

manual  
VCS  
visual crash studio

THEORETICAL  
BACKGROUND



*The fastest way in Pre Design*

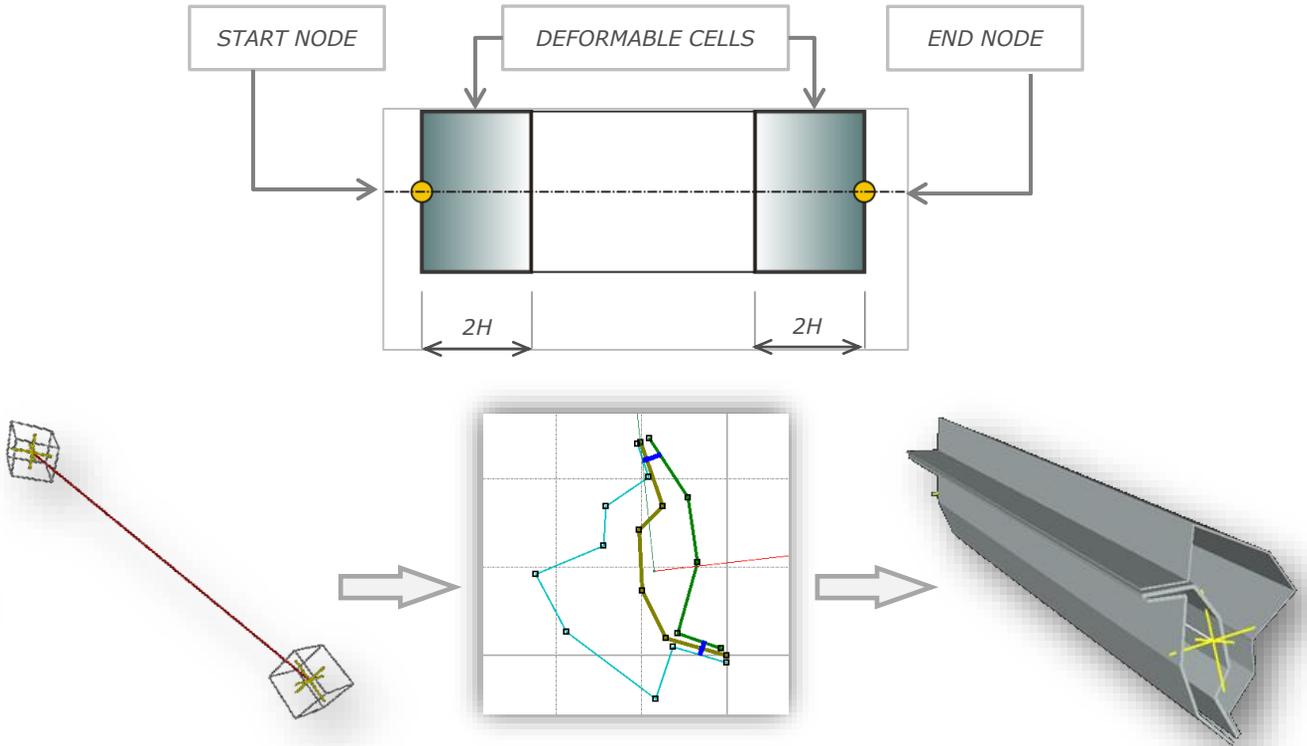
# SUPER BEAM'S PROPERTIES

## Important :

After being created in the VCS 3D view, the Super Beam has no mechanical properties which must be defined in the Beam Properties window.

In other words a Cross Section needs to be assigned to each end of the Super Beam.

## Mechanical Response of a Super Beam

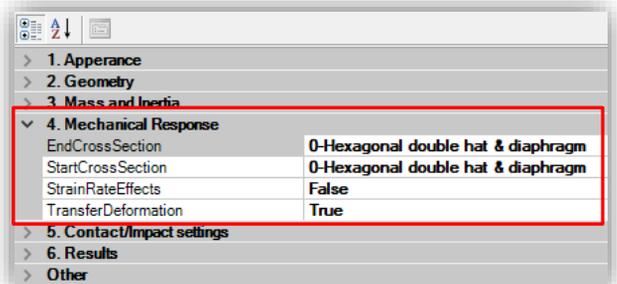


In the Properties window of the Super Beam you can define mechanical response of the beam. In the Mechanical Response section of the Properties window you will find the Start Cross Section and End Cross Section field which will display a drop-down list with all thin walled cross sections defined in the Solution. One cross section should be selected as Start and one as End deformable cells of the Super Beam.

If the same cross section is defined at the start and end nodes the prismatic Super Beam is created. In the case of different cross section a stepped Super Beam is created. In the Solution 3D view the defined Super Beam will be automatically visible.

Moreover in the **Mechanical Response** section you will find:

- Strain Rate Effect field – in this field you can switch on/off ('True' / 'False') the strain rate sensitivity of the Super Beam Material.
- Transfer Deformation field - in this field you can switch on/off ('True' / 'False') deformation transfer to elements connected to end Nodes of the selected Beam.



## **Orientation of the Beam**

Important point in definition of a Super Beam is proper handling of Beam orientation in the global coordinate system.

Global (reference) coordinate system of VCS is denoted by capital letters  $\{X, Y, Z\}$ . The local (corotational) coordinate systems are denoted by small letters  $\{x, y, z\}$ . On the 3D views of VCS coordinate systems are marked by color lines of various thicknesses:

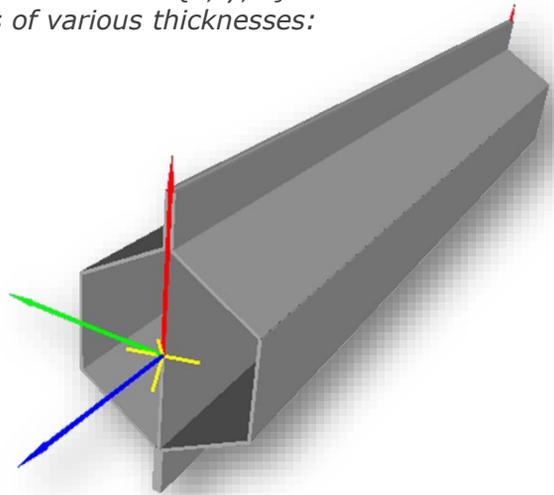
**Red** – local and global x axes

**Green** – local and global y axes

**Blue** – local and global z axes

Thicknesses 1 pixel (corotational frames):

- global coordinate system
- node corotational frame
- rigid bodies
- honeycomb barriers



Thickness 2 pixels (corotational frames) – Super Beams

## **Corotational Frames**

All local frames of reference in VCS are defined as corotational Euclidean frames. The corotational frame is a frame rigidly attached to an object. The corotational frame moves and rotates together with an object. The most common example of a corotational frame is the central principal coordinate system of a rigid body: frame is rigidly attached to the center of mass, corotational axes coincide with principal axes. In the case of deformable objects corotational frame is typically coupled with principal stress or strain directions (3D elements) or principal axes (beam elements).

The concept of local corotational frame greatly simplifies formulation and numerical solution to nonlinear systems since all the nonlinear terms related to rigid body rotation are effectively handled by the kinematics of corotational frame.

The corotational frame is sometimes confused with a curvilinear coordinate system where base vectors are functions of the deformation. Since the corotational system is simply a rotated global system this interpretation is incorrect.

## **Position and Orientation of Beam Element**

The following nomenclature is used in VCS Super Beam formulation:

- Position of a beam is defined by the spatial position of centroid spanned between two limit nodes of the beam, the start node and the end node.
- Orientation of a beam is defined by a corotational frame attached to the boundary cross sections (start and end) of a beam. The initial position of the corotational frame coincides with (elastic) principal axes of the beam (the origin lies at the centroid line, axes are parallel to principal axes).

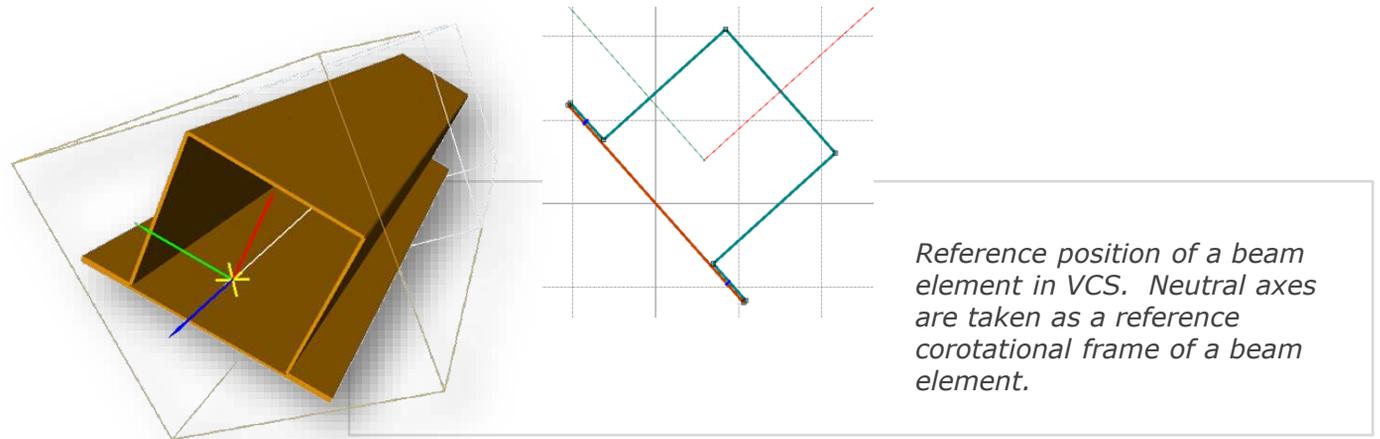
Note that in the case of tapered, stepped or user defined beams orientation of corotational frames at start and end of the Super Beam may differ.

# SUPER BEAM'S PROPERTIES

## Reference Position of Beam Element

The definition of local coordinate system of a Super Beam follows standards of classic beam mechanics. In the reference position the centroid of the beam element is along z axis while cross section lies in the  $\{x, y\}$  plane. In the reference VCS configuration, the centroid of a beam coincides with Z axis of global system (the start node is in the origin of global system the end node at positive Z axis).

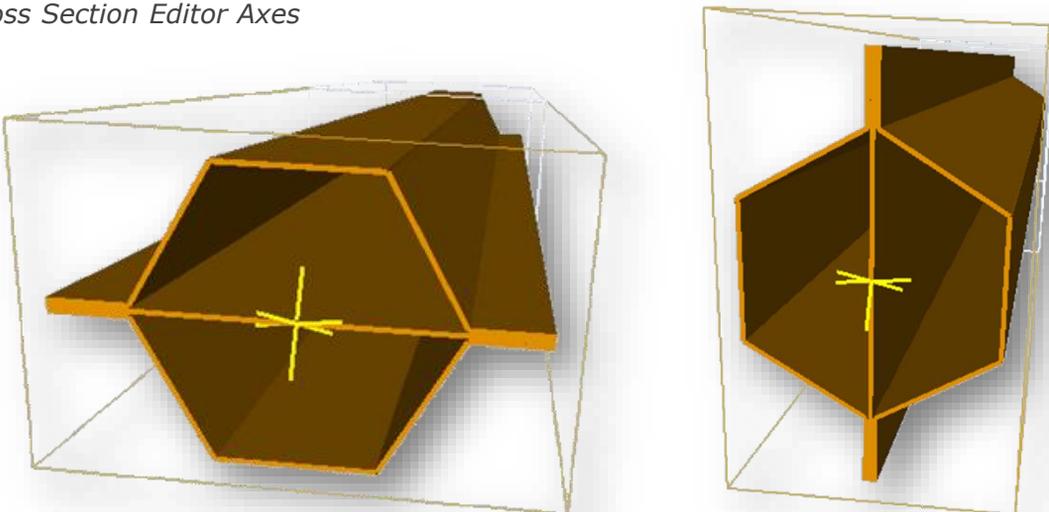
It should be remembered that by default VCS uses neutral axes system of the cross section as a corotational frame of beam element. Therefore, in the reference configuration shown below the neutral axes rather than axes of Cross Section Editor are parallel to the global axes.



Orientation of a beam can also be defined by using orientation of the coordinate system. In the Geometry section of the Properties window the Orientation Angle field defines angular position of the cross section with respect to the local coordinates system attached to the beam's centroid. In this field the setting of the Rotation (in deg.) of the Super Beam around centroid axis from the default position is done.

In the Geometry section of the Properties window you will find the Reference Frame 2D field. The Reference Frame 2D defines the reference set of cross sectional axes. In the reference Beam position (centroid along global Z axis) global X, Y axes can be parallel to:

- Neutral Axes of Cross Section
- Cross Section Editor Axes

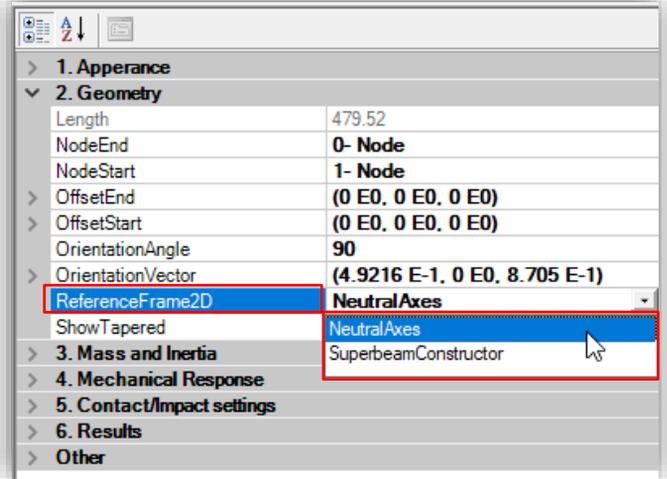


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The definition of local coordinate system of a Super Beam follows standards of classic beam mechanics. In the reference position the centroid of the beam element is along z axis while cross section lies in the  $\{x, y\}$  plane.

In the reference VCS configuration the centroid of a beam coincides with Z axis of global system (the start node is in the origin of global system the end node at positive Z axis).

It should be remembered that by default VCS uses neutral axes system of the cross section as a co-rotational frame of a Beam.

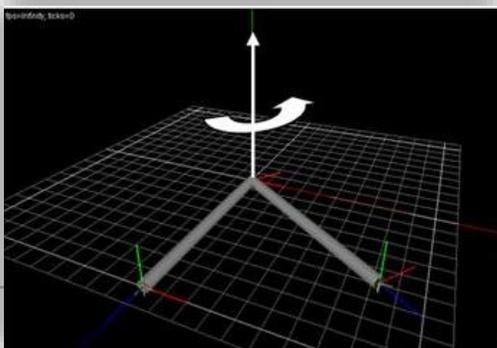


## Reminder:

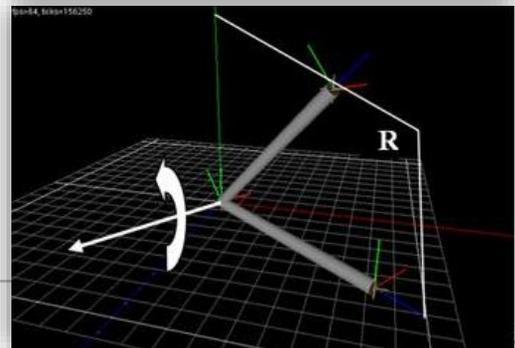
The definition of local coordinate system of a Super Beam follows standards of classic beam mechanics. In the reference position the centroid of the beam element is along z axis while cross section lies in the  $\{x, y\}$  plane. In the reference VCS configuration the centroid of a beam coincides with Z axis of global system (the start node is in the origin of global system the end node at positive Z axis) It should be remembered that by default VCS uses neutral axes system of the cross section as a corotational frame of a Beam.

## Rotation and Shift

Transformation of the beam element from the reference position to an actual position in the VCS model is achieved by two consecutive rotations and parallel shift. The beam is rotated first around Y axis then around axis perpendicular to the plane, R, defined by centroid and Y axis, see below. Rotated beam is then shifted to its final position in the model



First rotation,  $\alpha_1$ , around Y axis



Second rotation,  $\alpha_2$ , centroid and Y axis remain in the same plane.

Two consecutive rotations of a beam from the reference to an actual configuration (prior to the shift).



# ***SUPER BEAM'S PROPERTIES***

There are two characteristic features of the beam rotations:

- following the first rotation local  $y$  axis of the beam is parallel to  $Y$  axis,
- during the second rotation centroid, global  $Y$  axis and local beam axis  $y$  remain in  $R$  plane.

In the special case of an upright element (centroid along  $Y$  axis,  $a_1=0$ ) the  $R$  plane is reduced to  $Y$  line and local  $z$  axis is parallel to global  $Z$  axis.

The deviation of the beam axis  $y$  from the  $R$  plane is controlled by a single parameter orientation (varying in the range 0-360 degrees). Orientation simply defines rotation of the local frame (and at the same time rotation of the cross section) around centroid of the beam. Depending on the ReferenceFrame2D the  $y$  axis corresponds to:

- neutral axis  $y$  (Neutral Axes)
- direction (but not location) of the  $y$  axis of the drawing editor

## **Modeling Recommendations**

Proper orientation of a Beam in VCS model is crucial for reliable simulation results; therefore care must be exercised when orientation is defined on the basis of CAD data, blue prints or conceptual models. Typically, the cross-sections and beams processed in VCS are optimized for better crash performance. Therefore, the choice of orientation routine should rely on coordinate system that does not change when cross-section and/or beam is modified.

There is a number of ways to define orientation of a Beam. In each case orientation is defined by applying, in reverse order, rotations and then defining natural angle (0-360 degrees) between local and global  $y$  axes. The difficult point is to decide on which local coordinate system should be taken as a reference. The most common choices are now critically reviewed.

### **1. Neutral Axes**

Neutral axes are typically defined in CAD software as standard parameters of the cross section therefore selection of natural axes appears to be a natural choice. However, this method has several drawbacks:

- First, orientation of principal axes is not unique and depends on the type of the eigenvalue routine. The simplest example is neutral axes rotated by 180 degrees. Another example is a cross section with one or two axes of symmetry –e.g. hexagonal tube. In this case any corotational frame with one axis containing corner point of a tube is an eligible neutral axes system.
- When cross section is modified orientation of neutral axes system changes.
- Any inaccuracy in eigenvalue routine would affect results of simulation.

### **2. Spatial position of two Points of the cross section**

In this case orientation can be easily defined by comparing spatial position of two cross section points, defined together with the beam element and orientation that follows from the rotation transformation.

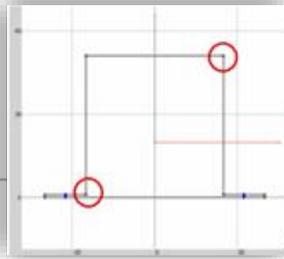
In this case beam orientation is defined by the (positive or negative) angle between vectors  $A$  and  $B$ .



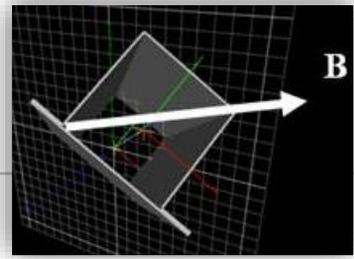
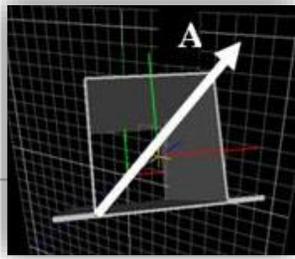
# SUPER BEAM'S PROPERTIES

Drawbacks of this method are similar like in the previous case:

- Orientation given by vector A, would be changed when position of corner points in the drawing editor is changed
- Orientation given by vector B is meaningless when the position of the beam centroid is changed in VCS editor.



Orientation vector defined by position of two selected Points of the cross section (marked in red) – given by standard VCS procedure



Orientation of the same points defined separately by the user s by specifying 3D coordinates of the Points

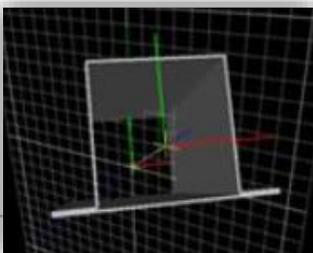
## 1. Spatial position of local coordinate system

Instead of two cross-section points discussed in preceding point one may define spatial coordinates of the versor  $\vec{e}_y [a_x, a_y, a_z]$  ;  $|\vec{e}_y|=1$  of the local coordinate system. In this case vector A in the figure above coincides with y versor of the drawing editor while vector B is replaced by user defined versor  $\vec{e}_y$ . In this case orientation is insensitive to the cross section modification but depends on the position of the centroid.

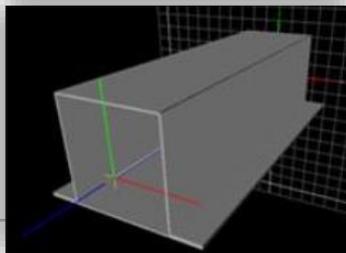
## 2. Compatible orientation of the local coordinate systems

The difficulties described in preceding point disappear when the spatial two-dimensional coordinates of the cross section are defined on the  $\{X, Y\}$  plane of the global coordinate system – or in the system that is shifted but remains parallel to the global system  $\{X, Y, Z\}$ . In other words a beam defined in CAD program must be transformed to the reference VCS position (centroid at the Z axis). When this is done the  $\{X, Y\}$  coordinates of corner points define compatible representation of the cross section in VCS and its orientation will be uniquely defined even when the position of centroid is changed. In the case of an upright position (centroid along Y axis) orientation is defined by orientation angle. The complete procedure of cross section definition in CAD software is shown schematically in the pictures below:

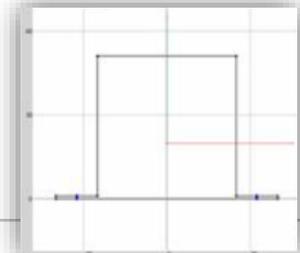
CAD software – definition of compatible cross section model



STEP 1 – (optional) shift beam to  $\{0.0.0\}$



STEP 2 – rotate beam to reference position (parallel to Z)



STEP 3 – define cross section in the  $\{X, Y\}$  plane



# ***SUPER BEAM'S PROPERTIES***

*The above procedure solves the orientation problem at the level of a single beam.*

*In VCS single cross section can be used to define a number of beams of various length and various orientations in space. It would be impractical to define cross-section points for each beam separately.*

*Significant simplification is achieved in this case by definition of the orientation angle. The angle is defined by transforming each beam to the reference position and defining its orientation by using any object mentioned above (principal axes, two point of the cross-section etc.).*

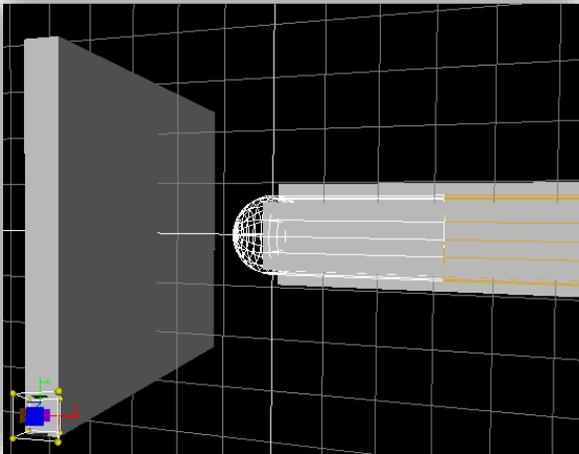


# CONTACT ENVELOPES FOR BEAM ELEMENTS

*In classic beam theory loading can be applied in two manners: concentrated forces and moments are applied to the beam cross-section – treated as a rigid body with the center of gravity at the Beam origin, while distributed loading is applied directly to the centroid of the beam. Therefore, in contact/impact problems classic beam element can be considered as "rigid" in the sense that all the contact forces applied to the beam side faces generate reactions at both end cross-sections of the beam.*

*These reactions, in turn, treated as regular beam loadings, result in beam deformation. It is further assumed that contact forces do not induce any direct deformation of the beam side faces and therefore do not influence the response of the beam. It follows that from the perspective of classic beam theory the contact/impact forces are treated in the same manner as any other types of beam loading.*

*Therefore, in the implementation of the classic beam is plausible to use a simplified beam contact algorithm that properly handles the distribution of reactions and does not perform CPU demanding detailed checking of the contact point for complex cross sections.*



In VCS the default Beam Contact algorithm uses the concept of Contact Envelopes. The envelope consists of cylinder and sphere. Both surround one half of the beam element together with corresponding node.

The default radius of the envelope is defined as an average width of cross section and can be modified by the user for specific contact models.

The Contact Check switch and controls of the envelope type are collected in the Contact/Impact setting section of the Beam's Properties Window.

