Beam Elements

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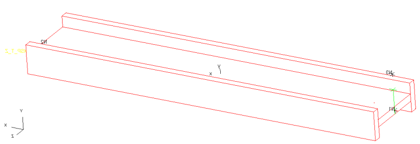
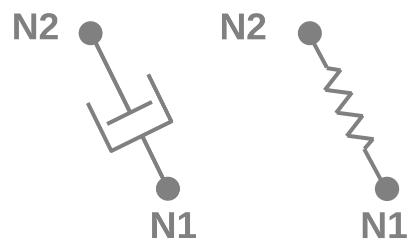
- In LS-DYNA it is useful to consider the various one-dimensional (1D) elements in various categories:

1D elements

- Beam elements
  *ELEMENT_BEAM
  *SECTION_BEAM
  - Structural beams
    ELFORM = 1, 2
  - Discrete beams
    ELFORM = 6
    - Finite-length discrete beams
      SCOOR = ±2, ± 3
    - Zero-length discrete beams
      SCOOR = ±1
- Discrete elements (springs, dampers)
  *ELEMENT_DISCRETE
  *SECTION_DISCRETE

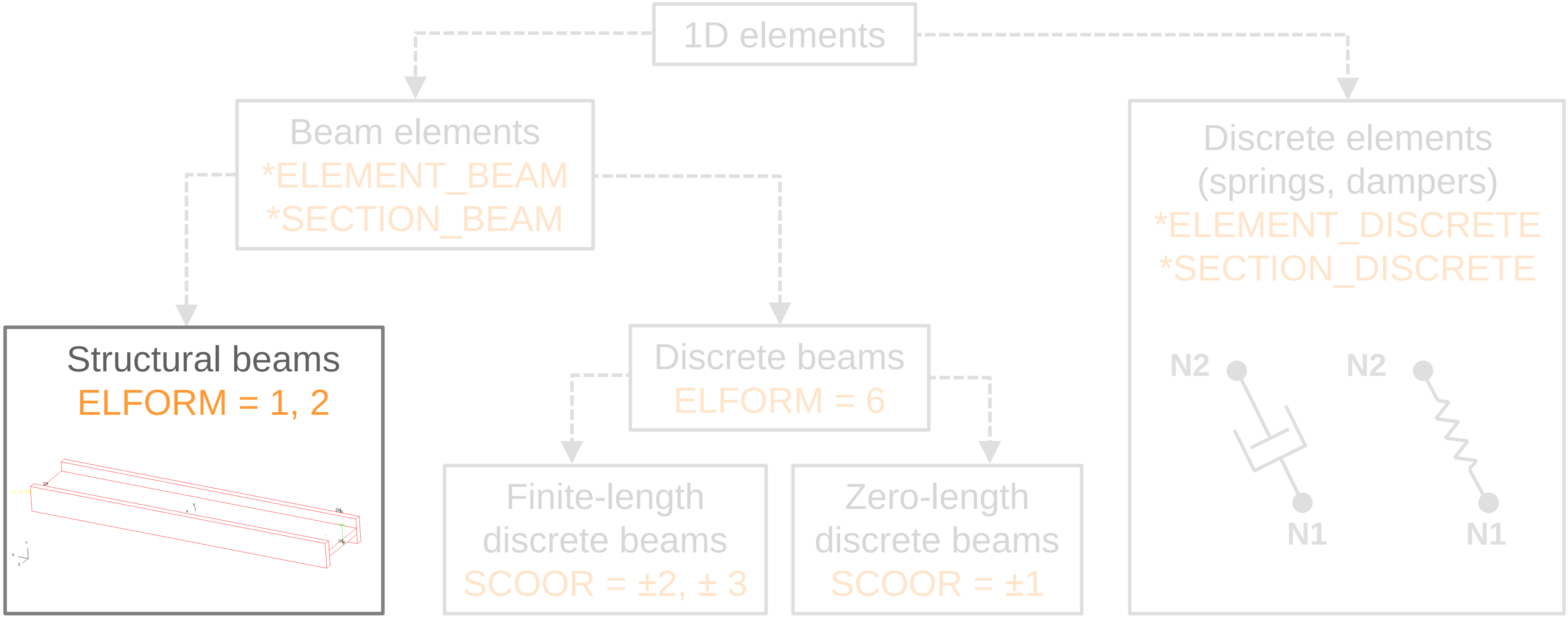




Used for structural components with physical material and section properties

Typically used to ***represent*** *a connection (e.g. a single bolt or an entire connection detail) instead of modelling the components explicitly*

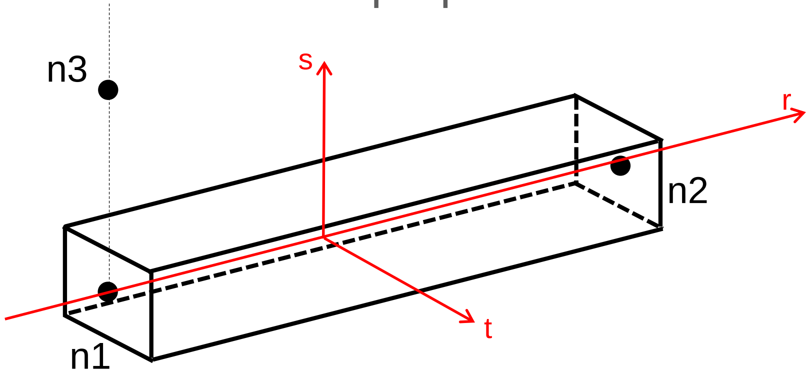
Used to define a simple stiffness and/or damping relationship between two nodes

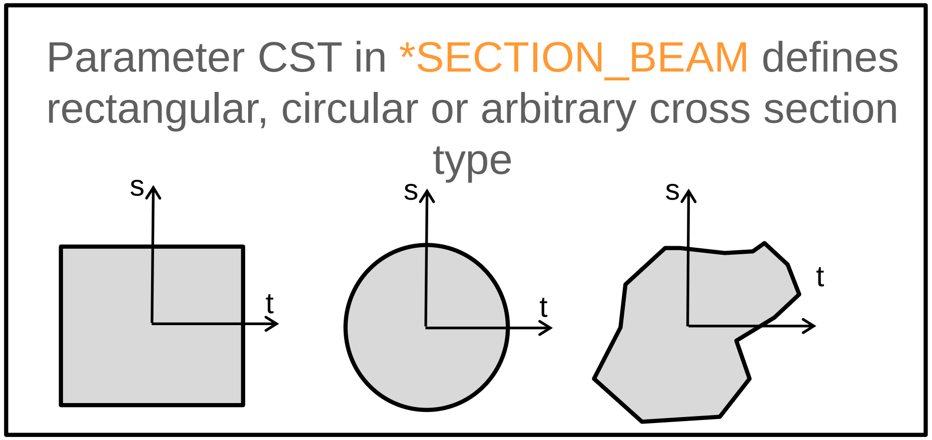


Used for structural components with physical material and section properties

*ELEMENT_BEAM, *SECTION_BEAM, *ELFORM = 1, 2*

- 2 node beam elements, mass is lumped at nodes, 6 DOFs at each node.
- 3rd node used to define orientation of the section
  (see next few slides on *CONTROL_ OUTPUT and NREFUP).
- Solid or tubular circular or rectangular sections can be defined, or user specified cross section properties used.



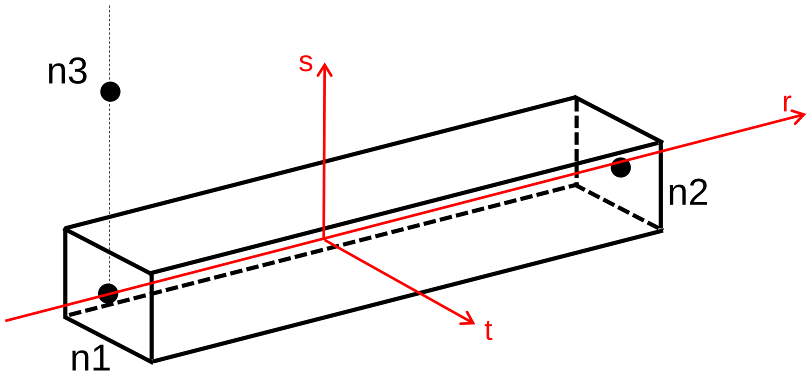


- A multitude of pre-determined section types can also be specified using the STYPE option on *SECTION_BEAM card, or using the OR/IRID option to reference a *INTEGRATION_BEAM card depending on beam element type.

- There are two ways to define beam element orientation:

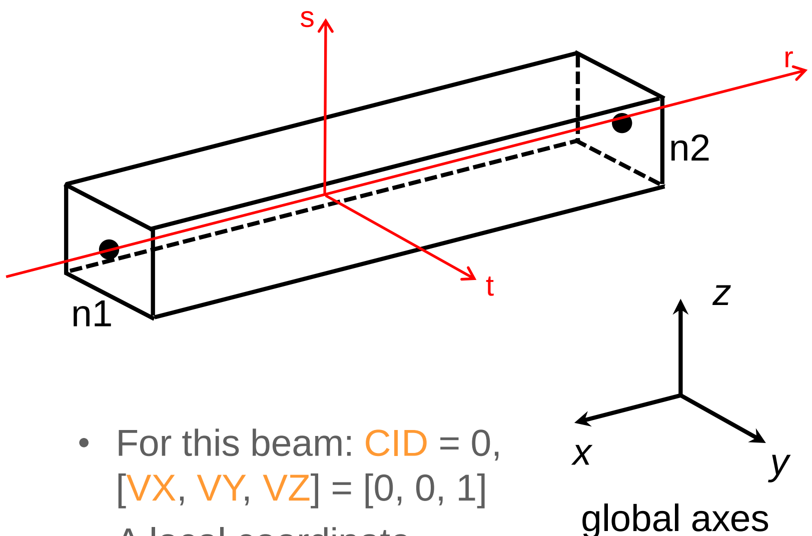
Third node:

N3



Orientation option:

*ELEMENT_BEAM_ORIENTATION

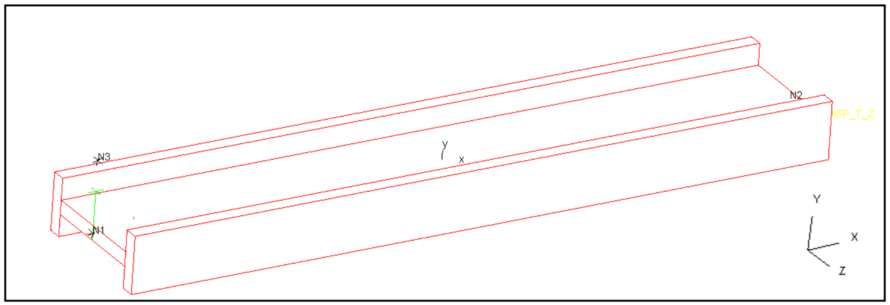


- The orientation option [right] is a convenient way to define the orientation of several similar beams (no need to create lots of third nodes).
- However, the orientation of the beams is only visualised correctly (e.g. in D3PLOT) if the third node is used and if NREFUP = 1 (see next slides).

- For this beam: CID = 0, [VX, VY, VZ] = [0, 0, 1]
- A local coordinate system can also be used when defining orientation.

Beam Elements – Visualisation

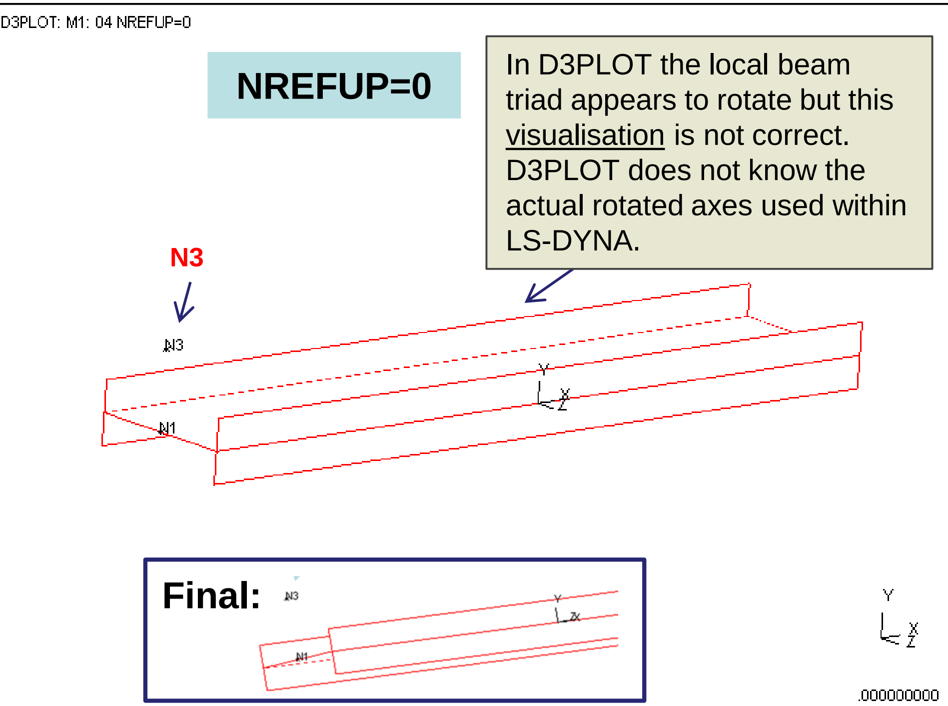
- The slides make the following points:
  - LS-DYNA uses node N3 only once, at initialisation. After that it is ignored.
  - If NREFUP=0, the visualisation of beam rotation is not correct.



Keyword Manual:

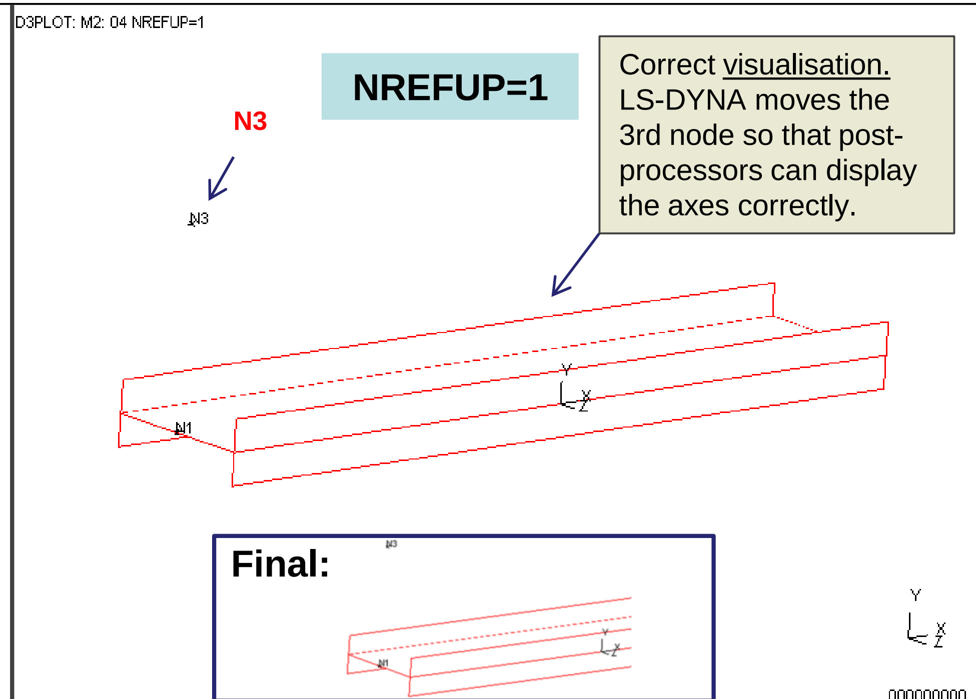
“NREFUP = 0 : Do not update reference node.

NREFUP = 1 : Update reference node. This update is required for proper visualisation of the beam cross-section orientation beyond the initial (t = 0) plot state. NREFUP does not affect the internal updating of the beam cross-section orientation in LS-DYNA.”



NREFUP=0

In D3PLOT the local beam triad appears to rotate but this visualisation is not correct. D3PLOT does not know the actual rotated axes used within LS-DYNA.



NREFUP=1

Correct visualisation. LS-DYNA moves the 3rd node so that post-processors can display the axes correctly.

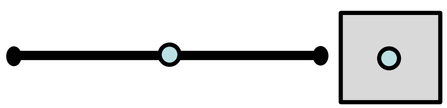
Beam Elements – Type 1

ELFORM = 1 **Hughes-Liu Integration Beam (Type 1 – default):**

- Single integration location along the length of the beam.
- Default 2×2 grid of integration points (**QR/IRID** option *SECTION_BEAM)

QR/IRID=2 (default for integrated beams)
(2×2 Gauss quadrature)

QR/IRID=1
(one integration point)



- **QR/IRID** can also be used to reference the *INTEGRATION_BEAM keyword, where more complicated cross sections profiles can be specified:

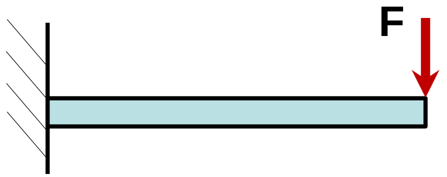
  e.g. I-Section, Channel, T-Section, etc

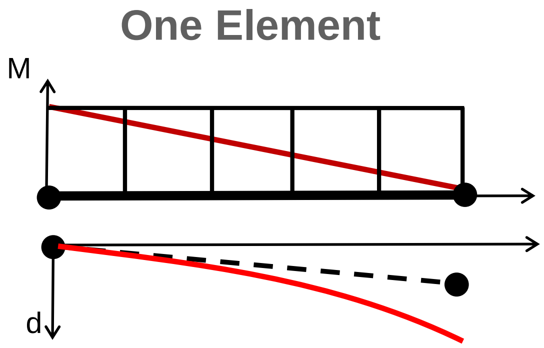
- Should be used where the material behaviour is to be defined in terms of stress/ strain, or if stress/ strain results in the beam are needed

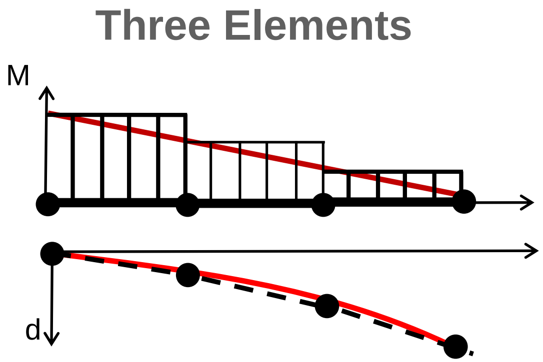
Beam Elements – Type 1

ELFORM = 1 Hughes-Liu Integration Beam (Type 1 – default):

- The bending moment is constant along the length due to single integration point.
- So, in order to model a cantilever, several elements are required along the length for accuracy:

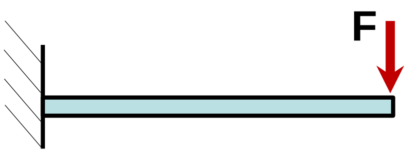


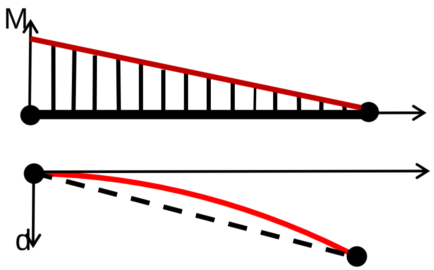




ELFORM = 2 **Belytschko-Schwer Resultant Beam (Type 2):**

- Uses an explicit linear beam formulation. Some material types offer plastic conditions introduced at the ends ($F=\delta AE/L$).
- Area (A) and 2nd Moments of Area (I_{ss}, I_{tt}) are defined on the *SECTION_BEAM card, or the **STYPE** option can be used to specify a particular cross section using a set of dimensions.
- Values are calculated at the nodes.
- The bending moment varies linearly along the length.
- So in order to model a cantilever only one element is required along the length for accuracy (small deflection only). However typically several elements are used to capture the deformed shape along the whole length.

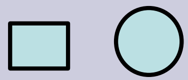
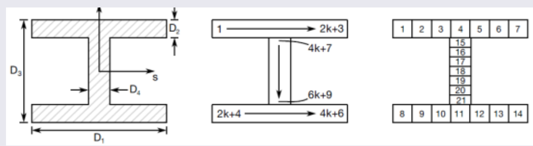
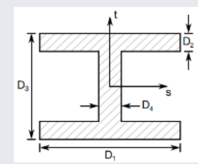
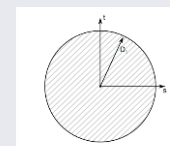




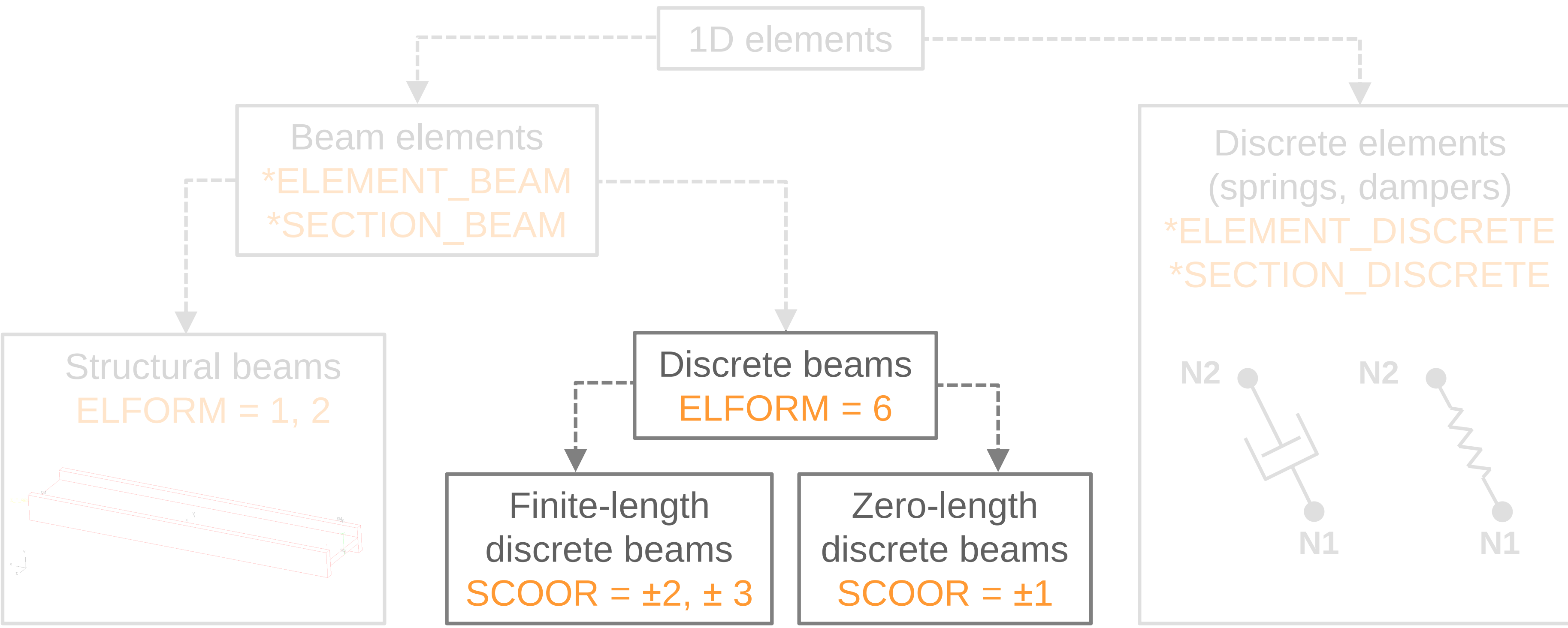
- No stresses are output for this type; useful if only need to transfer loads, or if results are required only in terms of forces and moments.
- This type only works with a limited number of material types, see next slide

Beam Elements – Type 1 and 2

- The table below shows a comparison between beam types 1 and 2:

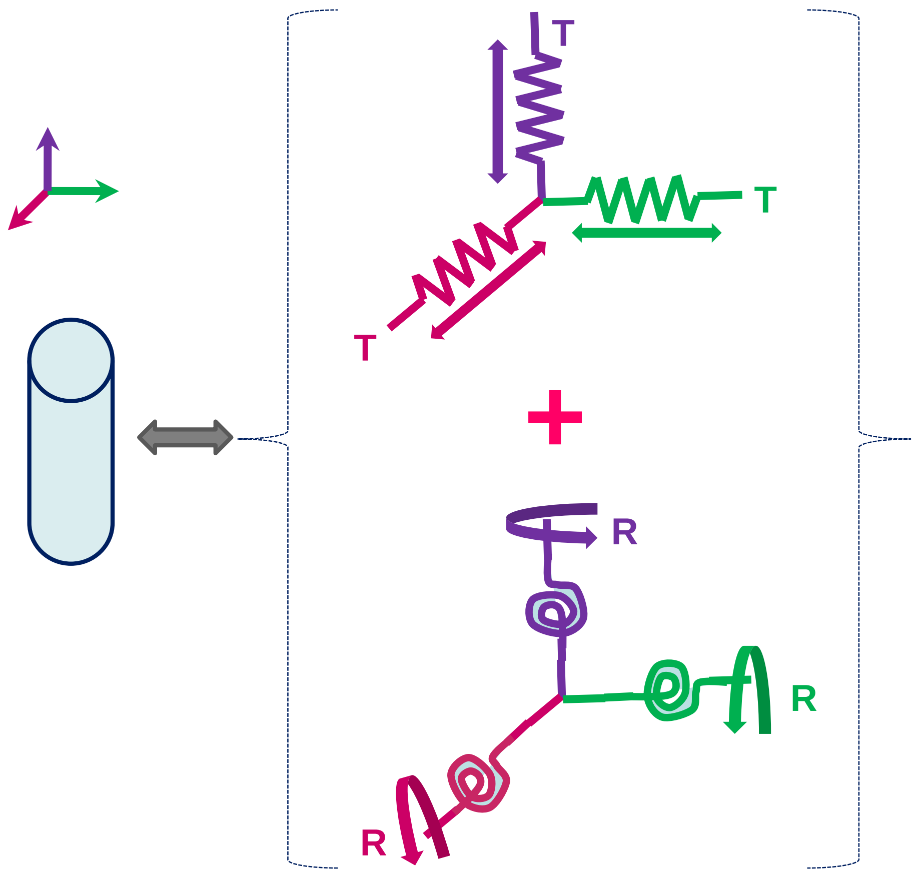
Element Beam Formulation	**Type #1 (Integration beam)**	**Type #2 (Resultant beam)**
Simple cross section shape (rectangular or tubular)	CST =0 or 1 on *SECTION_BEAM 	Doesn’t use CST; by default no need to specify the shape of x-section, only area and moment of inertia needed
Has option for standard cross section:	Via *INTEGRATION_BEAM w/ QI/IRID=-n and CST=2 on *SECTION_BEAM 	Via STYPE on *SECTION_BEAM  
Results location:	At beam integration points – which are located at centre of beam	At beam end nodes
Results:	Forces, Moments, Stresses	Moments, Forces
Materials:	001, 003, 004, 006, 009, 018, 020, 024, 041-50, 098, 124, 153, 172, 174, 195, 202, 238	001, 028, 029, 098, 139, 166, 171, 191
Usage:	Many elements needed per span for accurate results.	Fewer needed – however note that some of the materials above are special for this type and only work with a single element per span.

Discrete Beams

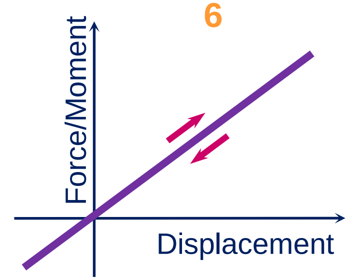


Typically used to ***represent*** *a connection (e.g. a single bolt or an entire connection detail) instead of modelling the components explicitly*

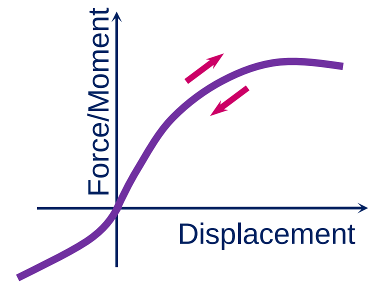
Discrete beams can be used when translational and rotational stiffness information for connections is available, in conjunction with materials 66-67-68-119; it uses 6 linear or nonlinear springs to define stiffness in 6 degrees-of-freedom.



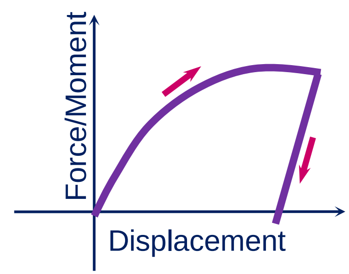
*MAT_06
6



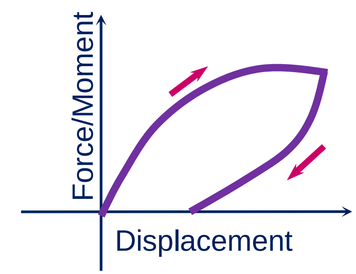
*MAT_067



*MAT_068
with failure



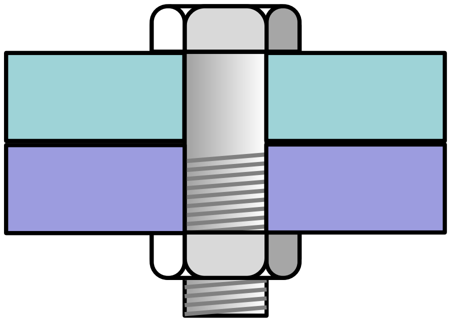
*MAT_119
with unloading



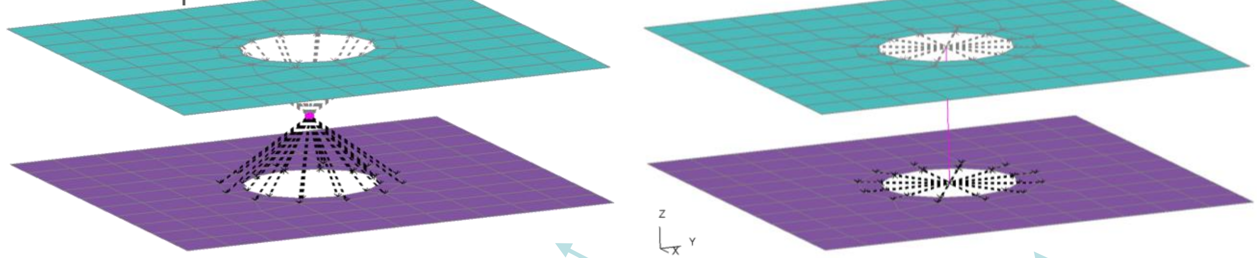
Discrete Beams – applications

- Example applications for discrete beams:

Bolt assembly

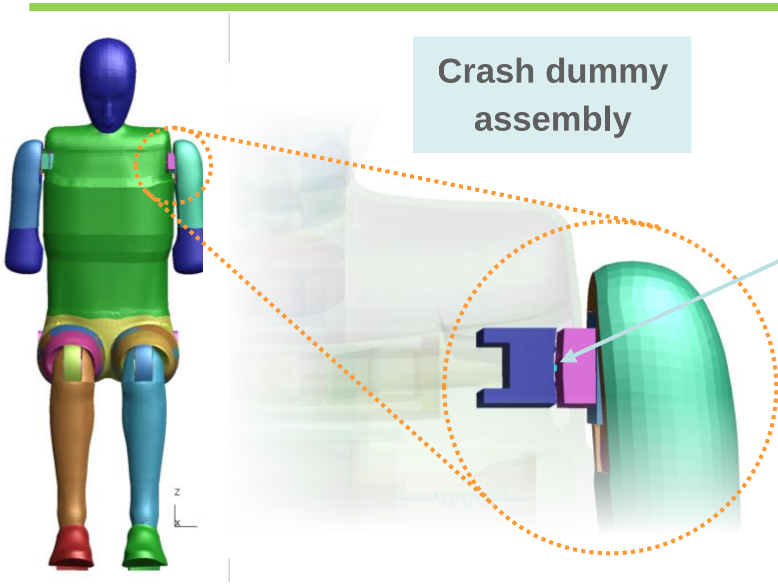


Discrete beam (shown in **magenta**) between two nodal rigid body spiders



Whether a zero-length or finite-length discrete beam is used depends on the desired behaviour (explained in the following slides)

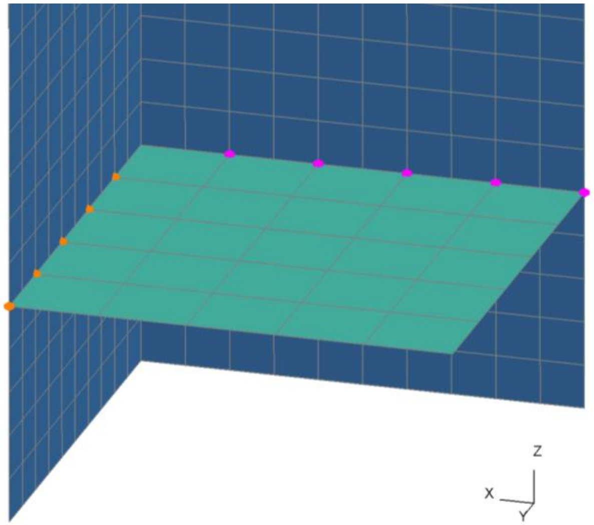
Crash dummy assembly



Discrete beam (shown with **cyan** blob) used to measure forces and moments for injury criteria calculations

Discrete Beams – applications

- Structural engineering applications:

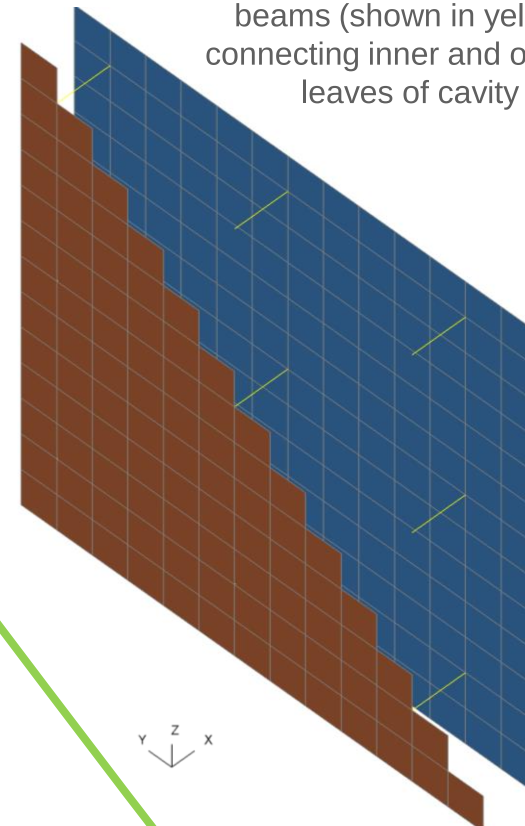


Floor ties

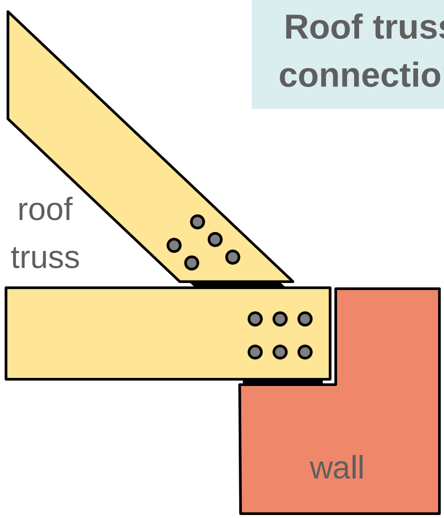
Zero length discrete beams (shown in **orange** and **magenta**) connecting floor to wall. Beams assigned different force-deflection properties in different directions.

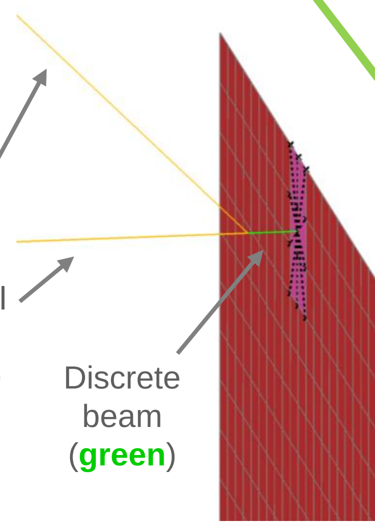
Cavity wall ties

Finite length discrete beams (shown in yellow) connecting inner and outer leaves of cavity wall



Roof truss connection



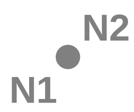


Structural beams (**orange**)

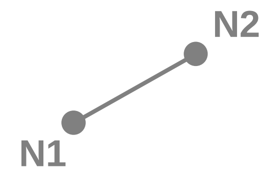
Discrete beam (**green**)

Connections – Discrete Beams *ELEMENT_BEAM

- The discrete beam element can have *zero* or *finite* length:



Zero-length discrete beams SCOOR = ±1	Finite-length discrete beams SCOOR = ±2, ± 3

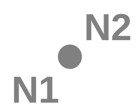


- In section card *SECTION_BEAM must define the following:
  - **ELFORM** – *element Type 6 = discrete beam*.
  - **CID** – refers to a coordinate system ID to orient the beam element (CID = 0 for global axes or define a local coordinate system using *DEFINE_COORDINATE).
  - Define beam volume on VOL to give mass – important for timestep.
  - Define beam mass moment of inertia – required for rotational stability of discrete beam.
  - If <u>*zero*</u> length beam element, set **SCOOR** to 1 (or -1).
  - If <u>*finite*</u> length beam element, set **SCOOR** to 2 or 3 (-2 or -3), for correct beam orientation – the coordinate system will follow the beam tracking of its rotations; in this case true beam-like behaviour is invoked to provide equilibrating torques to offset any force couples that arise due to translational stiffness or translational damping. See manual for details.

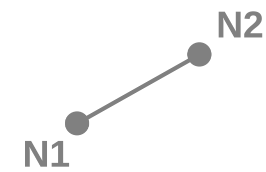
Discrete Beams – Orientation

- The **initial** discrete beam orientation (*r, s, t*) is determined differently depending on SCOOR:

Zero-length discrete beams
SCOOR = ±1



Finite-length discrete beams
SCOOR = ±2, ± 3



- For zero-length discrete beams, it is not necessary to define a third node (nor use the ORIENTATION option). N1 and N2 are coincident so a third node would be meaningless.
- Instead, **the initial orientation is based on global coordinates** (unless you define a local CID on the SECTION_BEAM card).
- This means that in the material cards, stiffness or force-deflection curves defined for *r*, *s* and *t* directions correspond to the *x*, *y* and *z* axes of the coordinate system.
- For example, if N2 moves in the negative *z* direction relative to N1, LS-DYNA will refer to the negative part of the *t*-axis force-deflection curve.

- If you select SCOOR = ± 3, the **initial** beam orientation will match global coordinates **even if you have defined a third node**. This means that (as with zero-length discrete beams) stiffness or force-deflection curves defined for *r*, *s* and *t* directions correspond to the *x*, *y* and *z* axes of the coordinate system specified by CID on the SECTION_BEAM card.
- The third node is considered **if and only if** SCOOR = ± 2. In this case, the *r*, *s* and *t* directions in the material cards correspond to the orientation of N1, N2 and N3.
- The SCOOR variable affects how the orientation changes as the beam rotates or deforms – see the next few slides.

Discrete Beams – Orientation

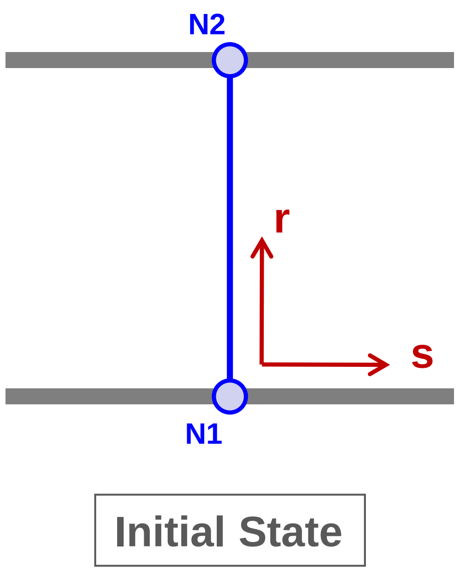
- Orientation summary:

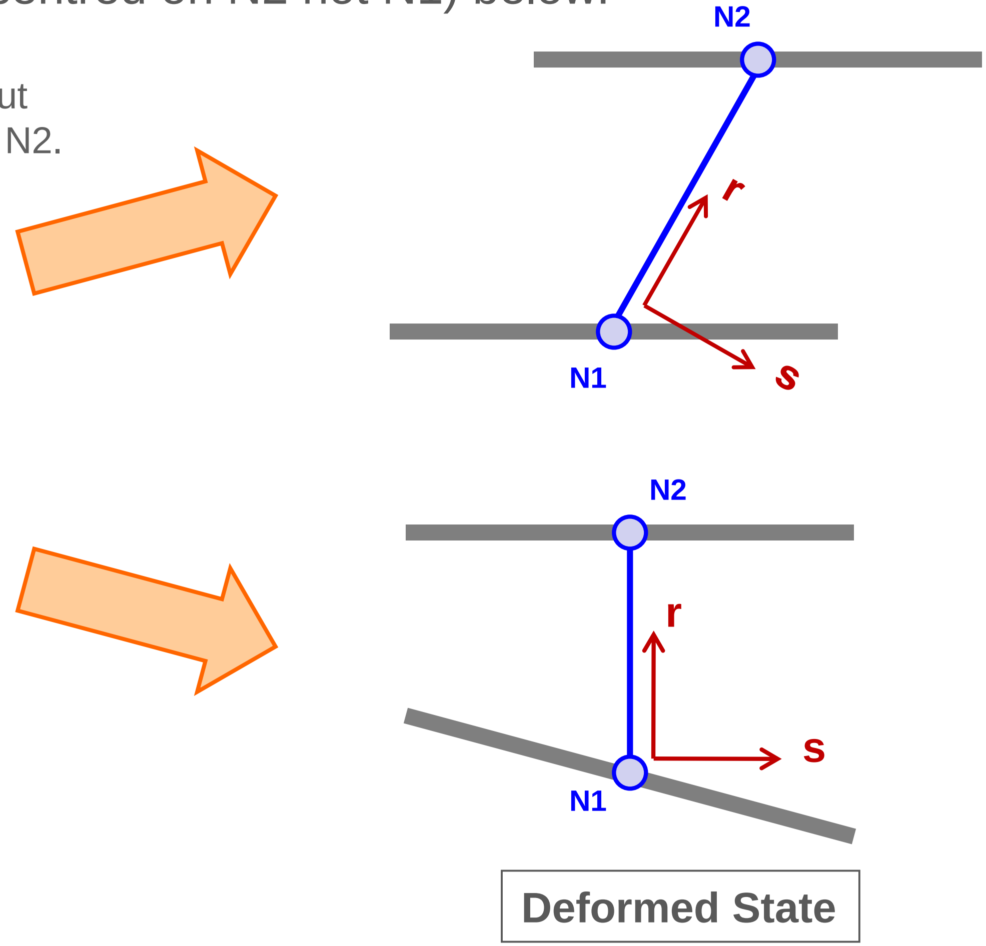
Discrete beam	**SCOOR**	**Define initial (*r, s, t*) orientation using…**	**During analysis, triad rotates according to the rotation of…**	**Remarks**
Zero length	-1	CID on *SECTION card	N1	Orientation: • initially based on coordinate system • affected by nodal rotation • unrelated to N1→N2 direction
	0	CID on *SECTION card	average(N1, N2)	
	1	CID on *SECTION card	N2	
Finite length	-3	CID on *SECTION card	N1	
	3	CID on *SECTION card	N2	
	-2	Third node N3	N1 (but *r*-axis always aligned with N1→N2)	Orientation: • always follows N1→N2 direction • spin of (*s*, *t*) axes about *r* axis governed by nodal rotation
	2	Third node N3	N2 (but *r*-axis always aligned with N1→N2)	

For a non zero length beam the **SCOOR** = -3, -2, 2, or 3 options should be used.

<u>SCOOR = -2</u> (2 is the same but centred on N2 not N1) below:

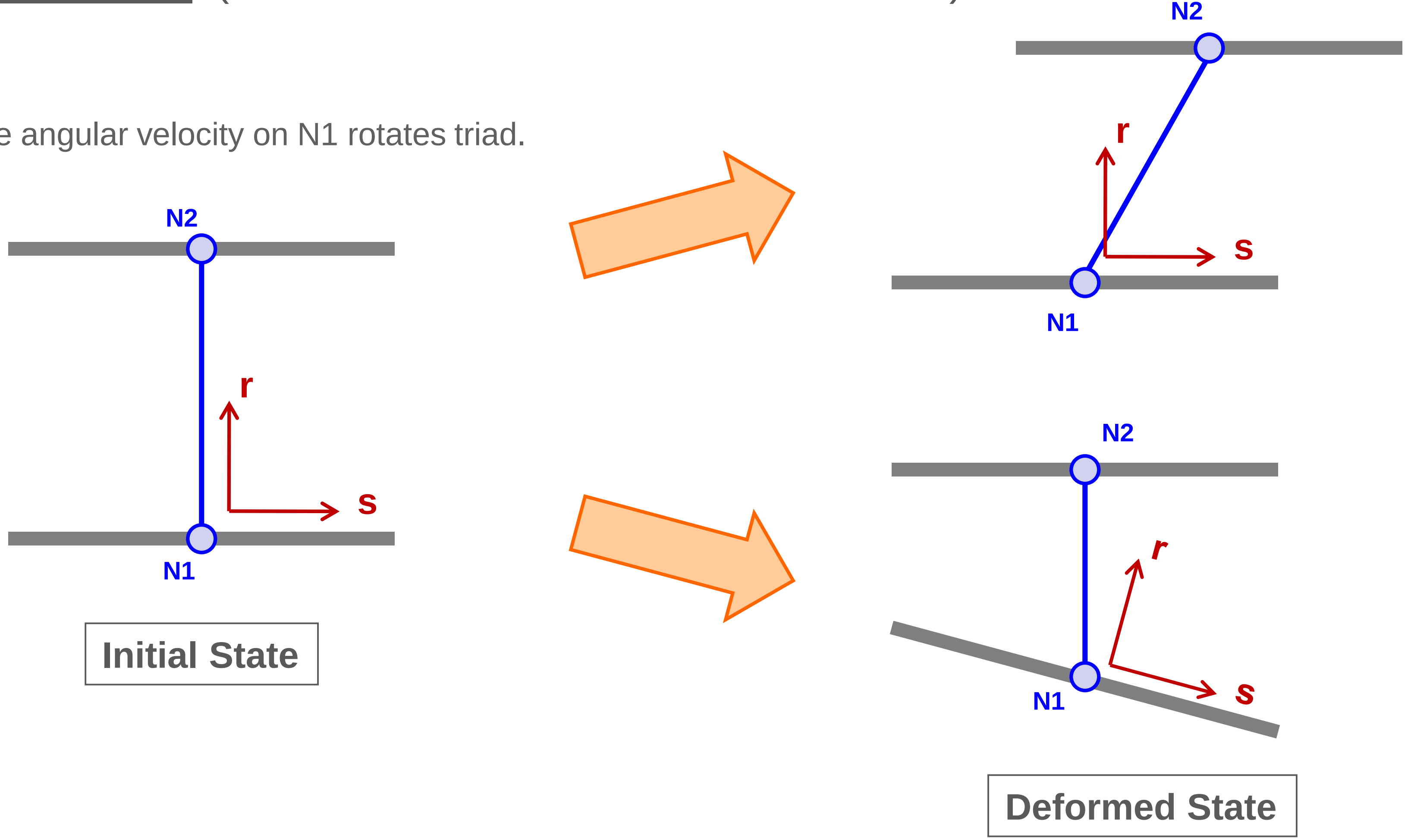
The angular velocity on N1 rotates triad, but
the r-axis follows the line between N1 and N2.





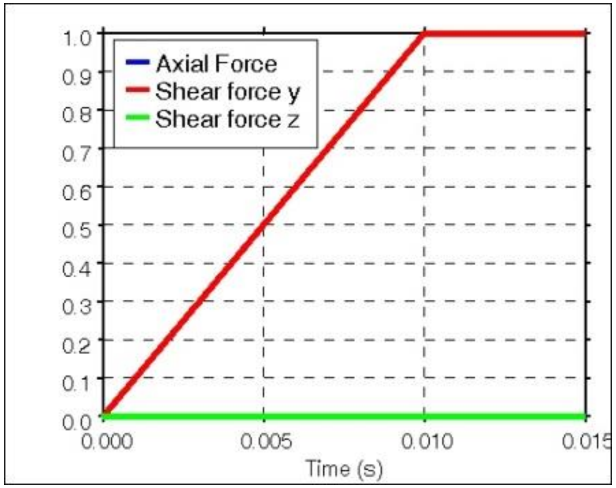
<u>SCOOR</u> *<u>= -3</u>* (3 is the same but centred on N2 not N1) below:

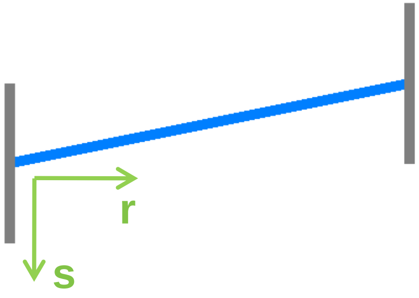
The angular velocity on N1 rotates triad.



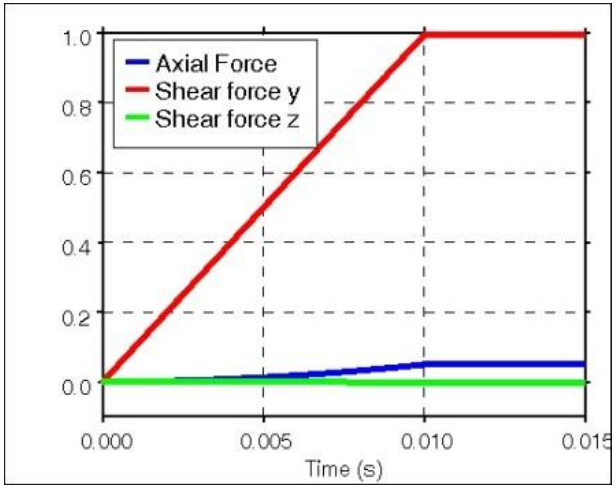
In the case of the y or z shear loading it can be seen that as the beam rotates with **SCOOR**=-3 no axial force is generated whereas with **SCOOR**=-2 a force is generated.

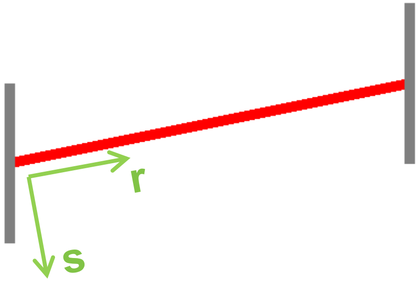
SCOOR = -3





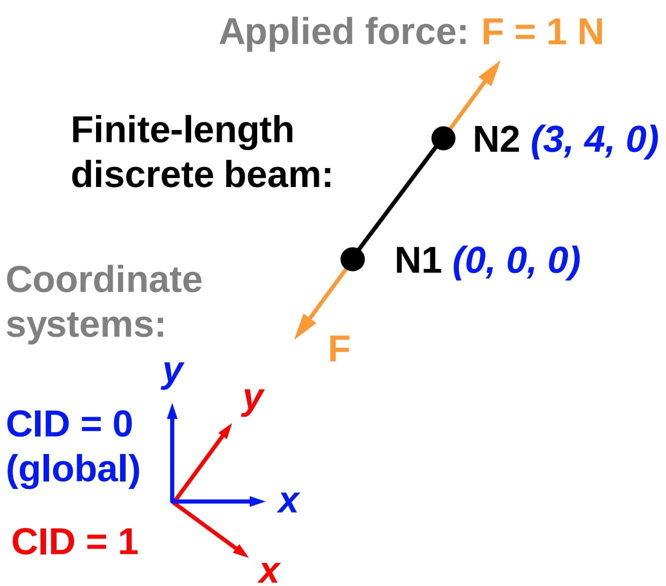
SCOOR = -2

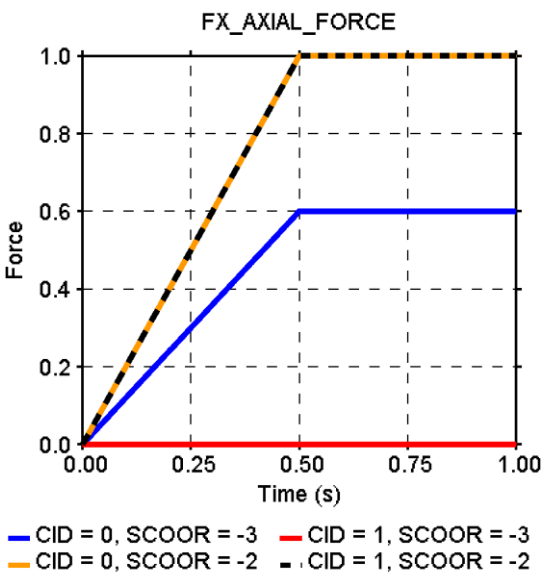


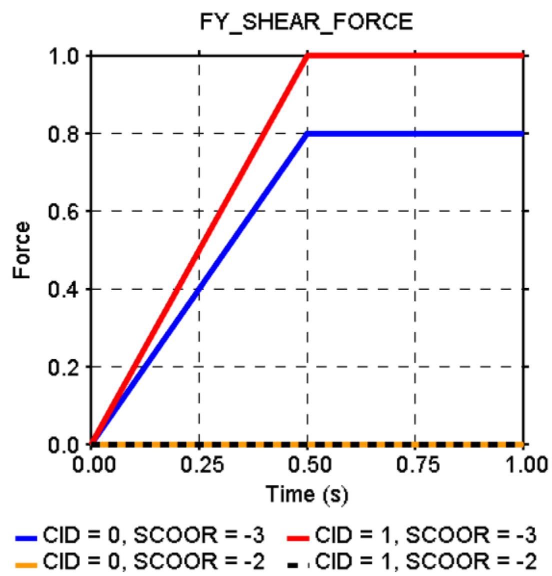


Discrete Beams – Post-processing

- In post-processing software the resultant forces and moments are reported in the (*r*, *s*, *t*) coordinate system. For example, in D3PLOT: *FX_AXIAL_FORCE*, *FY_SHEAR_FORCE* and *FZ_SHEAR_FORCE* report forces in the *r*, *s* and *t* axes respectively.
- In the example below:
  - The discrete beam is positioned at an angle to the global axis
  - The initial triad orientation (*r, s, t*) depends on the SCOOR and CID settings
  - An axial force is applied and the *FX_AXIAL_FORCE* and *FY_SHEAR_FORCE* results are plotted for different SCOOR and CID settings



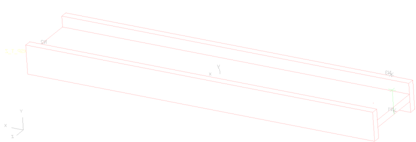




1D elements

Beam elements
*ELEMENT_BEAM
*SECTION_BEAM

Structural beams
ELFORM = 1, 2

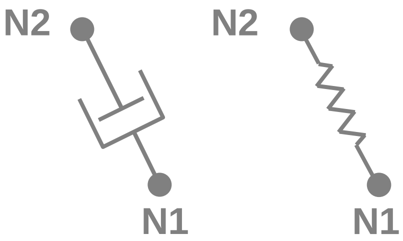


Discrete beams
ELFORM = 6

Finite-length discrete beams
SCOOR = ±2, ± 3

Zero-length discrete beams
SCOOR = ±1

Discrete elements (springs, dampers)
*ELEMENT_DISCRETE
*SECTION_DISCRETE



Used to define a simple stiffness and/or damping relationship between two nodes

Note: wherever possible, the use of discrete beams (*ELEMENT_BEAM, ELFORM = 6) is preferred over *ELEMENT_DISCRETE, especially when orientation is specified. Discrete beams tend to be more accurate and cost effective. Discrete elements are no longer being developed.

*ELEMENT_DISCRETE, *SECTION_DISCRETE

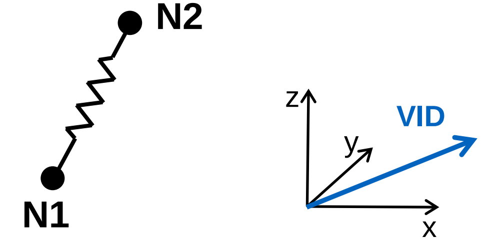
- 2 node elements apply force to end nodes depending on user specified characteristics; can also define between one node and ground (N2 = 0).
- The actual elements have no mass – they get the mass from the nodes they are connecting to – and therefore can cause timestep problems (extra *ELEMENT_MASS elements may need to be added to the nodes).
- Translational or rotational (angles in radians) specified using the **DRO** option on *SECTION_DISCRETE card.
- Linear, nonlinear and general springs/dampers can be defined depending on the material chosen.

  e.g. *MAT_SPRING_ELASTIC, *MAT_SPRING_ELASTOPLASTIC, *MAT_DAMPER_VISCOUS, etc.

- nonlinear properties input as curves of force vs displacement.

- By default, discrete elements act in the direction between nodes (and "displacement" means change of length).
- Optionally, an orientation vector can be defined for each discrete element using *DEFINE_SD_ORIENTATION so that discrete element acts along vector – need to consider carefully if vector definition should vary during the event.
- An orientation vector must be defined for *rotational* and *zero-length* elements.
- Define using card *ELEMENT_DISCRETE:

Variable	EID	PID	N1	N2	VID	S	PF	OFFSET
Type	I	I	I	I	I	F	I	F
Default	none	none	none	none	0	1.	0	0



- **VID** orientation option is used to reference a *DEFINE_SD_ORIENTATION card for the vector.
- **IOP** option on *DEFINE_SD_ORIENTATION sets the orientation:
  - along or normal to a vector = fixed during the analysis
  - along or normal to vector defined using two nodes = varies with the motion of the nodes

*DATABASE_BINARY_D3PLOT - continued

For *ELEMENT_DISCRETE (spring elements) LS-DYNA outputs by default 'fake' beams in the D3PLOT (.ptf) files, with the sole purpose of visualization.

It is possible to stop these 'fake' beams being output, using the parameter BEAM below:

Card	1	2	3	4	5	6	7	8
Variable	DT/CYCL	LCDT/NR	BEAM	NPLTC	PSETID			
Type	F	I	I	I	I			
Default	-	-	-	-	-			
Remarks								

BEAM – If =0 - (default) beam elements are added to the D3PLOT files

If =1 - no beams are added to the D3PLOT files

If =2 – as =0 but forces output differently – see manual for details www.arup.com/dyna

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