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Specification of Directional Depended Materials in LS-DYNA®

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Acknowledgements

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Introduction

Introduction

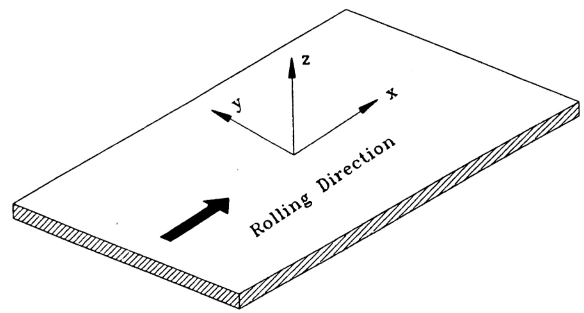
- Many materials have strength that are directional depended, this is e.g. the case for composite materials, low carbon deep drawing steels etc. These are anisotropic and orthotropic materials.

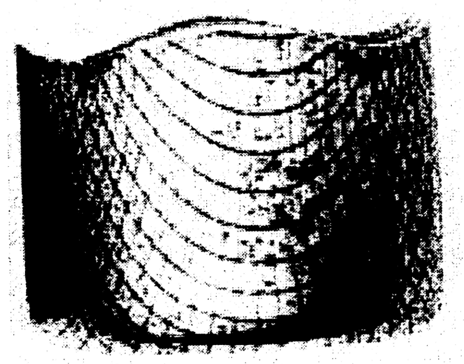
- Some materials that have this option are:
  - *MAT_002, *MAT_022, *MAT_036, *MAT_054, *MAT_058
  - And many more…..

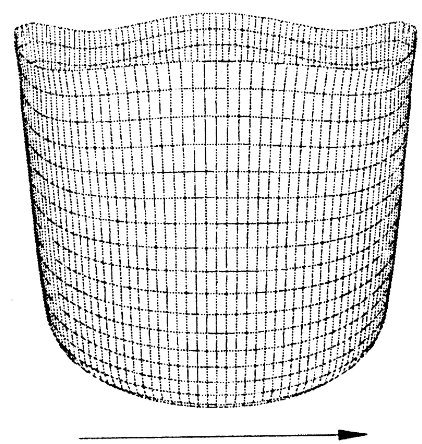
- In e.g. Sheet Metal Forming, the rolling direction of the sheet is typically given as the 0° direction and specimens for uniaxial tensile tests are done in 0°, 45° and 90° to the rolling direction. This anisotropic material behavior is clearly seen when deep drawing e.g. cylindrical cups – the difference in drawing behavior is seen as “ears”.

Introduction

- The influence of anisotropic material behavior is clearly seen in conventional deep drawing of e.g. FeP04 low carbon steel.







[Moshfegh et. al, 1999]

Introduction

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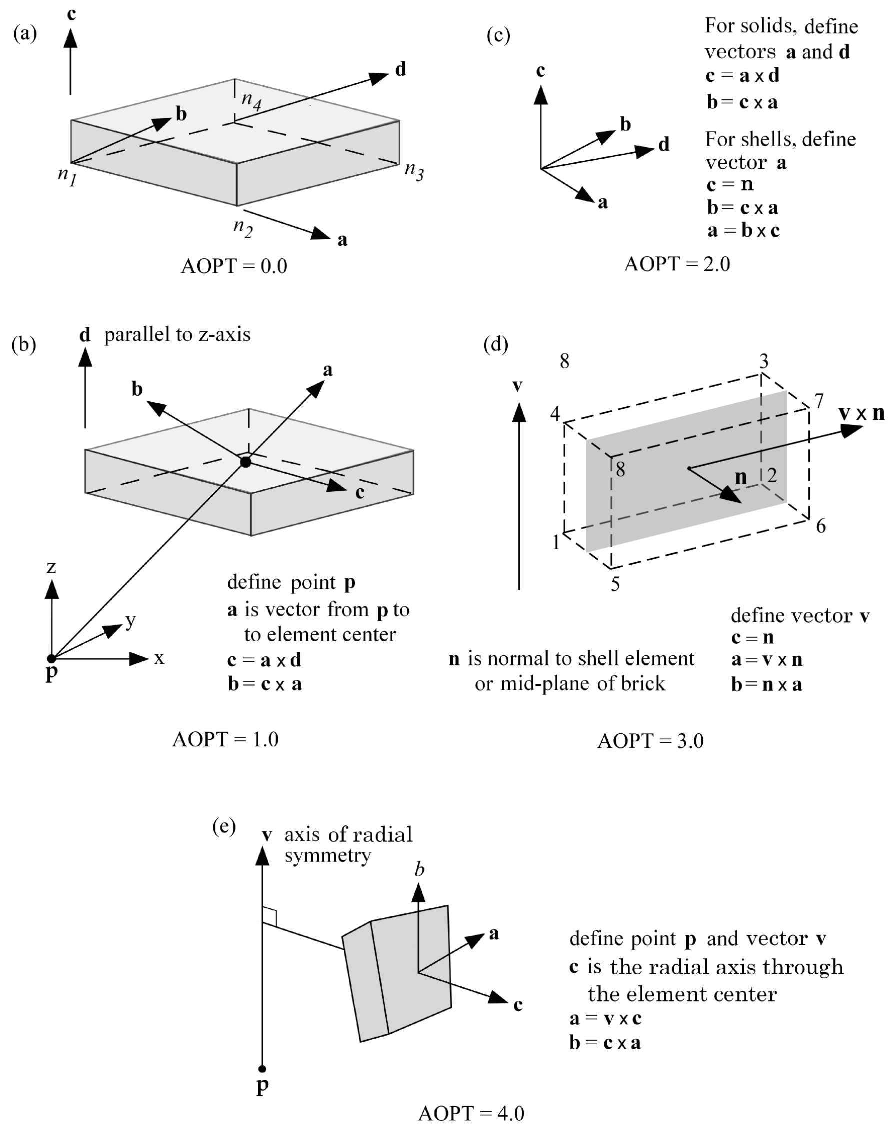
- In order to give the material properties in the different directions, one need a material coordinate system, a-b-c. This is given at the *MAT card, at least as a first step, by the AOPT option, which has several different ways to define it.

- There are in total 14 flags that are related to specifying the material coordinate system. These are the AOPT flag itself, the point P, the vectors A, V, D and the angle BETA. These will be described in more details later.

```
$ ------------- MATERIALS ----------------
*MAT_ORTHOTROPIC_ELASTIC
$      MID        RO        EA        EB        EC      PRBA      PRCA      PRCB
         1     7.e-9  4.05E+05 2.034E+05 1.775E+05      0.41      0.35      0.31
$      GAB       GBC       GCA      AOPT
 0.6879E+5 1.8644e+4 0.6775e+4       2.0
$       XP        YP        ZP        A1        A2        A3
       0.0       0.0       0.0      -1.0       0.0       0.0
$       V1        V2        V3        D1        D2        D3      BETA       REF
       0.0       0.0       0.0       0.0       1.0       0.0       0.0       0.0
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
```

Introduction

- There are six different ways to specify the a-b-c coordinate system at the material cards (*MAT_). The best description is under *MAT_002 [Hallquist, 2007b]. The options are specific mentioned under the different sections that describes their features in details.



Introduction

- Other options then rotates the material coordinate system specified by AOPT, e.g. a rotation angle can be specified. This can be done at:
  - *SECTION_SHELL (ICOMP)
  - *ELEMENT_ SHELL_BETA
  - *ELEMENT_SHELL_MCID
  - *ELEMENT_SOLID_ORTHO (can also define a-axis)

Shell:

*MAT_ → *SECTION_SHELL → *ELEMENT_SHELL_BETA / *ELEMENT_SHELL_MCID

Solid: *MAT_ → *ELEMENT_SOLID_ORTHO

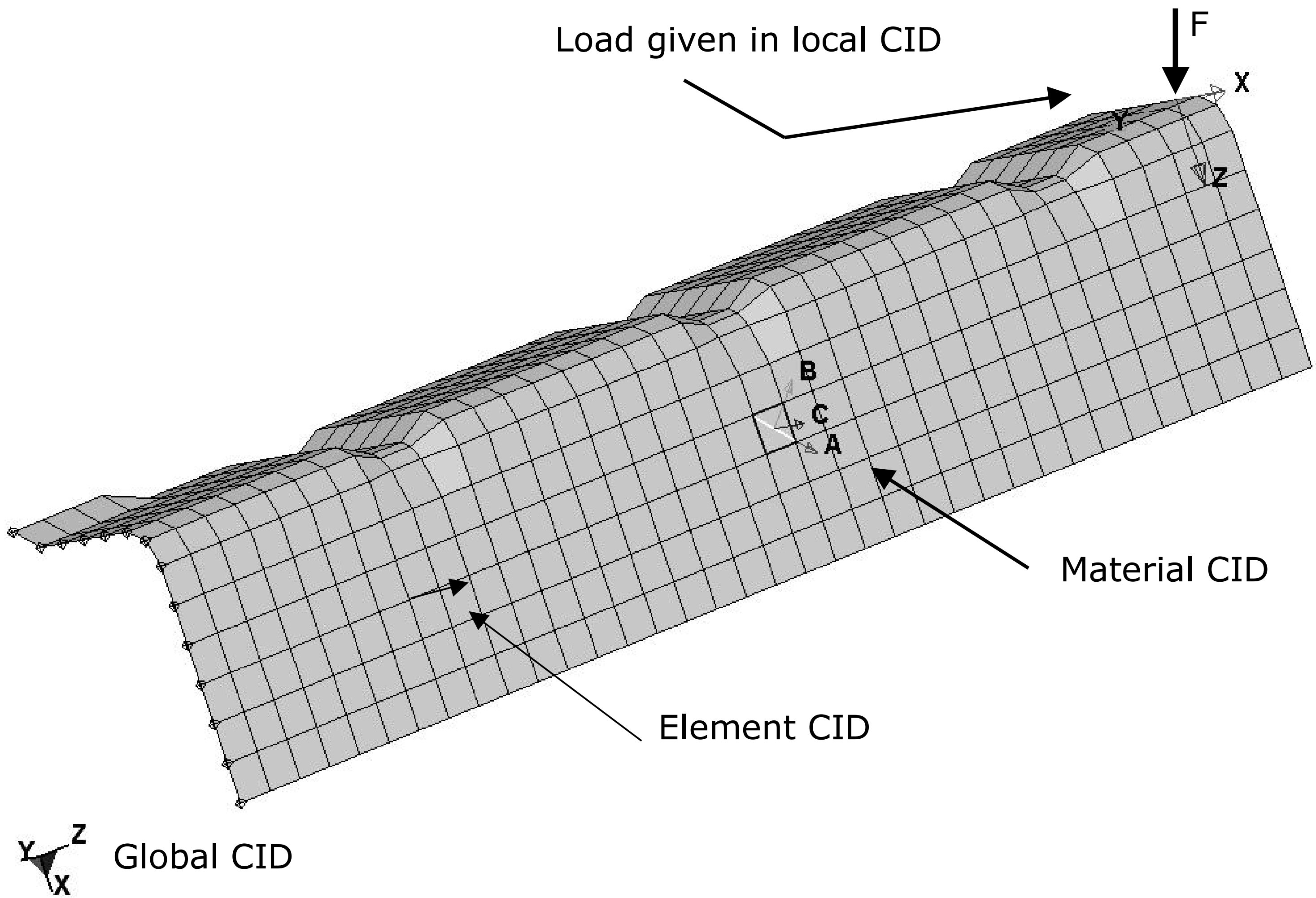
Introduction

As mentioned the coordinate system considered in these notes is the material coordinate system but there are in general four different coordinate systems in LS-DYNA®:

- Global coordinate system
  - This is the default system in LS-DYNA® and is used for geometry, boundaries, loads etc.
- Local element coordinate system
  - Each element will have an element system and this is often determined by the node connectivity, see e.g. [MacNeal, 1994]. [Belytschko et al, 81] and [Hallquist, 2006] describes the coordinate system for the Belytschko-Tsay element, the default shell element in LS-DYNA®. The stress update is performed in this local coordinate system.
- Material coordinate system
  - This is the coordinate system that is used with the material properties in order to make the material direction depended.
- Local user defined coordinate system
  - The user can specify a local coordinate systems to be used e.g. with load options etc.

Introduction

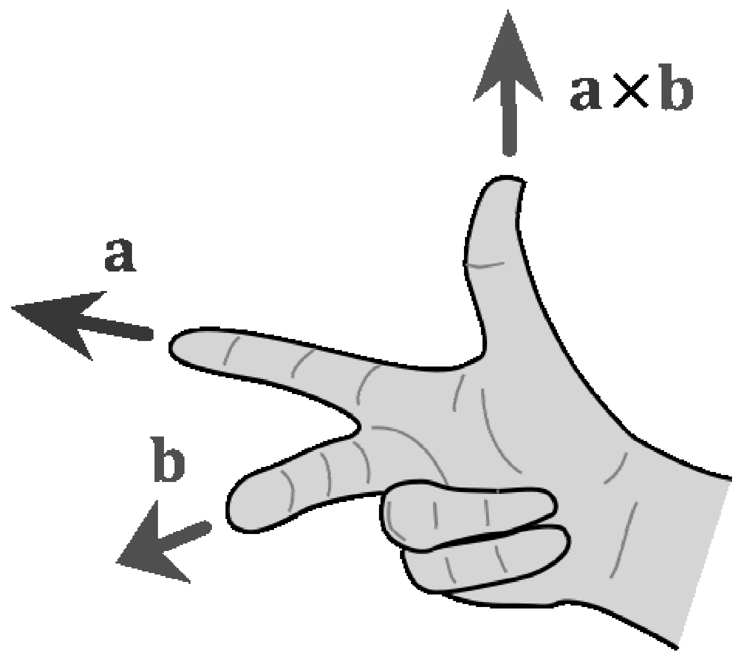
- There are four different coordinate systems in LS-DYNA®



Introduction

Defining Coordinate Systems

- The way to specify the material coordinate system is based on the different ways to specify coordinate systems in LS-DYNA®.
- The coordinate systems in LS-DYNA® are all Cartesian coordinate systems, following the right hand rule. There is no Cylindrical nor Spherical coordinate systems in LS-DYNA®.



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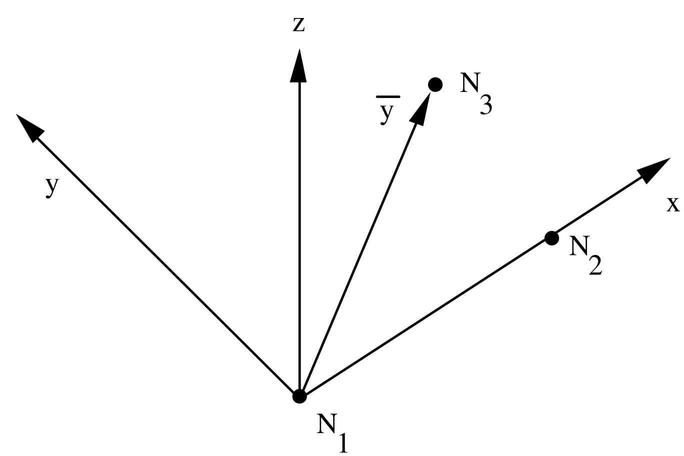
Introduction

Defining Coordinate Systems

- There is three different ways to defined coordinate systems in LS-DYNA® as shown in the following.

  - *DEFINE_COORDINATE_NODES
    - Three nodes (N1, N2, N3) are given
    - Local x is from N1 to N2
    - A vector α is given from N1 to N3 (named $\bar{y}$ in the manual)
    - Local z is calculated as $x \times \alpha$
    - Local y is then given by $y = z \times x$



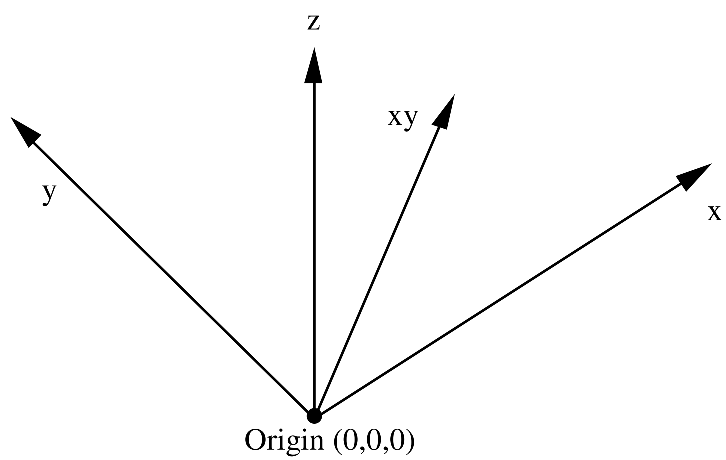
Definition of coordinate system [Hallquist, 2007].

Introduction

Defining Coordinate Systems

- *DEFINE_COORDINATE_SYSTEM
  - This specification is very similar to the one used at *DEFINE_COORDINATE_NODES. Instead of three nodes, there points are given as input. The coordinates for each point is specified.
  - N1 is given by (X0, Y0, Z0)
  - N2 is given by (XL, YL, ZL)
  - N3 is given by (XP, YP, ZP)

- *DEFINE_COORDINATE_VECTOR
  - Two vectors are given, x and α (x-y in manual). For both vectors, origin is (0, 0, 0) so only one point is specified for each vector.
  - Vector x is taken as local x
  - Local z is calculated by $z = x \times \alpha$
  - Local y is calculated by $y = z \times x$

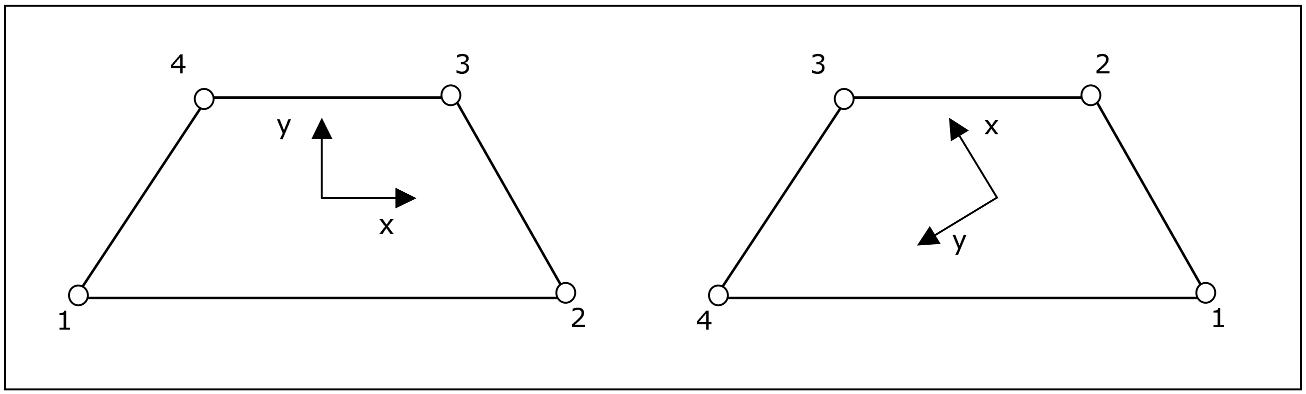


Definition of coordinate system [Hallquist, 2007].

Introduction

Invariant Node Numbering

- For the default shell element in LS-DYNA®, type 2 shell, the local element x-axis is in the direction given by node 1 to node 2. The local element coordinate system is based on this axis and the shell normal, see e.g. [Belytschko et al, 81] . This means that for irregular shaped elements, the results can change if the connectivity for the element changes.
- Since direction depended materials local material coordinate system is tied to the element coordinate system, it is important to make it independent of change in the connectivity.

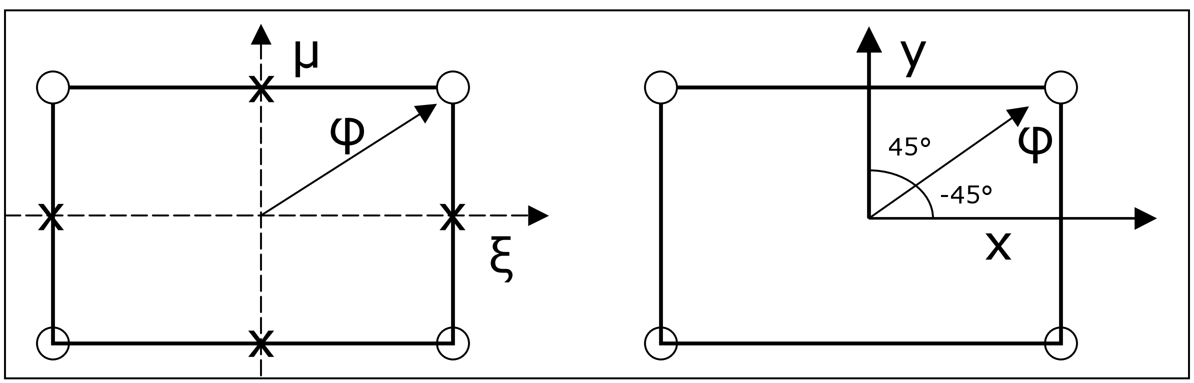


Introduction

Invariant Node Numbering

- This can be handled by the option Invariant Node Numbering, specified by the INN flag at *CONTROL_ACCURACY.
  - INN=1: Off
  - INN=2: On for shells
  - INN=3: On for solids
  - INN=4: On for shells and solids

- The option defines two vectors in the plane of the shell, ξ and μ. They each connect the mid-side points of opposite shell edges. Halfway in between these two vectors, the vector φ is located and the local element x-axis is taken 45° to one side of this vector. The local element y-axis is given as 45° to the opposite side of the φ vector.



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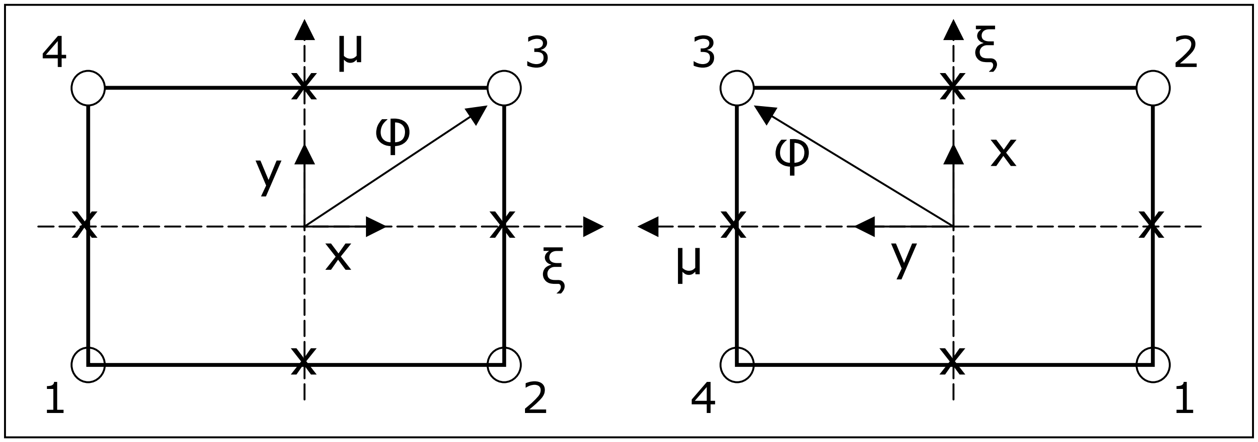
Introduction

Invariant Node Numbering

- This means that the the local element coordinate system rotates exactly 90° when an element is renumbered.



- The Invariant Node Numbering also helps so there is less influence from hourglassing on the material directions and it helps for long time periods models more stable [Hallquist, 2007].
- The CPU penalty is less than 5% [Hallquist, 2007].
- It is only implemented for shells 1, 2, 5, 7, 9, 10, 11 and 16.

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Introduction
Invariant Node Numbering

- What has been shown is only for shell elements.
- For solid elements the invariant option also exist but is somewhat more complicated:
  - There vectors are defined from the center of one face to the center of the opposite face.
  - Cross products are made from these vectors.
  - Dot products are made between the cross products and the vectors and testing are done to make an orthogonal system.
  - It can take some iterations to achieve the orthogonal system.

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AOPT for Shells

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AOPT For Shells

- For shell elements the shell normal is always taken as the c material direction. And the a and b directions are forced to be in the plane of the shell. This is ensured by projections of the axis into the shell plane.

- There are four of the AOPT options that are valid for shell elements:
  - AOPT=0
  - AOPT=2
  - AOPT=3
  - AOPT=LT.0

- These are shown in the following. As mentioned earlier additional options can be specified besides the AOPT option to rotate the material coordinate system. This is shown in a later section.

AOPT For Shells

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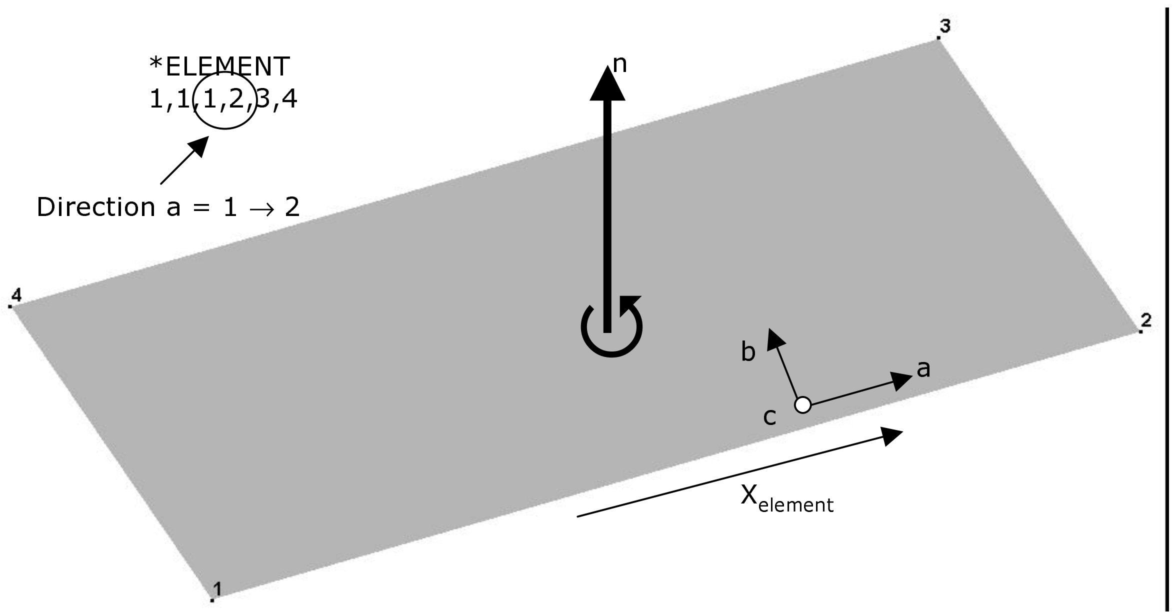
- AOPT=0
  - This is the default option and it will not require any further input.
  - The a axis is taken as the vector between node 1 and node 2 in the specification of the element.
  - The c direction is the shell normal direction. The b direction is formed as b = c x a.



  - The dependency of the element connectivity means that one should be very careful with the connectivity for the elements since that directly influence the material directions.

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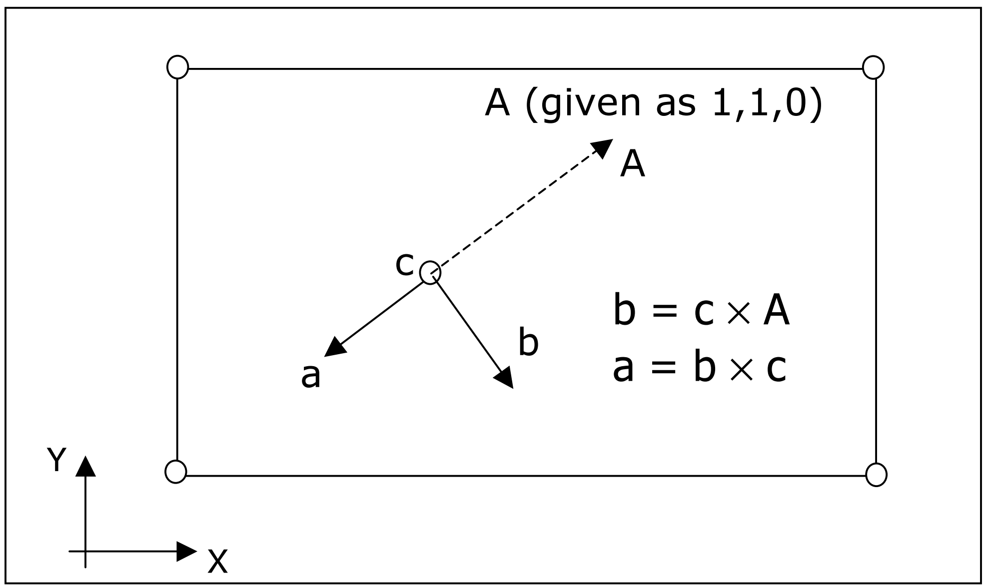
AOPT For Shells

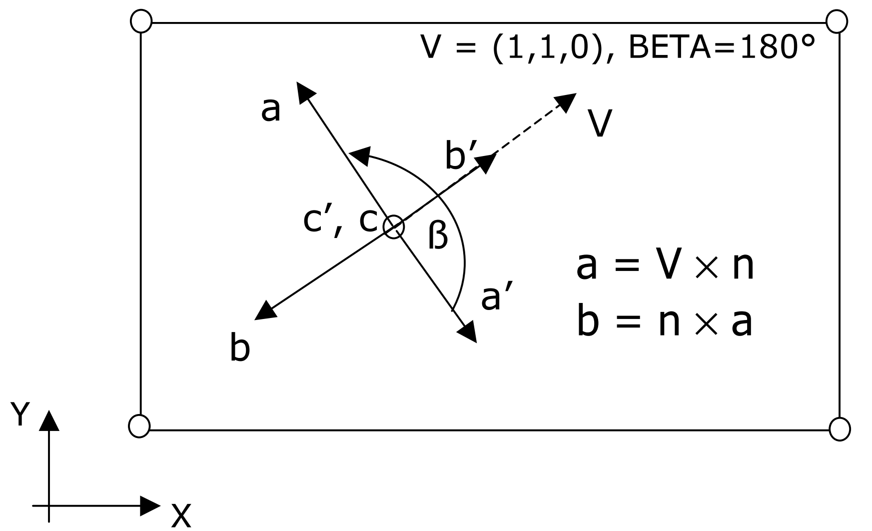
- AOPT=2
  - A vector A is given as input.
  - The c axis is taken as the shell normal.
  - Material axis b is then found by $b = c \times A$
  - The a axis is calculated as $a = b \times c$
  - This option is global orthotropic since the material system is based on global entities.



AOPT For Shells

- AOPT=3
  - A vector V and an angle BETA is given.
  - The material axis a is defined by $a = V \times n$ where n is the shell normal
  - Material axis b is then found from $b = n \times a$
  - The BETA angle rotates this coordinate system from the a-axis.
  - This option is local orthotropic since it involves local entities, here the shell normal.

a', b', c' is coordinate system before rotation with BETA



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AOPT For Shells

- AOPT=LT.0
  - The absolute value of AOPT is the coordinate system ID (CID) for the specified coordinate system to be used.
  - The coordinate system can be specified by: (see earlier slides)
    - *DEFINE_COORDINATE_NODES
    - *DEFINE_COORDINATE_SYSTEM
    - *DEFINE_COORDINATE_VECTOR
  - For the case where the coordinate system not is in the shell plane, the axis will be projected down into the plane.

- At the end of this presentation are given several examples of these different options.

AOPT for Solids

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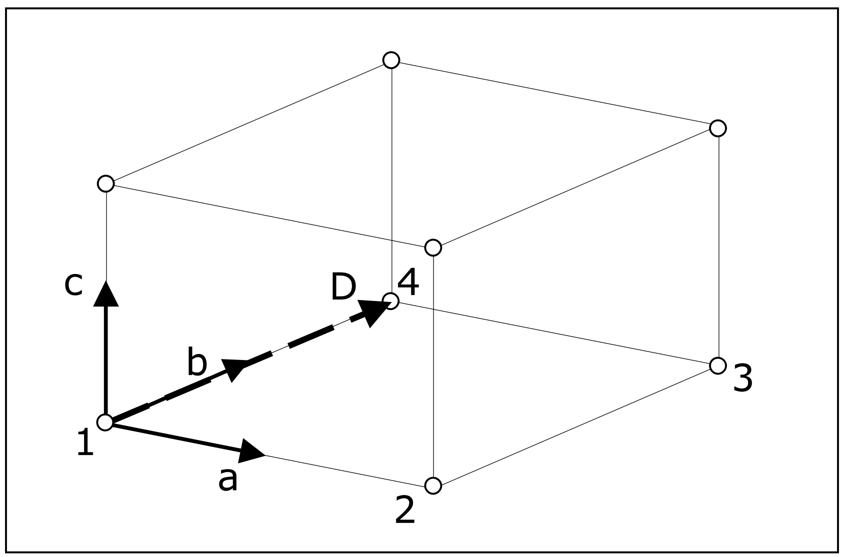
AOPT For Solids

- All of the AOPT options (6) are valid for solid elements:
  - AOPT=0
  - AOPT=1
  - AOPT=2
  - AOPT=3
  - AOPT=4
  - AOPT=LT.0
- These are shown in the following. As mentioned earlier additional options can be specified besides the AOPT option to rotate the material coordinate system. This is shown in a later section.

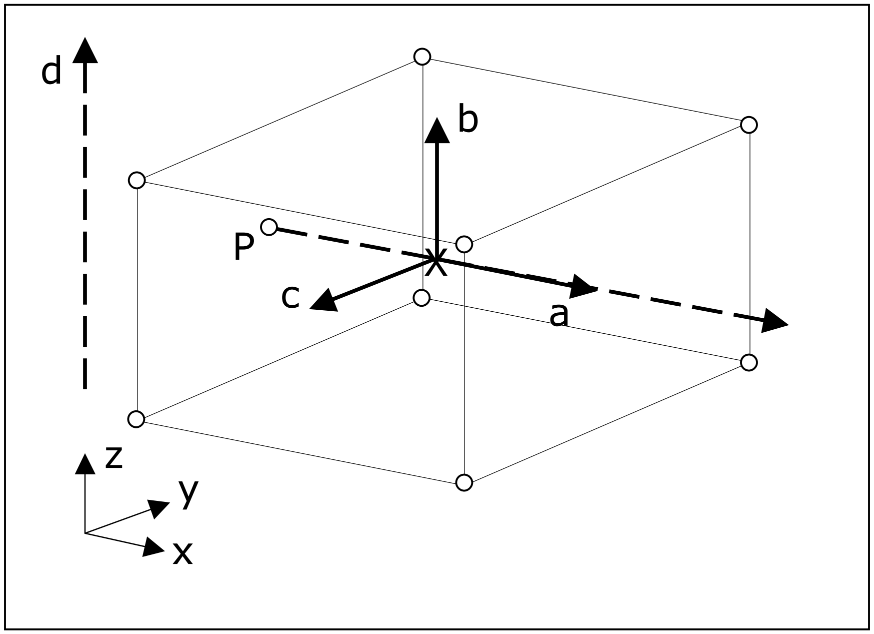
AOPT For Solids

- AOPT=0
  - This is the default option and it will not require any further input.
  - The a axis is taken as the vector between node 1 and node 2 in the specification of the element.
  - A vector D is given as the vector between node 1 and node 4. The c axis is then calculated as c = a x D.
  - The b direction is formed as b = c x a.
  - This means that one should be very careful with the connectivity for the elements since that directly influence the material directions.



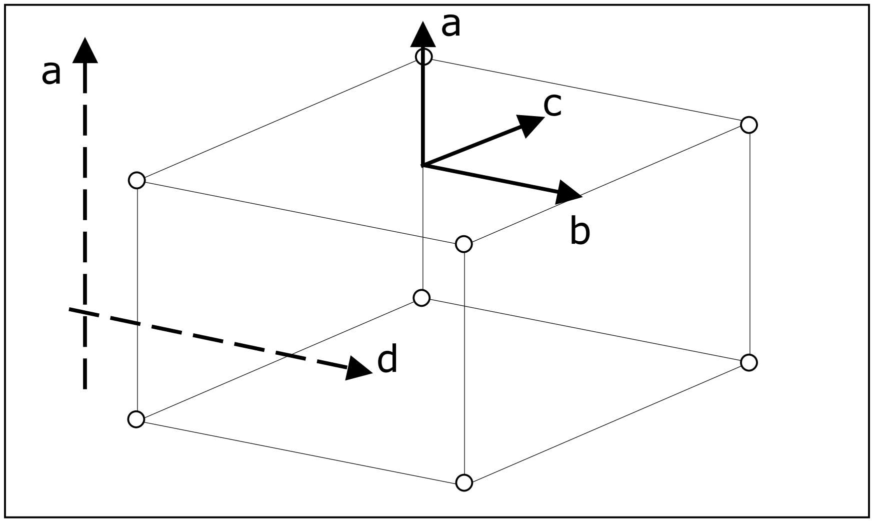
AOPT For Solids

- <u>AOPT=1</u>
- A point *P* is given (*XP*, *YP*, *ZP*)
- The *a* direction is from *P* to the center of the element.
- The *c* direction is given by $c = a \times d$ where *d* is parallel to the global z axis.
- The *b* direction is then determined by $b = c \times a$.
- This option is local orthotropic since the material system is based on local entities.



AOPT For Solids

- <u>AOPT=2</u>
- Vectors *a* and *d* are given as input.
- The *a* direction is given directly by vector *a*
- The *c* direction is then determined as $c = a \times d$
- *b* is calculated as $b = c \times a$
- This option is global orthotropic since the material system is based on global entities.



AOPT For Solids

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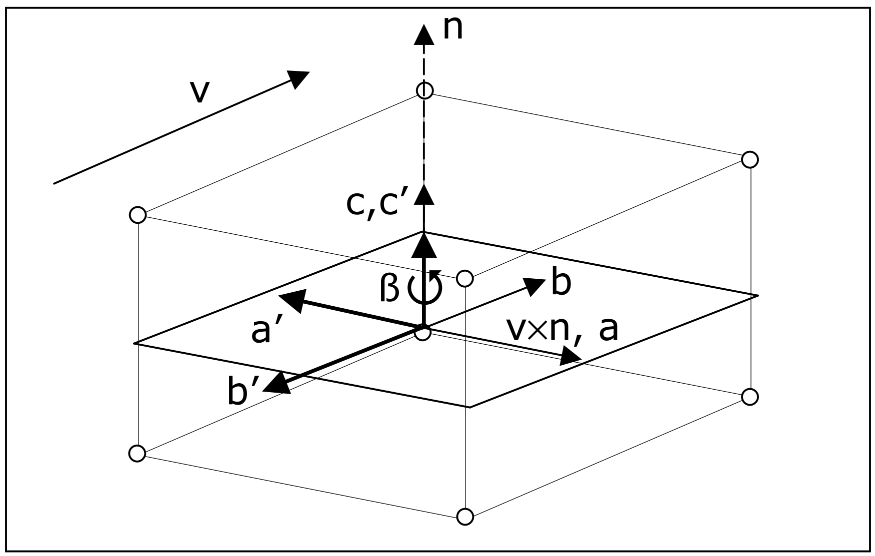
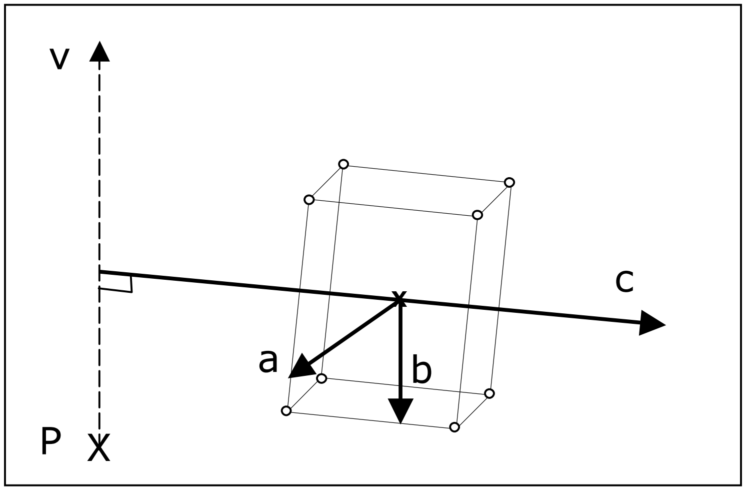
- AOPT=3
  - A vector v and an angle BETA is given.
  - The material axis a is defined by $a = v \times n$, where n is the normal of a midsurface determined by the node connectivity.
  - Material axis b is then found from $b = n \times a$
  - The BETA angle rotates this coordinate system from the a-axis.
  - This option is local orthotropic since it involves local entities.



- The a'-b'-c' coordinate system is the final used one

AOPT For Solids

- AOPT=4
  - A vector v and a point P is given. The defines the axis of symmetry
  - The material axis c is the radial axis from this symmetry axis to the element center.
  - The material axis a is defined by $a = v \times c$.
  - Material axis b is then found from $b = c \times a$
  - This option is local orthotropic since it involves local entities.



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AOPT For Solids

- <u>AOPT=LT.0</u>
  - The absolute value of AOPT is the coordinate system ID (CID) for the specified coordinate system to be used.
  - The coordinate system can be specified by: (see earlier slides)
    - *DEFINE_COORDINATE_NODES
    - *DEFINE_COORDINATE_SYSTEM
    - *DEFINE_COORDINATE_VECTOR
- At the end of this presentation are given several examples of these different options.

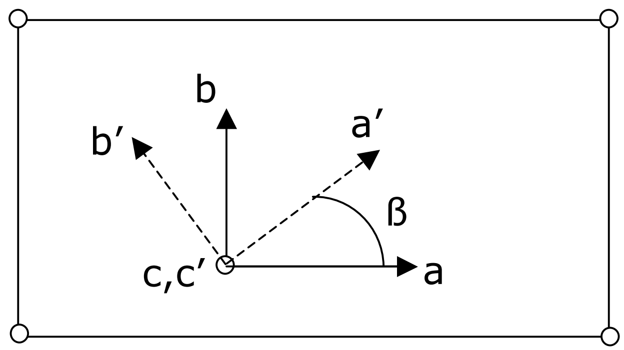
Rotation of the Coordinate System

Rotation of the Coordinate System

Introduction

- The AOPT gives the initial orientation of the material and this can then be rotated. The are several places this can be done.

- The rotation is rotating the coordinate system around the *c*-axis. The rotation is counter clockwise and the angle is given in degrees.



- For AOPT=3 a rotation angle can be given directly using the BETA option.

- The options that can be used are different for shells and solids, as will be shown in the following.

Rotation of the Coordinate System

Solids

- For solid elements there are two places that the rotation angle can be specified:

  - *MAT_

  For AOPT set to 3, an angle BETA is given.

  - *ELEMENT_SOLID_ORTHO

  A new material system can be defined using the a and d vector, however if the d vector is given as zero length then the given A1 rotates the *a-b-c* system defined at the *MAT_ card. It will over the BETA angle given at *MAT_ card if any.

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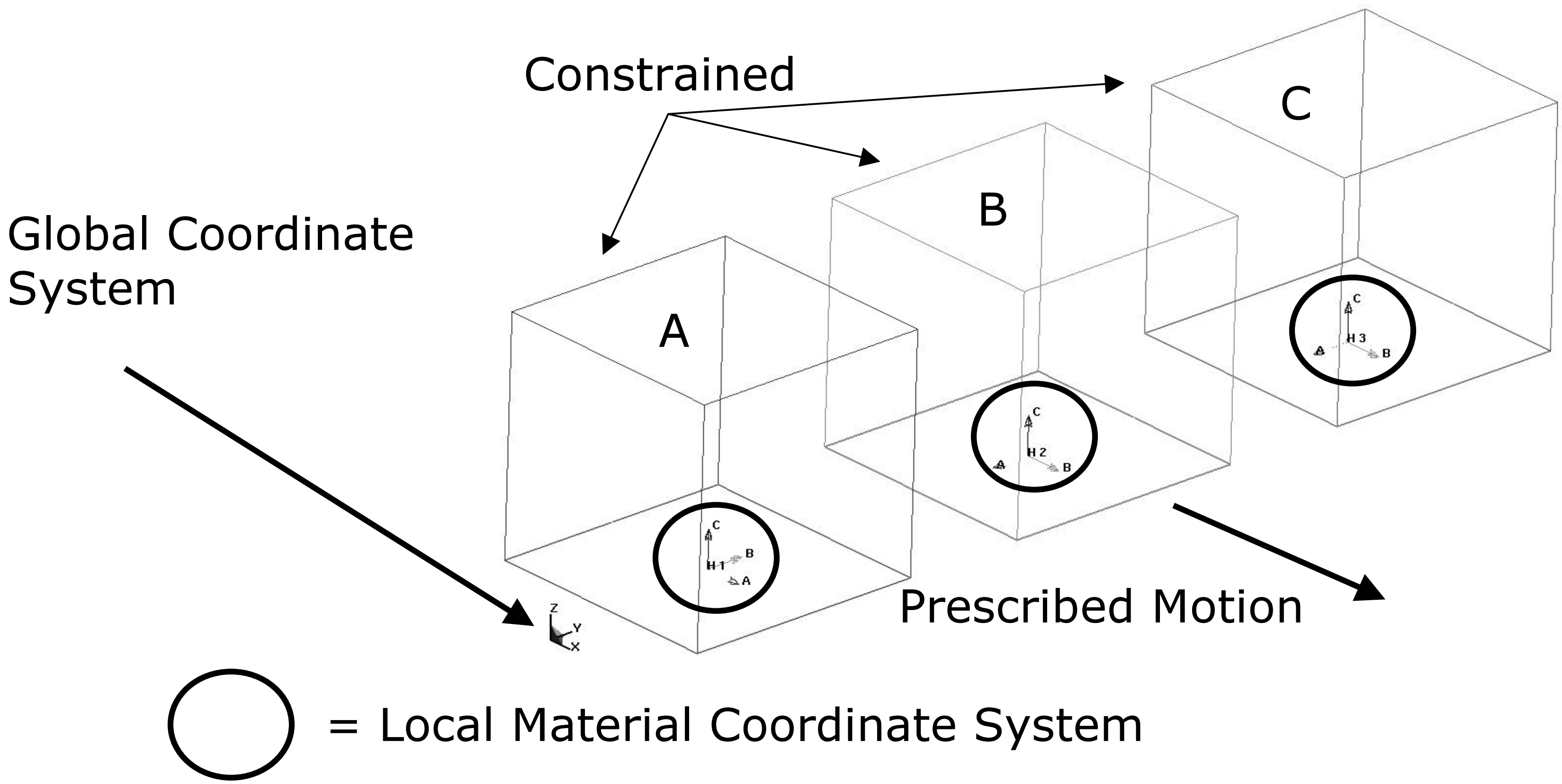
Rotation of the Coordinate System

Solids - Example

- The set-up is three single solid elements that are in uniaxial tension. The loading direction is in global X direction. The loading is done by prescribing displacement to four nodes. The opposite surface of the solid is fully constrained.



Rotation of the Coordinate System

Solids - Example

- The three solid elements uses the same values for the material parameters. However the *a-b-c* coordinate system is rotated in different directions, leading to different material directions:

  - Case A: No BETA is used at *MAT_ and direction *a* direction is global X direction.

  - Case B: BETA at *MAT_ is given as –90 deg so *a* direction is opposite to the global Y direction.

  - Case C: No BETA is set at *MAT_ but A1 is set to –90 deg at *ELEMENT_SOLID_ORTHO (and d is zero length) leading to the same material coordinate system as in Case B.

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Rotation of the Coordinate System

Solids - Example

- Specification for CASE A (*a-b-c* given at *MAT_):

```
*MAT_COMPOSITE_DAMAGE
$A     mid        ro        ea        eb        ec      prba      prca      prcb
         1 5.0000E-9 1.3200E+5 10755.000 10755.000  0.019000  0.019000  0.490000
$#     gab       gbc       gca     kfail      aopt      macf
 5653.0000 3378.0000 5653.0000     0.000  3.000000     0.000
$#      xp        yp        zp        a1        a2        a3
     0.000     0.000     0.000     0.000     0.000     0.000
$#      v1        v2        v3        d1        d2        d3      beta
     0.000  1.000000     0.000     0.000     0.000     0.000     0.000
$#      sc        xt        yt        yc      alph        sn       syz       szx
     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
```

- Specification for CASE B (*a-b-c* given at *MAT_ together with BETA):

```
*MAT_COMPOSITE_DAMAGE
$B     mid        ro        ea        eb        ec      prba      prca      prcb
         2 5.0000E-9 1.3200E+5 10755.000 10755.000  0.019000  0.019000  0.490000
$#     gab       gbc       gca     kfail      aopt      macf
 5653.0000 3378.0000 5653.0000     0.000  3.000000     0.000
$#      xp        yp        zp        a1        a2        a3
     0.000     0.000     0.000     0.000     0.000     0.000
$#      v1        v2        v3        d1        d2        d3      beta
     0.000  1.000000     0.000     0.000     0.000     0.000-90.000000
$#      sc        xt        yt        yc      alph        sn       syz       szx
     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
```

The strength values are taken from [Chatiri et. al, 2010]

Rotation of the Coordinate System

Solids - Example

- Specification for CASE C (*a-b-c* given at *MAT_ and an angle A1 is given at the *ELEMENT_SOLID_ORTHO CARD):

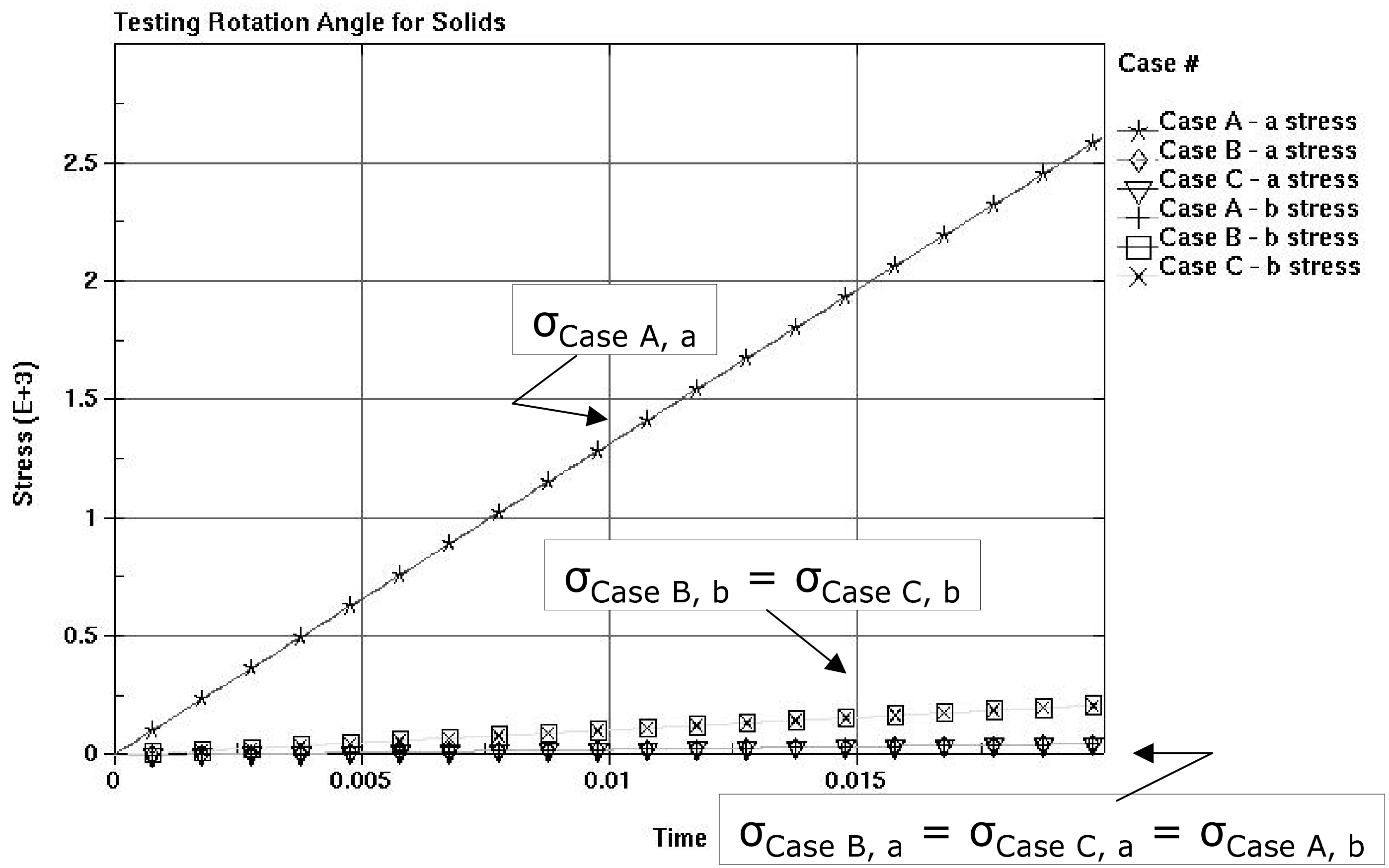
```
*MAT_COMPOSITE_DAMAGE
$C     mid        ro        ea        eb        ec      prba      prca      prcb
         3 5.0000E-9 1.3200E+5 10755.000 10755.000  0.019000  0.019000  0.490000
$#     gab       gbc       gca     kfail      aopt      macf
 5653.0000 3378.0000 5653.0000     0.000  3.000000     0.000
$#      xp        yp        zp        a1        a2        a3
     0.000     0.000     0.000     0.000     0.000     0.000
$#      v1        v2        v3        d1        d2        d3      beta
     0.000  1.000000     0.000     0.000     0.000     0.000     0.000
$#      sc        xt        yt        yc      alph        sn       syz       szx
     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
…………………………..
…………………………..
*ELEMENT_SOLID_ORTHO
$#   eid     pid      n1      n2      n3      n4      n5      n6      n7      n8
       3       3      17      18      20      19      21      22      24      23
$#             a1              a2              a3
     -90.0000000           0.000           0.000
$#             d1              d2              d3
           0.000           0.000           0.000
```

The strength values are taken from [Chatiri et. al, 2010]

Rotation of the Coordinate System

Solids - Example

- The strongest direction is the *a* direction and it is then expected that the largest stress will be when the *a* direction is in the loading direction which is global X. This is the case for Case A. It also expected that the Case B response is identical to the response of Case C.



Rotation of the Coordinate System

Shells

- For shell elements there are four places that the rotation angle can be specified:

  - *MAT_
  For AOPT set to 3, an angle BETA is given. From now named BETA_MAT.

  - *SECTION_SHELL
  If ICOMP is set to 1, a rotation angle can be given for each through the thickness integration point. This is only valid for a certain number of materials [Hallquist, 2007b]:
  22, 23, 33, 34, 36, 40, 41-50, 54-56, 58, 59, 103, 116 and 194.
  This angle is now named BETA_SECTION.

  - *ELEMENT__SHELL_BETA
  The angle is given directly by BETA. The angle is now named BETA_ELEMENT. It overrides the angle BETA_MAT but is added to the angle BETA_SECTION.

Rotation of the Coordinate System

Shells

- For shell elements there are four places that the rotation angle can be specified, continued:
  - *ELEMENT_SHELL_MCID

  An coordinate system ID is given by the MCID flag. The rotation angle is then the angle between the projected x-axis to the shell surface and the side 1-2 determined by the element connectivity. This angle is now named BETA_ELEMENT. It overrides the angle BETA_MAT but is added to the angle BETA_SECTION.

- This means that one have to be careful specifying the angles since some overwrites and some are cumulative. The table on the next slide shows a table that summaries the options.

Draft

Rotation of the Coordinate System

Shells

Rotation of the material coordinate system

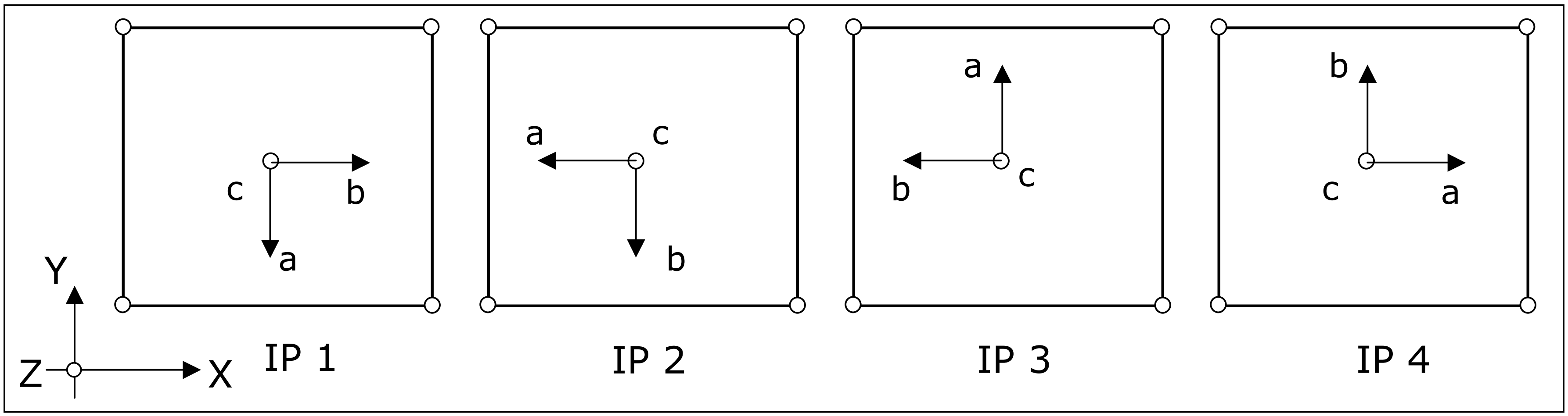
BETA_MAT	BETA_SECTION	BETA_ELEMENT	RESULT
X	X		BETA_MAT + BETA_SECTION
X		X	BETA_ELEMENT
	X	X	BETA_SECTION + BETA_ELEMENT
X	X	X	BETA_SECTION + BETA_ELEMENT

BETA_MAT : Given at the *MAT_ card
BETA_SECTION : Given at the *SECTION_SHELL card
BETA_ELEMENT : Given using *ELEMENT_SHELL_BETA or *ELEMENT_SHELL_MCID

Rotation of the Coordinate System

Shells – Example 1

- The set-up is a single elements in uniaxial tension. The loading direction is in global X direction. The loading is done by prescribing displacement to two nodes. The opposite side of the shell is fully constrained.
  - The element uses *MAT_COMPOSITE_DAMAGE and AOPT=3 where the BETA_MAT is set to -90°. The shell has four integration points and ICOMP is set to 1 at the *SECTION_SHELL card where four BETA_SECTION angles are given as 0°, -90°, -180° and 90°. No angle is set at the *ELEMENT_SHELL card.
- The material coordinate systems are then (with the given material – see next slide):



Draft Rotation of the Coordinate System

Shells – Example 1

- The specification for *MAT and *SECTION is given as:

```
*MAT_COMPOSITE_DAMAGE
$A     mid        ro        ea        eb        ec      prba      prca      prcb
         1 5.0000E-9 1.3200E+5 10755.000 10755.000  0.019000  0.019000  0.490000
$#     gab       gbc       gca     kfail      aopt      macf
 5653.0000 3378.0000 5653.0000     0.000  3.000000     0.000
$#      xp        yp        zp        a1        a2        a3
     0.000     0.000     0.000     0.000     0.000     0.000
$#      v1        v2        v3        d1        d2        d3      beta
     0.000  1.000000     0.000     0.000     0.000     0.000     -90.0
$#      sc        xt        yt        yc      alph        sn       syz       szx
     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
$ -------------------------------------------------------------------------------
*SECTION_SHELL
$#   secid    elform      shrf       nip     propt   qr/irid     icomp     setyp
         1        16     0.000         4         0         0         1         0
$#      t1        t2        t3        t4      nloc     marea      idof    edgset
  1.000000  1.000000  1.000000  1.000000     0.000     0.000     0.000         0
$#      bi        bi        bi        bi        bi        bi        bi        bi
     0.000-90.000000-180.00000 90.000000     0.000     0.000     0.000     0.000
```

- This means that it can be expected that the results for IP 1 are the same as the results found for IP 3. The same is the case for IP 2 versus IP 4, they are expected to be the same.

The strength values are taken from [Chatiri et. al, 2010]

Draft

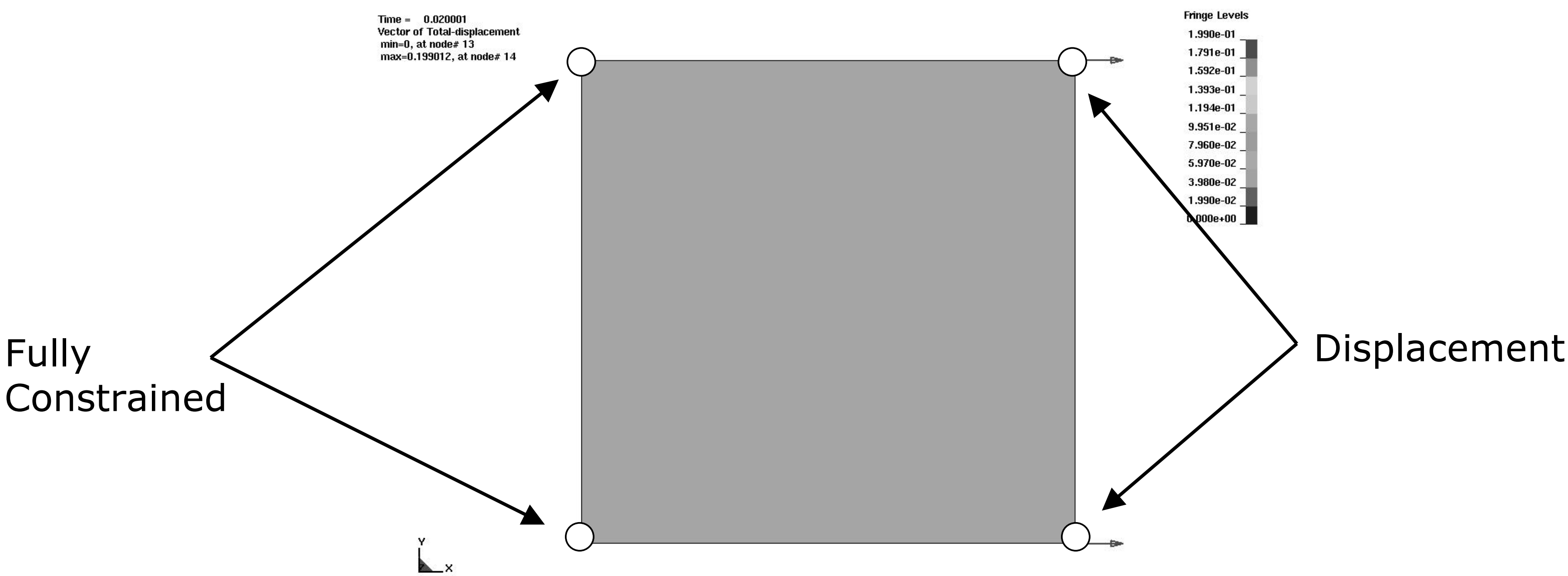
Rotation of the Coordinate System

Shells – Example 1

$$\sigma_a^{IP1} = \sigma_a^{IP3}, \quad \sigma_b^{IP1} = \sigma_b^{IP3}$$

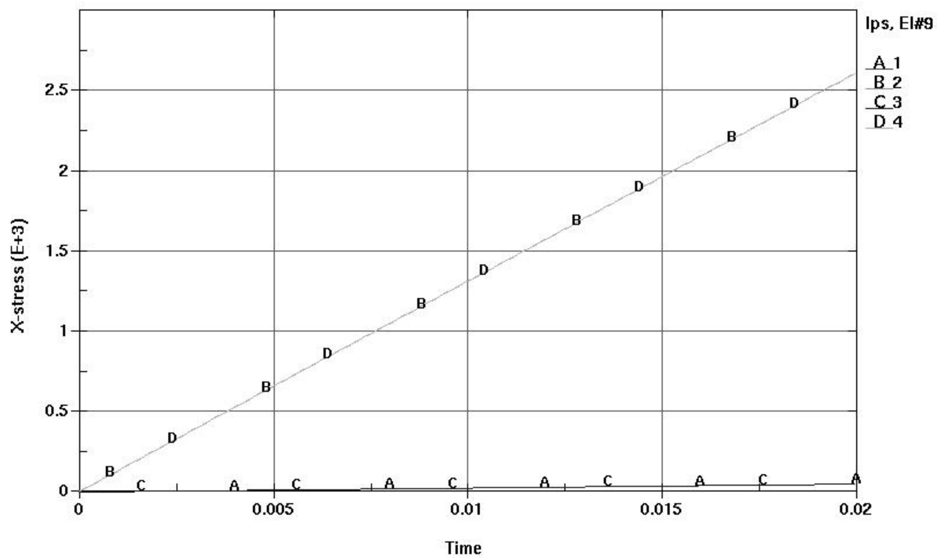
$$\sigma_a^{IP2} = \sigma_a^{IP4}, \quad \sigma_b^{IP2} = \sigma_b^{IP4}$$

- The set-up is:

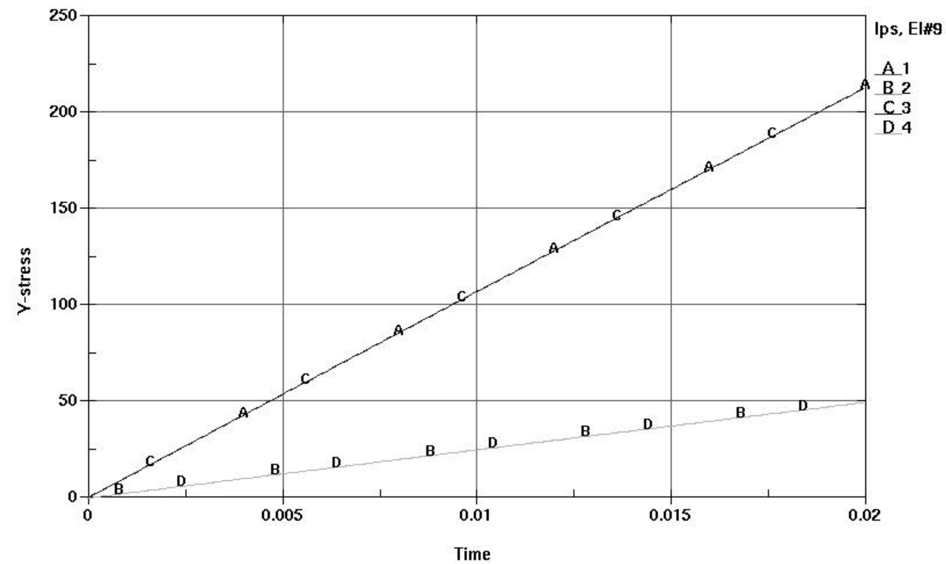


Rotation of the Coordinate System

Shells – Example 1



A=IP 1
B=IP 2
C=IP 3
D=IP 4



- The results are as expected.

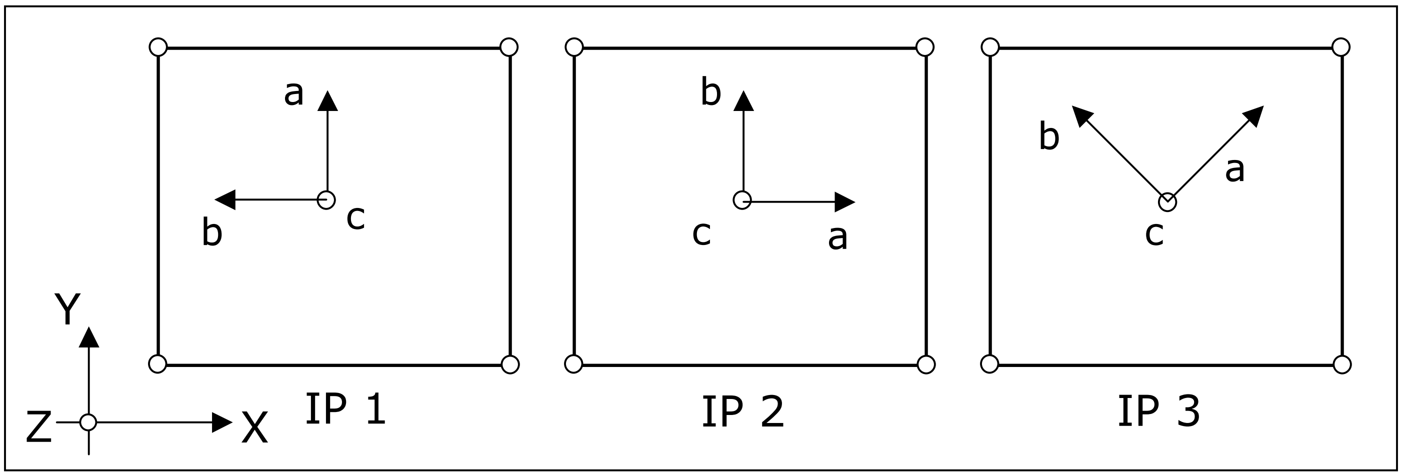
- The example shows that the BETA_MAT and BETA_SECTION are cumulative, else e.g. the results from IP 1 and IP 2 would be identical, since BETA_MAT is the same as BETA_SECTION.

Rotation of the Coordinate System

Shells – Example 2

- The set-up is the same as used in Example 1 so one single shell element constrained in one end and pulled in the other.
  - The element uses *MAT_COMPOSITE_DAMAGE and AOPT=3 where the BETA_MAT is set to 45°. The shell has there integration points and ICOMP is set to 1 at the *SECTION_SHELL card where three BETA_SECTION angles are given as 0°, -90° and -45°. The angle at the ELEMENT_SHELL card is set to 90.

- The material coordinate systems are then:



Rotation of the Coordinate System

Shells – Example 2

- The specification for *MAT, *SECTION and *ELEMENT is given as:

```
NEEDS MORE WORK
```

- This means that it can be expected that the results for IP 1 are the same in magnitude as the results found for IP 3. The same is the case for IP 2 versus IP 4, they are expected to be the same.

The strength values are taken from [Chatiri et. al, 2010]

Draft

Rotation of the Coordinate System

Shells – Example 2

$$\sigma_a^{IP1} = \sigma_b^{IP2}, \quad \sigma_b^{IP1} = \sigma_a^{IP2}$$

Rotation of the Coordinate System

Shells – Example 2

A=IP 1
B=IP 2
C=IP 3
D=IP 4

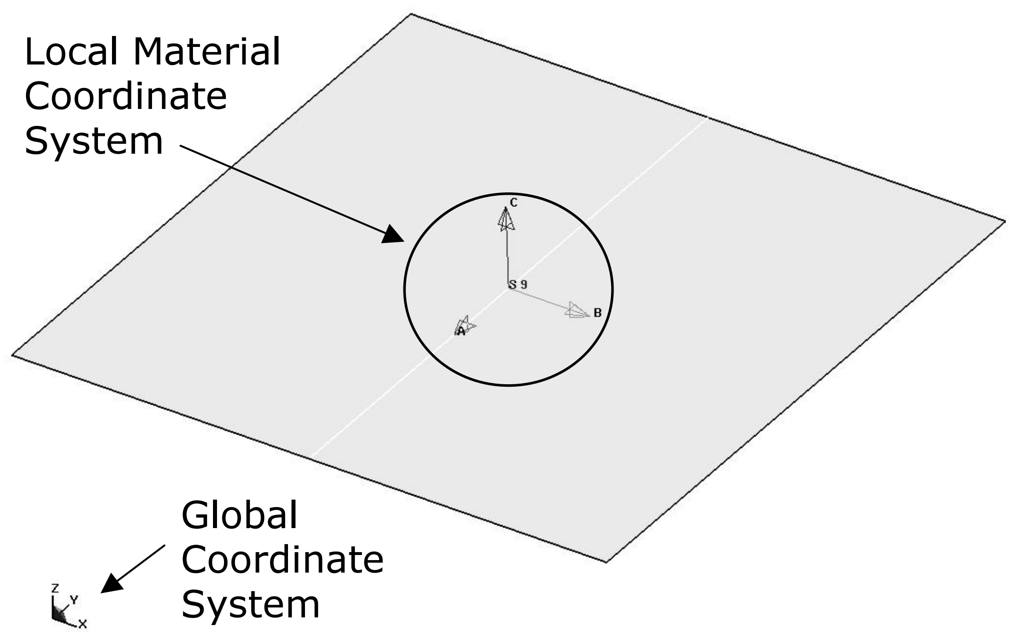
- The results are as expected.

- The example shows that the BETA_MAT and BETA_SECTION is added, else would e.g. the results from IP 1 and IP 2 be identical, since BETA_MAT is the same as BETA_SECTION.

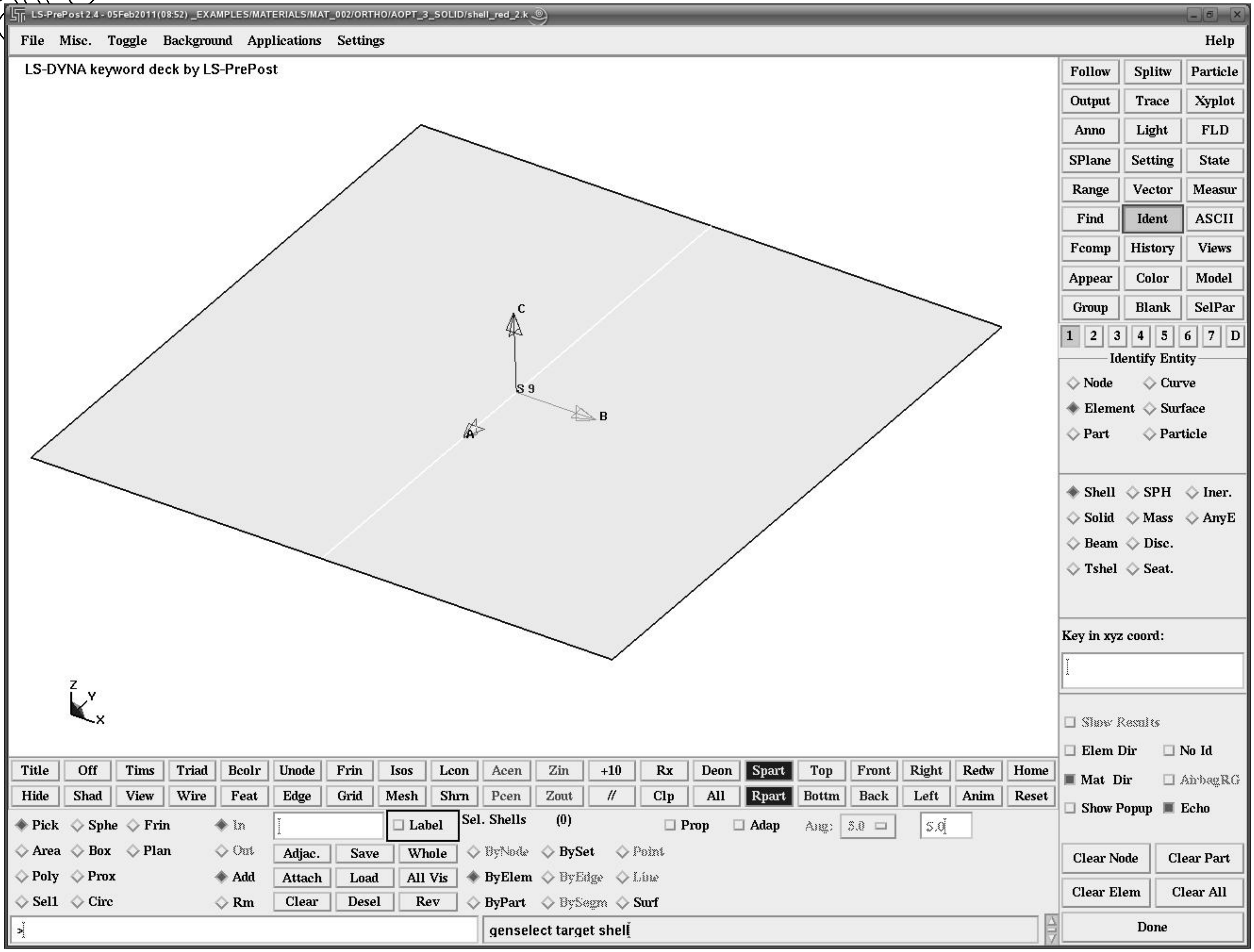
Pre and Post-processing in LS-PrePost®

Displaying the Coordinate System in LS-PrePost®

- In LS-PrePost® it is possible to show the material coordinate system that is defined in the input deck.
- This is done using the Ident button at Page 1 (when input deck is loaded):
  - Select Element
  - Select Type
  - Select Mat Dir
  - Use e.g. All Vis and *a-b-c* coordinate system is shown on the screen for each element.
  - The screen is shown in next slide.



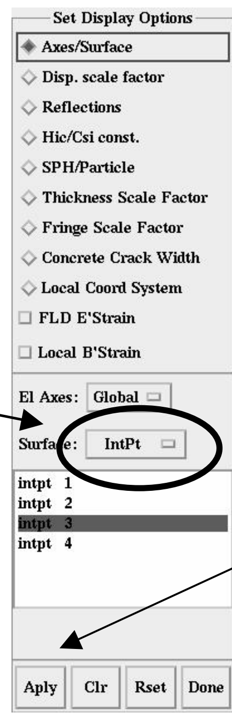
Displaying the Coordinate System in LS-PrePost®



Displaying the Coordinate System in LS-PrePost®

Draft

- As shown in the last section, shell elements can have a different material coordinate system for each integration point. In order to show these one will have to toogle between the int.Pt
- Page 1:
  - Ident -> Element -> Shell -> Mat Dir
  - Setting -> Surface -> IntPt -> Toogle between int.Pt and use Aply to apply



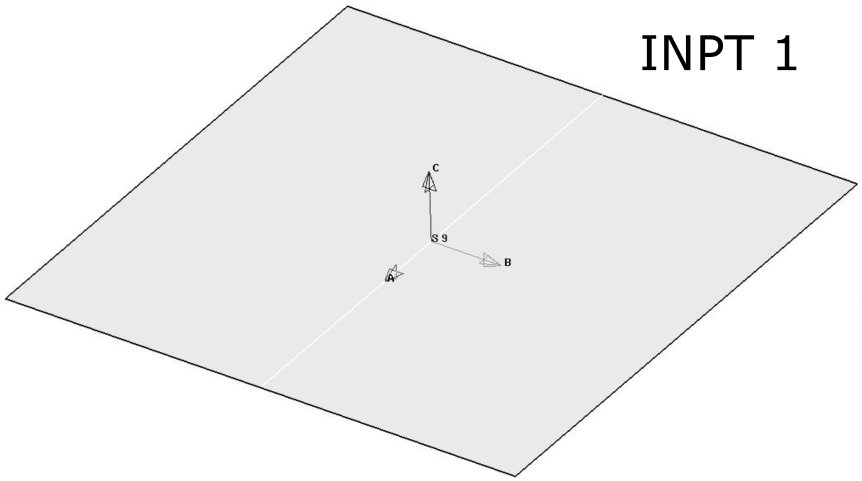
Roll Down Menu with options. Maxima is default and must be changed to IntPt for integration points

Aply is used to apply selected integration point.

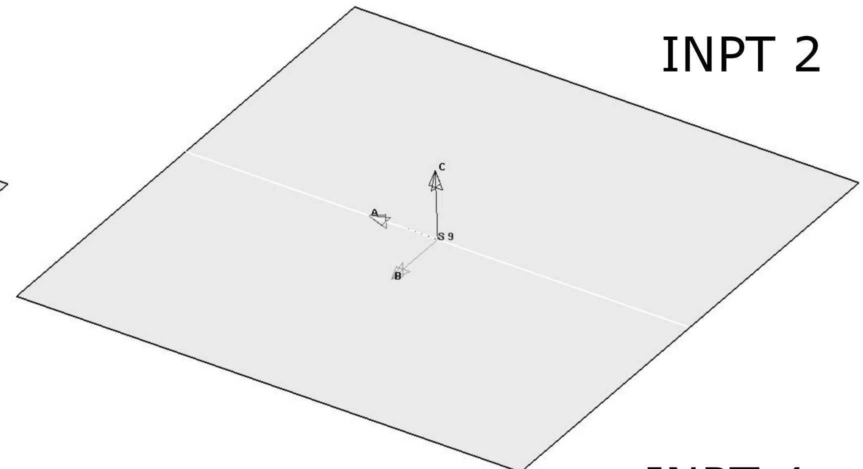
Displaying the Coordinate System in LS-PrePost®

- For shell example 1 in the last section, the four shown coordinate systems are then shown as:

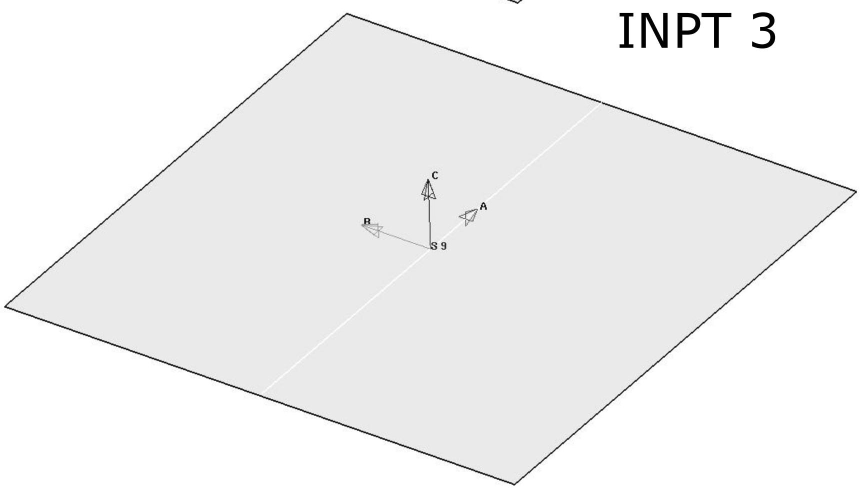
INPT 1



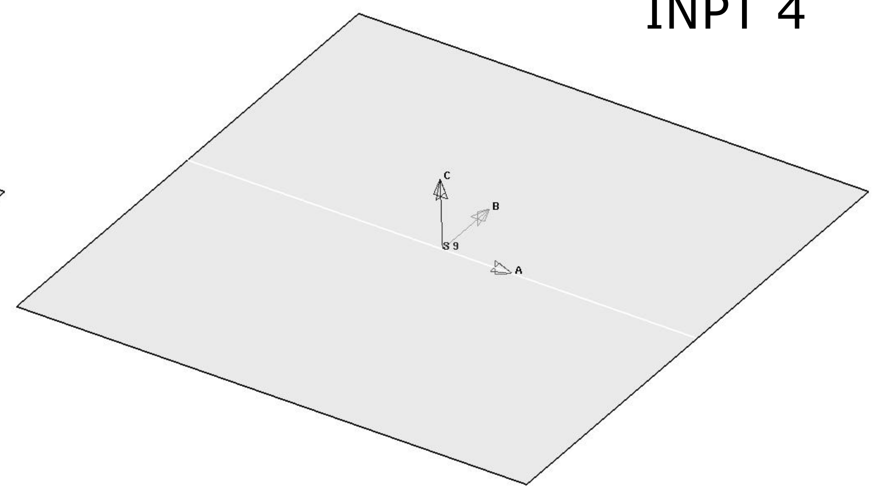
INPT 2



INPT 3



INPT 4



Plotting *a-b-c* results in LS-PrePost®

- When using a material coordinate system one also would like to postprocess the stresses in this local material coordinate system. This is not done by default but has to be specified.
- This is done by using the CMPFLG flag at the *DATABASE_EXTENT_BINARY card.
- The stresses and strains in LS-PrePost® are then:
  - Component in *a* direction is found by plotting results for X direction.
  - Component in *b* direction is found by plotting results for Y direction.
  - Component in *c* direction is found by plotting results for Z direction.
- The labels in the fringe and history plots will <u>not</u> change when plotting.
- The "Global/local" button in LS-PrePost® (Page 1 – bottom) has no relevance for the material coordinate system. That is for plotting results in the local element coordinate system.

```
*DATABASE_EXTENT_BINARY
$#   neiph     neips    maxint    strflg    sigflg    epsflg    rltflg    engflg
         0         0         4         1         0         0         0         0
$#  cmpflg    ieverp    beamip     dcomp      shge     stssz    n3thdt   ialemat
         1         0         0         0         0         0         0         0
$# nintsld   pkp_sen      sclp    unused     msscl     therm    intout    nodout
         0         0  1.000000         0         0         0
```

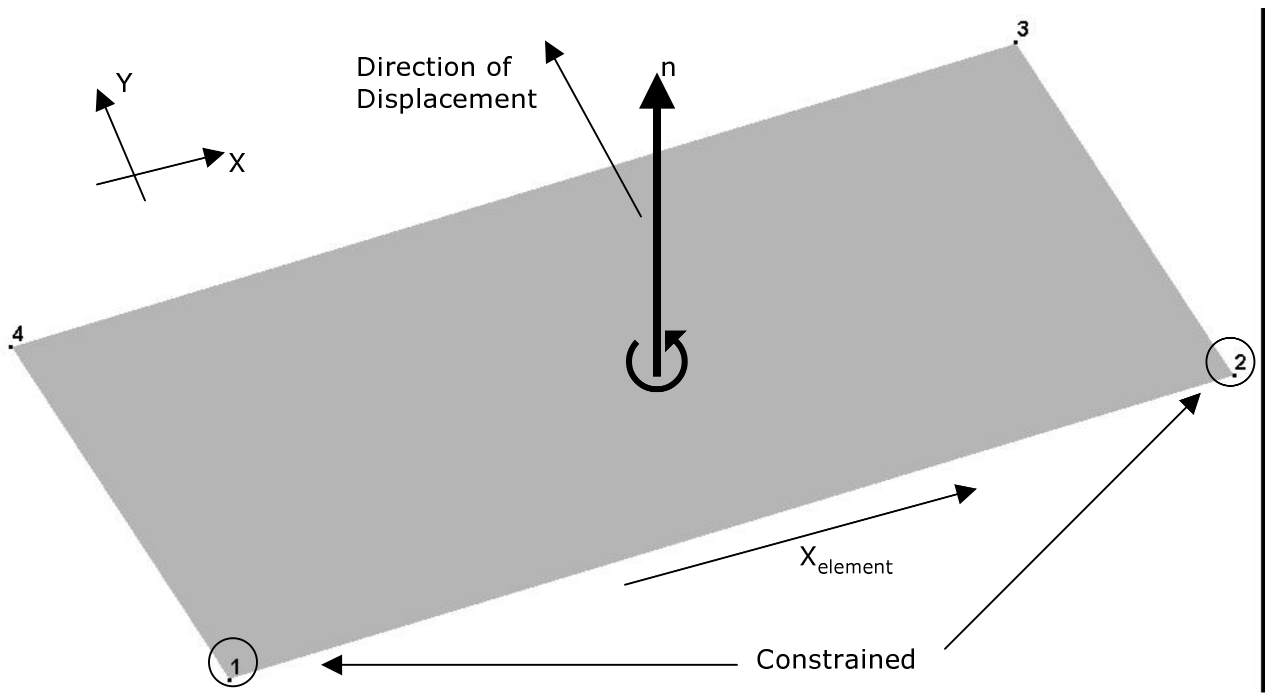
Draft

Examples

Examples

AOPT=2

- In this example is modeled four single shells, which are fully constrained at one side and pulled at the opposite side. They all have different specification as shown in the following.
- The shell is aligned so the maximal stress is in the global Y direction and the local element x axis ($x_{element}$) is in the global X direction. The element connectivity is defined so that the shell normal (n) is in the global Z direction.



Examples

AOPT=2

- The material model used is *MAT_COMPOSITE_DAMAGE (*MAT_022).

- The four different cases all uses AOPT=2 and has the same initial a,b,c material coordinate system. Different options are then used to rotate this coordinate system, in all cases the angle is 90°. The four cases are:

  - CASE A: No rotation
  - CASE B: The rotation is done by used ICOMP=1 and specifying BETA for each integration point at *SECTION_SHELL.
  - CASE C: One BETA angle is given at *ELEMENT_SHELL_BETA
  - CASE D: The BETA angle is calculated by LS-DYNA® by using a local coordinate system, which x-axis is projected down to element surface in order to calculate BETA. This is specified at *ELEMENT_SHELL_MCID. The option is new in the 971 version.

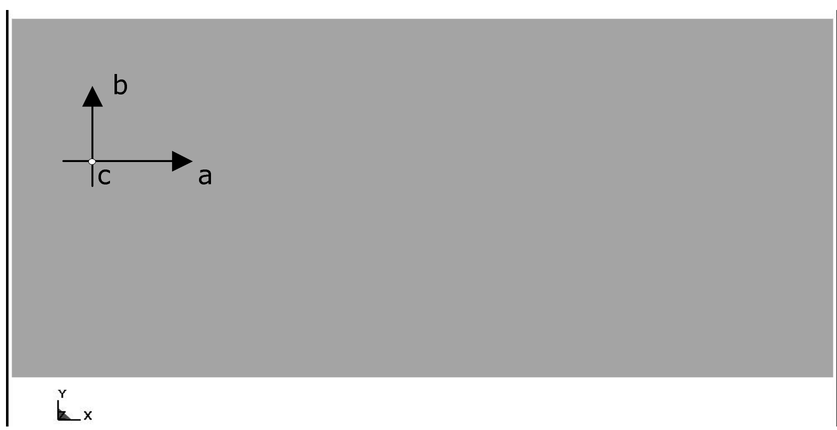
Draft

Examples

AOPT=2

Case A:

- AOPT=2 is used with a_{given} = (1, 0, 0). This gives the following local material coordinate system directions a, b, c:
  - c = n = Z
  - b = c x a_{given} = Y
  - a = b x c = X = a_{given}
- With the max deformation, the maximum stress is in the global Y, which is the material direction b. Since CMPFLG is set to 1, the stresses are outputted in the material directions in the *d3plot* database. In LS-PrePost®, there stresses are X=a, Y=b and Z=c. This means that in this case the maximum stress in LS-PrePost® should be σ_Y.



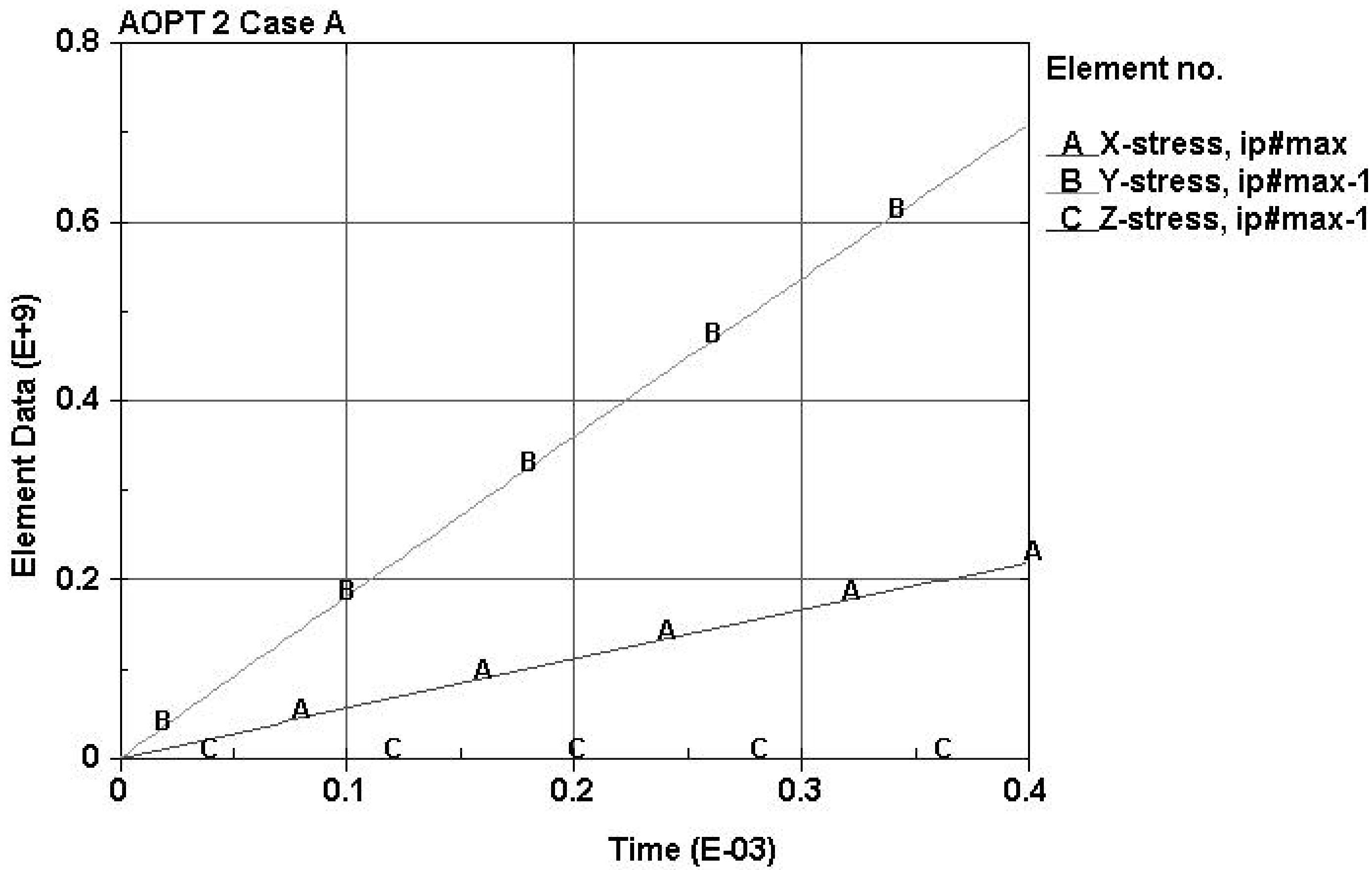
Examples

AOPT=2

Draft

Case A:

- The results from LS-PrePost® shows that the maximum stresses are in the global Y direction:



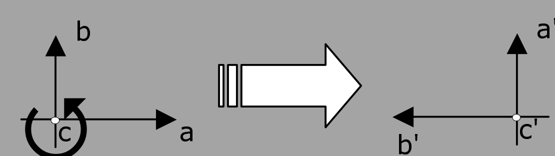
Examples

Case B: AOPT=2

- AOPT=2 is used with a_{given} = (1, 0, 0). This gives the same local material coordinate system directions as in Case A, however now this system is rotated 90° by setting ICOMP=1 and specifying B1 = B2 = B3 = 90° at *SECTION_SHELL, resulting in the a', b', c' material coordinate system.

```
*SECTION_SHELL
$#   secid    elform      shrf       nip     propt   qr/irid     icomp     setyp
         2         2  1.000000         3                             1
$#      t1        t2        t3        t4      nloc     marea      idof    edgset
  3.800000  3.800000  3.800000  3.800000
       90.       90.       90.
```

- With the max deformation, the maximum stress is in the global Y, which is the material direction a'. This means that in this case the maximum stress in LS-PrePost® should be σ_X.



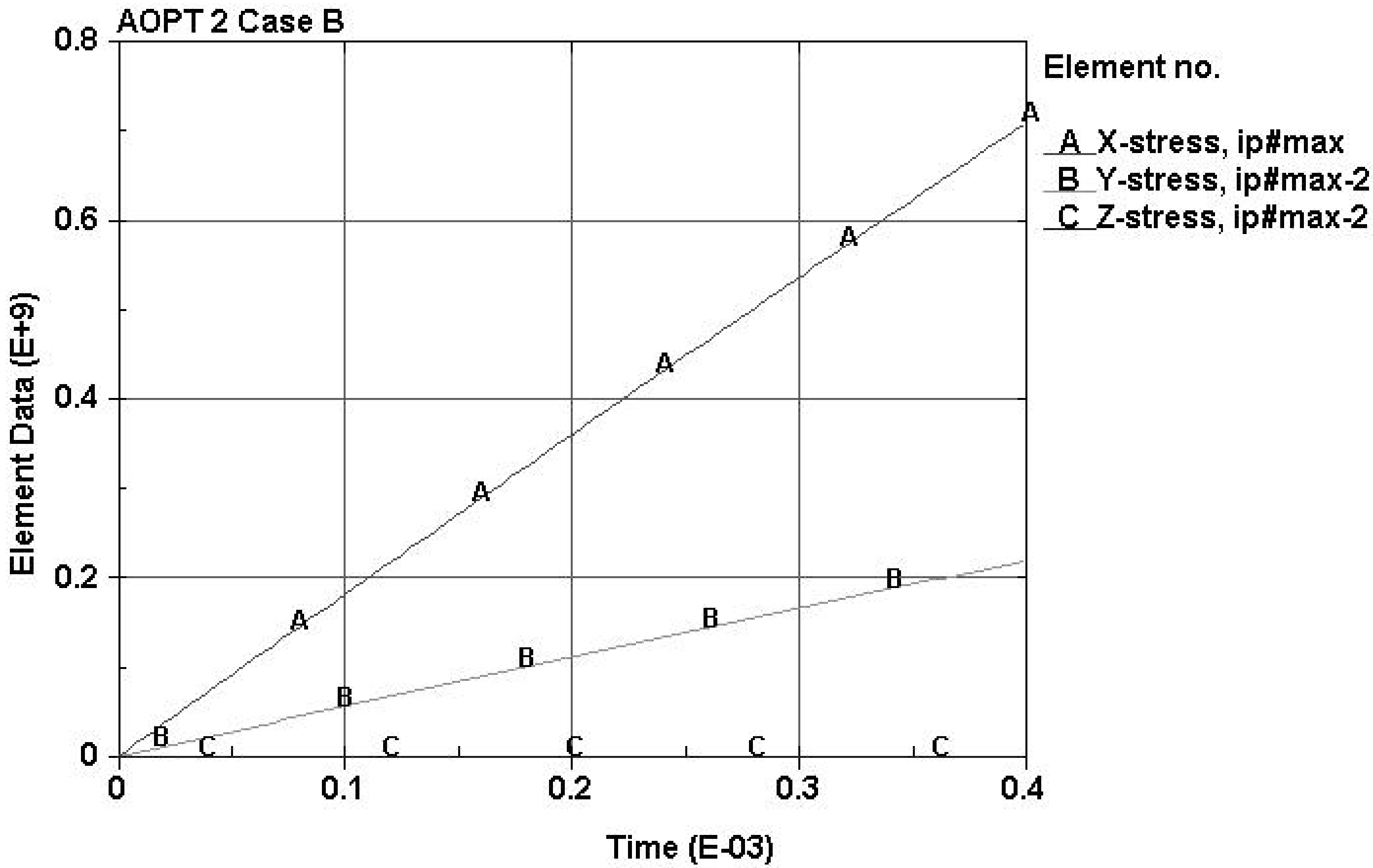
Rotating coordinate system 90° around the shell normal

Examples

AOPT=2

Case B:

- The results from LS-PrePost® shows that the maximum stresses are in the global X direction:



Examples

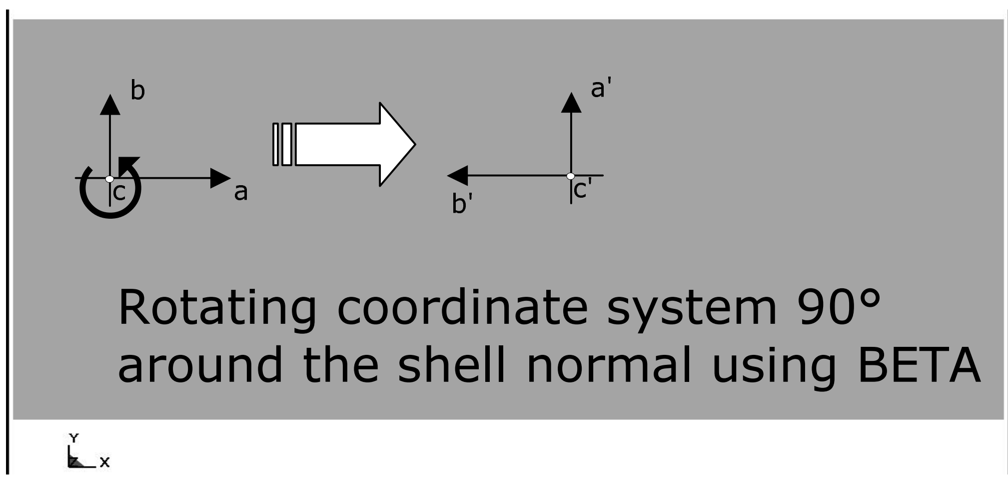
AOPT=2

Case C:

- AOPT=2 is used with a_{given} = (1, 0, 0). This gives the same local material coordinate system directions as in Case A and B, however now this system is rotated 90° by setting BETA = 90 at *ELEMENT_SHELL_BETA.

```
*ELEMENT_SHELL_BETA
$#   eid     pid      n1      n2      n3      n4      n5      n6      n7      n8
       3       3       9      10      11      12
$   T1, T2, T3, T4, BETA
 , , , ,90.
```

- With the max deformation, the maximum stress is in the global Y, which is the material direction a'. This means that in this case the maximum stress in LS-PrePost® should be σ_X.



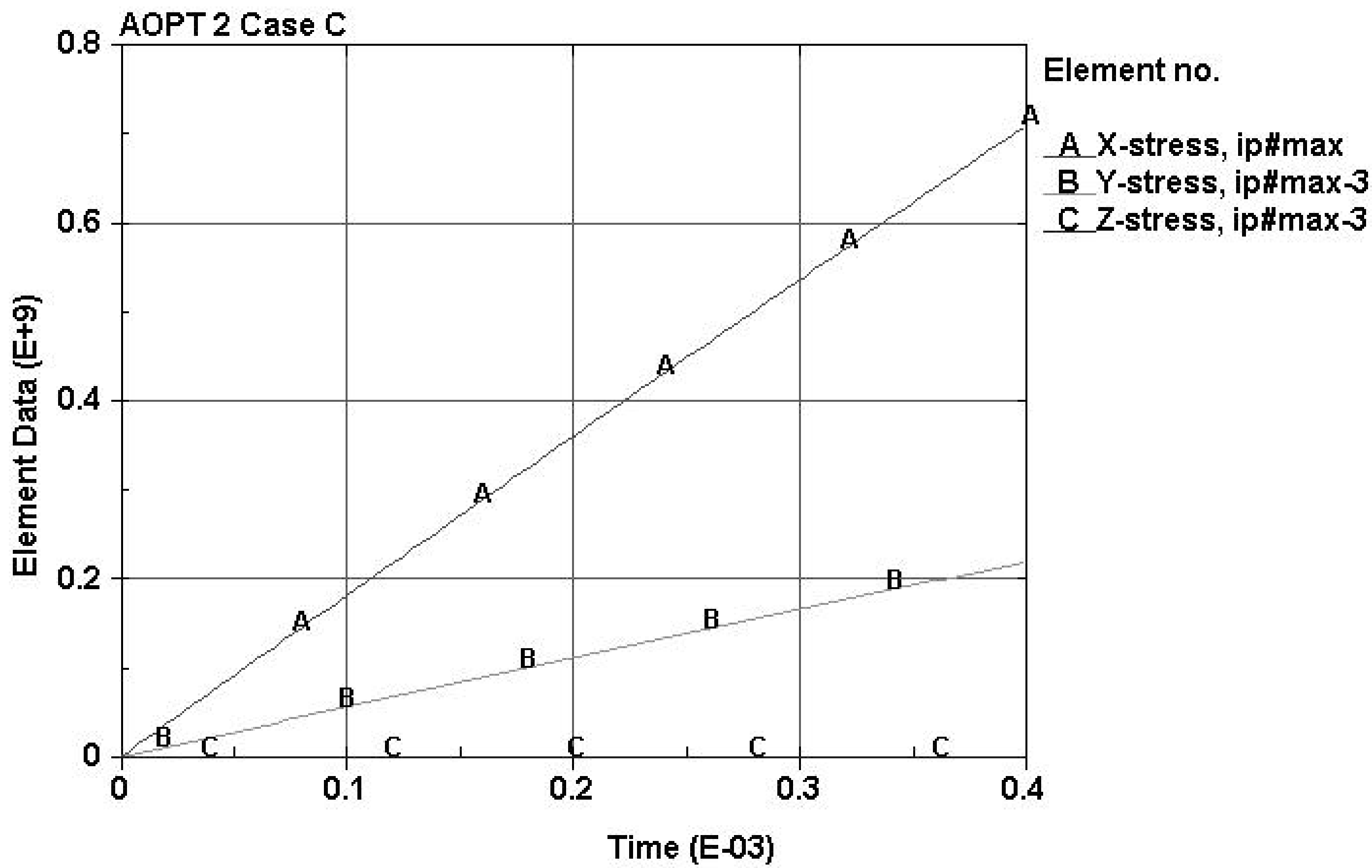
Draft

Examples

AOPT=2

Case C:

- The results from LS-PrePost® shows that the maximum stresses are in the global X direction:



Examples

Case D: AOPT=2

- AOPT=2 is used with a_{given} = (1, 0, 0). This gives the same local material coordinate system directions as in Case A, B and C, however now this system is rotated 90° by *ELEMENT_SHELL_MCID to obtain the a’, b’, c’ material coordinate system.

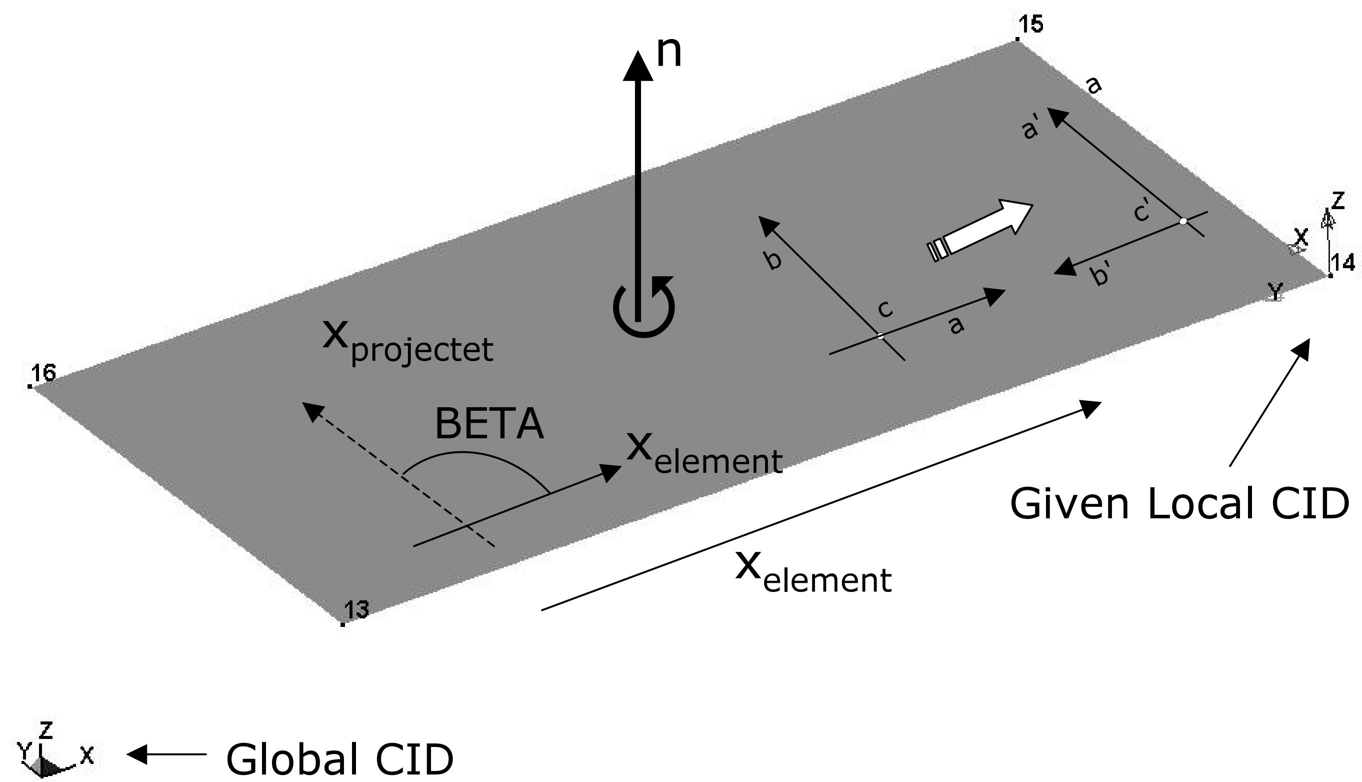
```
*ELEMENT_SHELL_MCID
$#   eid     pid      n1       n2       n3       n4       n5       n6       n7       n8
       4       4      13       14       15       16
 , , , ,1
$ ----------------------------------------
*DEFINE_COORDINATE_NODES
$#     cid         n1         n2         n3      flag       dir
         1         14         15         13
```

- This option projects the x-axis of a given local coordinate system down to the shell surface resulting in $x_{projected}$. Then a rotation angle, BETA, is calculated between this projected axis and the local element axis, $x_{element}$. This BETA angle is now used to rotate the a, b, c material coordinate system around the shell normal giving the resulting a’, b’, c’ material coordinate system. This option is new in the ls971 version of LS-DYNA®.

Examples

Case D: AOPT=2

- The defined local CID has x_{local} = Y, y_{local} = -X and z_{local} = Z as shown in the figure. The angle BETA between $X_{projectet}$ and $x_{element}$ is calculated to 90°, which then rotates the a, b, c material system into the a', b', c' material coordinate system.

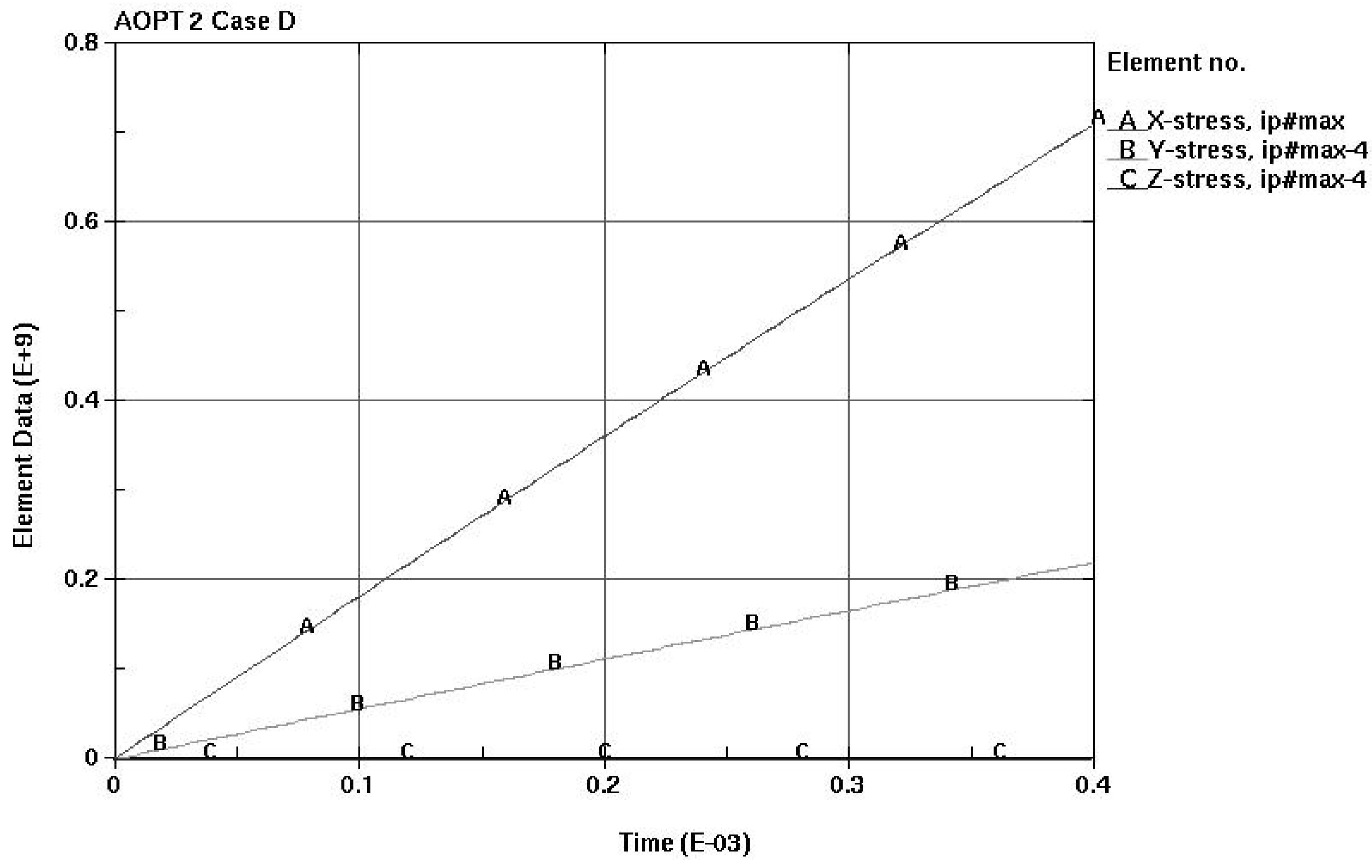


Examples
AOPT=2

Draft

Case D:

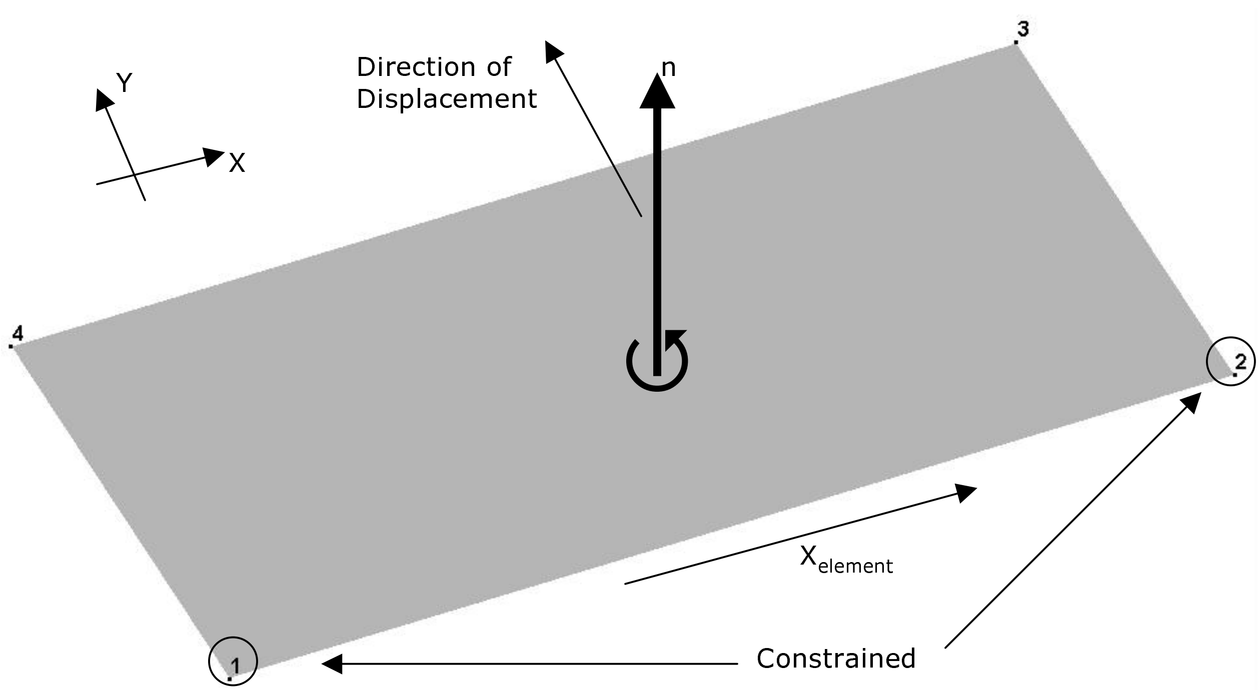
- The results from LS-PrePost® shows that the maximum stresses are in the global X direction as expected:



Examples

AOPT=|-CID|

- In this example is modeled four single shells, which are fully constrained at one side and pulled at the opposite side. They all have different specification as shown in the following.
- The shell is aligned so the maximal stress is in the global Y direction and the local element x axis ($x_{element}$) is in the global X direction. The element connectivity is defined so that the shell normal (n) is in the global Z direction.



Examples

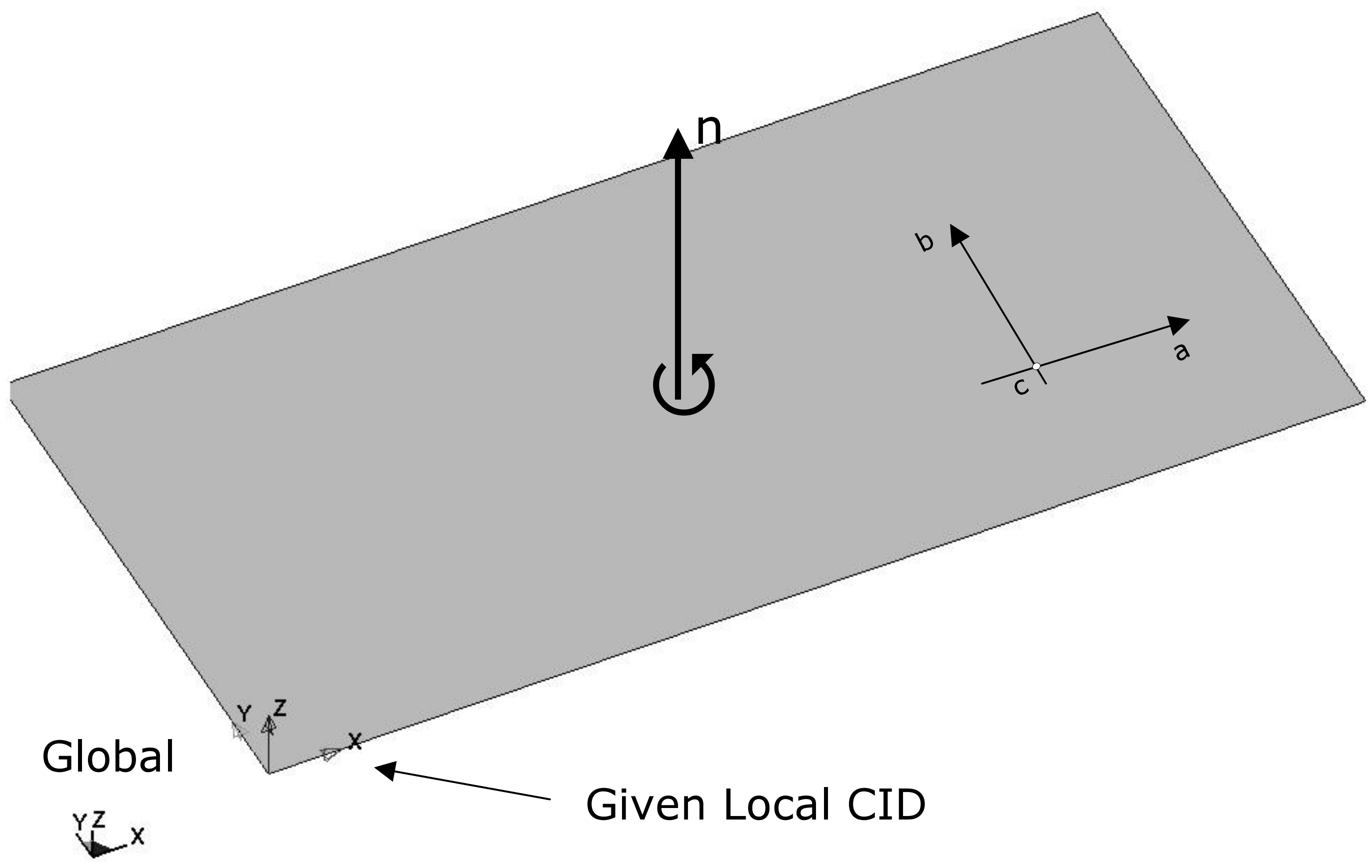
AOPT=|-CID|

- The material model used is *MAT_COMPOSITE_DAMAGE (*MAT_022).
- The four different cases all uses AOPT=|-CID|, given at the *MAT_COMPOSITE_DAMAGE card.
- The four different shells use four different local coordinate systems that are to be projected down to the element surface.
- The material coordinate system a, b, c is determined from the projected x_{local}, y_{local}, z_{local} system as:
  - $a = x_{local,projected}$
  - c = n (shell normal)
  - b = c x a

Examples

Case A: AOPT=|-CID|

- The defined local CID (CID=1) has x_{local} = X, y_{local} = Y and z_{local} = Z as shown in the figure. This means that the material coordinate system a, b, c has same directions as the global X, Y, Z coordinate system.



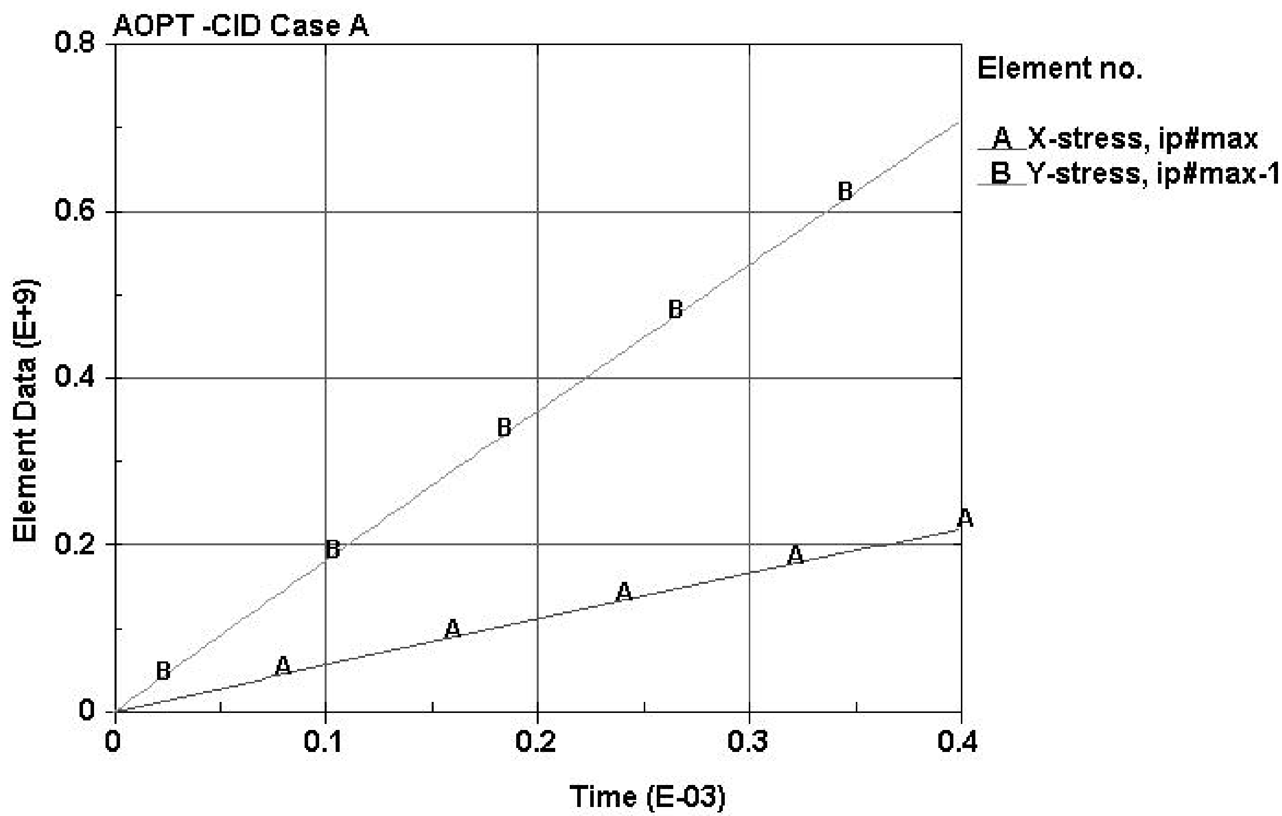
Draft

Examples

AOPT=|-CID|

Case A:

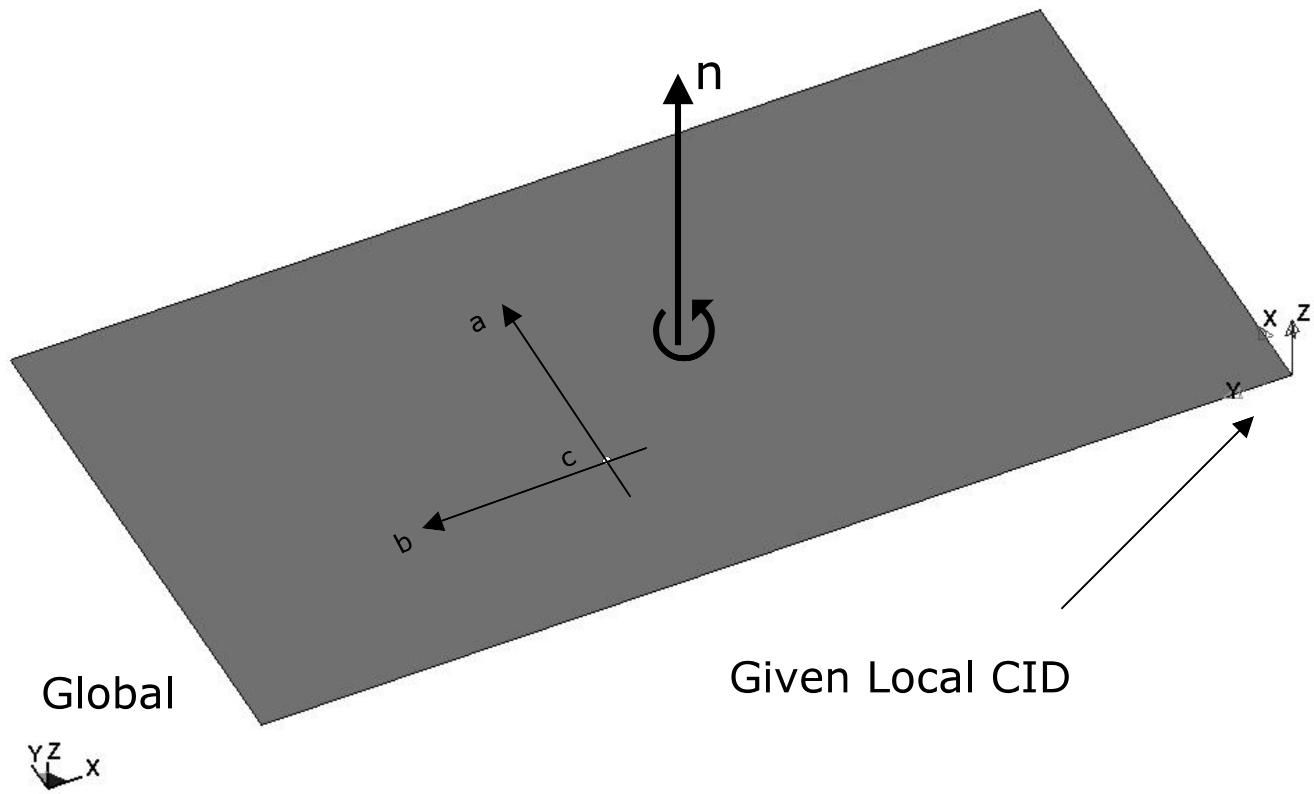
- The maximum stress is in global Y, which is the b material direction. Therefore, the maximum stress is in the Y direction in LS-PrePost®. The results from LS-PrePost® confirm this.



Examples

Case B: AOPT=|-CID|

- The defined local CID (CID=2) has x_{local} = Y, y_{local} = -X and z_{local} = Z as shown in the figure. This means that the material coordinate system a, b, c is a = Y, b = -X and c = Z.

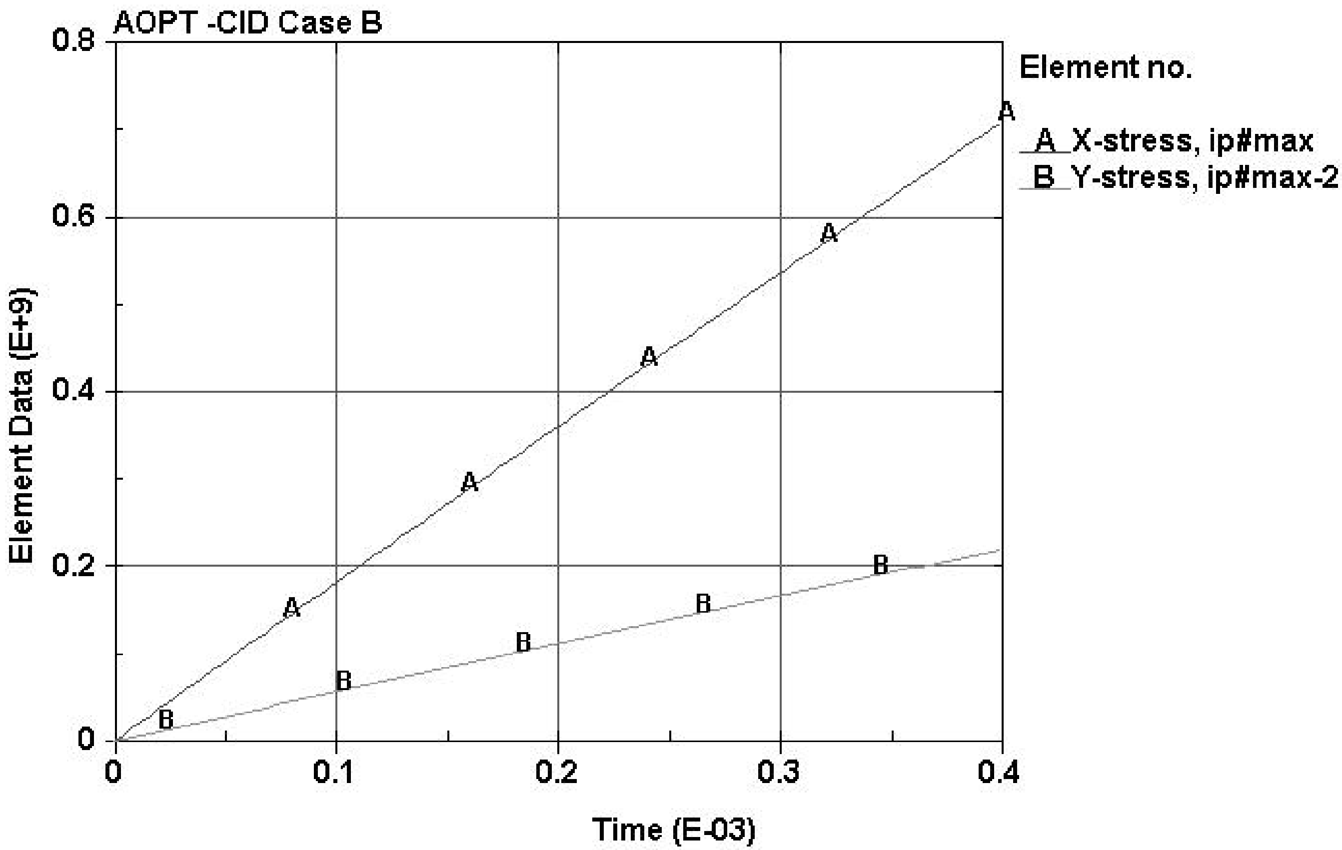


Examples

AOPT=|-CID|

Case B:

- The maximum stress is in global Y, which in this case is the a material direction. Therefore, the maximum stress is in the X direction in LS-PrePost®. The results from LS-PrePost® confirm this.

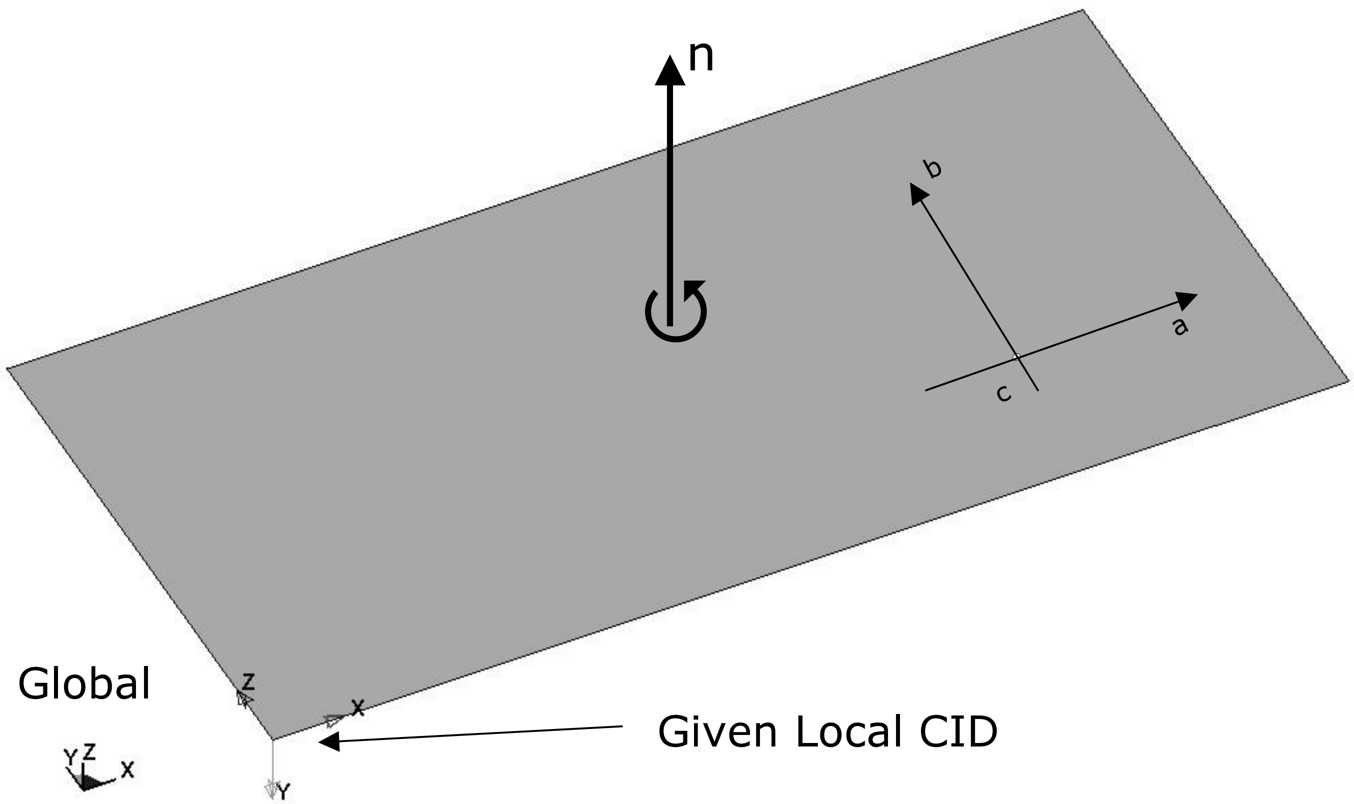


Examples

AOPT=|-CID|

Case C:

- The defined local CID (CID=3) has x_{local} = X, y_{local} = -Z and z_{local} = Y as shown in the figure. This means that the material coordinate system a, b, c is a = X, b = Y and c = Z.



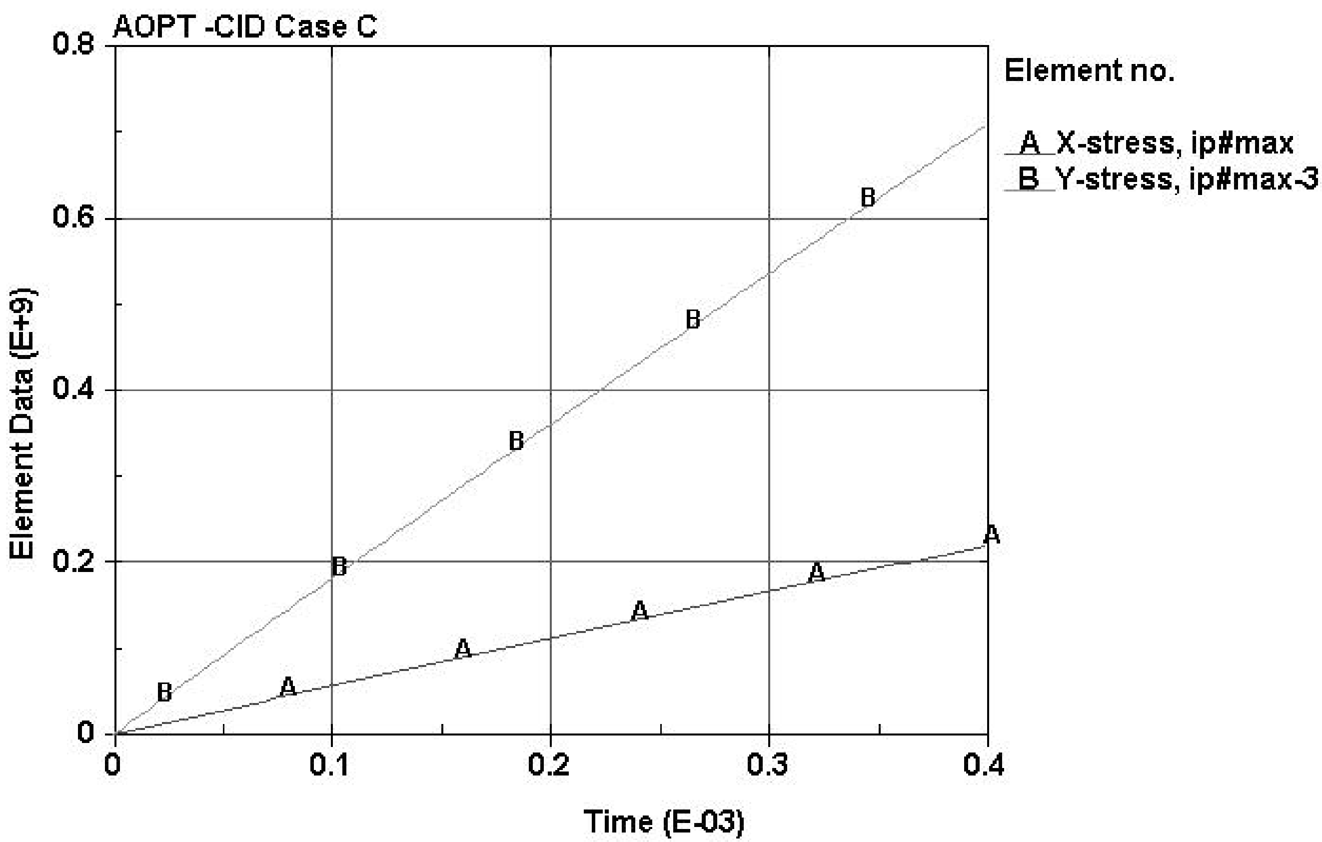
Examples

AOPT=|-CID|

Draft

Case C:

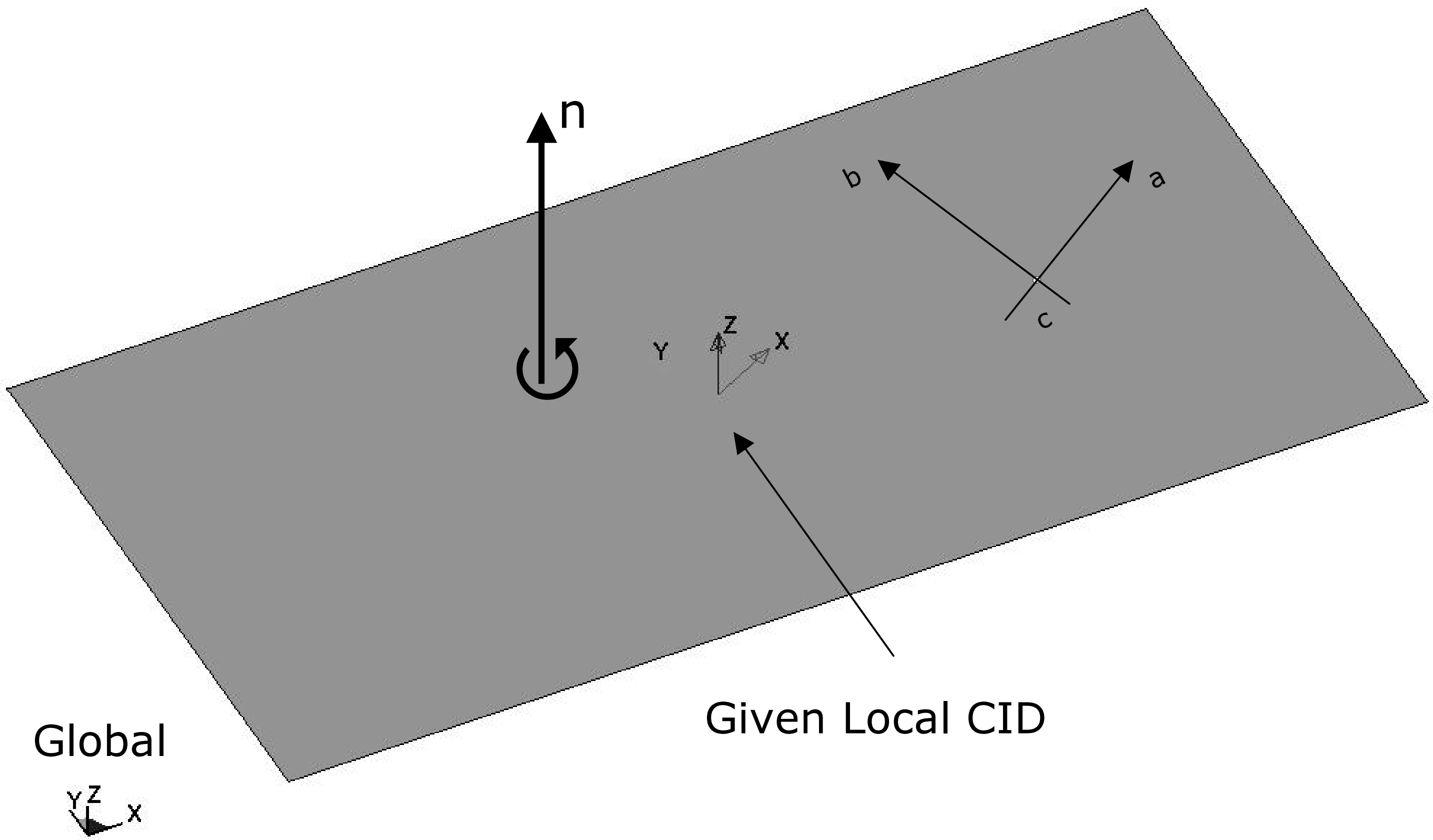
- The maximum stress is in global Y, which in this case is the b material direction. Therefore, the maximum stress is in the Y direction in LS-PrePost®. The results from LS-PrePost® confirm this.



Examples

Case D: AOPT=|-CID|

- The defined local CID (CID=4) is rotated 45 counterclockwise around the shell normal as shown in the figure. This means that the material coordinate system a, b, c has same directions as the local defined coordinate system.



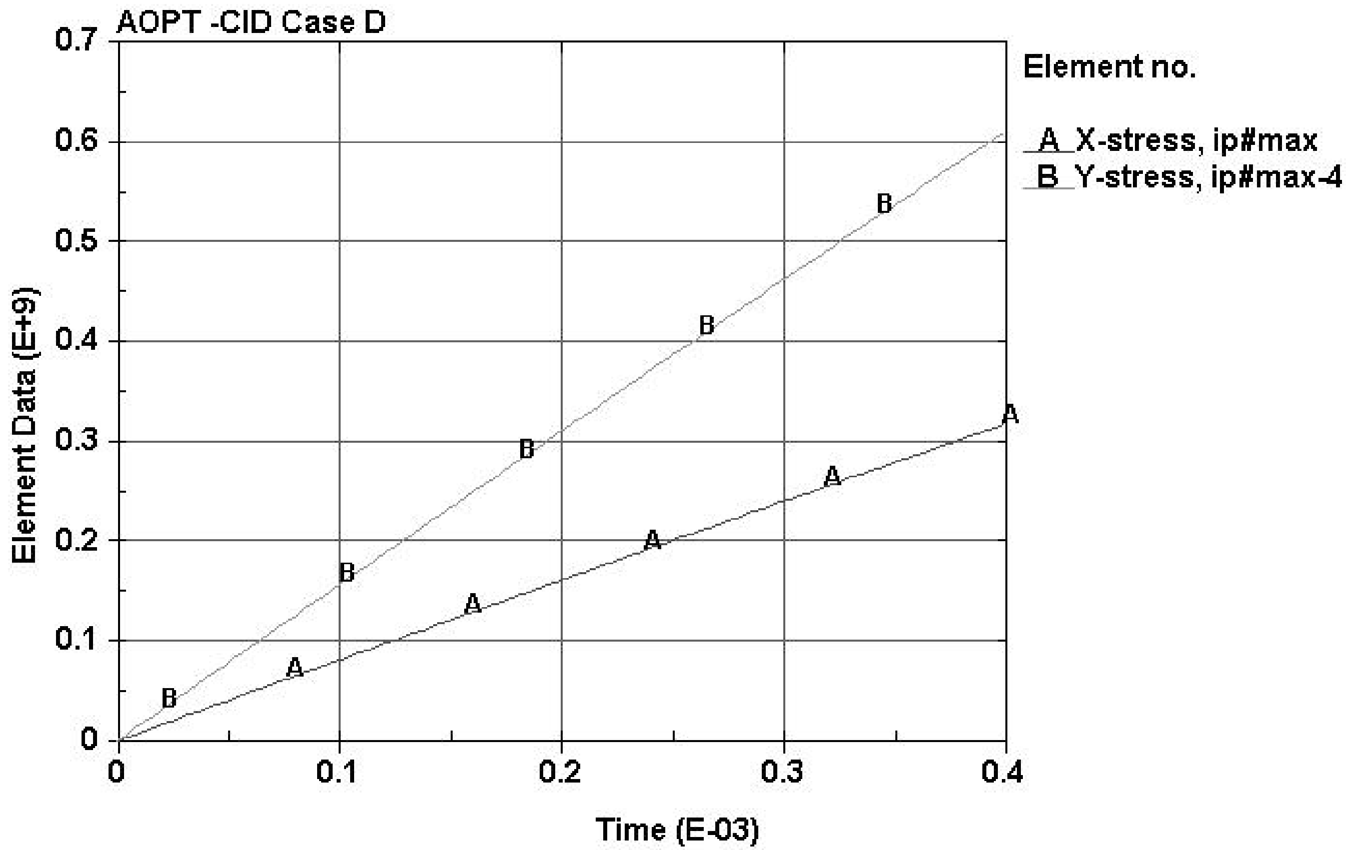
Examples

AOPT=|-CID|

Draft

Case D:

- The maximum stress is not in any of the main directions but is in an off angle direction.



Draft

References

Draft

References

[Belytschko et al, 1981]

T. Belytschko and C. S. Tsay, "Explicit Algorithms for Nonlinear Dynamics of Shells", AMD, 48, ASME, 1981, Page 209-231.

[Chatiri et al., 2010]

M. Chatiri, T. Schütz and A. Matzenmiller, "An Assessment of the New LS-DYNA® Multi-Layered Solid Element: Basics, Patch Simulation and its Potential for Thick Composite Structural Analysis", 11th International LS-DYNA® Users Conferences, June 6-8, 2010, Dearborn, Michigan, USA, ISBN 0-9778540-5-1, Page 2-1:2-18.

[Hallquist, 2006]

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