a	n/a	n/a
current norm	1.436E-01	0.000E+00	2.494E+02	0.000E+00	6.433E+04	0.000E+00
initial norm	1.803E+00	0.000E+00	3.392E+05	0.000E+00	9.245E+04	0.000E+00
-----	trans	rot	trans	rot	trans	rot
nodal max	3.023E-02	0.000E+00	-5.639E+01	0.000E+00	1.469E+03	0.000E+00
at node ID	<u>10231</u>	n/a	10231	n/a	9985	n/a

TROUBLESHOOTING TIPS

- D3HSP VIEW

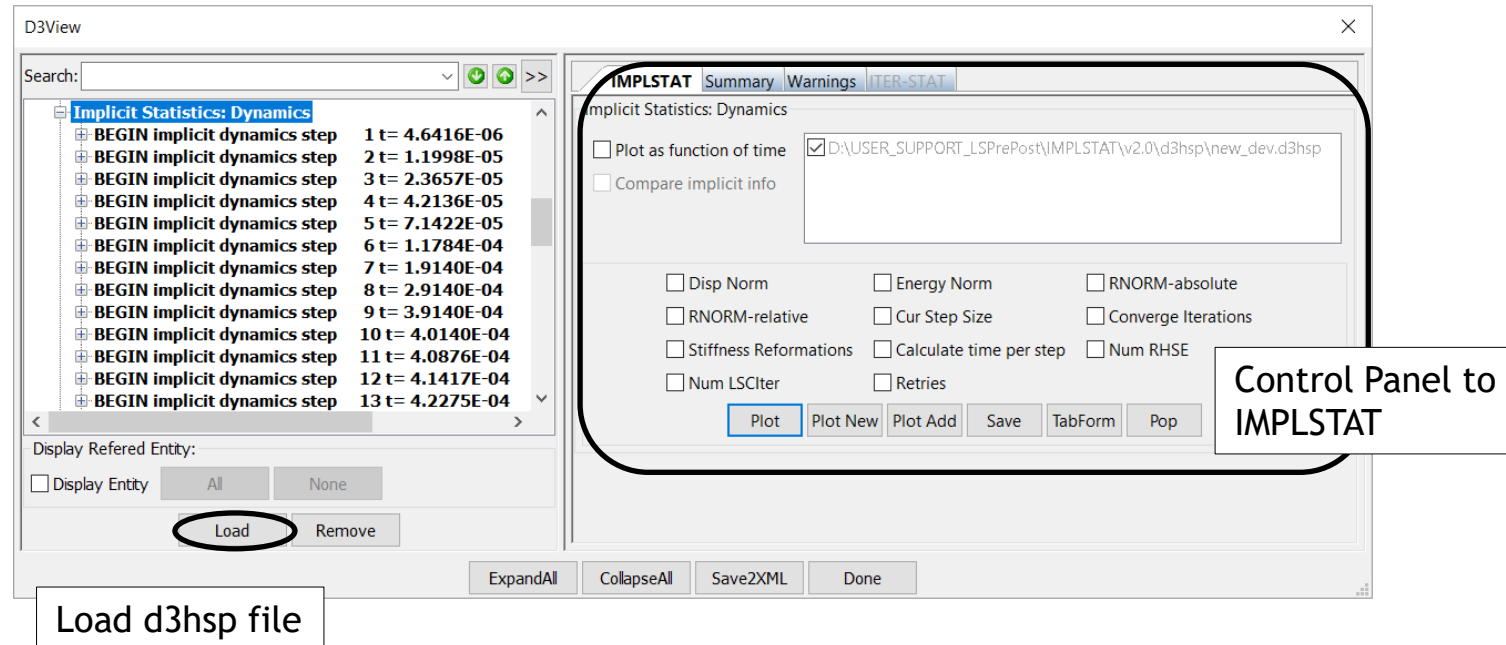
D3HSP view - IMPLicit STATistics (IMPLSTAT)

- **NLPRINT=3** *information is collected and can be viewed graphically in LS-PrePost*
 - *D3hsp View > IMPLicit STATistics (IMPLSTAT)*



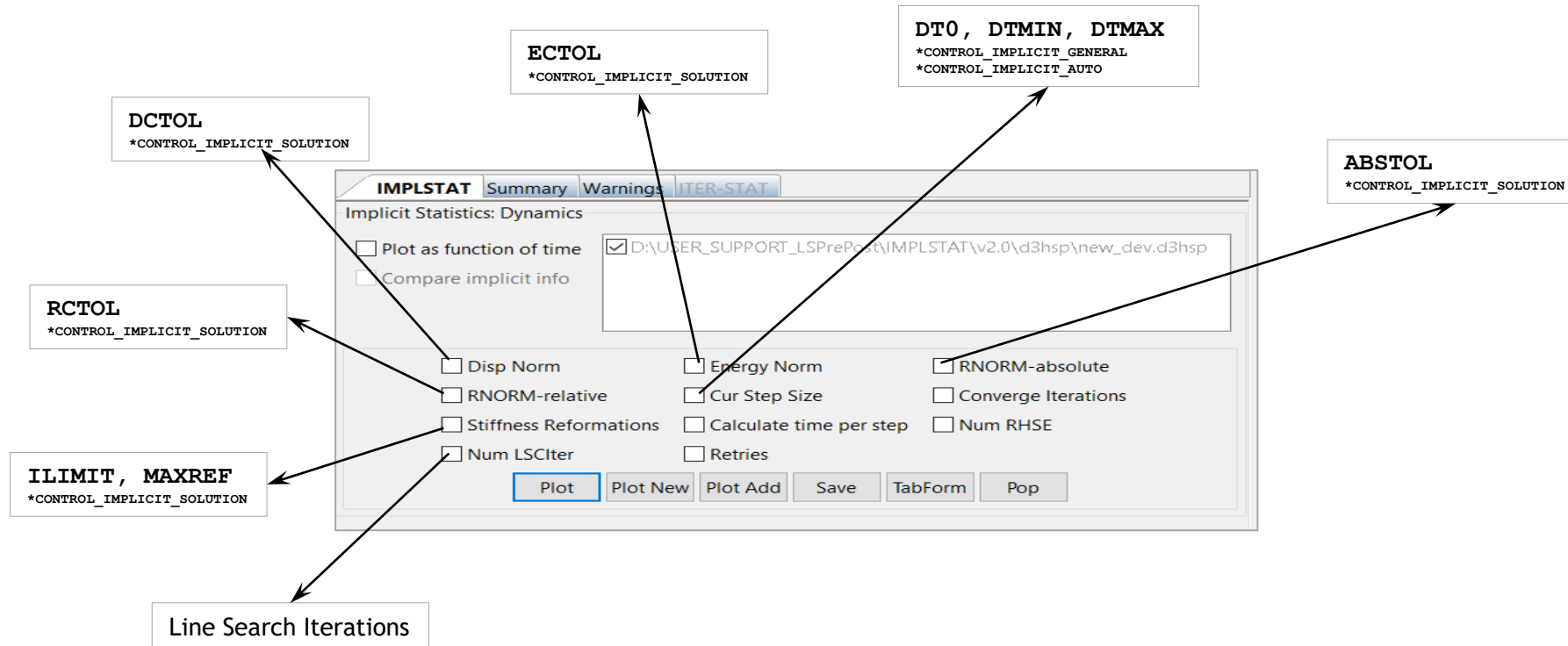
D3HSP view - IMPLicit STATistics (IMPLSTAT)

- Using d3hsp view
 - Load keyword file
 - Load d3hsp file



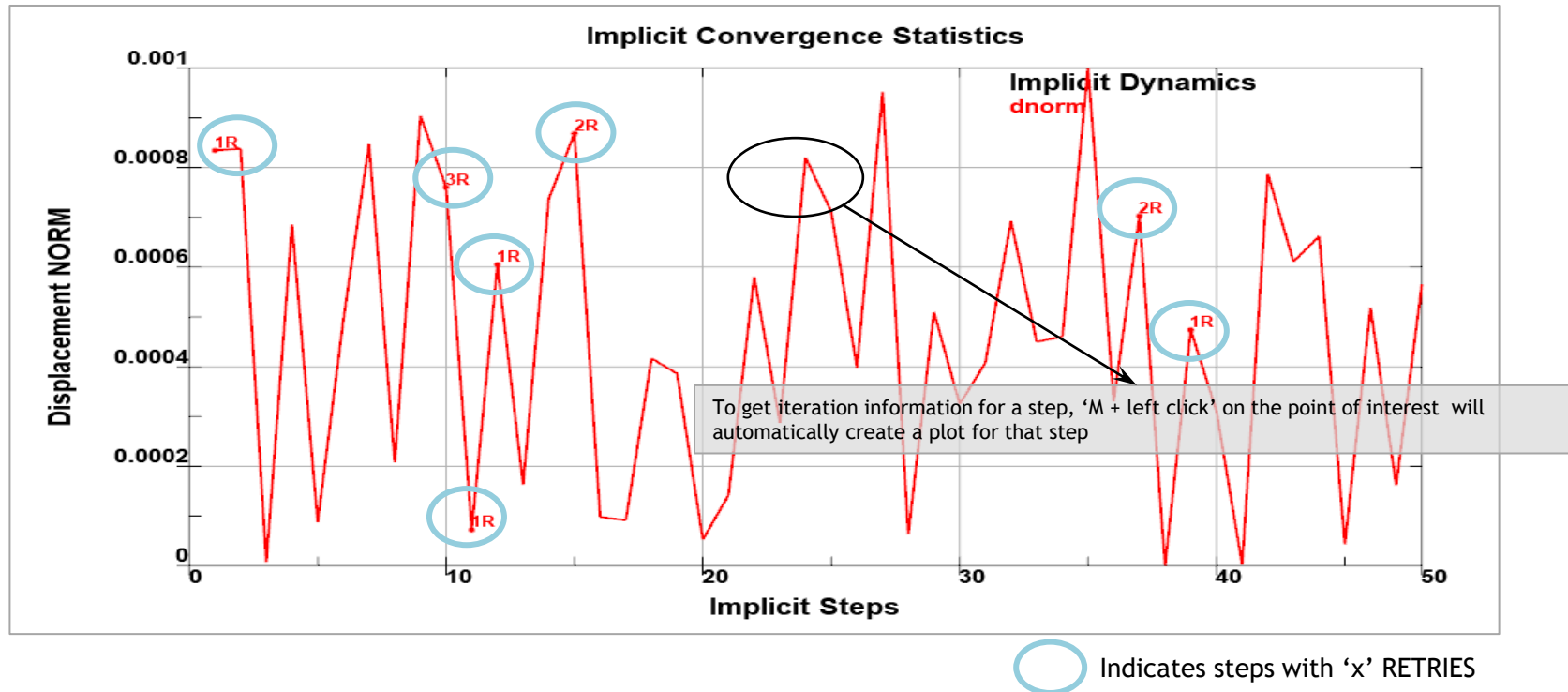
D3HSP view - IMPLicit STATistics (IMPLSTAT)

- Using d3hsp view
 - Convergence related items



D3HSP view - IMPLicit STATistics (IMPLSTAT)

- Using d3hsp view
 - Plot items



Displacement Norm: DCTOL was set to 0.001. In the above plot DNORM is < 0.001 for every step, which means convergence was driven by this criteria

D3HSP view - IMPLicit STATistics (IMPLSTAT)

- Using d3hsp view
 - Iteration statistics

Search:

▼ **BEGIN implicit dynamics step** 1 t = 1.0000E-05
time = 1.00000E-05
current step size = 1.00000E-05

- > **Iteration: 1** displacement energy resid
- > Iteration: 2 displacement energy resid
- > Iteration: 3 displacement energy resid
- > Iteration: 4 displacement energy resid
- > Iteration: 5 displacement energy resid
- > Iteration: 6 displacement energy resid
- > Iteration: 7 displacement energy resid
- > Iteration: 8 displacement energy resid
- > Iteration: 9 displacement energy resid
- > Iteration: 10 displacement energy resid
- > Iteration: 11 displacement energy resid
- > Iteration: 12 displacement energy resid
- > Iteration: 13 displacement energy resid
- > Iteration: 14 displacement energy resid
- > Iteration: 15 displacement energy resid
- > Iteration: 16 displacement energy resid

Display Referred Entity:
☐ Display Entity

D3View

IMPLSTAT Summary Warning **ITER-STAT**

Components

☒ Translational
☐ Rotational

☐ Highlight nodes

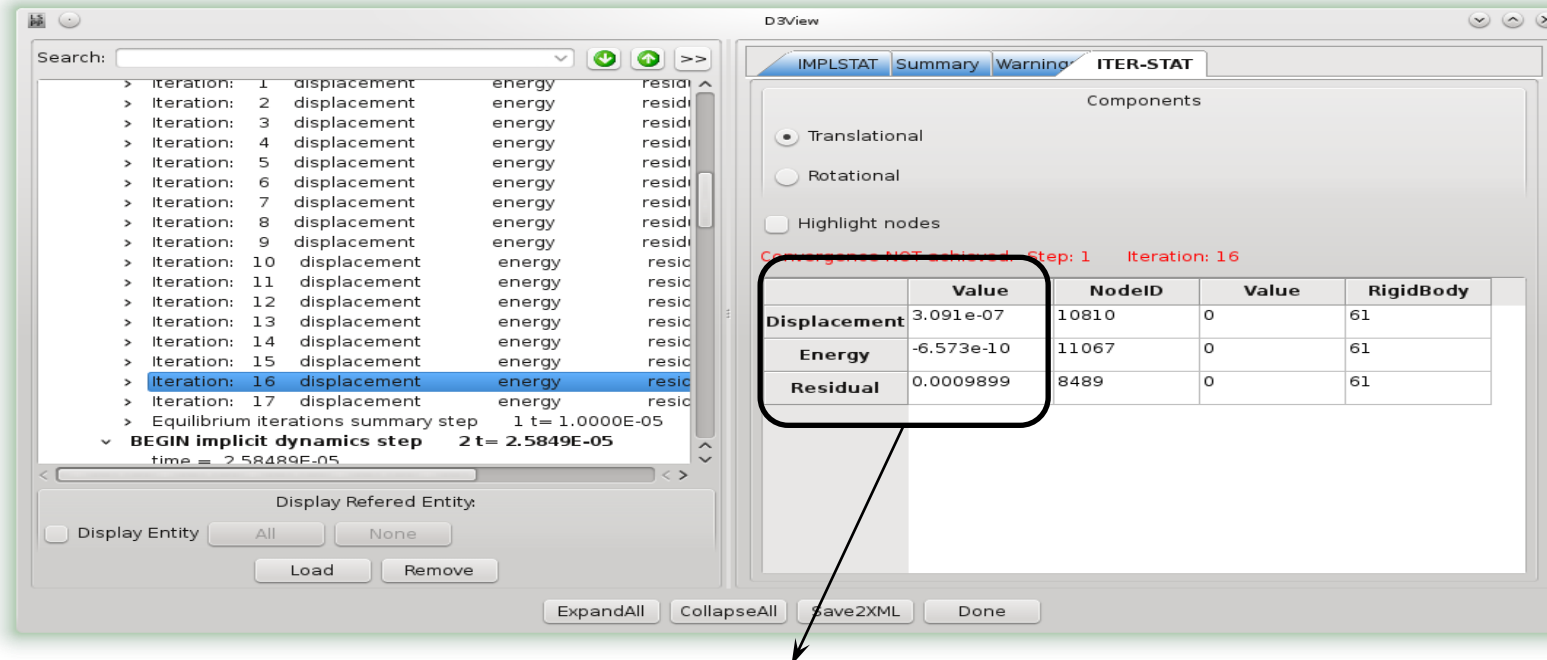
Convergence NOT achieved. Step: 1 Iteration: 1

	Value	NodeID	Value	RigidBody
Displacement	0.0001441	712	0	61
Energy	-1.217e-05	10805	0	61
Residual	0.9466	13377	0	61

To get iteration details, select an **Iteration** and use ITER-STAT tab

D3HSP view - IMPLicit STATistics (IMPLSTAT)

- Using d3hsp view
 - Iteration progress - not yet converged



As we select higher iteration numbers, if the solution is being solved on a good path, one should expect the norm numbers to decrease from previous iteration.

D3HSP view - IMPLicit STATistics (IMPLSTAT)

- Using d3hsp view
 - Iteration progress - converged

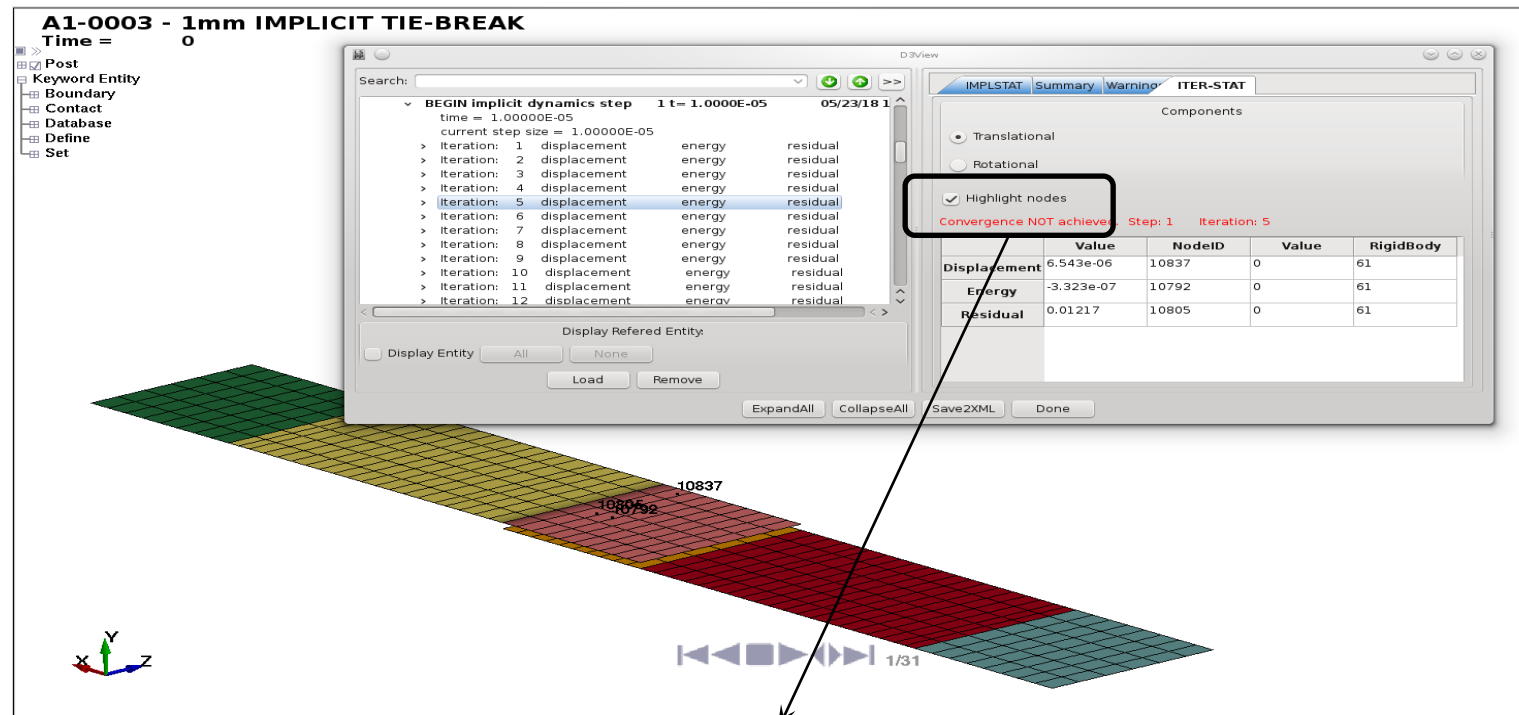
The screenshot shows the D3View software interface. The left pane displays a list of iterations from 1 to 17, with iteration 17 highlighted. The right pane shows the IMPLSTAT window with the ITER-STAT tab selected. A table titled 'Converged iteration information' is displayed, showing values for Displacement, Energy, and Residual for iteration 17. An arrow points from the text 'Converged iteration information' to the table.

	Value	NodeID	Value	RigidBody
Displacement	1.239e-07	8519	0	61
Energy	-2.567e-10	8487	0	61
Residual	0.001021	8471	0	61

Converged iteration information

D3HSP view - IMPLicit STATistics (IMPLSTAT)

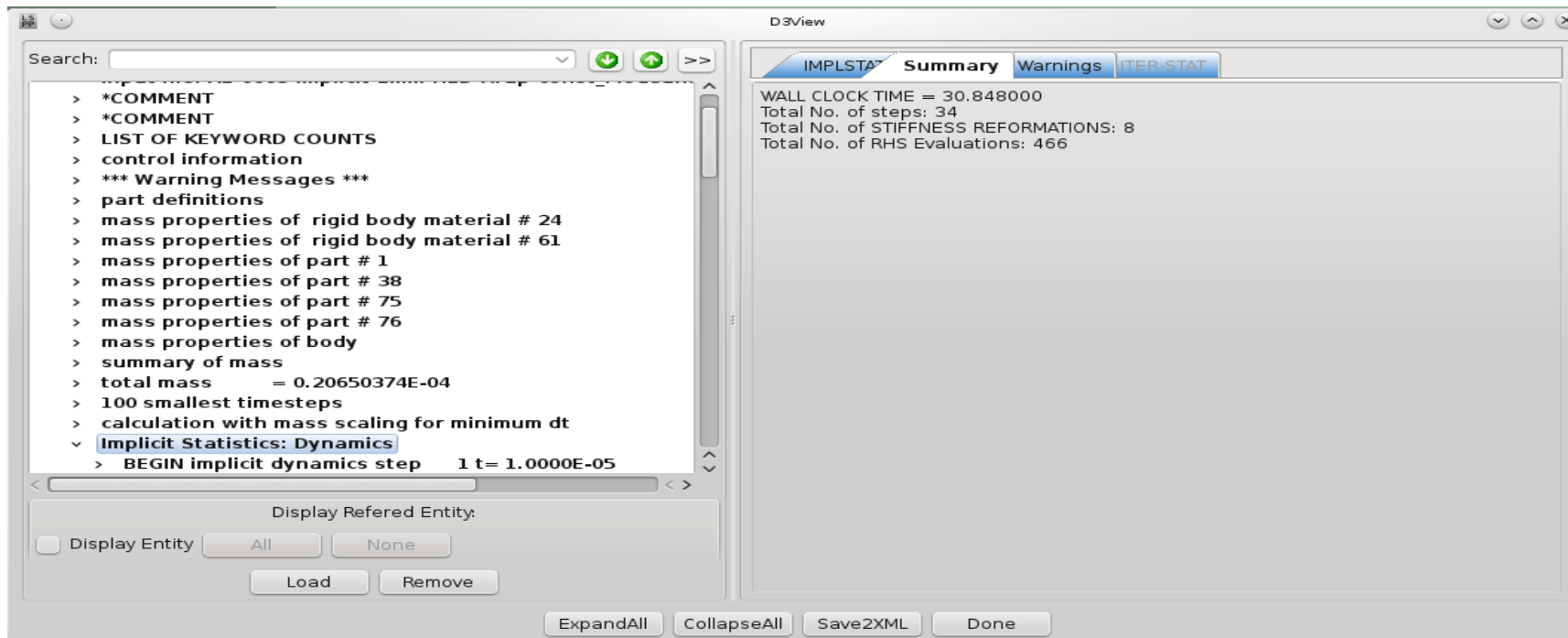
- Using d3hsp view
 - Iteration progress - Visualization



After you load a d3plot+keyword file, nodes that are most “active” during an iteration can be highlighted. Useful to understand which ‘area’ of the model is influencing convergence/solution

D3HSP view - IMPLicit STATistics (IMPLSTAT)

- Using d3hsp view
 - Summary



A quick summary for a run, global picture

More information

- Other sources of useful information regarding implicit analyses in LS-DYNA:
 - www.dynasupport.com/howtos/implicit
 - <http://www.dynaexamples.com/implicit>
 - www.dynalook.com - search conference papers
 - “Client Area”
 - Guidelines
 - Recorded webinars
 - www.dynamore.se - Video Library, short videos with useful information
- DYNAmore / LST also gives courses in implicit analyses:
 - See also: <https://www.dynamore.se/en/training/seminars>
- Please report bugs and errors! To support@dynamore.se

Thank you!



Your LS-DYNA distributor and
more

