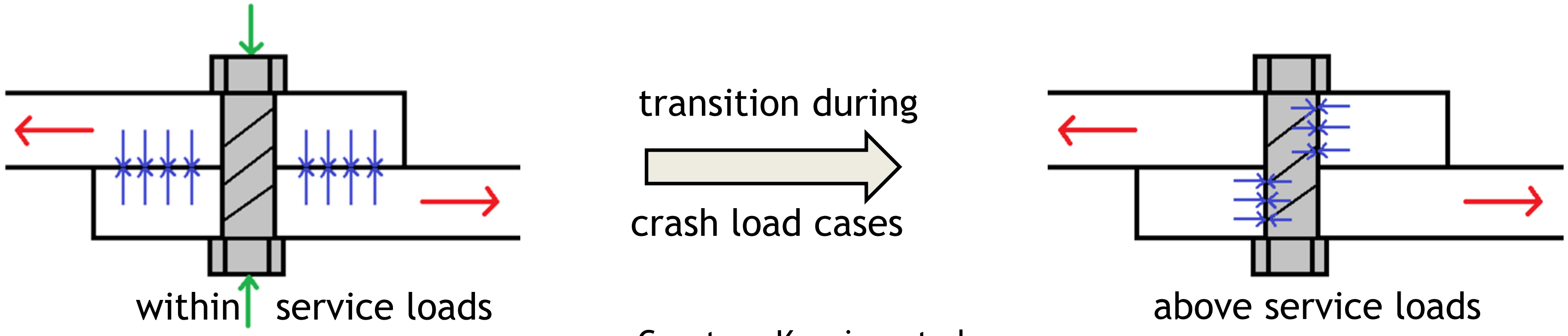
Bolt pre-tensioning in LS-DYNA

Jimmy Forsberg

Physical system – Bolted connections

- Shear load transfer using friction between clamped surfaces
  - Bolt is pre-tensioned, typically 70-90% of yield strength
  - Controlled through moment to tighten bolt
  - Overloads will subject to bolt to shear loads
- Washer may be used to distribute the contact pressure over larger area
- Failure in connection
  - Bolt shank
    - Shear overload
    - (Tension)
  - Connected sheets/parts
    - Pull-out



Courtesy Karajan et al.

Modelling techniques in LS-DYNA - Rigid

- Rigid connection
  - CNRB of complete connection. Mass element for added bolt mass.

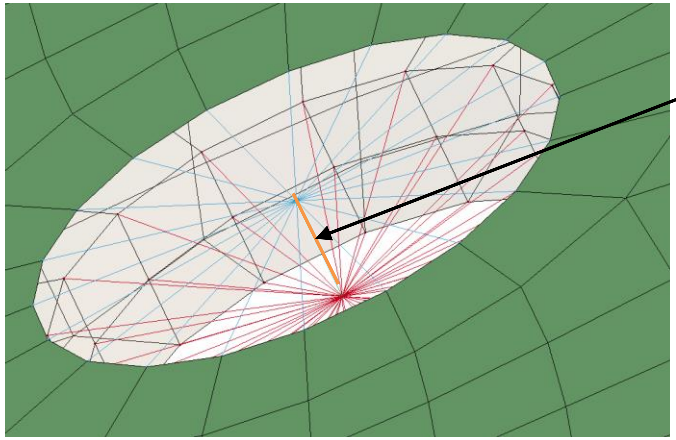
  - + Simple connection
  - + Rigid connection to sheet → No vibrations through loose fitting and contact

  - - Frictional functionality of bolted connection not captured
  - - Overly stiff
  - - Chock-wave distortion due to the nature of rigids (infinite speed of sound)

  - No contact requirements. Sheets in normal single surface contact algorithm.

Modelling techniques in LS-DYNA – Beam shank

- Deformable shank – 1D element
  - CNRB/rigid patch for head and nut.
  - Beam element for shank of bolt.



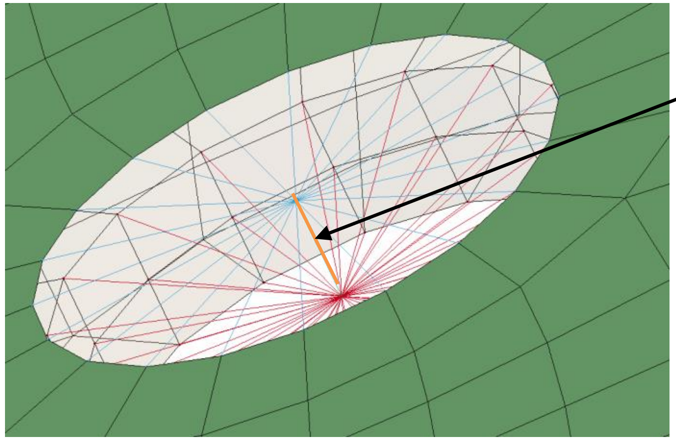
Beam connected to shell and solid modelled sheet with CNRB

  - - Overly stiff head and nut.
  - - Chock-wave distortion due to the nature of rigids (infinite speed of sound)
  - - Extra contact definition needed depending on connection (three+ layers)
  - - Extra nullbeams along intermediate sheets edges needed (both shell and solid modelled sheets)

  - + Non-linear material models are available hence more physical
  - + Rigid connection to sheets → No vibration through loose fitting and contact
  - + Interface frictional behavior captured with pre-tensioning of bolt

Modelling techniques in LS-DYNA – Beam shank

- Deformable shank – 1D element
  - 1 single surface contact for sheet parts
  - Possibly: Extra contact to capture edge contact between intermediate (third sheet) hole edge.
    - Coat edges of third sheet with null beams and use: *CONTACT_AUTOMATIC_GENERAL to capture contact between null beams and bolt.
      - CPARM8 to exclude beam contact within same part.



Beam connected to shell and solid modelled sheet with CNRB

Modelling techniques in LS-DYNA – Solid meshed shank

- Deformable shank – 1D element
  - CNRB/rigid patch for head and nut.
  - Solid elements for shank of bolt.

  - - Overly stiff head and nut.
  - - Chock-wave distortion due to the nature of rigids (infinite speed of sound)
  - Depending on global contact, if soft=1:
    - - Extra contact definition needed depending on connection (three+ layers)
    - - Extra nullbeams along intermediate sheets edges needed

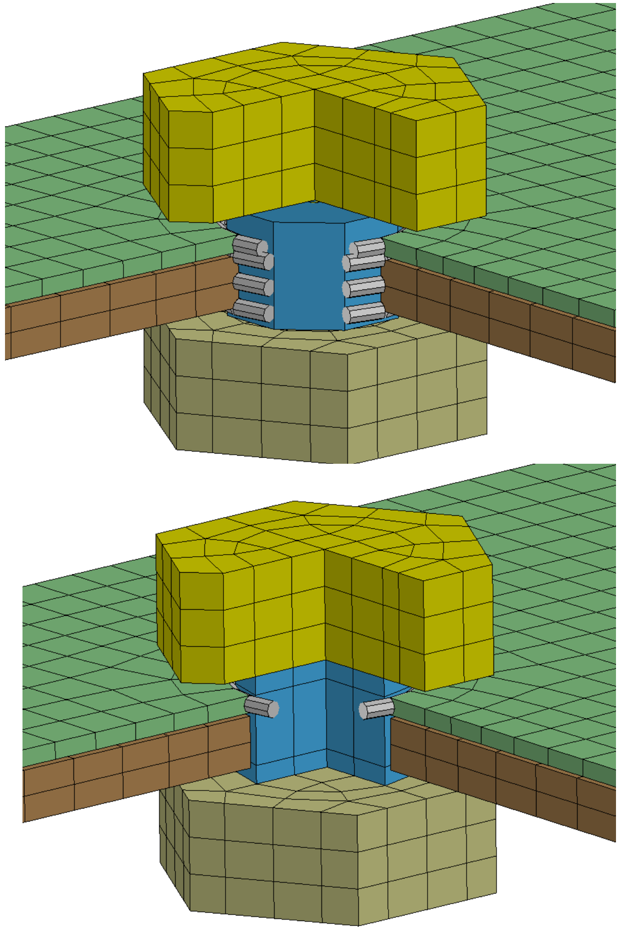
  - + Non-linear material models are available hence more physical
  - + Rigid connection to sheets → No vibration through loose fitting and contact
  - + Interface frictional behavior captured with pre-tensioning of bolt

Modelling techniques in LS-DYNA – Head/Nut

- Contact between head/nut and sheets
  - Head/nut modelled using shell/solid elements
  - Head/nut rigid or deformable
  - Shank modelled using beam or solid element.

  - Head/nut into global contact single surface
  - Shank modelled using beams
    - Extra contact according to shank modelled beam
  - Shank modelled using solid elements
    - Extra contact if using soft=1 for global contact
    - No extra contact needed if using soft=2 and edge contact turned on

  - PRE-STRESS connection!!!



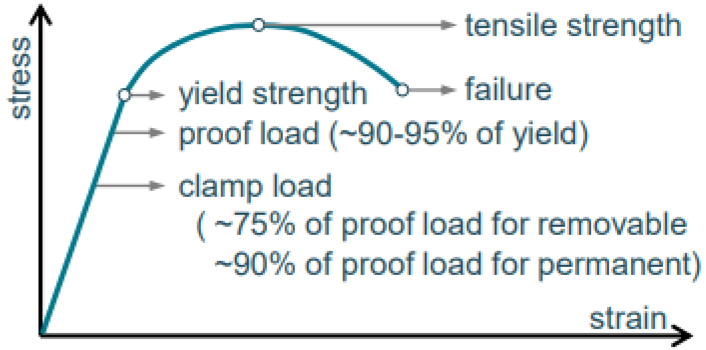
Courtesy Karajan et al.

Pre-tension of bolts – Why?

- More realistic simulation model!
- Reduce the noise in results
  - Bolts vibrating
- Increase robustness of simulation model
  - Contact pairs are initiated
  - Energy dissipation through sliding

Pre-tensioning of bolts

- Typical elasto-plastic material
  - The pre-tension defined as %-age if yield strength
  - Transfer loads by friction of the clamped surface
  - Overload of connection → bolt carries more load



- Pre-tensioning possibilities in LS-DYNA
  - Thermal material
  - Initial axial force beam (beam elform=9)
  - Initial stress section
  - Pre-simulation (Dynain file)
  - Parameter on element card (old element discrete)
  - Material law possibilities

  - Ref. N Karajan, A Gromer, M Schenke, T Borrvall, K Pydimarry: ‘Modelling bolts in LS-DYNA using explicit and implicit time integration’, 15th German LS-DYNA Forum, Bamberg Germany, 2018
- Solid elements, Initial stress section!

Basic parameters model – solid elements for bolt

- *SECTION
  - Underintegrated solid – elform=1, only hex-element
- *HOURGLASS
  - Formulation 6, QM=0.1
- *CONTACT_AUTOMATIC_SINGLE_SURFACE – Global contact

Card 1	SSID (X)	MSID (0)	SSTYP (2)	MSTYP (0)	SBOXID (0)	MBOXID (0)	SPR (0)	MPR (0)
Card 2	FS (0.3)	FD (0.3)	DC (0)	VC (0)	VDC (30)	PENCHK (0)	BT (0)	DT (0)
Card 3	SFS (1.0)	MFS (1.0)	SST (0)	MST (0)	SFST (0)	SFMT (0)	FSF (0)	VSF (0)
Opt. A	SOFT (2)	SOFSCL (0)	LCIDAB (0)	MAXPAR (0)	SBOPT (3)	DEPTH (35)	BSORT (0)	FRCFRQ (0)
Opt. B	PENMAX (0)	THKOPT (0)	SHLTHK (0)	SNLOG (0)	ISYM (0)	I2D3D (0)	SLDTHK (0)	SLDSTF (0)
Opt. C	IGAP (0)	IGNORE (2)	DPRFAC (0)	DTSTIF (Y)			FLANGL (0)	CID_RCF (0)
Opt. D	Q2TRI (0)	DTPCHK (0)	SFNBR (-1)	FNLSCL (0)	DNLSCL (0)	TCSO (0)	TIEDID (0)	SHLEDG (1)
Opt. E	SHAREC (0)	CPARM8 (0)	IPBACK (0)	SRNDE (0)	FRICSF (0)	ICOR (0)	FTORQ (0)	REGION (0)
Opt. F	PSTIFF (-1)	IGNROFF (0)		FSTOL (0)	2DBINR (0)	SSFTYP (0)		

Basic input pre-stressing

- *INITIAL_STRESS_SECTION

Control stress initiation methodology

	1	2	3	4	5	6	7	8
Card 1	ISSID	CSID	LCID	PSID	VID	IZSHEAR	ISTIFF	

  - Elements selected by being in partset and touched by the cross-section

- *DATABASE_CROSS_SECTION_PLANE_ID

	1	2	3	4	5	6	7	8
ID	CSID	HEADING						
Card 1	PSID	XCT	YXT	ZCT	XCH	YCH	ZCH	RADIUS
Card 2	XHEV	YHEV	ZHEV	LENL	LENM	ID	ITYPE	

Recommended

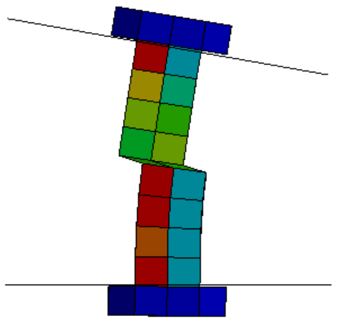
- *DATABASE_CROSS_SECTION_SET_ID

	1	2	3	4	5	6	7	8
ID	CSID	HEADING						
Card 1	NSID	HSID	BSID	SSID	TSID	DSID	ID	ITYPE

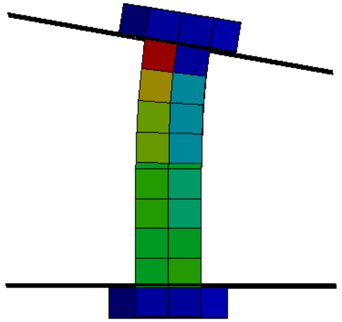
Prestress of solid meshed bolts - history

- Progress in LS-DYNA
  - IZSHEAR=0
    Prescribe the normal stress, other terms=0
  - IZSHEAR=1
    Prescribe normal stress in element, other terms from material response
  - IZSHEAR=2
    Prescribe average normal stress in section, other terms from material respnse
- Still only applied on one element row along shank

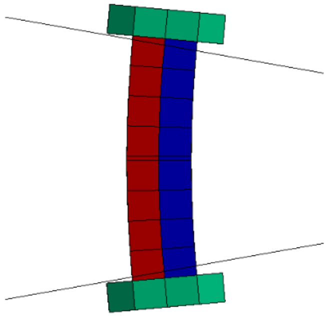
IZSHEAR=0



IZSHEAR=1

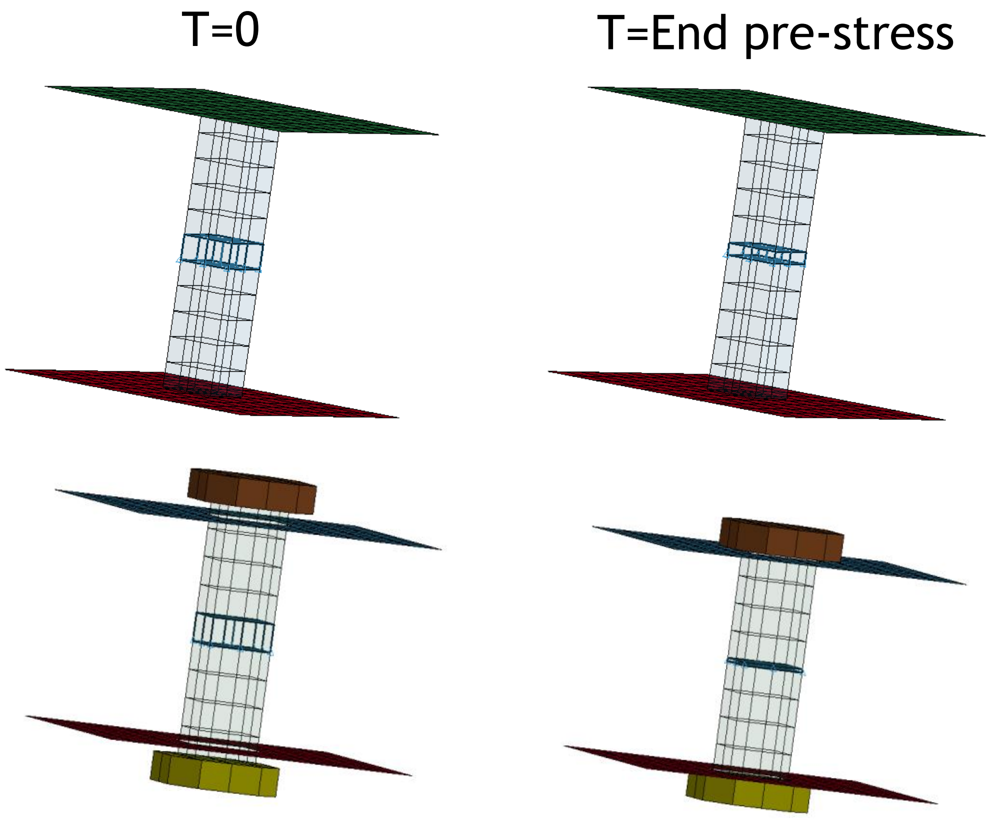


IZSHEAR=2



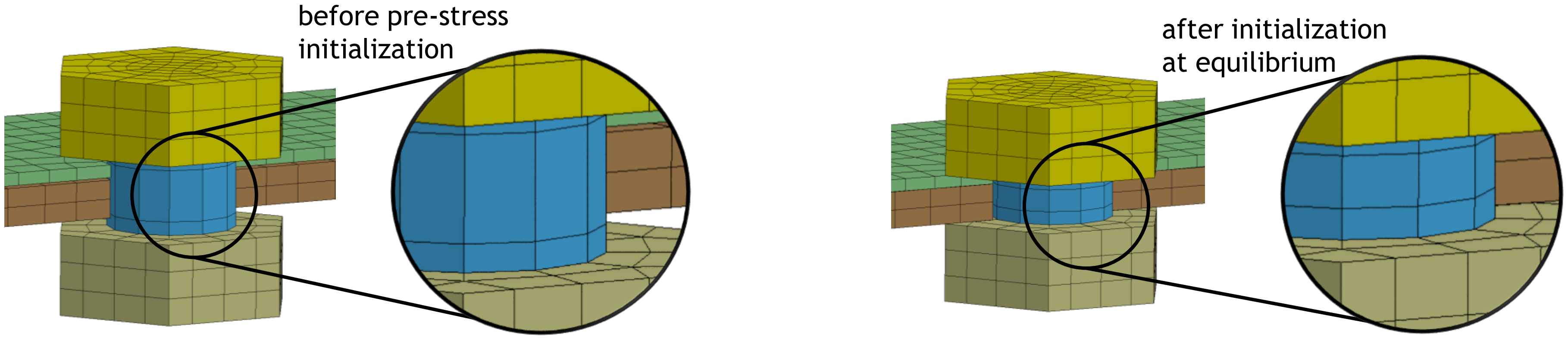
Problems with one row of elements

- One element row will be distorted in order to induce requested stress state. Problems occur if:
  - High stress state wanted
  - Plastic deformation of bolt shanks
  - Small element sizes
  - Gaps in model



One row of element work-around for pre-tension

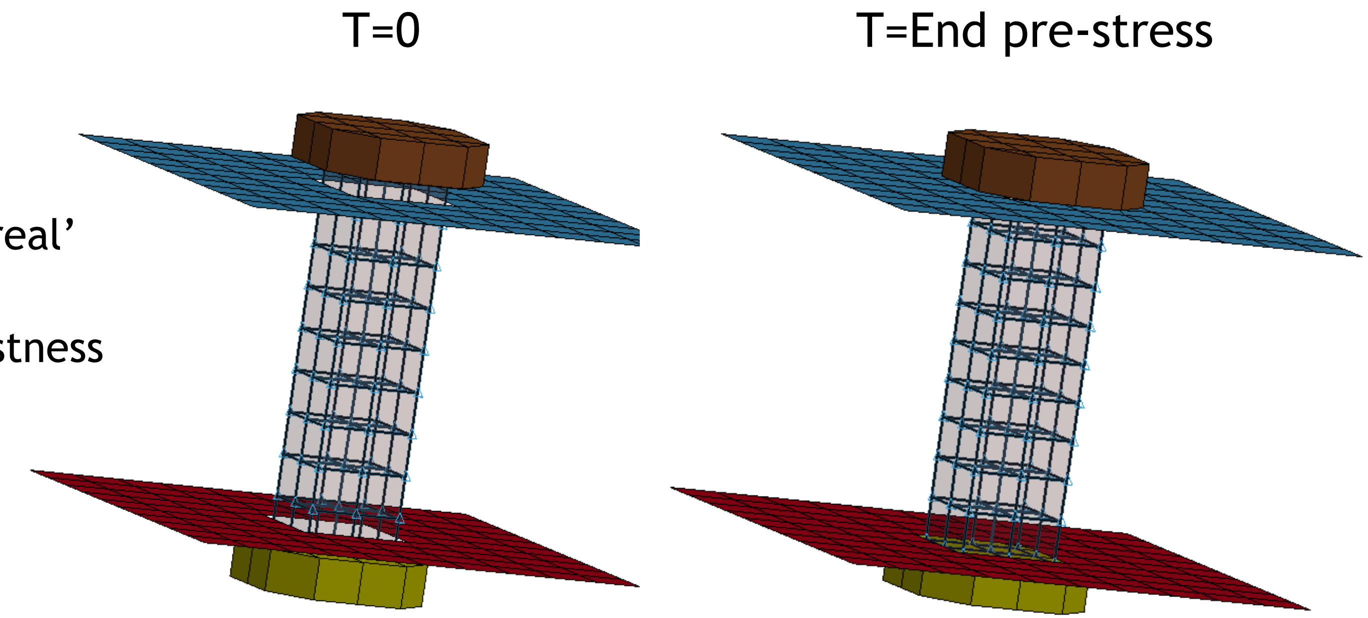
- Manually account for pre-tension distortion:
  Make the layer of elements ‘longer’
  - Need to know of much distortion there will be in advance...



Courtesy Karajan et al.

Distribute the deformation along the shank - manually

- Double defined elements
  - DATABASE_CROSS_SECTION_SET
  - Small stiffness to extra elements
    - How large stiffness?
      - Too large → affects stress level in 'real' elements.
      - Too small → affects numerical robustness
    - Treatment of failed elements?



Basic input pre-stressing

- *INITIAL_STRESS_SECTION

New parameter

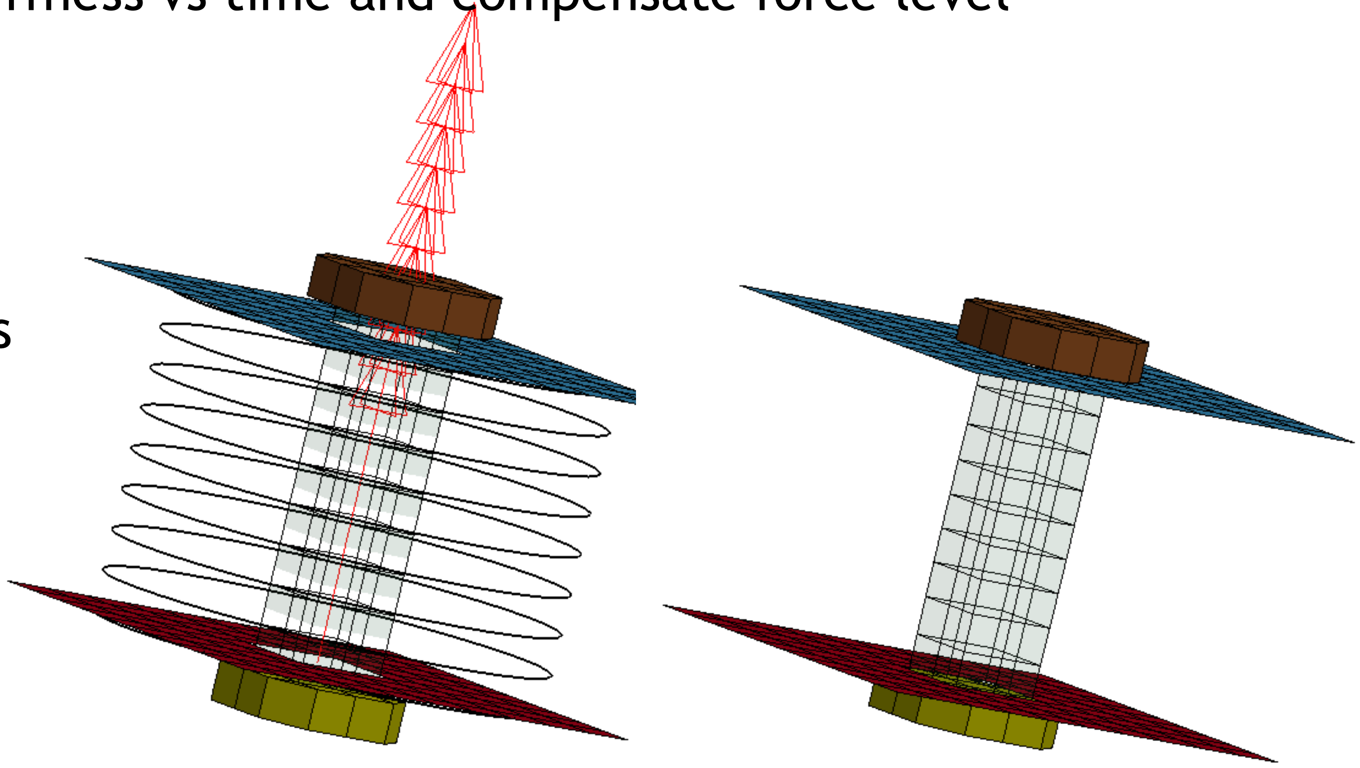
	1	2	3	4	5	6	7	8
Card 1	ISSID	CSID	LCID	PSID	VID	IZSHEAR	ISTIFF	

  - Elements selected by being in partset and touched by the cross-section
- ISTIFF
  - Positive – LCID for stiffness fraction as function of time
  - Negative – |LCID|for stiffness fraction as function of time – with correction

Current ISTIFF implementation in LS-DYNA

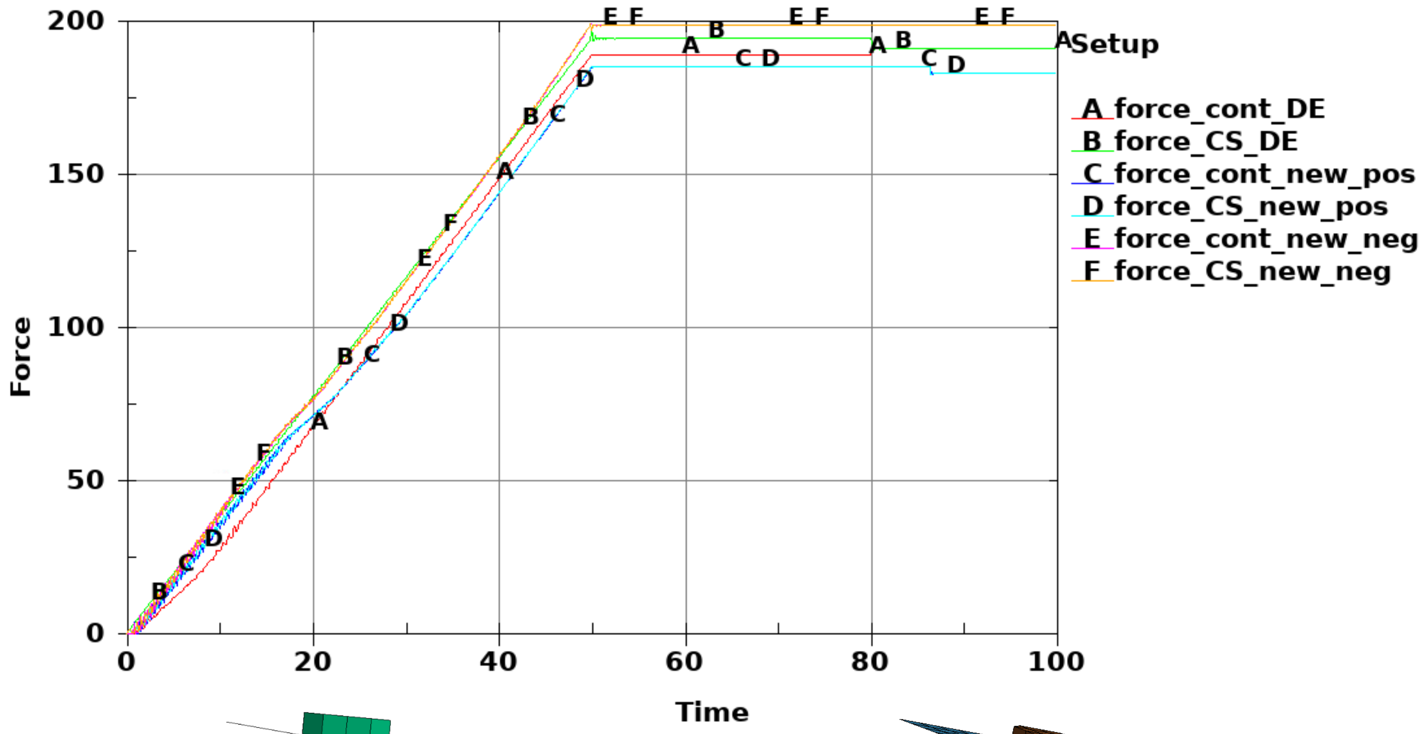
- INITIAL_STRESS_SECTION
  - ISTIFF>0 → LCID for ghost element stiffness vs time
  - ISTIFF<0 → LCID for ghost element stiffness vs time and compensate force level

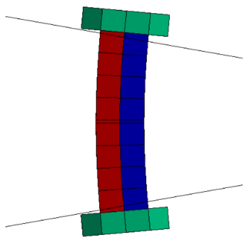
- DATABASE_CROSS_SECTION_PLANE
  - One for each prescribed element row
  - Works for 1-point integrated elements

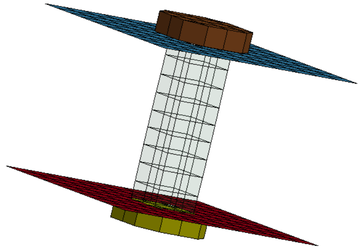


Force levels obtained for different options of ISTIFF

- Force should be ~200
  - DE→ Double elements manually
  - Cont → measure force in contact
  - CS → measure force in cross-section
  - A/B curves shows jump when double elements are deleted.
  - C/D curves with ISTIFF>0 shows too low achieved force level
  - E/F curves with ISTIFF<0 shows great results







Future investigations for ISTIFF options

- Industrial environment
- Appearance of stiffness curve for ISTIFF
  - Time frame?
  - How to apply pre-stress?
- Eroding elements?
- Poisson’s ratio effects?

- User friendliness of implementation to be improved.
- Available in R12 – needs to be tested by user applications.

Thank you!

Your LS-DYNA distributor and more