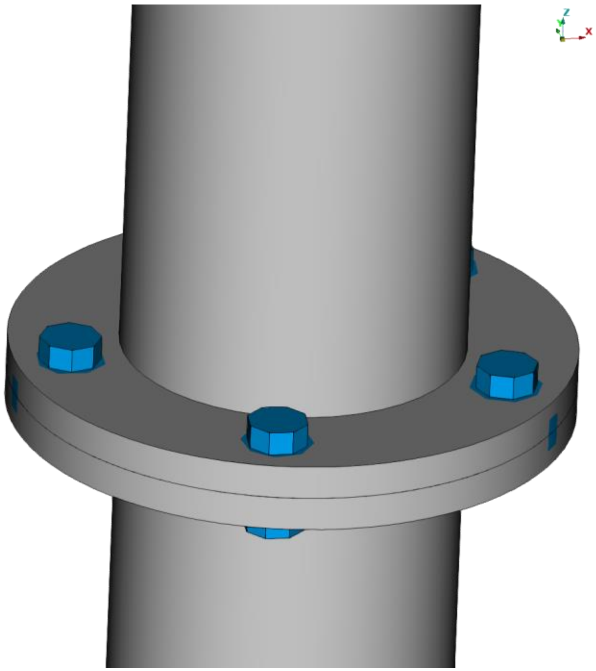
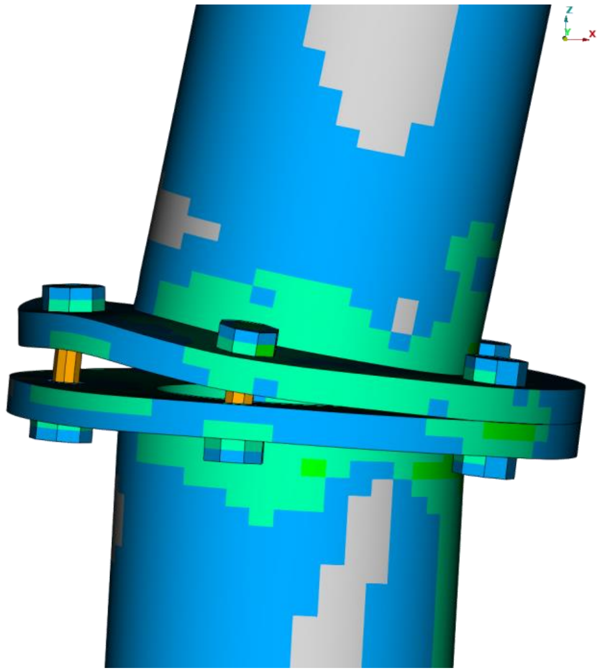
# Pre-tensioning techniques in LS-DYNA implicit





Anders Jonsson

# Pre-tensioning techniques in implicit LS-DYNA

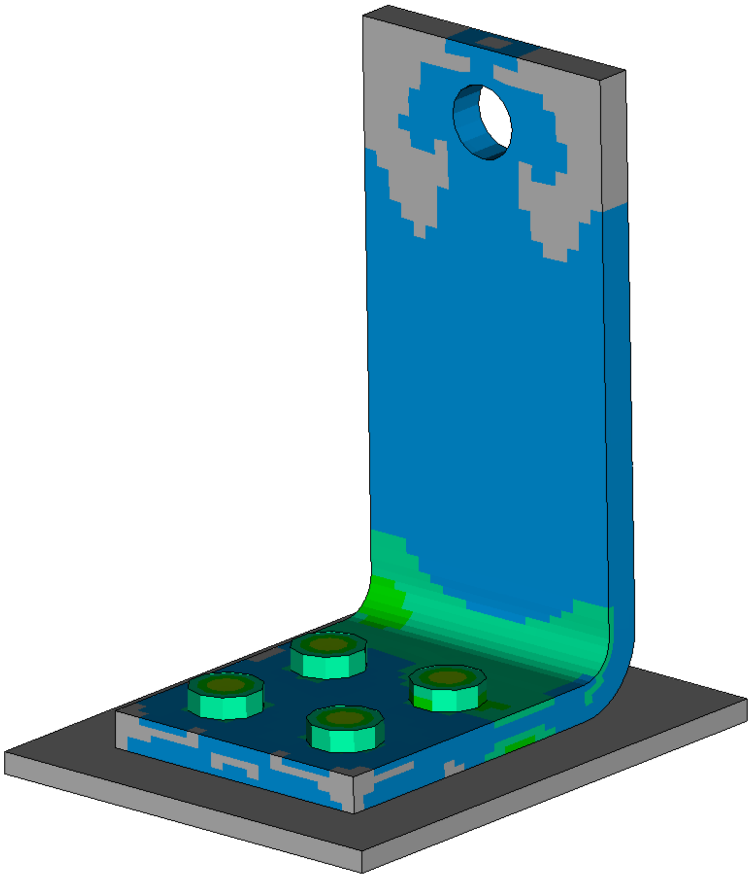
- Implicit set up

- Pre-tensioning
  - Modelling of bolts in LS-DYNA
  - Parametrized bolt models in ANSA

- Press-fit
  - Grip in contacts

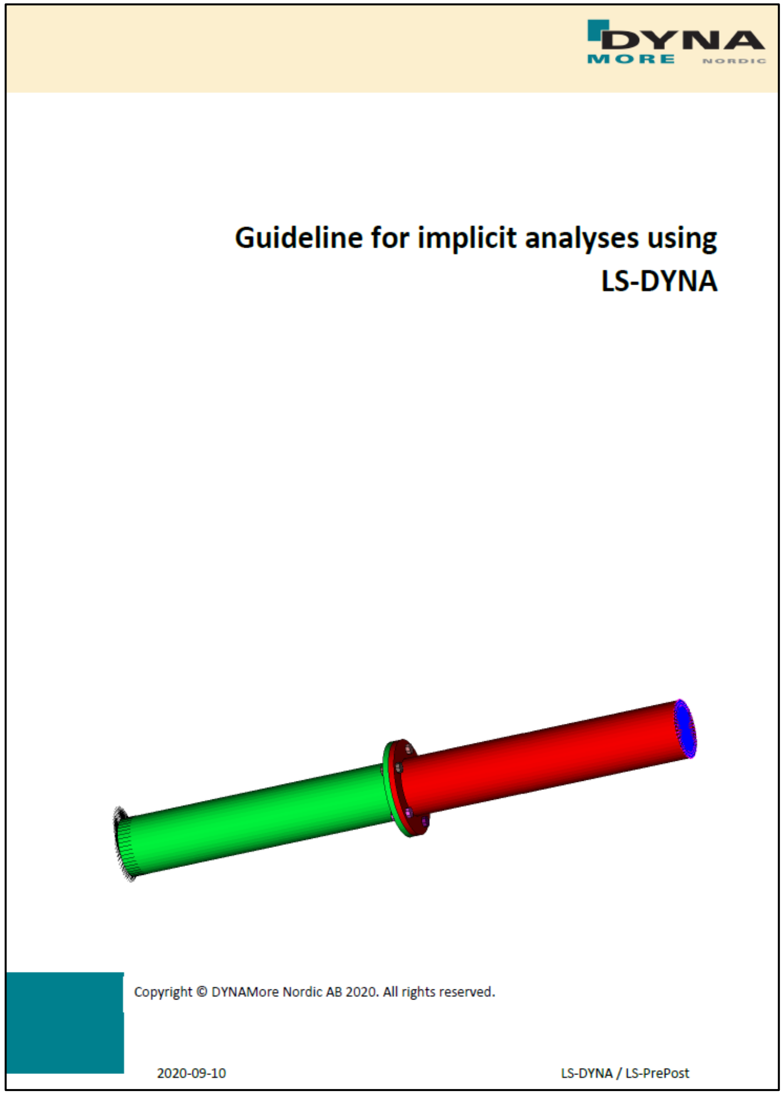
- Pre-stress
  - Stresses from previous analysis steps
  - For example forming

# IMPLICIT SET-UP



# Basic implicit set-up in LS-DYNA




DYNA MORE NORDIC

**Guideline for implicit analyses using LS-DYNA**



2020-09-10

LS-DYNA / LS-PrePost

# Basic implicit set-up in LS-DYNA

- The Guideline for implicit analyses is available for download for Dynamore Nordic customers, from files.dynamore.se > Client Area

- The **Appendix P** of the LS-DYNA keyword manual (R9.0 and later) also provides recommendations, background and motivation to implicit control card settings.

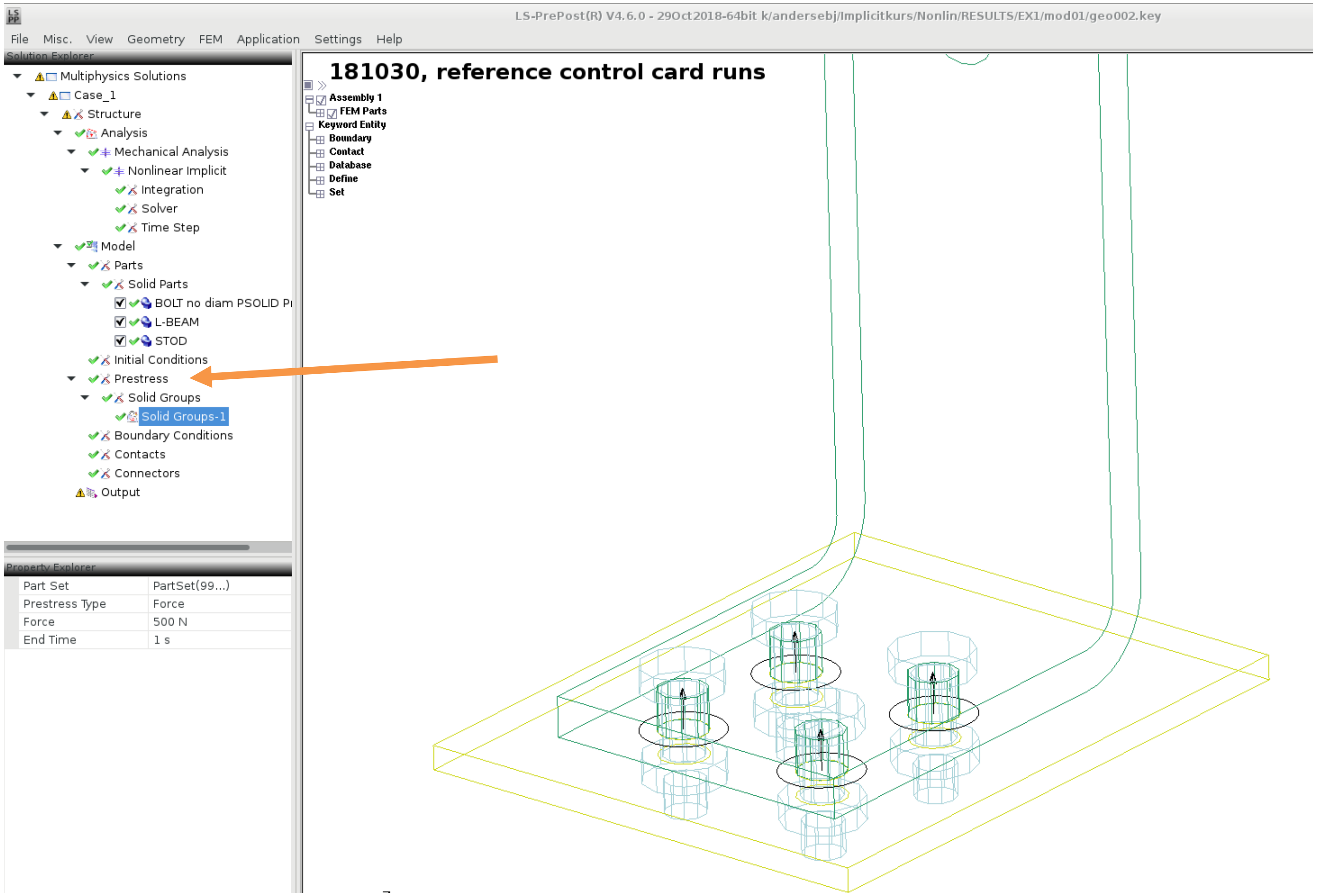
- A very educational Webinar from Christoph Schmied, DYNAmore Germany:

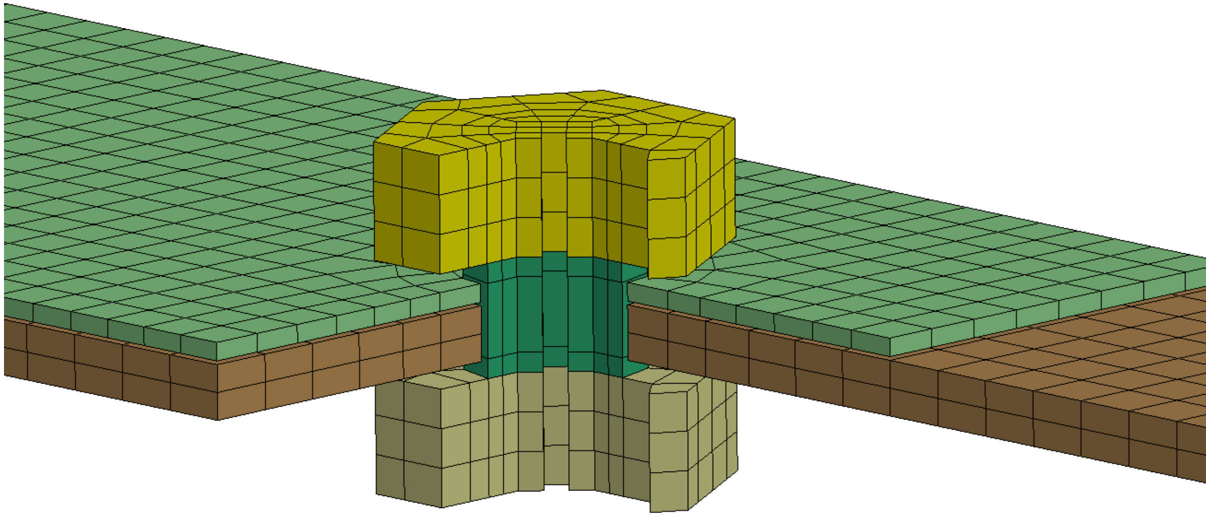
  YouTube [https://www.youtube.com/watch?v=7SL321fO7_4&t=781s](https://www.youtube.com/watch?v=7SL321fO7_4&t=781s)

- Dynamore / Ansys LST also gives courses in implicit analyses:
  - Non-linear implicit analysis in LS-DYNA (T. Borrvall)
  - From explicit to implicit (A. Jonsson)
  - Implicit analysis using LS-DYNA (DYNAmore Germany)
- see also: https://www.dynamore.se/en/training/seminars and https://www.dynamore.de/en/training/seminars

# Pre-processing

- GUI dedicated for implicit set up is available in LS-PrePost from v4.6
  - Including convenient support for Pre-stressing



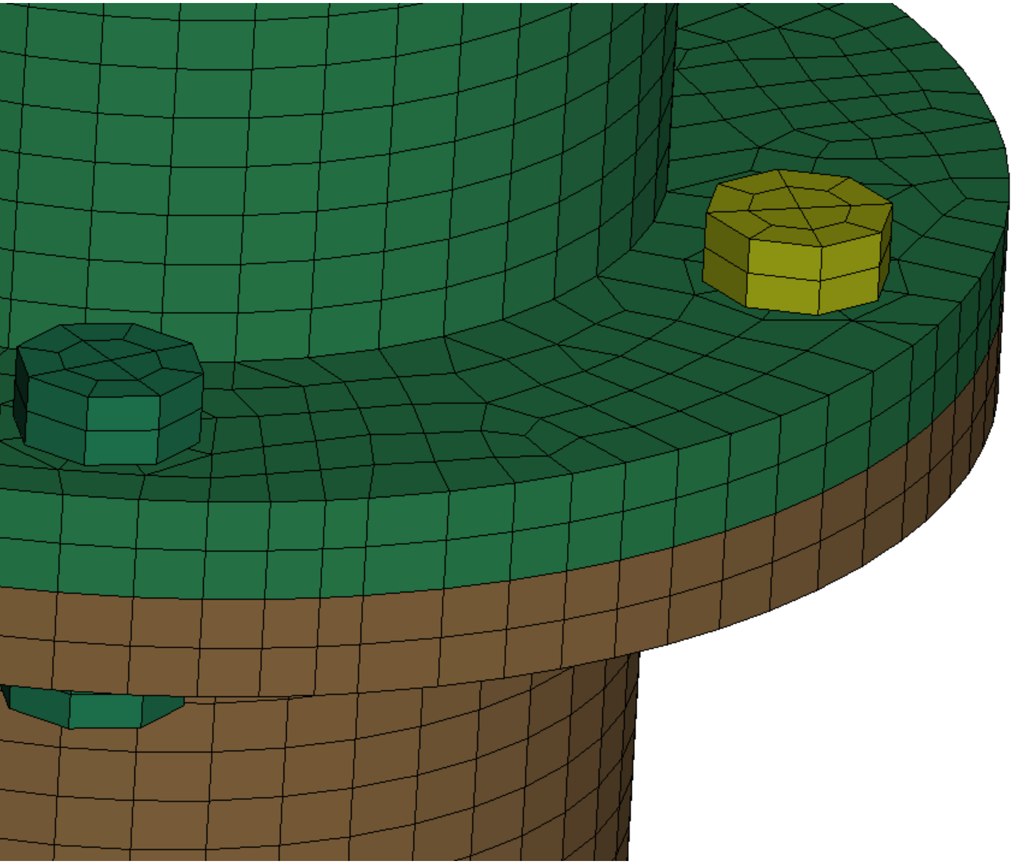


# BOLT PRE-TENSIONING

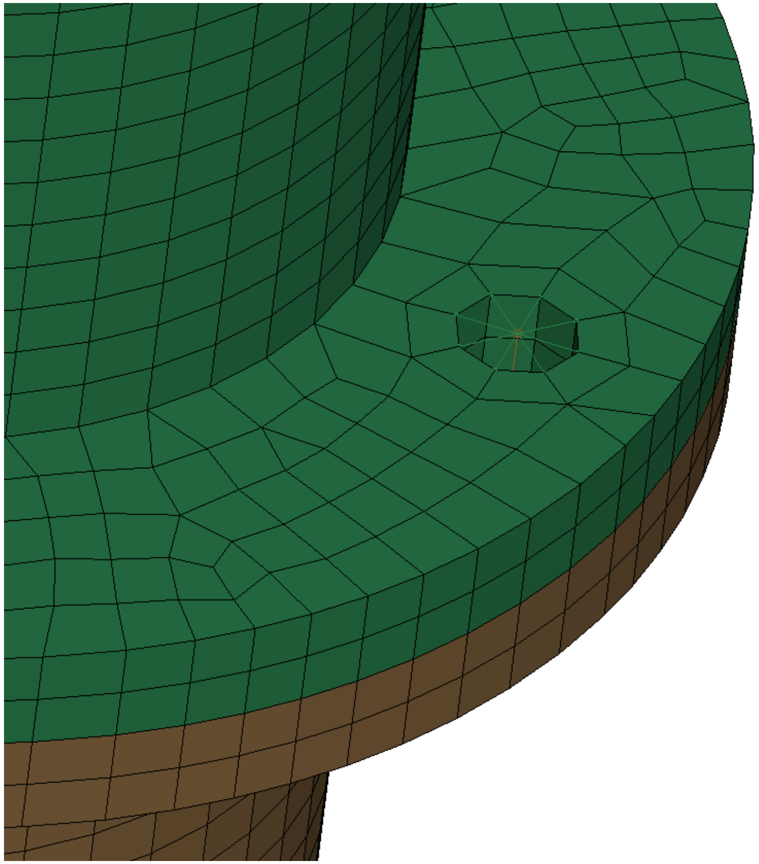
# Bolt pre-tensioning

- General background
  - See https://www.dynaexamples.com/show-cases/bolts
  - For an extensive description of bolts modelling, see Karajan, N., et *al*., Modeling bolts in LS-DYNA using explicit and implicit time integration, 15$^{th}$ Int. LS-DYNA Users Conf. (https://www.dynalook.com/15th-international-ls-dyna-conference/implicit/modeling-bolts-in-ls-dyna-c-using-explicit-and-implicit-time-integration)
  - Webinar by J. Forsberg, Bolt pre-tensioning in LS-DYNA (2020-10-07), available from files.dynamore.se > Client Area > 7_Webinars
- Bolt pre-tensioning
  - Overview
  - Solid bolts
  - Beam bolts
  - Some remarks on bending stiffness
  - Bolt connections in ANSA
  - Procedures for applying the pre-tensioning

# Bolt pre-tensioning – overview

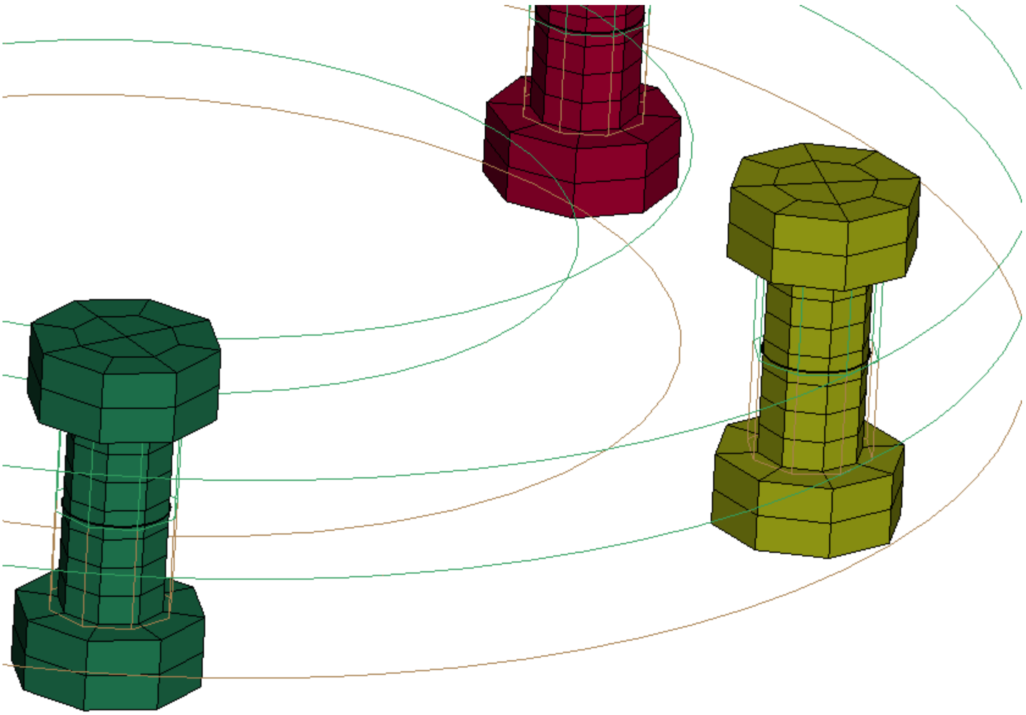


Solid bolts

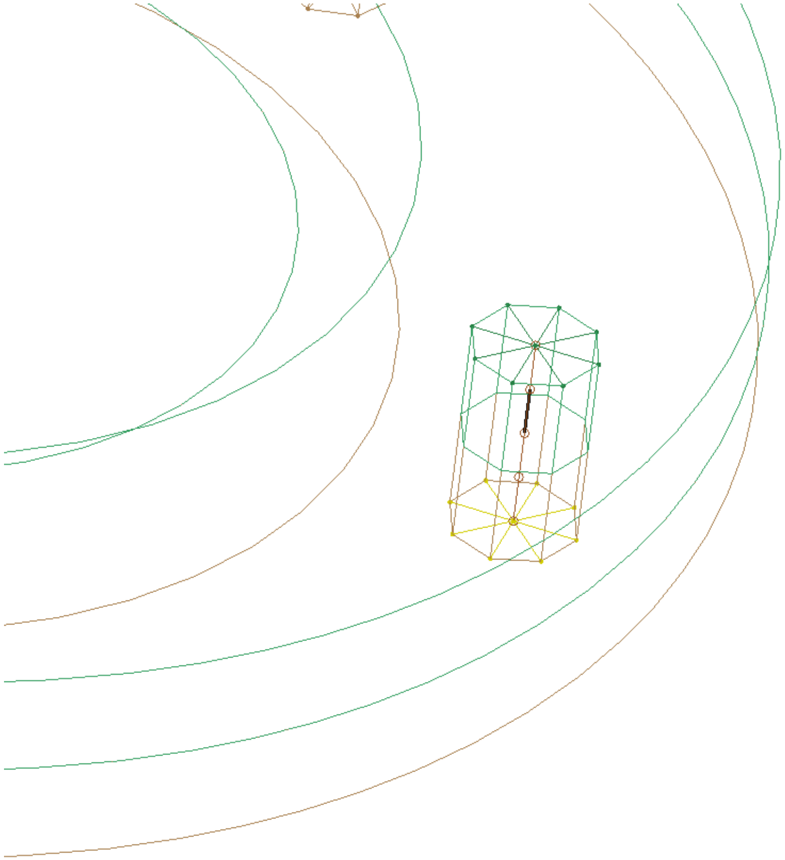


Beam bolts

# Bolt pre-tensioning - overview



Solid bolts



Beam bolts

# Bolt pre-tensioning - overview

## Solid bolts

- Keyword: `*INITIAL_STRESS_SECTION` and `*DATABASE_CROSS_SECTION`
- Applies a ***stress***.
- Solid element formulations ±1, ±2
- Connected by contacts

## Beam bolts

- Keyword: `*INITIAL_AXIAL_FORCE_BEAM`
- Applies a ***force***.
- Beam element formulation 9 and `*MAT_SPOTWELD`
  - From R12.0.0, also beam element formulation 1 can be used, with any sensical material
- Connected by CNRBs

# Bolt pre-tensioning – Load curves

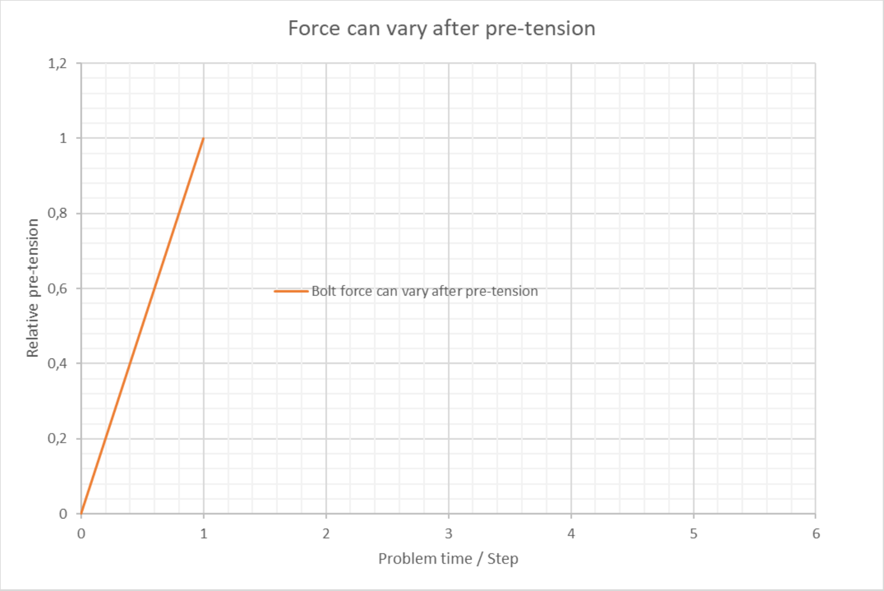
- A load curve is required to apply the pre-tensioning.
- Let the curve end when the initialization is completed.
- For example, for pre-tensioning in implicit (solid bolts):

```
*DEFINE_CURVE_TITLE
Bolt pre-tensioning stress (MPa)
100,
0.,0.
1.,400.
```

- This means that the pre-tensioning is ramped up from t = 0 to t = 1. During this time, the force in the bolt is controlled according to the curve.
- For t > 1, the force in the bolt can change due to the external loading.

# Bolt pre-tensioning – Load curves

- In order to end the pre-tensioning, let the load curve end
- Should a constant force be required, let the load curve continue on a constant level



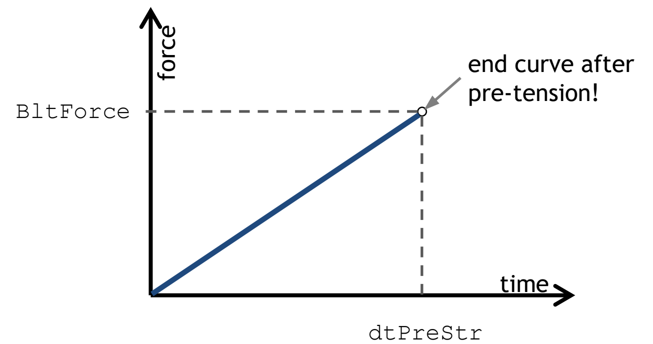

# Bolt pre-tensioning – Load curves

- In order to end the pre-tensioning, let the load curve end
- Should a constant force be required, let the load curve continue on a constant level
- LS-DYNA will print an information message in the d3hsp – file when the pre-tensioning is completed
  - For beams: "`beam stress initialization is off`"
  - For solids: "`stress initialization is off`"
  - For solids, from R12.0.0, additional information is printed
    "`initial stress complete for cross-section` *N* `at time ...`"

# Bolt pre-tensioning – Beam bolts

- *INITIAL_AXIAL_FORCE_BEAM for pre-tension of beam-style bolts. Applies a *force*.
- NOTE! Spotweld beam (elform 9) with *MAT_SPOTWELD must be used.
  - From R12, also beam elform 1 is allowed, with any (reasonable) material
- Make sure that all DOFs of the beam end nodes are connected! Avoid release conditions on CNRB:s! If *CONSTRAINED_INTERPOLATION is used, set *DDOF* = 123456

```
*INITIAL_AXIAL_FORCE_BEAM
$#     bsid      lcid     scale     kbend
        100       100                   1
*DEFINE_CURVE_TITLE
Pre-tension ramp
$#     lcid      sidr       sfa       sfo      offa      offo
        100            &dtPreStr &BltForce
$#                 a1                  o1
                  0.0                 0.0
                  1.0                 1.0
```

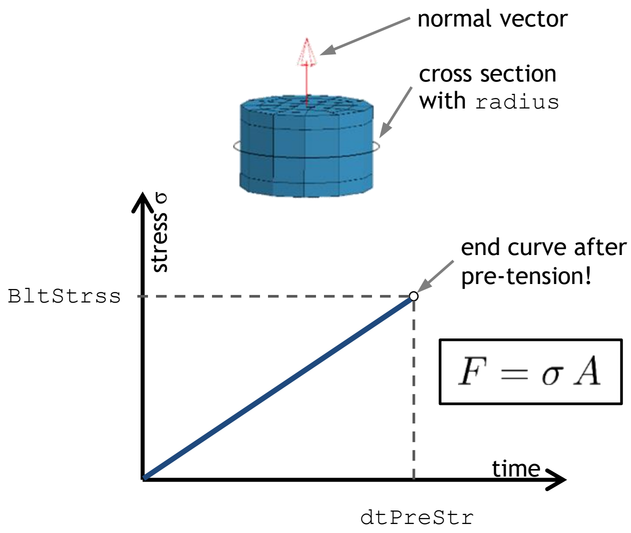



  - bsid: beam set ID containing the (spot weld) beams to be pre-tensioned
  - dtPreStr: parameter defining the initialization time of the pre-tension
  - BltForce: parameter defining the pre-tension force
  - Bending stiffness of bolt during initialization
    - kbend=0: no bending stiffness
    - kbend=1: beam has bending stiffness (from R10)

# Bolt pre-tensioning – Solid bolts

- Initialization of a normal stress in a cross section of the solid elements

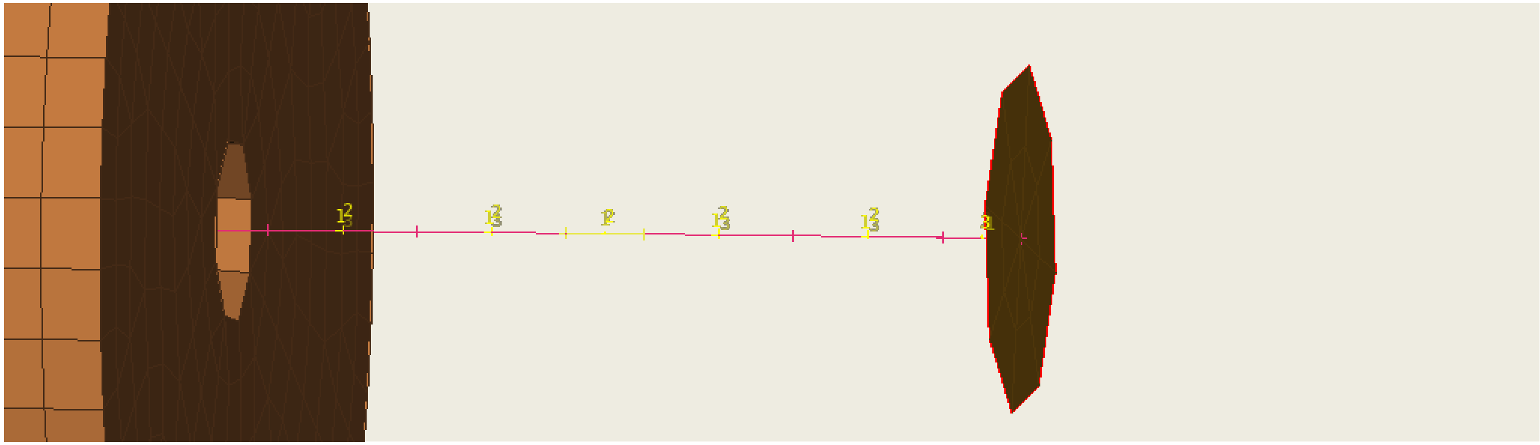
```
*INITIAL_STRESS_SECTION
$#   issid      csid      lcid      psid       vid   izshear
       100       100       100       100                   2
*DEFINE_CURVE_TITLE
Pre-tension stress ramp
$#    lcid      sidr       sfa       sfo      offa      offo    dattyp     lcint
       100            &dtPreStr &BltStrss
$#                a1                  o1
                 0.0                 0.0
                 1.0                 1.0
*DATABASE_CROSS_SECTION_PLANE_ID
$#    csid                                                                 title
       100 Cross Section Bolt
$#    psid       xct       yct       zct       xch       ych       zch    radius
       100                -1.6                           0.6                 5.5
$#    xhev      yhev      zhev      lenl      lenm        id     itype
```




- `psid`: part set ID containing the solid elements to be pre-stressed
- `vid`: normal vector, required if `*DATABASE_CROSS_SECTION_SET` defines the section
- `{x,y,z}ct {x,y,z}ch`: head and tail coordinate of normal vector of the cross section
- `BltStress`: the (normal) stress to be applied (provide reasonable value!)
- `izshear`: flag to activate shear (and bending) stiffness during pre-stressing phase

# Bolt pre-tensioning - recommendations

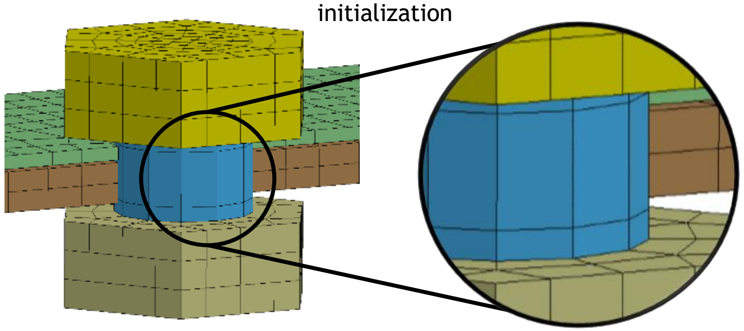
- If possible, minimize gaps between bolt heads / nuts and flanges
- If a beam bolt consists of many beam elements, apply `*INITIAL_AXIAL_FORCE_BEAM` to one beam element per bolt.
  - Set *KBEND* = 1 to account also for the bending stiffness of the beam

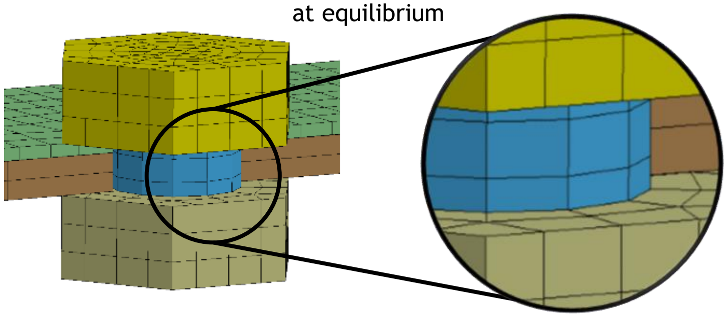


- Add `*DATABASE_HISTORY_BEAM_SET` for the beam elements which are being pre-tensioned.
  - Forces in spotweld beams (elform 9) are by default output in the `swforc` - file, if `*DATABASE_SWFORC` is active

# Bolt pre-tensioning - recommendations

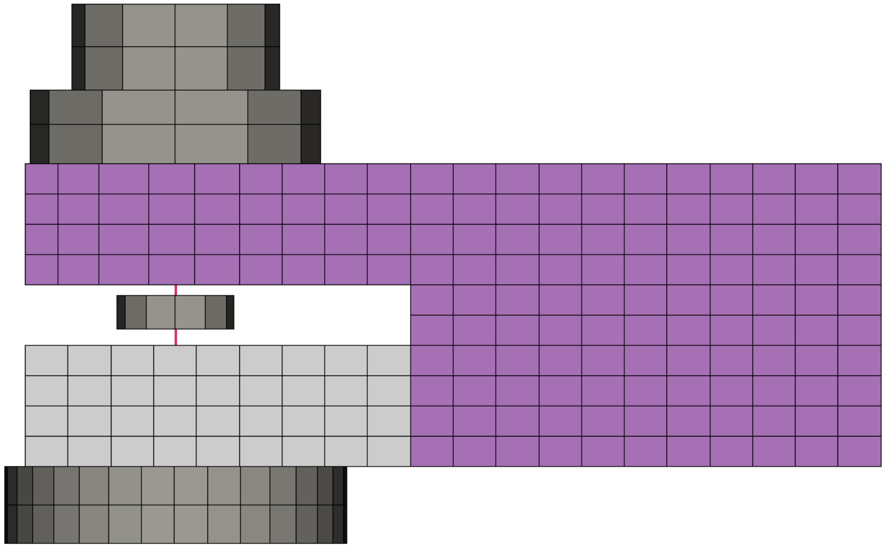
- Use an individual *DATABASE_CROSS_SECTION_PLANE for each *INITIAL_STRESS_SECTON for solid element bolts. By this, cross section forces and moments can be evaluated for each bolt individually from the secforc - file.
- Including geometric stiffness effects (IGS = 1 on *CONTROL_IMPLICIT_GENERAL, active in User's guide control cards) may aid convergence for pre-tensioning of solid bolts.
- Beware that if the elements are initially (very) "small" and/or the structure surrounding the bolt is weak, there is a risk of ending up with Error termination due to Negative volume in solid element. The remedy is often simply to mesh the pre-tension section a bit coarser.

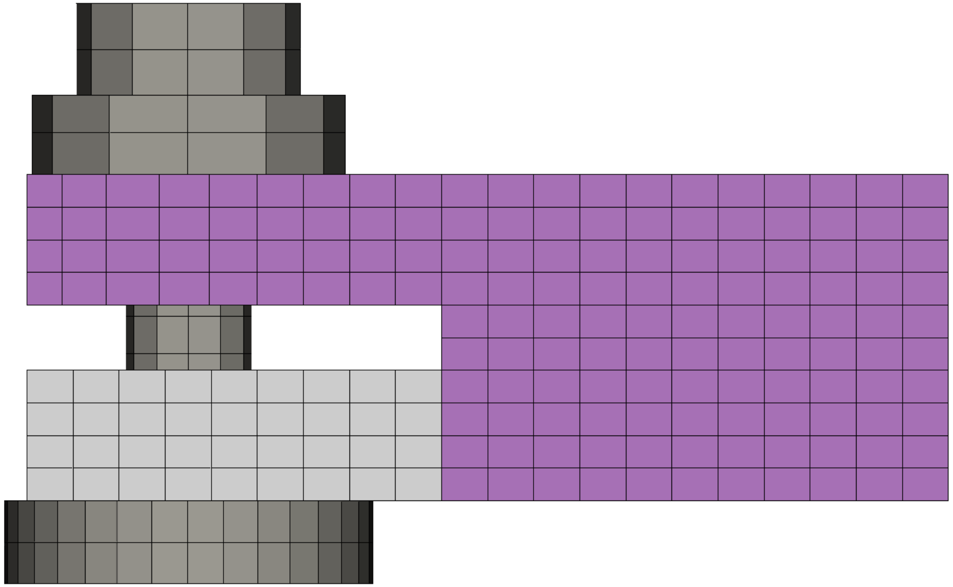


# Bolt pre-tensioning – options: kbend, izshear

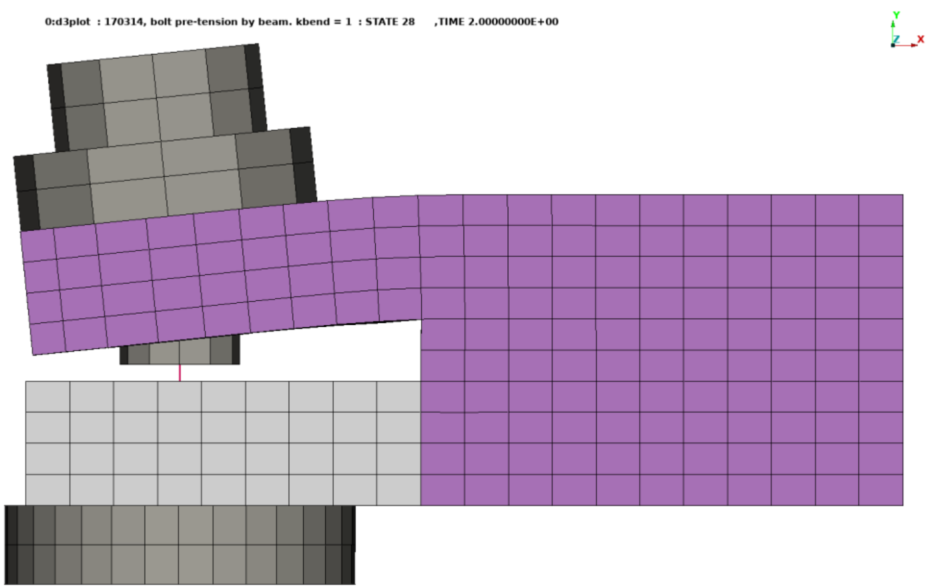
- By default, LS-DYNA applies the pre-tensioning only in the axial direction. Stress gradients are not considered.



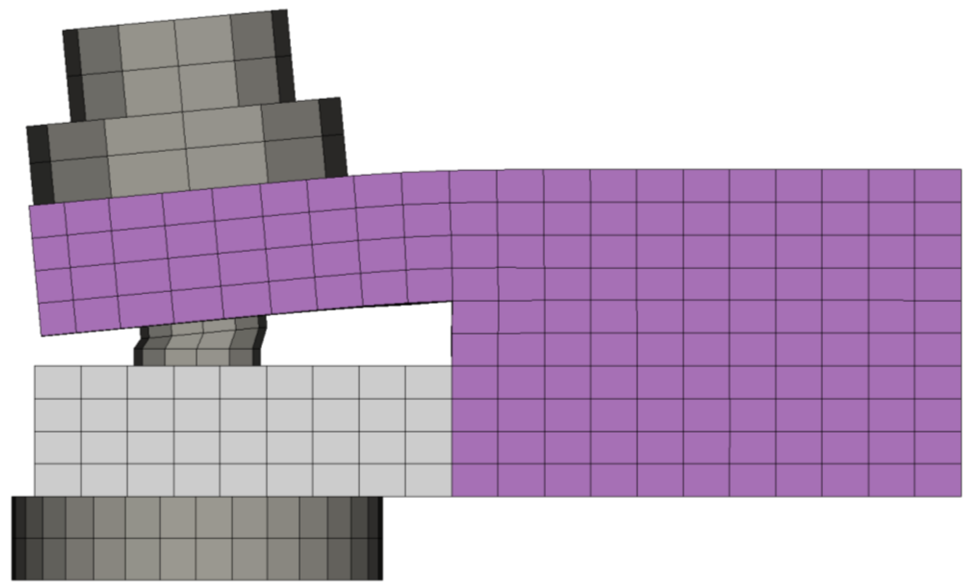


# Bolt pre-tensioning – options: kbend, izshear

- By default, LS-DYNA applies the pre-tensioning only in the axial direction. Stress gradients are not considered.



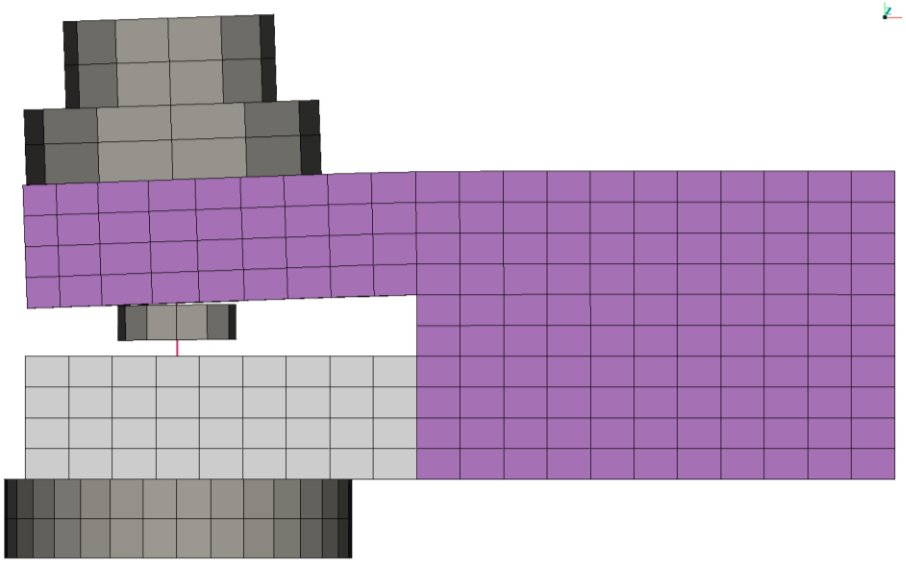

kbend = 0



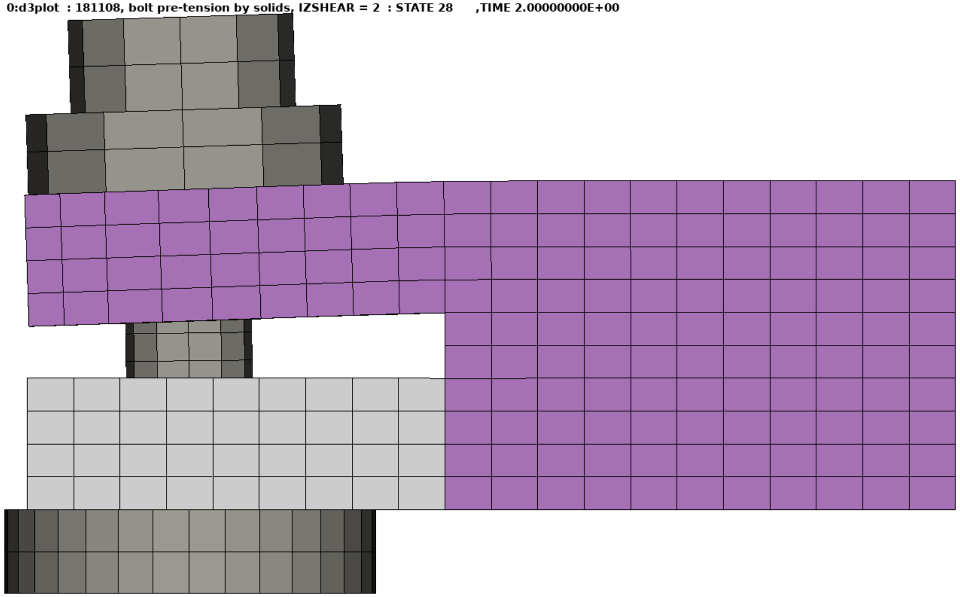
izshear = 0

# Bolt pre-tensioning – options: kbend, izshear

- For beam bolts, set `kbend` = 1 on the pre-tension card to account also for the bending stiffness of the beam.
- For solid bolts, set `izshear` = 2 on the pre-tension card to account also for the stress gradient across the pre-tension section.



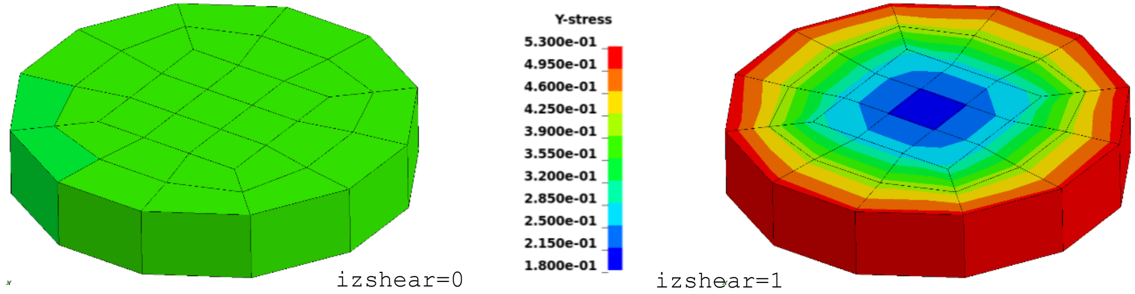
`kbend = 1, from R9`




`izshear = 2, R11.1`

# Bolt pre-tensioning – *IZSHEAR*

- `izshear`: Allow shear stresses to develop during the pre-stressing phase
  - Yields more realistic distribution of the normal stresses
  - Normal stress distribution in the bolt at equilibrium using LS-DYNA implicit (from R11.1)
    - `izshear=0`: yields homogeneous normal stress of 0.38 GPa
    - `izshear=2`: yields inhomogeneous normal stresses averaging 0.38 GPa over the cross section




  - Revised for implicit from R11.1
    - For explicit analysis this will be available as `izshear=2`
    - For implicit `izshear=1` and `izshear=2` are synonymous

# Bolt pre-tensioning - options: kbend, izshear

- For `*INITIAL_AXIAL_FORCE_BEAM` the bending stiffness in the beam can be accounted for by setting the flag *KBEND* = 1 (available from R10)

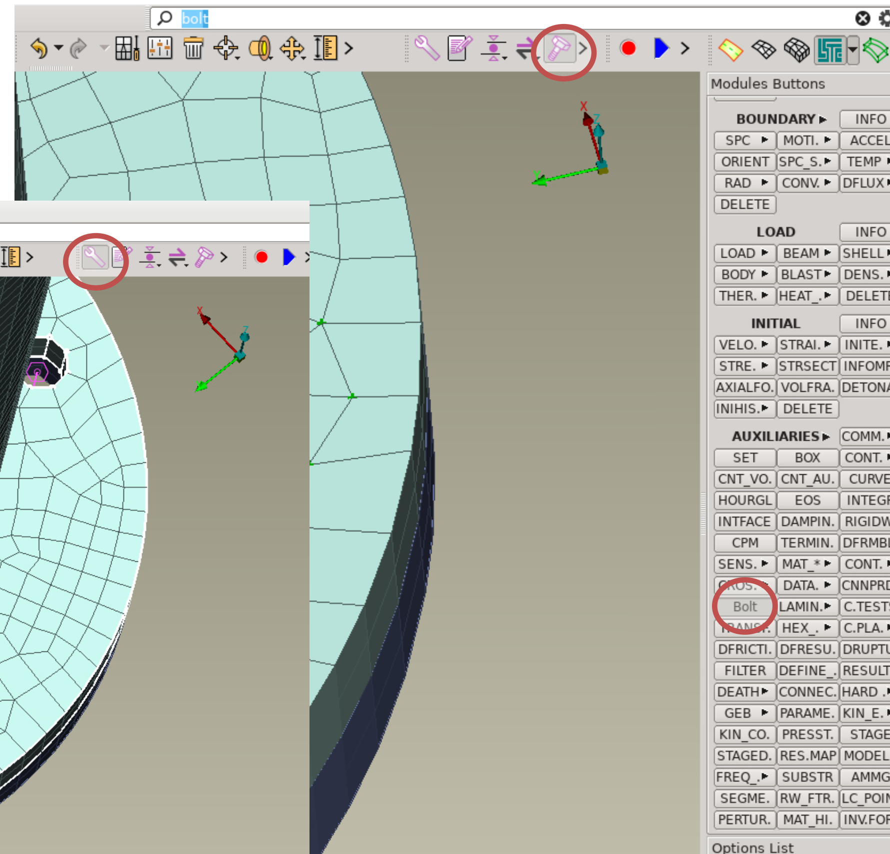
```
*INITIAL_AXIAL_FORCE_BEAM
$#     bsid         lcid       scale      kbend
        123            1       70.E3          1
```

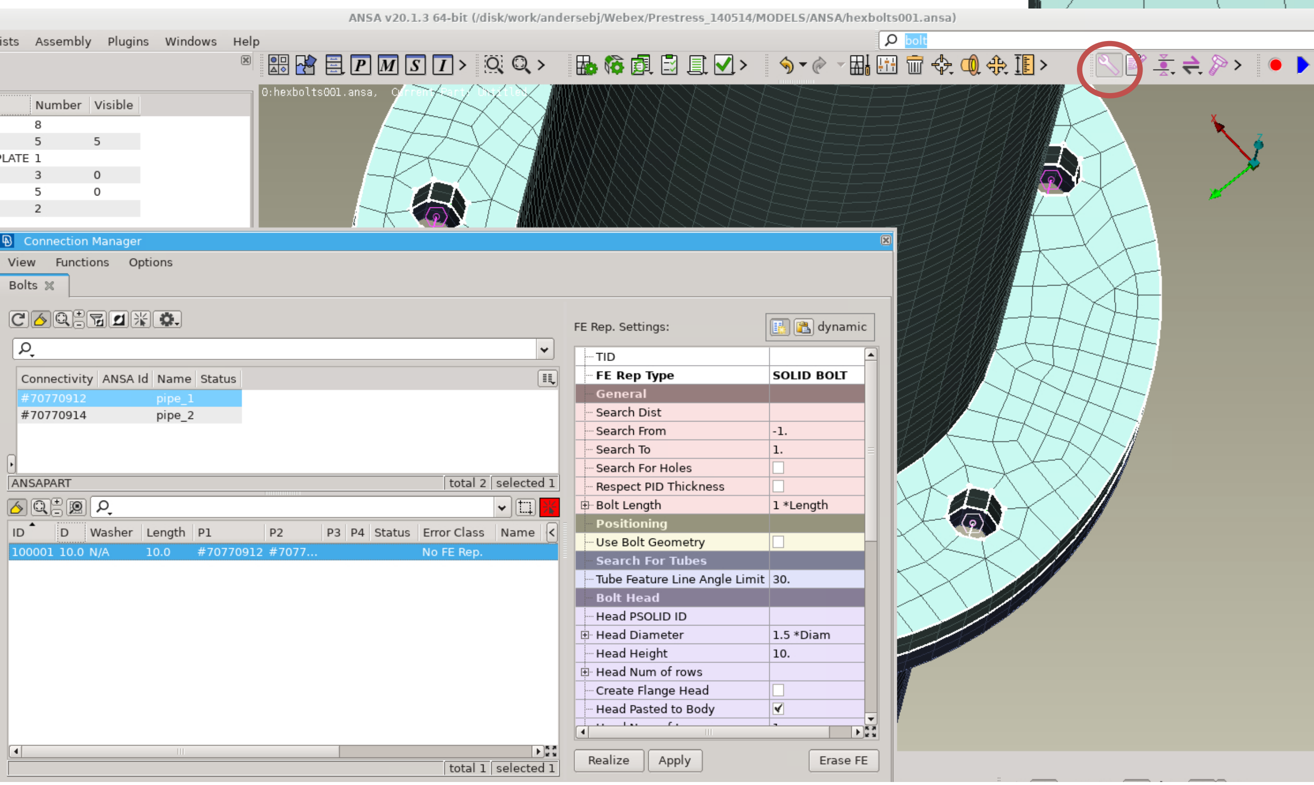
- For`*INITIAL_STRESS_SECTON` the bending stiffness of the cross section can be  accounted for by setting the flag *IZSHEAR* = 2 (available from R11.1).

```
*INITIAL_STRESS_SECTION
$     issid         csid        lcid       psid        vid    izshear
          1            1        1002        101                     2
```

# Creating bolts in ANSA

- There are two ways of creating bolts in ANSA
  - Via the AUXILIARIES > BOLT function
  - Via the Connection manager
- Demo!



# Procedures for applying the pre-tensioning

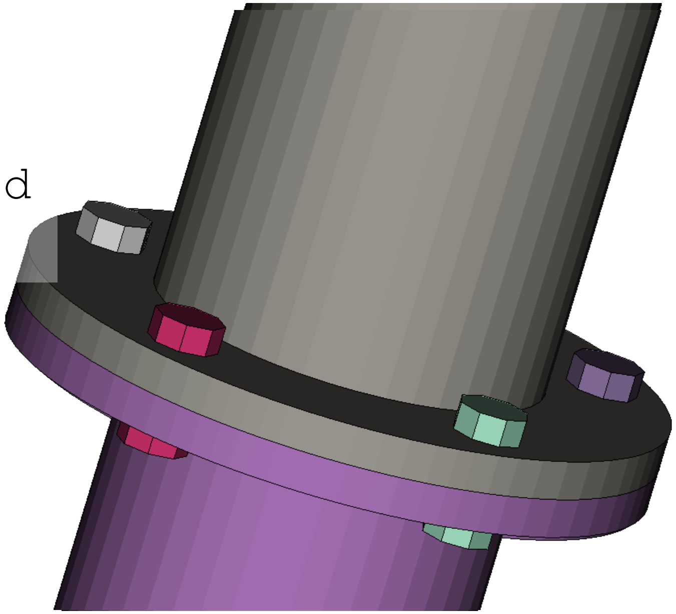
- Implicit static
- Implicit dynamics → implicit statics
- Dynamic Relaxation
  - Implicit
  - Explicit, followed by implicit
- (Explicit dynamics → implicit)

# Pre-tensioning using implicit statics

- Pre-tensioning is applied just like “normal” load application.
  - Don’t use a “too small” first time step size.
- Statics should work for beam bolts connected to the structure by constrained nodal rigid bodies.
  - Make sure that all DOFs of the beam nodes are connected! Avoid release conditions on CNRB:s! If `*CONSTRAINED_INTERPOLATION` is used, set *DDOF* = 123456
- If the assembly only is connected by the (solid) bolts and contacts, the model will have rigid body modes at t = 0.
  - LS-DYNA will print negative eigenvalue warnings.

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

  - Still, the pre-tensioning may converge.

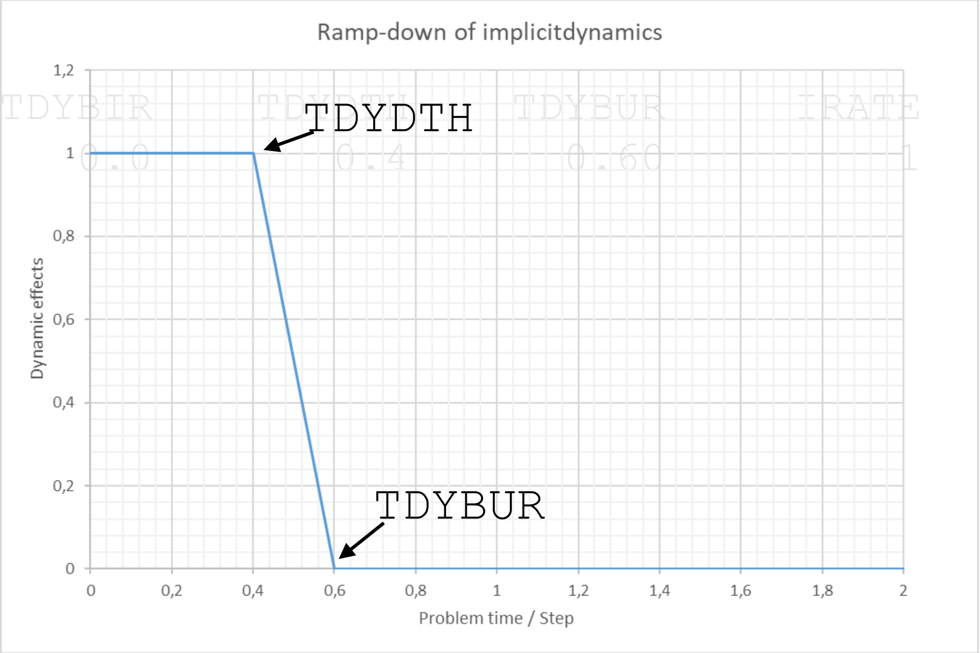


# Pre-tensioning using implicit dynamics

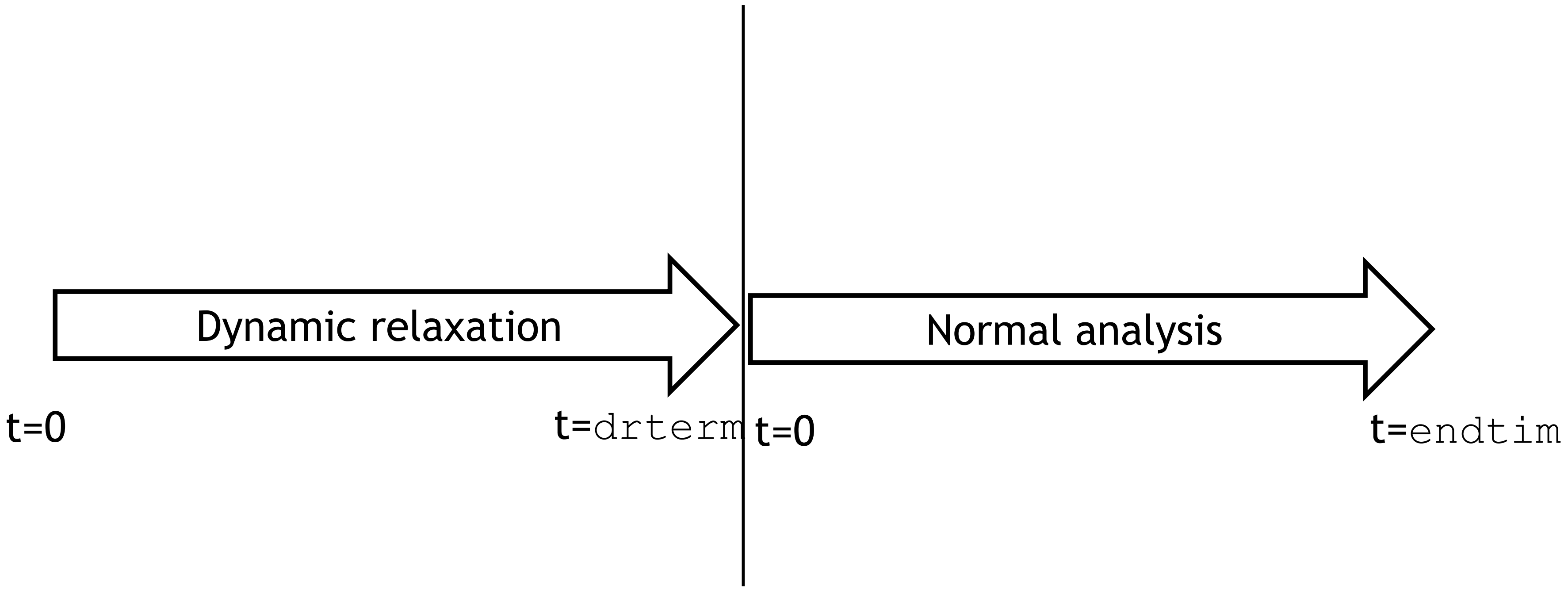
- Initial rigid body modes will be taken care of by the dynamics.
  - When dynamics is active, time means “physical time”. The time to ramp up the pre-tensioning becomes important.
  - For example, if the model is in the mm – ms – kg system, time is ms, and a ramp-up time of perhaps 100 ms may be required.
- Dynamic effects can then be ramped down, as the contacts establish, and the rest of the analysis can be performed as static.

```
*CONTROL_IMPLICIT_DYNAMICS
$     IMASS     GAMMA      BETA
          1       0.6      0.38
```

Settings for quasi-statics

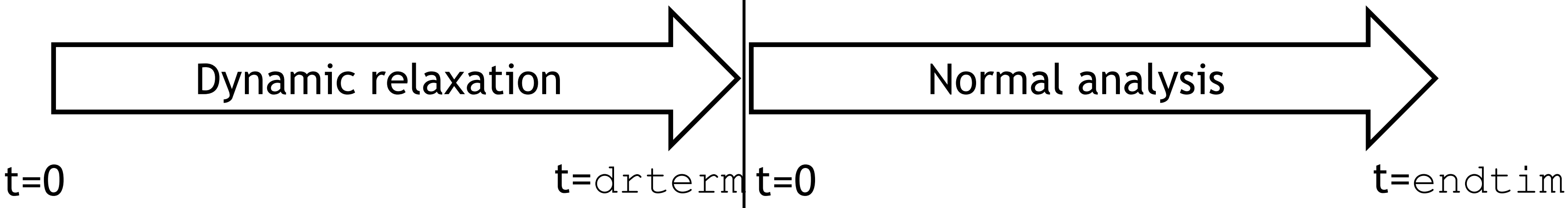


# Dynamic relaxation




- Dynamic Relaxation (DR) is a way of splitting a LS-DYNA analysis into two “phases”.
- In the first phase, the Dynamic Relaxation, pre-loading can be applied
- The “actual” loading of the structure (including pre-load) then takes place in the Normal analysis

# Dynamic relaxation




- Load curves with *SIDR* = 1, 2 active
- Separate implicit settings are possible
  `*CONTROL_IMPLICIT_..._DYN`
- Output may be requested by
  `*DATABASE_BINARY_D3DRLF`

- Load curves with *SIDR* = 0, 2 are active

- For bolt pre-tensioning, DR is “easy” to set up (bolt pre-tension is complete when the force/stress load curve ends, so only a load curve using *SIDR* = 1 is required) but care must be taken in the general case.
- Also take care with “birth” and “death” - time of for example contacts and prescribed displacements (if applicable)

# Pre-tensioning using implicit dynamic relaxation (DR)

- Implicit dynamic relaxation can be static and/or dynamic.
- Set *SIDR* = 1 on the pre-tension load curve to activate DR
- Set *DRTERM* on `*CONTROL_DYNAMIC_RELAXAITON` to specify the end time of the Dynamic Relaxation
  - Also set *NRCYCK* = 1 to make sure that convergence is checked after each iteration

- From R11, it is possible to specify separate implicit settings for the DR
  - `*CONTROL_IMPLICIT_GENERAL_DYN`
  - `*CONTROL_IMPLICIT_AUTO_DYN`
  - `*CONTROL_IMPLICIT_DYNAMICS_DYN`
  - `*CONTROL_IMPLICIT_SOLUTION_DYN`

# Pre-tensioning using implicit dynamic relaxation (DR)

- Set *SIDR* = 1 on the pre-tension load curve
  - Other load curves that are to be active during DR should have *SIDR* = 1 or 2 for example to specify variation of max time step

Pre-tensioning is ramped up

```
*DEFINE_CURVE_TITLE
Bolt pre-tension 600 MPa
$      LCID      SIDR
       1002         1
0.,.0
1.,600.
*CONTROL_DYNAMIC_RELAXATION
$    NRCYCK     DRTOL    DRFCTR    DRTERM    TSSFDR    IRELAL     EDTTL    IDRFLG
          1                              1.                                      5
*CONTROL_IMPLICIT_AUTO_DYN
$     IAUTO    ITEOPT    ITEWIN     DTMIN     DTMAX     DTEXP
          1       100        20        0.     -701.        0.
*CONTROL_IMPLICIT_DYNAMICS_DYN
$     IMASS     GAMMA      BETA    TDYBIR    TDYDTH    TDYBUR     IRATE
          1       0.6      0.38       0.0       0.4      0.60         1
```

# Pre-tensioning using explicit dynamic relaxation (DR)

- Can be very efficient for structures with many loose parts.
- Add contact damping to aid “convergence” (*VDC* = 20 - 40) of explicit DR.
- Set *SIDR* = 1 on the pre-tension load curve.
- In case of an implicit analysis, also setting *IDRFLG* = 1 on `*CONTROL_DYNAMIC_RELAXATION` will be required to activate <u>explicit</u> DR.
- `*CONTROL_TIMESTEP` is also recommended. Use moderate mass scaling (< 10 - 15 %) by *dt2ms* < 0.
- Explicit DR Applies similar to a mass damping to reduce nodal velocities
  - *DRFCTR* can be set on `*CONTROL_DYNAMIC_RELAXATION`, default is 0.995

$$\alpha = \frac{(1 - DRFCTR)}{\Delta t}$$

- Adding stiffness damping (~ 2.5 %) to parts in contact and up to 10 % to parts being pre-tensioned is recommended

# Pre-tensioning using explicit dynamic relaxation (DR)

- For explicit Dynamic relaxation, it is often most efficient to apply the pre-tension instantaneously, or using a very sharp ramp (~ 1 ms)
  - Try to minimize gaps between the parts subjected to pre-tension

```
*DEFINE_CURVE_TITLE
Bolt pre-tension 600 MPa
$      LCID      SIDR
       1002         1
0.,600.
1.,600.
*CONTROL_TIMESTEP
$     TDINT     TSSFAC       ISDO     TSLIMT      DT2MS
                                                -5.E-04
*CONTROL_DYNAMIC_RELAXATION
$    NRCYCK      DRTOL     DRFCTR     DRTERM     TSSFDR     IRELAL      EDTTL     IDRFLG
                                                                                        1
*DAMPING_PART_STIFFNESS_SET
...
*CONTACT_AUTOMATIC_SINGLE_SURFACE_..._ID
  19000001Global contact
        111                 2
$        FS         FD                                  VDC
        0.1                                              40
```

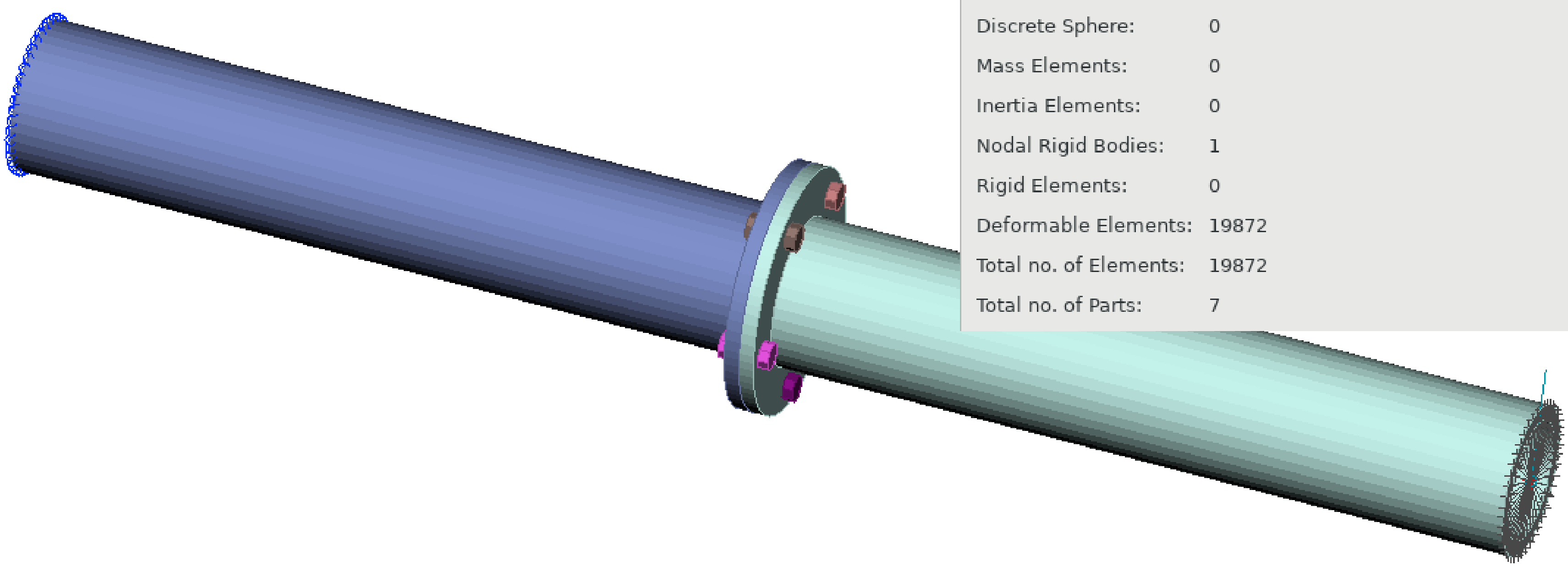
Pre-tensioning is constant

# Procedures for applying the pre-tensioning in implicit

- Implicit static
- Implicit dynamics → Statics
- Using dynamic relaxation (DR)
  - Implicit dynamics → Statics
  - Explicit
- Solution times comparison

General Info

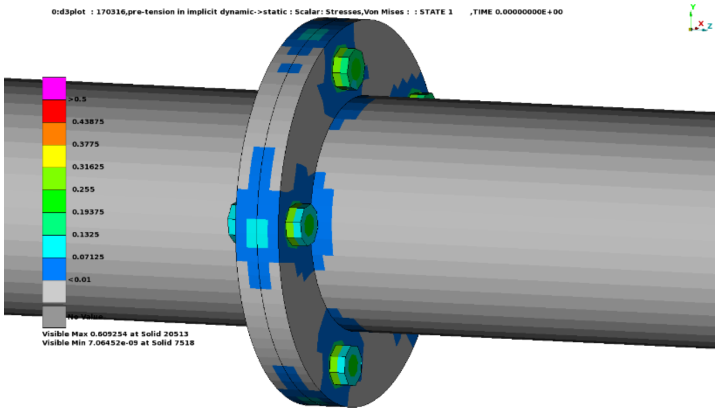
| | | | |
|---|---|---|---|
| State: | 1 | | |
| Nodes: | 30445 | | |
| Beams: | 0 | Beam Parts: | 0 |
| Shells: | 0 | Shell Parts: | 0 |
| TShells: | 0 | TShell Parts: | 0 |
| Solids: | 19872 | Solid Parts: | 7 |
| SPH Nodes: | 0 | SPH Parts: | 0 |
| Discrete Elements: | 0 | Discrete Parts: | 0 |
| Seatbelt Elements: | 0 | Seatbelt Parts: | 0 |
| Nurbs Elements: | 0 | Nurbs Parts: | 0 |
| Discrete Sphere: | 0 | | |
| Mass Elements: | 0 | | |
| Inertia Elements: | 0 | | |
| Nodal Rigid Bodies: | 1 | | |
| Rigid Elements: | 0 | | |
| Deformable Elements: | 19872 | | |
| Total no. of Elements: | 19872 | | |
| Total no. of Parts: | 7 | | |



# Possible procedures for applying bolt pre-tensioning

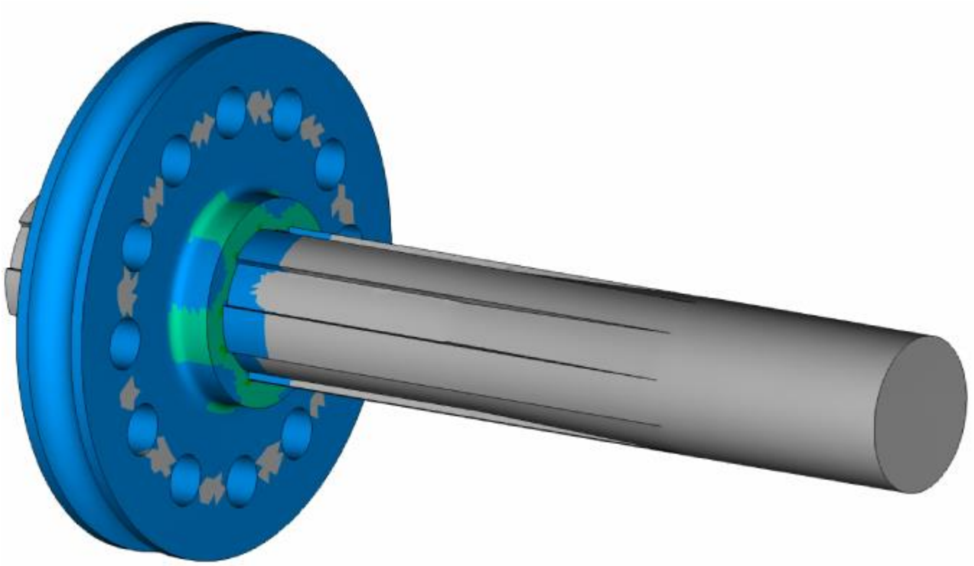
- Solution timesfor the pipe example. Run on 4 cores on Dynamore’s newest cluster nodes, using mpp/LS-DYNA R11.1 and *IZSHEAR* = 0

| Option | Time / seconds | Comment | Keyword file example |
|---|---|---|---|
| Dynamic → Static implicit | 52 | No negative eigenvalues | `pretens002.key` |
| Implicit DR | $52^{(1)}$ / $70^{(2)}$ | Same time for boltpre as in Normal time | `pretens004.key` |
| Implicit static | 79 | 11 negative eigenvalues during first time step | `pretens001b.key` |
| Explicit DR | $32^{(1)}$ / $56^{(2)}$ | The fastest boltpre! | `pretens003.key` |




Notes: (1) Time for bolt pre-tensioning. (2) Total time to normal termination, run 1 time unit with no additional loading

# PRESS-FIT



# Press fit in contacts

- Use Mortar contacts for implicit analyses, `*CONTACT_AUTOMATIC...SURFACE_MORTAR_ID`
- Mortar contact can also resolve press-fit

- Parameters on Optional Card C
  - *MPAR1* to specify time to resolve the initial penetrations.
  - *MPAR1* < -1.0: |*MPAR1*| is the ID of a curve defining the relative penetration reduction as function of time.
  - *IGNORE* = 3 for “small” penetrations (found in normal contact search)
  - *IGNORE* = 4 for “finite” penetrations, and *MPAR2* to specify search distance for penetrating nodes.
  - The solid contact thickness (*PENMAX* on Optional Card B) may require adjustment

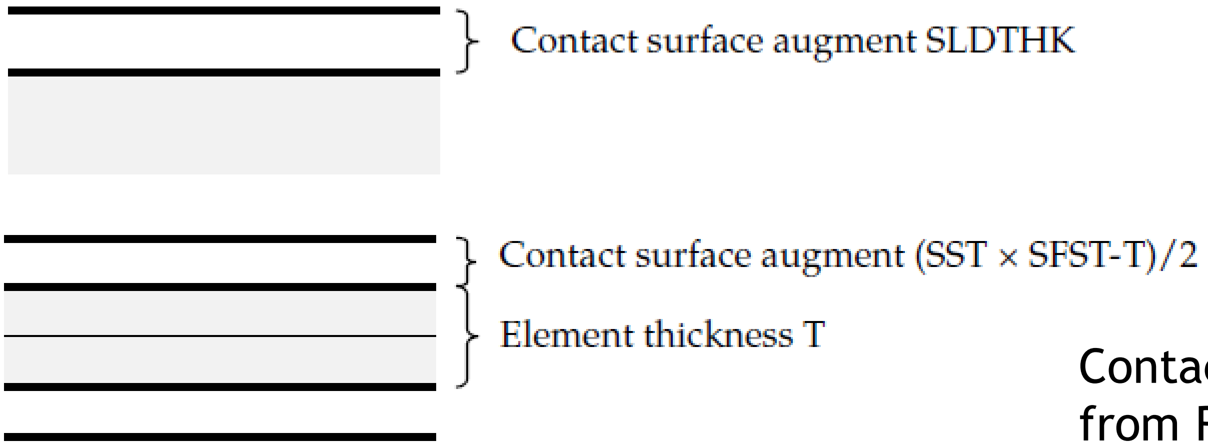
# Press fit in contacts

- Use Mortar contacts for implicit analyses, `*CONTACT_AUTOMATIC...SURFACE_MORTAR_ID`
- Mortar contact can also resolve press-fit

- The contact surface is adjusted at t = 0 so that no initial penetrations exist
- The contact surface is then moved out to coincide with the meshed surface
- It is possible to parametrize the grip by contact surface augmentation. For solids, the parameter *SLDTHK* (optional card B of the contact definition) can be used to directly specify the thickness increase.

# Press fit in contacts

- It is possible to parametrize the grip by contact surface augmentation. For solids, this is most conveniently done in R10, where the parameter *SLDTHK* (optional card B of the contact definition) can be used to directly specify the thickness increase. Note that both master and slave side will be augmented!
- NOTE! *SLDTHK* < 0 is also allowed




Contact surface augmentation from R10

# Contacts – Press-fit

- Mortar example for small penetration / press-fit

```
*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_MORTAR_ID
$#     cid                                                                 title
         1interference
$#    ssid      msid     sstyp     mstyp    sboxid    mboxid       spr       mpr
         9        10         3         3         0         0         0         0
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
  0.100000
$#     sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf

$#    soft    sofscl                                          bsort    frcfrq

$#  penmax    thkopt                                         sldthk    sldstf

$#    igap    ignodprfac/mpadtstif/mpar2   unused    unused    flangl   cid_rcf
         1         3  1.000000
```

*MPAR1* is the time when the press-fit should be resolved

Set *IGNORE* = 3 for “small” interference

# Contacts – Press-fit

- Mortar example for large penetration / press-fit

```
*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_MORTAR_ID
$#     cid                                                                 title
         1interference
$#    ssid      msid     sstyp     mstyp    sboxid    mboxid       spr       mpr
         9        10         3         3         0         0         0         0
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
  0.100000
$#     sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf

$#    soft    sofscl                                           bsort    frcfrq

$#  penmax    thkopt    shlthk     snlog      isym     i2d3d    sldthk    sldstf
       3.0
$#    igap    ignodprfac/mpadtstif/mpar2    unused    unused    flangl   cid_rcf
         1         4  1.000000  3.000000
```

*PENMAX* may require modification

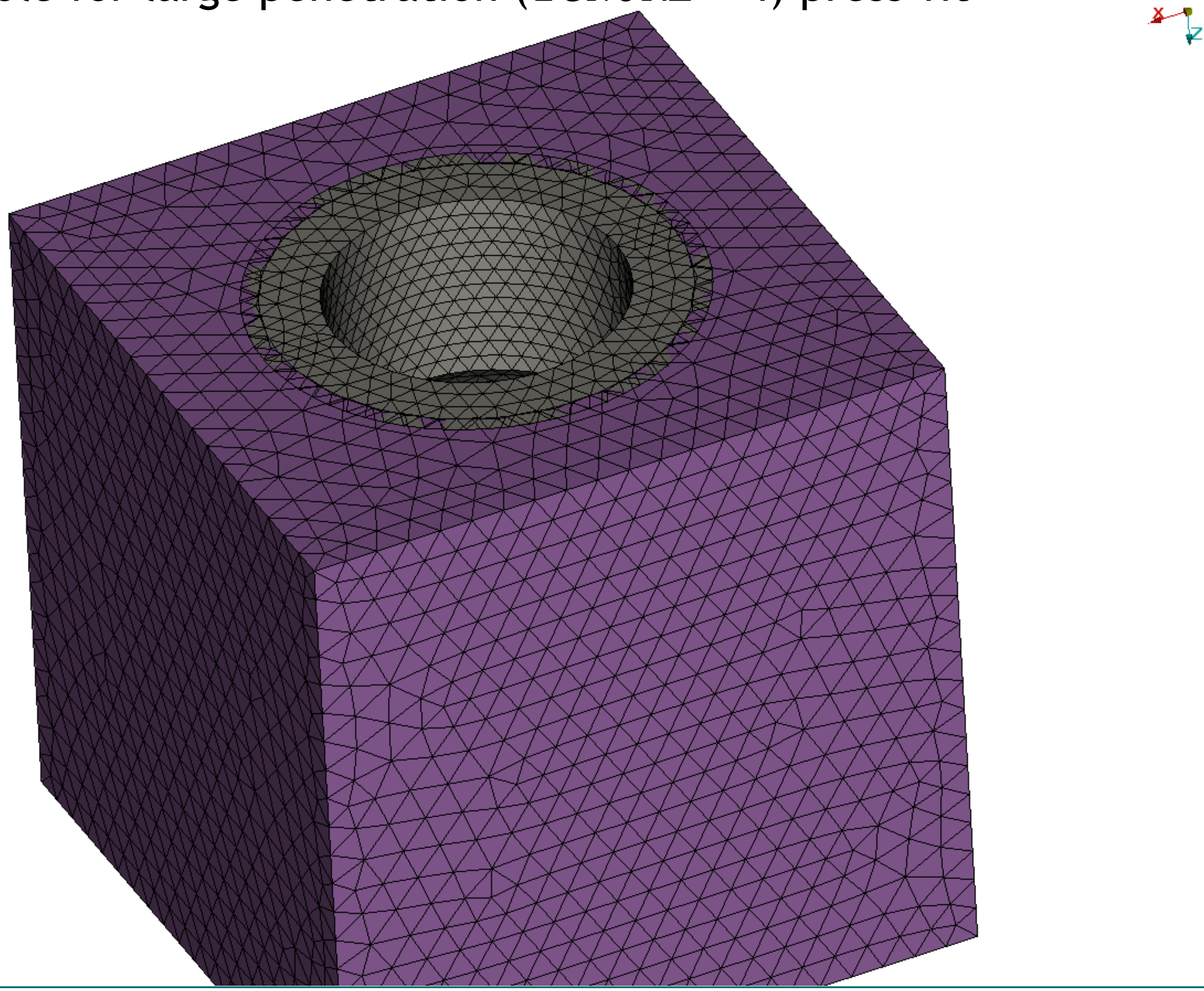
*MPAR1* is the time when the press-fit should be resolved

Set *IGNORE* = 4 for "finite" interference

*MPAR2* is the search distance

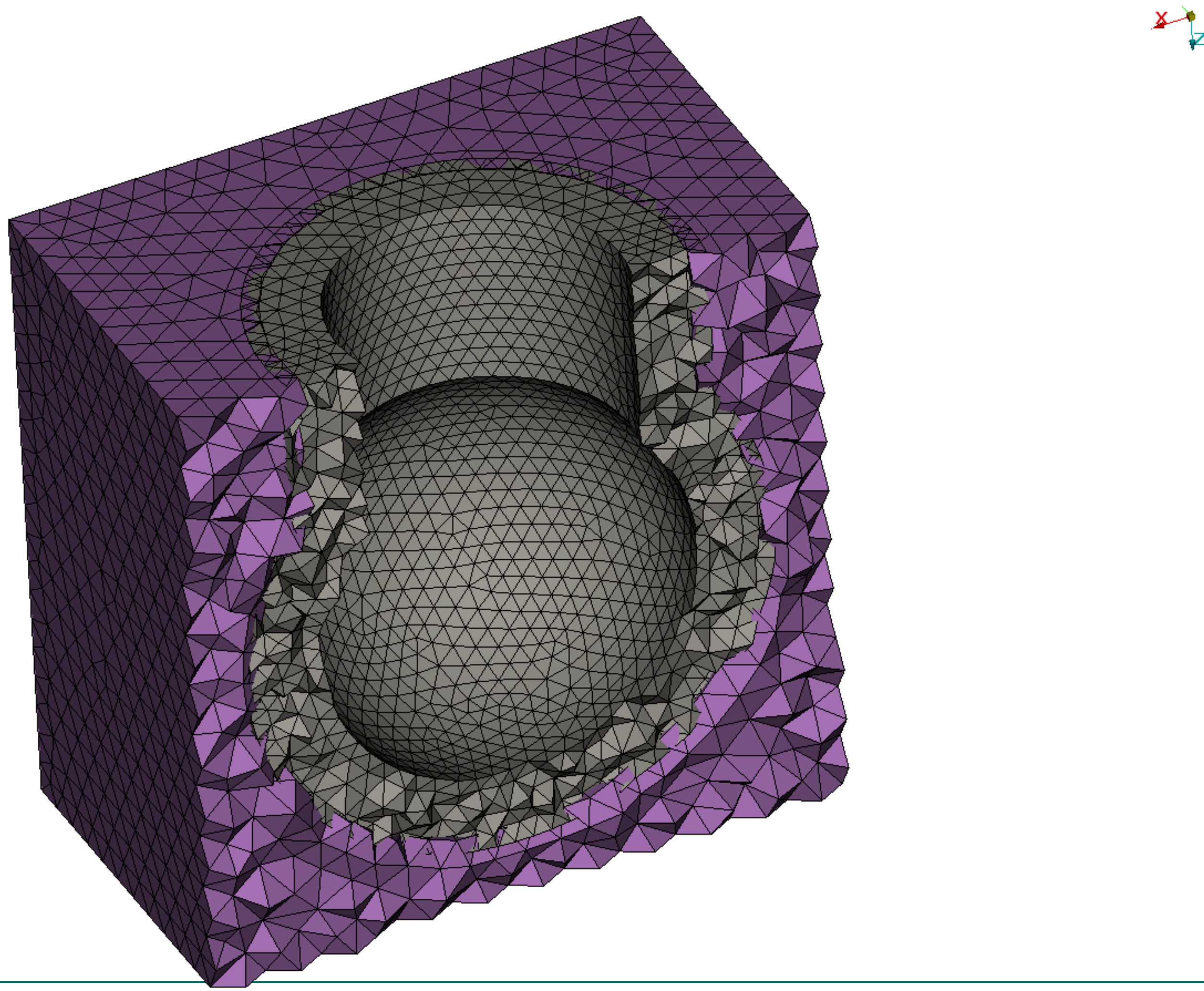
# Contacts – Press-fit

- Mortar example for large penetration (*IGNORE* = 4) press-fit



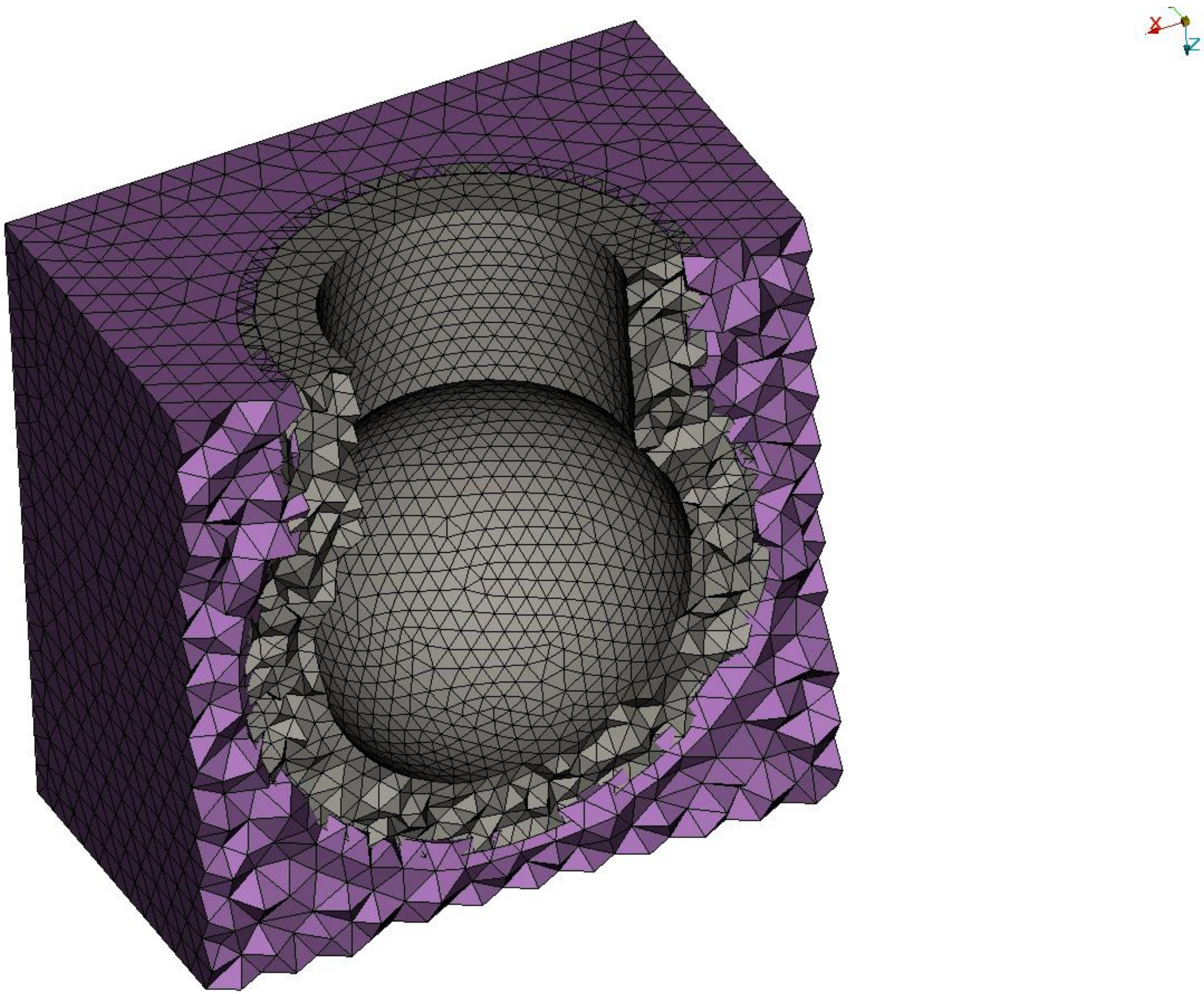
# Contacts – Press-fit

- Mortar example for large penetration (*IGNORE* = 4) press-fit



# Contacts – Press-fit

- Mortar example for large penetration (*IGNORE* = 4) press-fit



# Press fit in contacts

- In some cases for press-fit (often finite penetrations, *IGNORE* = 4) analyses using the Mortar contact may run into (convergence) problems.
- An option to try out is then

```
*CONTACT_SURFACE_TO_SURFACE_INTERFERENCE_ID
$#     cid                                                                 title
      1014Bellow - locking ring
$#    ssid      msid     sstyp     mstyp    sboxid    mboxid       spr       mpr
       101       104         3         3
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
       0.6
$#     sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf

$#   lcid1     lcid2
         0      1014
$#    soft    sofscl    lcidab    maxpar     sbopt     depth     bsort    frcfrq

$#  penmax    thkopt    shlthk     snlog      isym     i2d3d    sldthk    sldstf
       1.0         1         2
$#    igap    ignodprfac/mpadtstif/mpar2    unused    unused    flangl    cid_rcf
         2
```

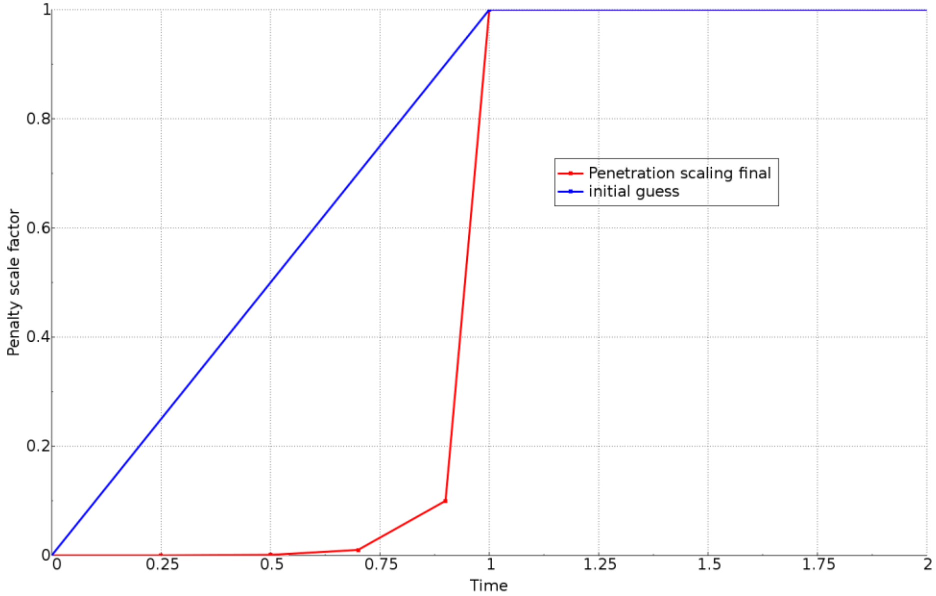
Curve for scaling penalty stiffness.
Start at (0., 0.) end at (t, 1.)

Activate shell thickness

Set *IGAP* = 2 to disable “sticky” contact

# Press fit in contacts

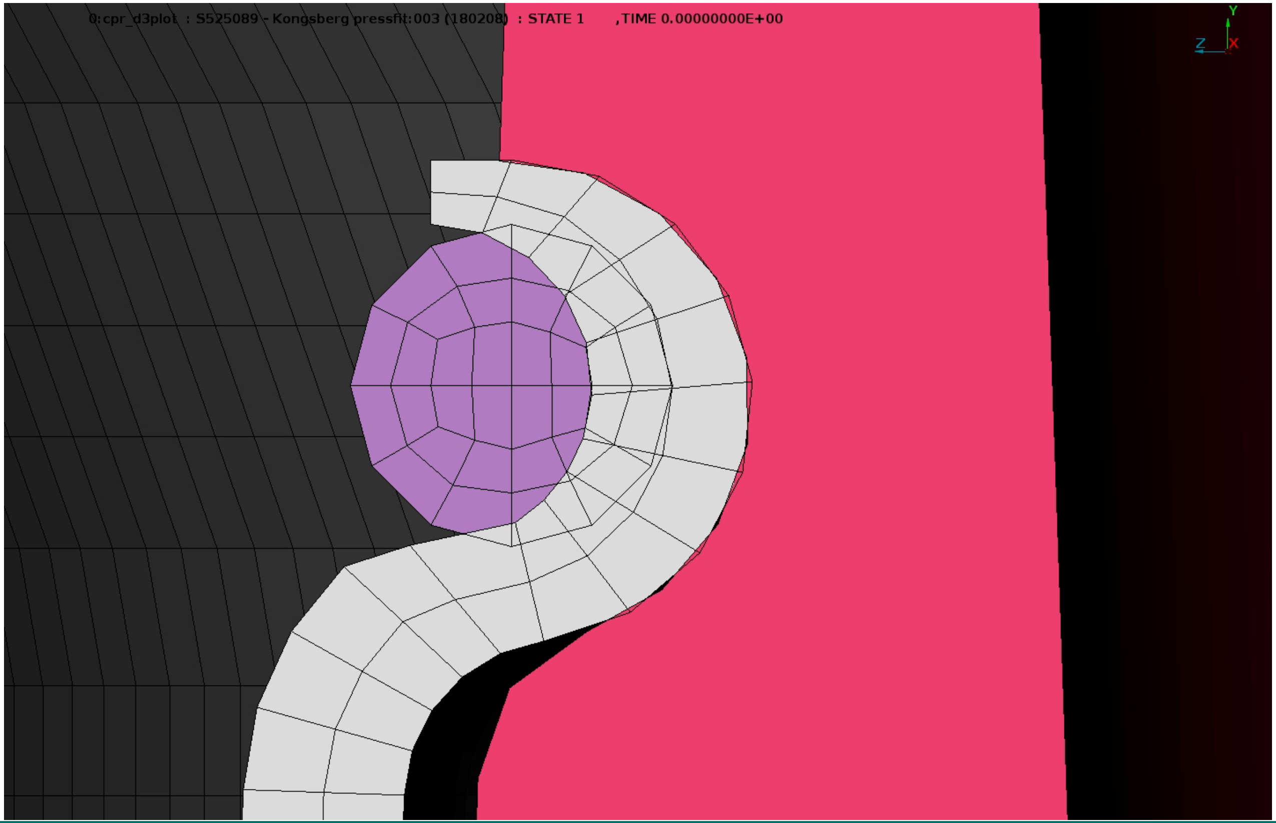
- `*CONTACT_SURFACE_TO_SURFACE_INTERFERENCE_ID`
- A curve - starting at (0., 0.) - is given for scaling the penalty stiffness up to 1.
  - May need some iterations to find the "right" curve. Start with linear ramp




- Set *IGAP* = 2 to disable "sticky" contact
- Activate shell thickness by *THKOPT* = 1, *SHLTHK* = 2
- Check orientation of shells in contact

# Contacts – Press-fit

- In some cases for press-fit (often finite penetrations, IGNORE = 4) analyses using the Mortar contact may run into (convergence) problems.
- An option to try out is then
  `*CONTACT_SURFACE_TO_SURFACE_INTERFERENCE_ID`



# Press fit in contacts

- `*CONTACT_AUTOMATIC_..._SURFACE_MORTAR_ID`
  - Developed for implicit
  - No “sticky” option, it is always off
  - Contact surface is “moved” away until no initial penetrations exist, then “moved” back to the original position
  - Cannot be used with Dynamic Relaxation (in current versions)

- `*CONTACT_.._INTERFERENCE_ID`
  - Developed for explicit
  - Separate option to resolve interference in Dynamic Relaxation
  - “Sees” all penetrations. Contact stiffness is ramped up to resolve them.
  - This contact has the “sticky” option on by default. Set *IGAP* = 2 to disable.

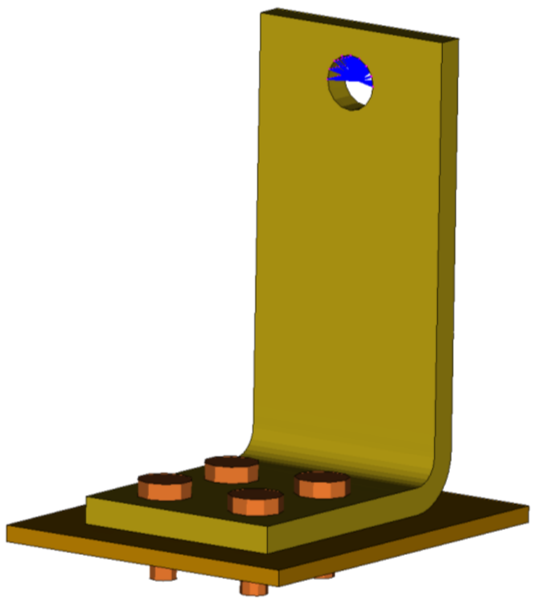
# STRESS INITIALIZATION

# Stress initialization

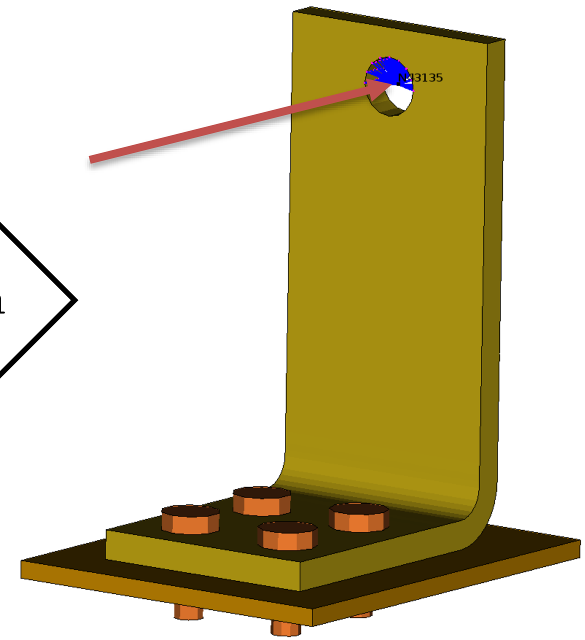
- The classical application of implicit: Springback after forming
- Use `*INTERFACE_SPRINGBACK_LSDYNA` to request `dynain` file
  - ASCII keyword format or LSDA Binary format
- LS-DYNA will output the deformed geometry and residual stresses. Keywords: `*NODE`, `*ELEMENT_...`, `*INITIAL_STRESS_...`
  - Note: Hyperelastic materials, like rubbers (`MAT_77`, `MAT_181` …) and foams, are initialized by `*INITIAL_FOAM_REFERENCE_GEOMETRY`
- May be useful for multi-step simulations, assembly in several steps
- May require re-pretension of bolts to obtain correct pre-tension, due to loss of information regarding contact status
- From R11.2, a binary format including contact state for Mortar contacts is available
  - Re-pretension should not be required
  - Should account for hyperelastic materials
  - Binary format under development, may be missing features

# Stress initialization example

- Bolt pre-tensioning followed by loading



dynain.lsda

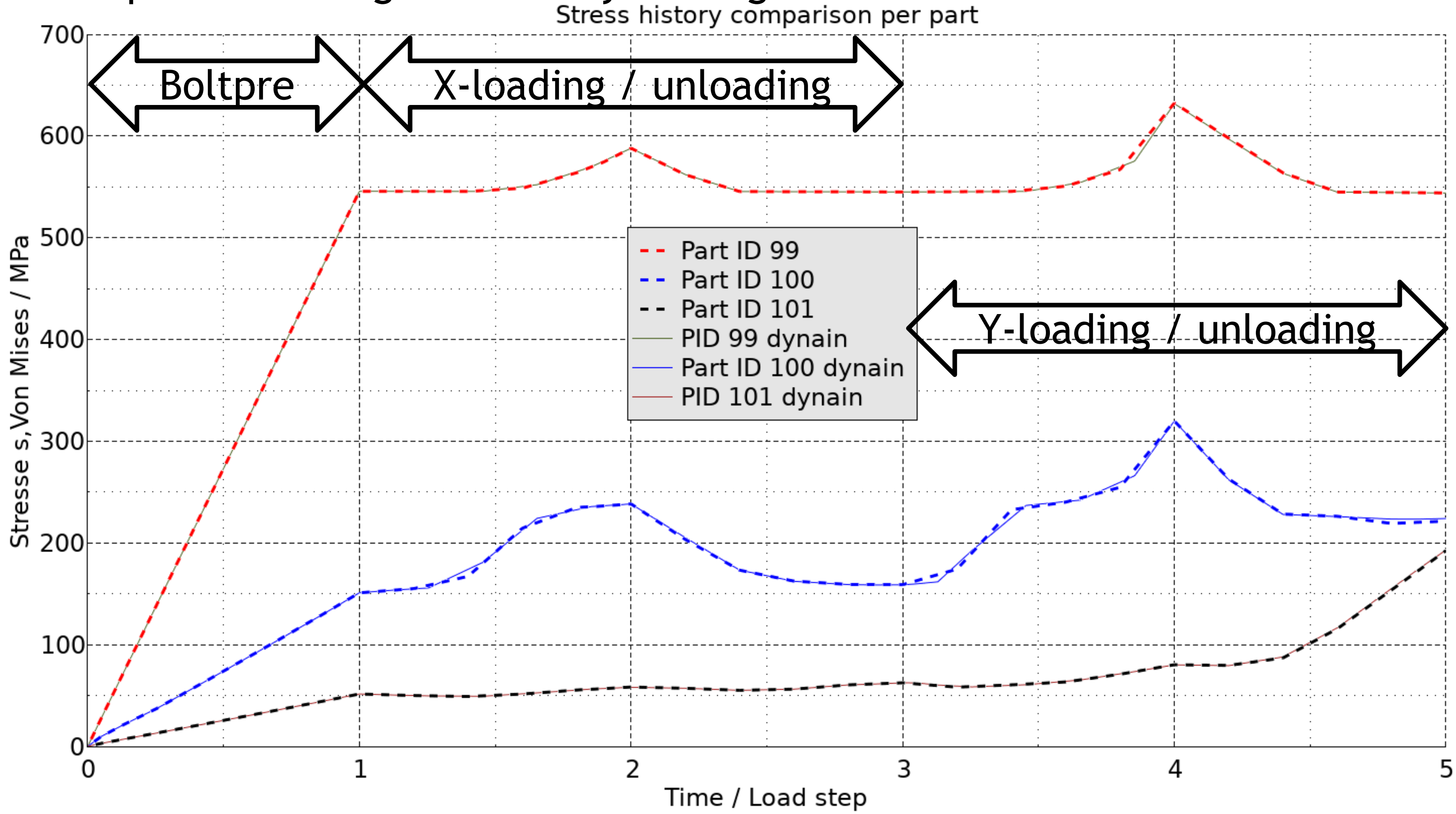


Step 1: Bolt pre-tension
*INITIAL_STRESS_SECTION
*INTERFACE_SPRINGBACK_LSDYNA

Step 2, 3: Loadings
*INCLUDE
dynain.lsda
*LOAD_NODE_SET

# Stress initialization example

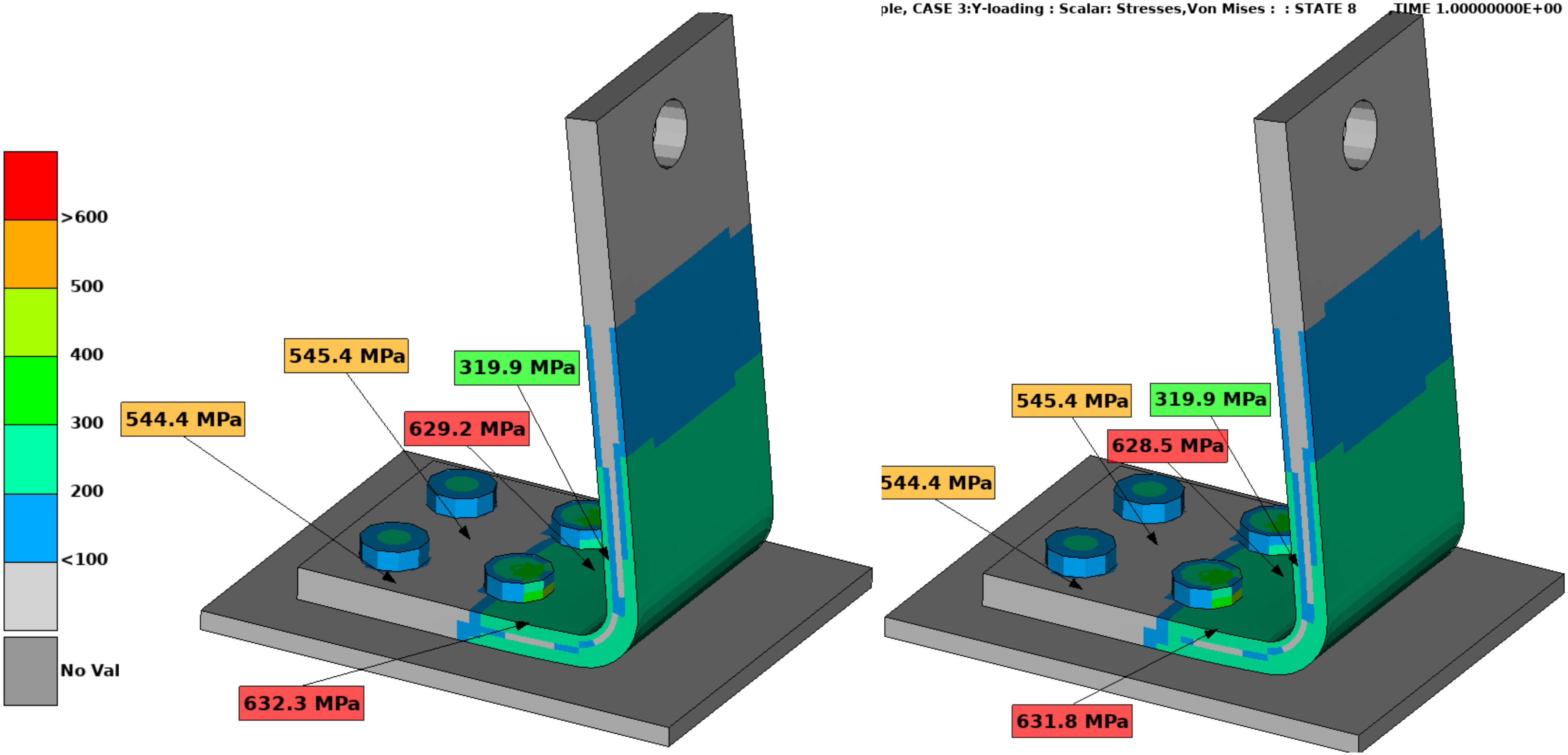
- Bolt pre-tensioning followed by loading




Stress history comparison: dynain.lsda w. solid lines, all-in-one with dashed

# Stress initialization example

- Stress at peak Y-loading




Peak stress all-in-one

Peak stresses using dynain.lsda

# Summary

- Main keywords in LS-DYNA for bolts pre-tensioning
  - `*INITIAL_AXIAL_FORCE_BEAM` for pre-tension of beam-style bolts. Applies a ***force***. Requires a spotweld beam (elform 9) with `*MAT_SPOTWELD`. To obtain an elastic beam bolt, specify a high yield stress.
    - From R12, also beam elform 1 works.
  - `*INITIAL_STRESS_SECTON` for solid element bolts. Applies a ***stress***. Works for the solid element formulations ±1, ±2
- For press-fit in contacts, use `MORTAR` contact with *`IGNORE`* = 3 ("small" penetrations) or 4 ("finite penetrations")
  - `*CONTACT_...INTERFERENCE` may be an option in some cases for "finite" penetrations
- Stress initialization can be used in a stepwise simulation process, using `dynain` - files (`*INTERFACE_SPRINGABACK_LSDYNA`)

**Thank you!**

Your LS-DYNA distributor and more