Appendix 2

Using Reference lines

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Appendix 2 - Using reference lines

This appendix includes a set of examples, which demonstrates the design process using the interaction between NovaFrame and NovaDesign.

The use of reference lines is essential in this approach.

First there is an introduction to the background, which includes:

- Reference lines in NovaDesign
- Reference lines in NovaFrame
- Interaction between NF/ND and description of various methods.

A few examples are presented showing the practical implementation.

1 Reference lines in NovaDesign

1.1 General

NovaDesign uses reference lines to keep control of cross sections. Reference lines are in general associated with a line and the variation of cross sections depending on the position along the line. This is also the main motivation for using a line for holding cross sections.

Reference line no 0 is an exception, it is not a "line" but a collection of cross sections by their numbers. (1, 2, 3… etc.)

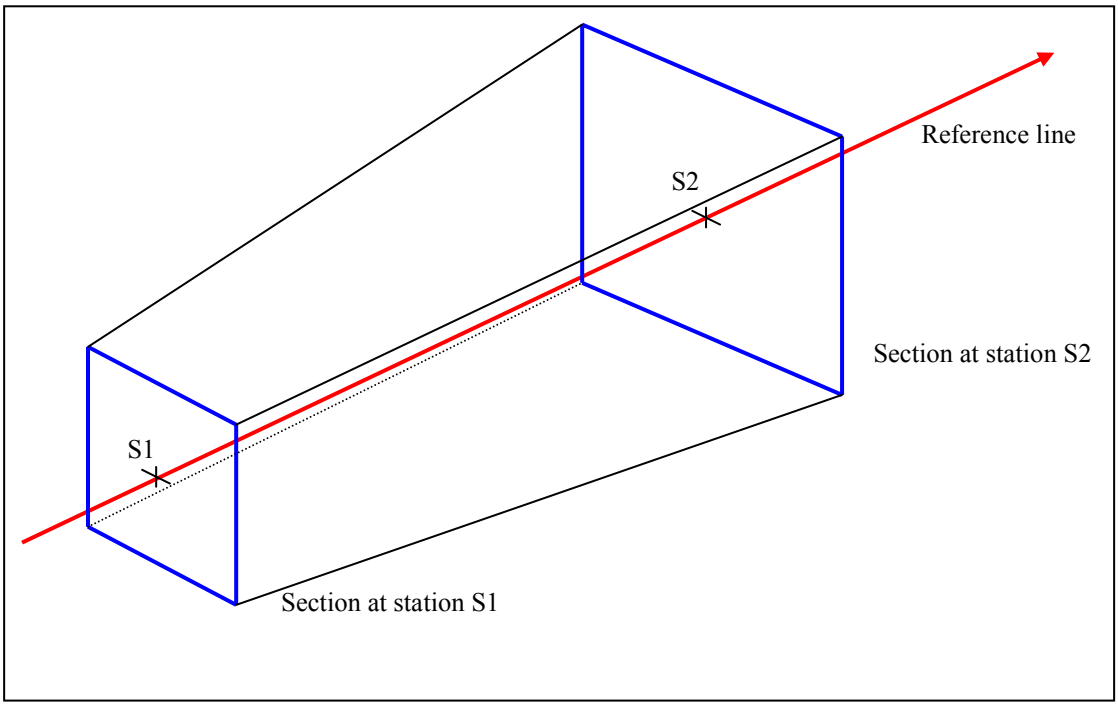


Fig.: 1.1-1 General concept of a reference line.

Station is position along the reference line in meters. Between station S1 and S2 on figure 1-1 the cross-section is calculated by linear interpolation.

The appearance of a reference line with several cross sections is shown on figure 1.1-2.

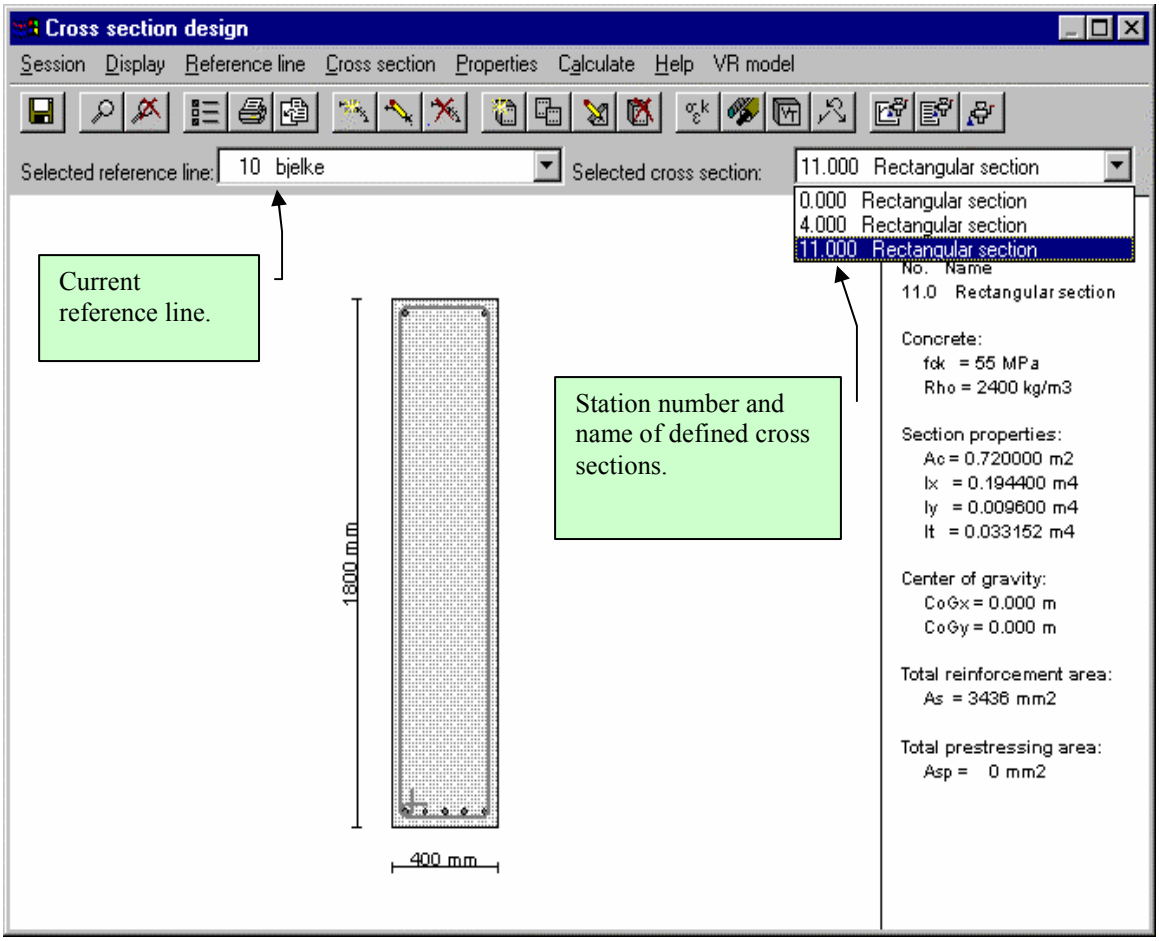
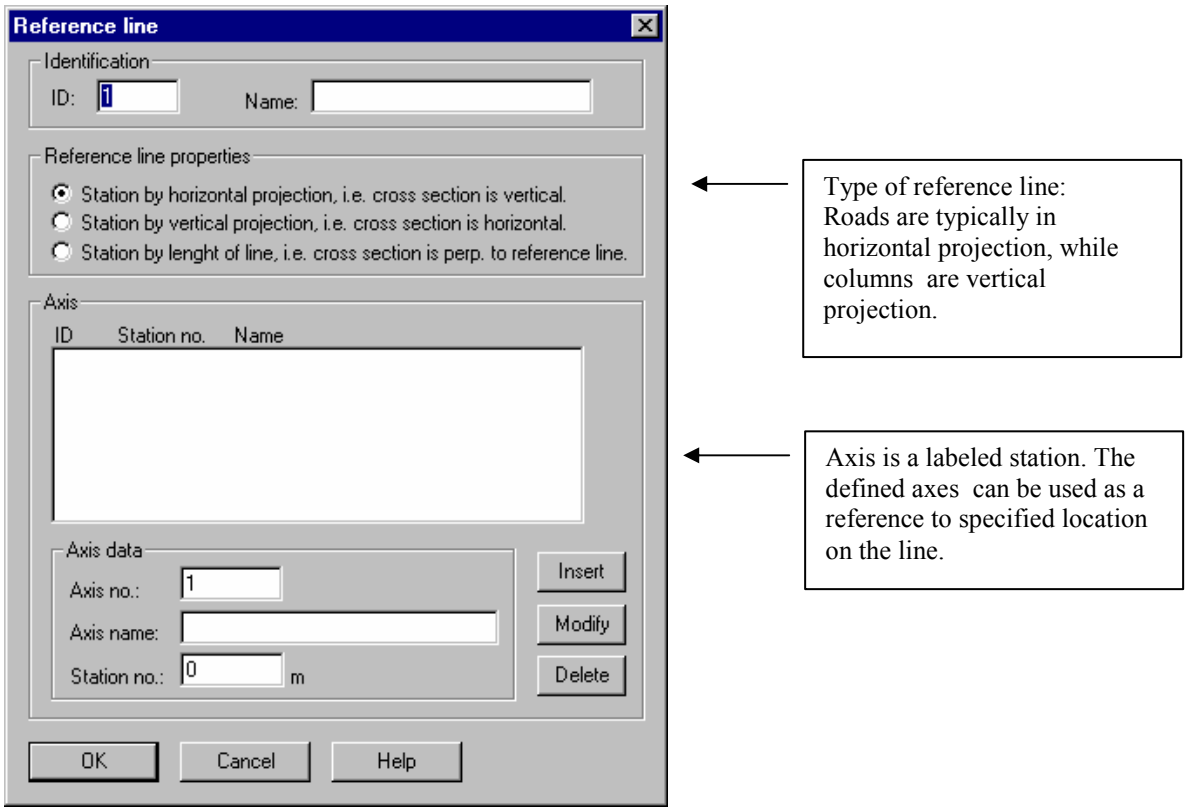


Fig.: 1.1-2 Reference line with 3 cross sections.

1.2 Adding or modifying a reference line

Reference lines can be added in NovaDesign by selecting **Reference line…** and **New..** in the ***Cross section design*** dialog menu:



By default only reference line 0 is defined.
The type of reference line is an important choice.

1.3 Types of Reference lines

Horizontal projection, type = 1:
This is the way roads are defined. The curvature is defined in the horizontal plane. The length position (stations) along the line is referred to the length in the horizontal plane independently of the vertical curvature of the road.

Vertical projection, type = 2:
This is preferred for columns, however even members with an inclination relative to the vertical Z-axis may use station numbering by vertical projection. The length position (stations) along the line is referred to the length of the projection on the Z-axis.

Station numbering by length of line, type = 3:
For more general geometric curves there is need to have a station numbering by the length of the actual curve. This implies no projections.

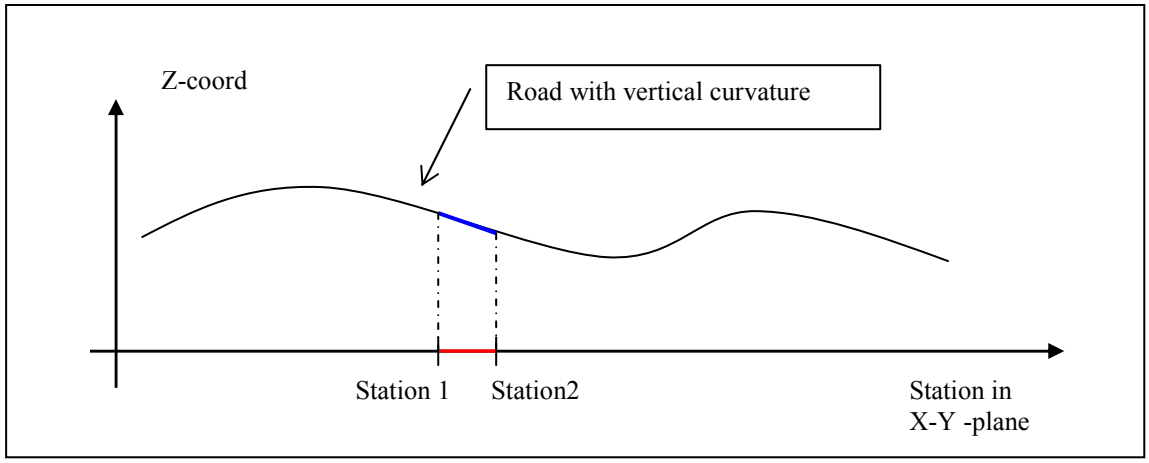


Fig.: 1.3-1 Reference line with horizontal projection.

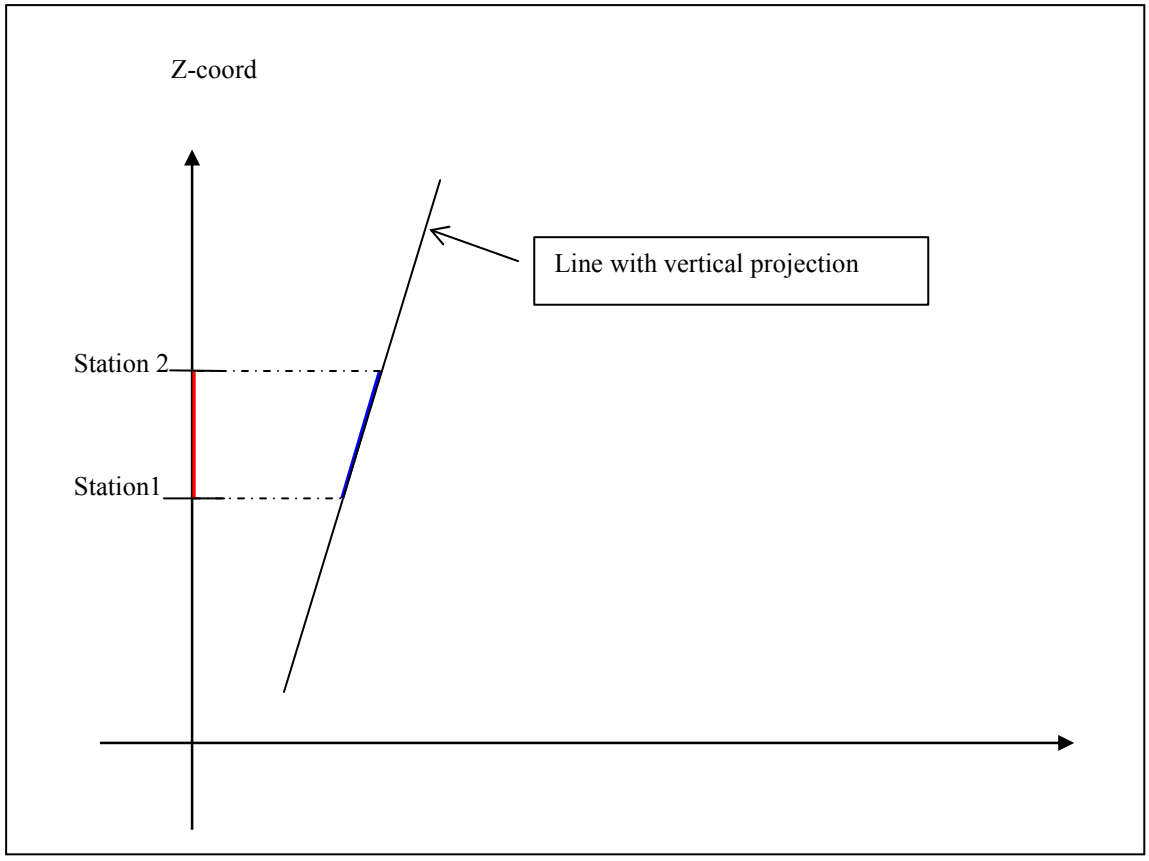


Fig.: 1.3-2 Reference line with vertical projection.

1.4 Cross section relative to reference line

In some situations it is advantageous not to position the cross section COG on the reference line.

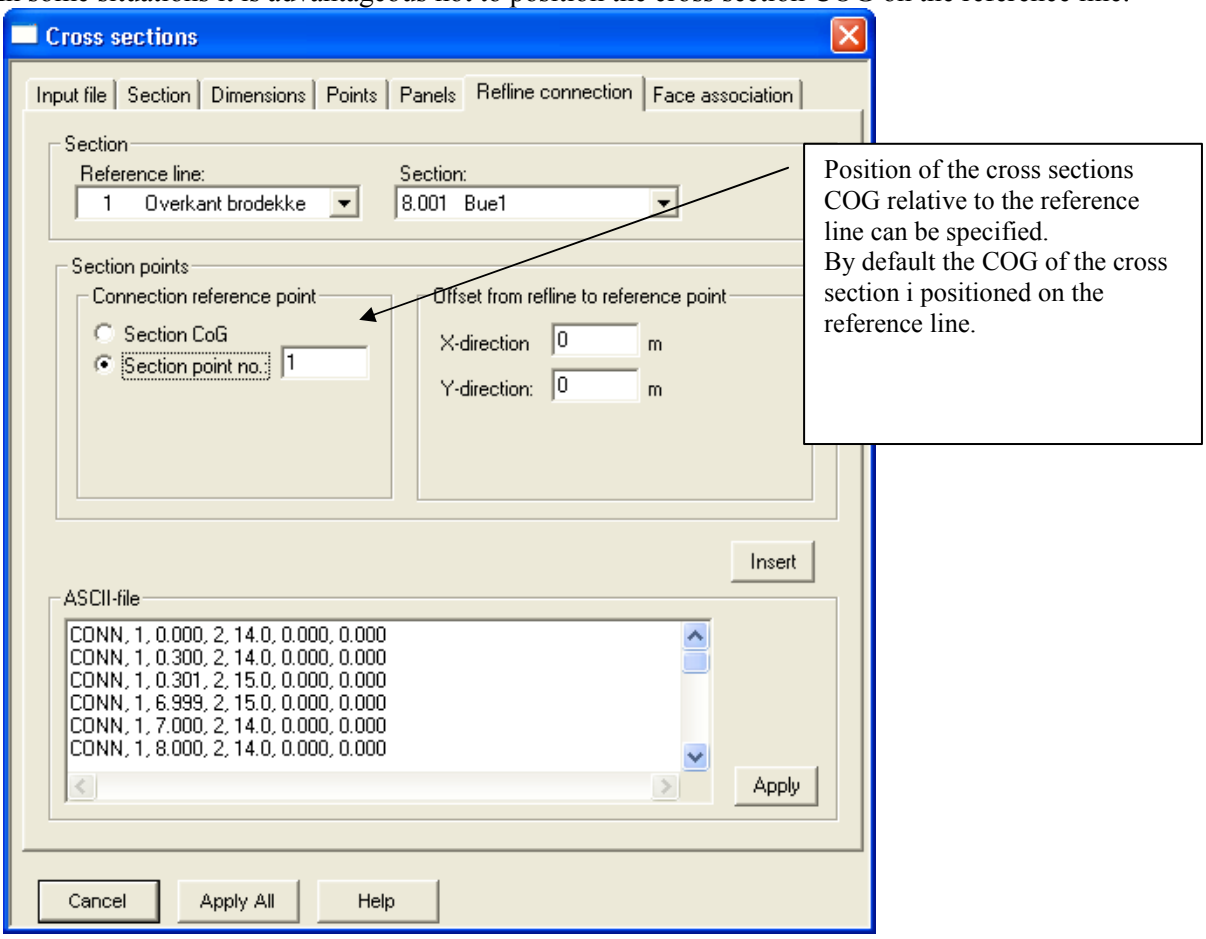


Fig.: 1.4-1 Positioning cross section COG relative to reference lines.

Note:
This option is only available for cross sections associated with a refernce line of type = 1, i.e. for sections associated with a road.
It is not recommended to use both COG offset and offset from a section point on the same reference line. Interpolation of offsets between sections with each of the two types will fail!

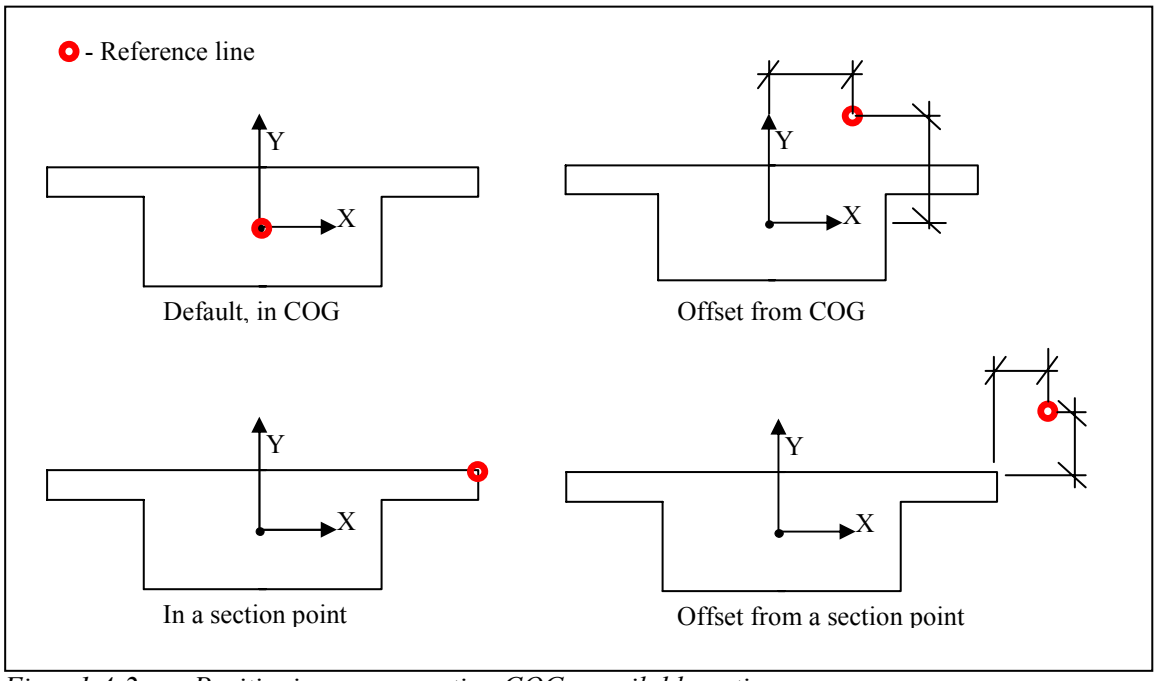


Fig.: 1.4-2 Positioning cross section COG , available option..

Please note that correct signs on the ordinates are found when positioning the section COG or section point relative the reference line position (= "local origo").

2 Reference lines in NovaFrame

2.1 General

NovaFrame and NovaDesign shares cross sections by using reference lines. This is done either by:

Reference Line = 0; Cross sections defined in NovaDesign can be assigned to elements in the frame model by their number. Available section shared with NovaDesign can be viewed in the "Available section -drop list" of the Element Specification card in the **Build Model** , menu selection.

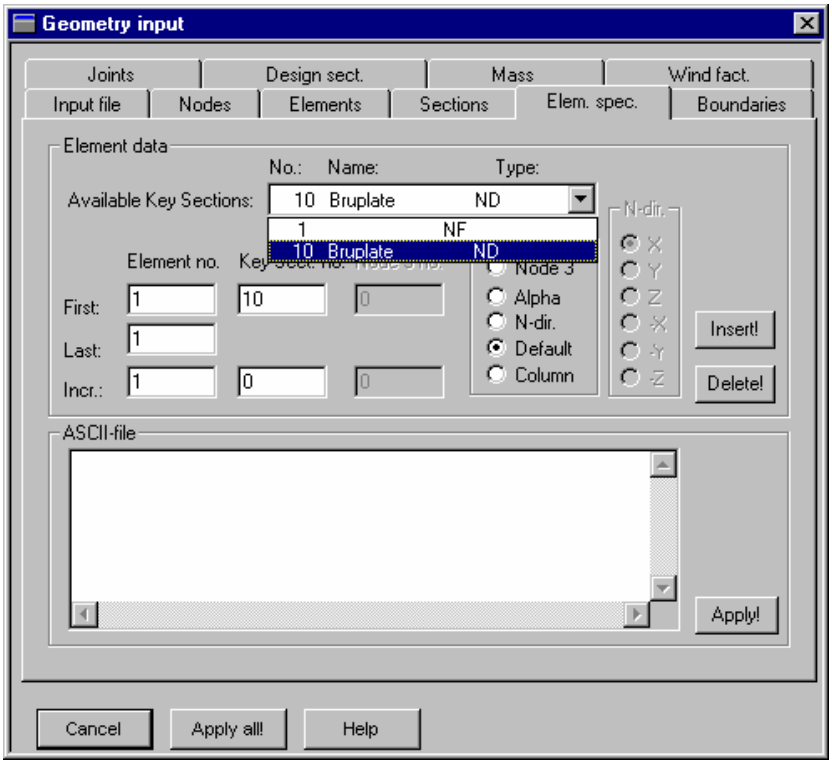


Figure 2.1-1 Assign cross sections on reference line 0 to elements.

Reference Line "not = 0"; Cross sections defined in NovaDesign along these reference lines can be assigned to elements in the frame model. This requires that the nodes in each end of the elements are generated based on stations on the reference line. For making this work the reference lines must be assigned to have geometry.

As a rule Reference line 0 does not have any geometry, others must have geometry if they are to be used by NovaFrame. See section 2.4.

2.2 Defining reference lines in NovaFrame

See section 1.3 on a description of the different reference line types. This description is shared with NovaFrame. Reference lines and their properties are found be selecting **Reference lines…** in the ***Frame*** **Preprocess** menu.

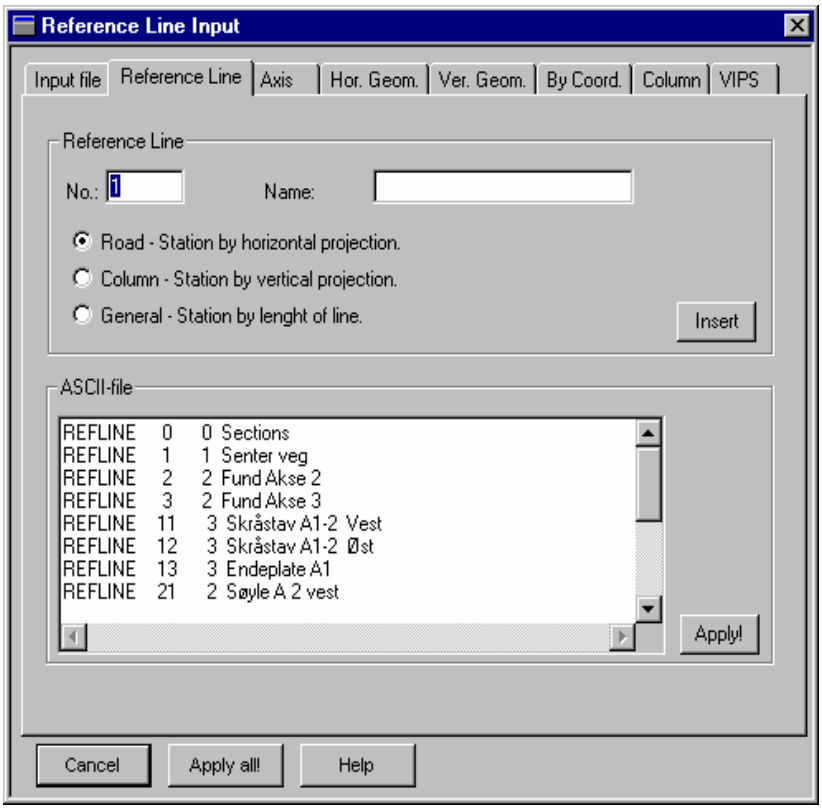


Fig.: 2.2-1 Input page for defining reference line in NovaFrame.

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2.3 Defining axes in NovaFrame

Axes are labeled station numbers.

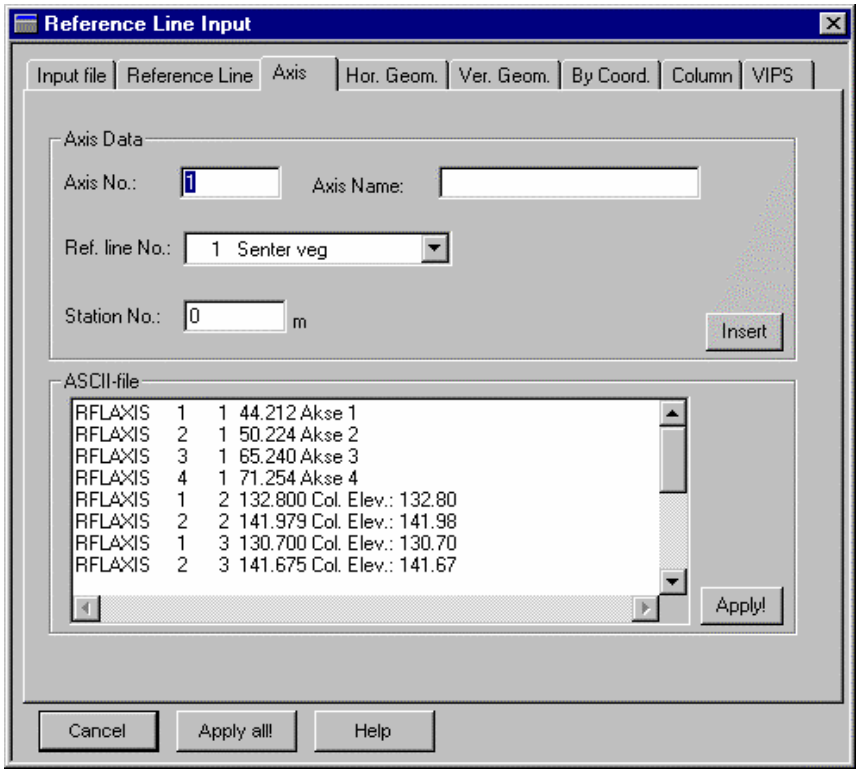


Fig.: 2.3-1 Input page for defining axes in NovaFrame

Using axes is fully optional, however it can improve both readability and reuseabilty to your structural model.

2.4 Reference line geometry

Assigning geometry to reference lines is done in NovaFrame. The methods for assigning geometry consists of either:

- Road geometry or
- a sequence of points

Assigning geometry as a road is only available for horizontal projection reference lines, i.e. type = 1. Geometry defined by a sequence of points is more general and can be used for all reference line types.

2.5 Road geometry - horizontal segments

This is used for defining curve segments representing the horizontal projection of the road in the horizontal plane. The method is common for defining roads or railway tracks. The horizontal segments consists of straight lines, circles or clotoides.

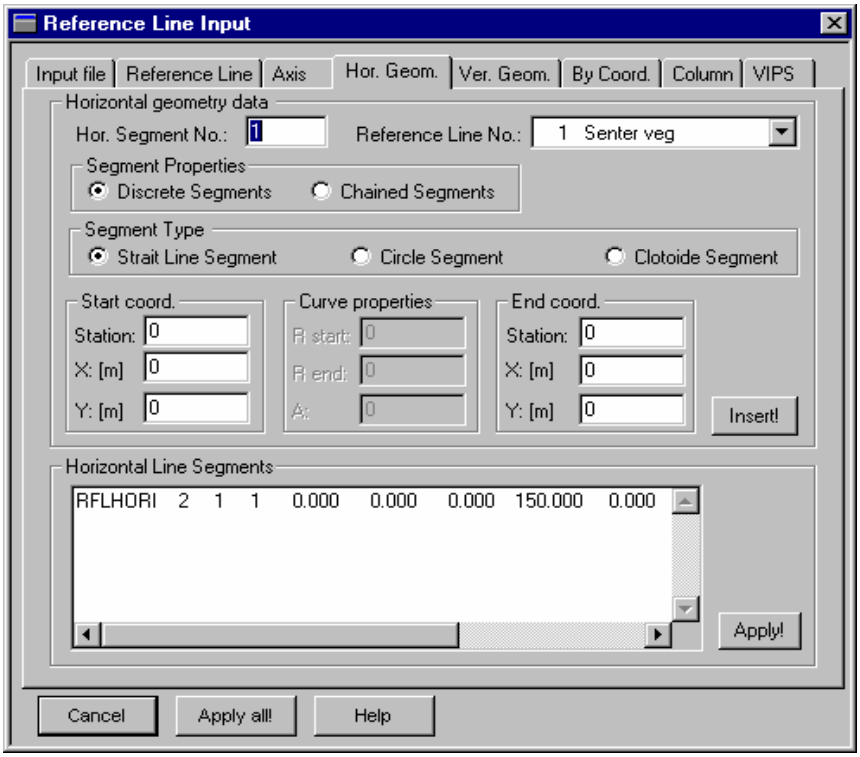


Fig.: 2.5-1 Input page for defining horizontal segments

The sequence of segments can be either chained or consists of discrete segments. The idea of this choice is to support the possibility to have lines, which have instant changes in their direction. The most common approach is however to use chained segments. Chained segments require less input data.

Chained segments uses the end-direction and the end coordinates of the preceding segment in order to calculate its own position and end properties. A sequence of chained segments must always start with one discrete segment.

Discrete segments are stand-alone segments, which does not use any information from other segments.

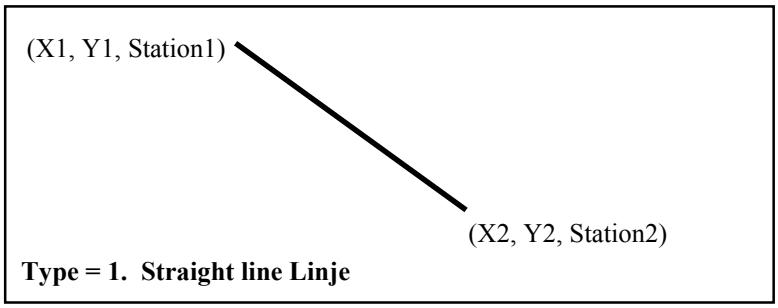


Fig.: 2.5-2 Horizontal segment type= 1

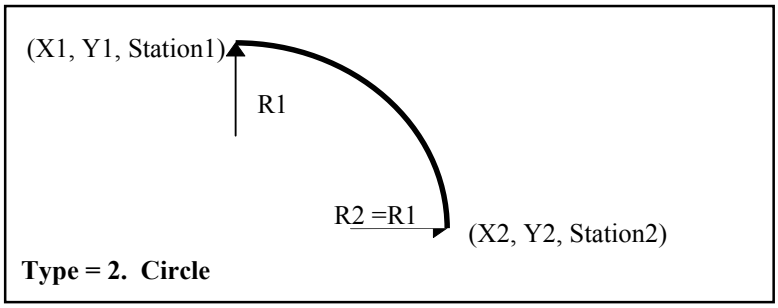


Fig.: 2.5-3 Horizontal segment type= 2

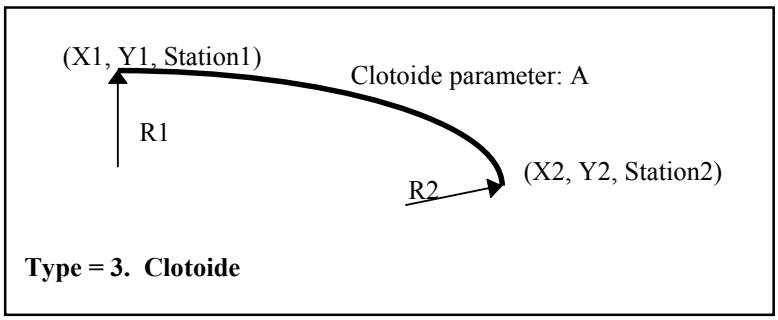


Fig.: 2.5-4 Horizontal segment type= 3

2.6 Road geometry - vertical segments

The vertical curvature of the road geometry is given by defining vertical segments. These consist of strait lines or circular curves.

The data for segment is start elevation and start station, end station and end elevation, radius of curve segment if this is a circle. There are no "chained" properties for vertical segments, each segment is discrete.

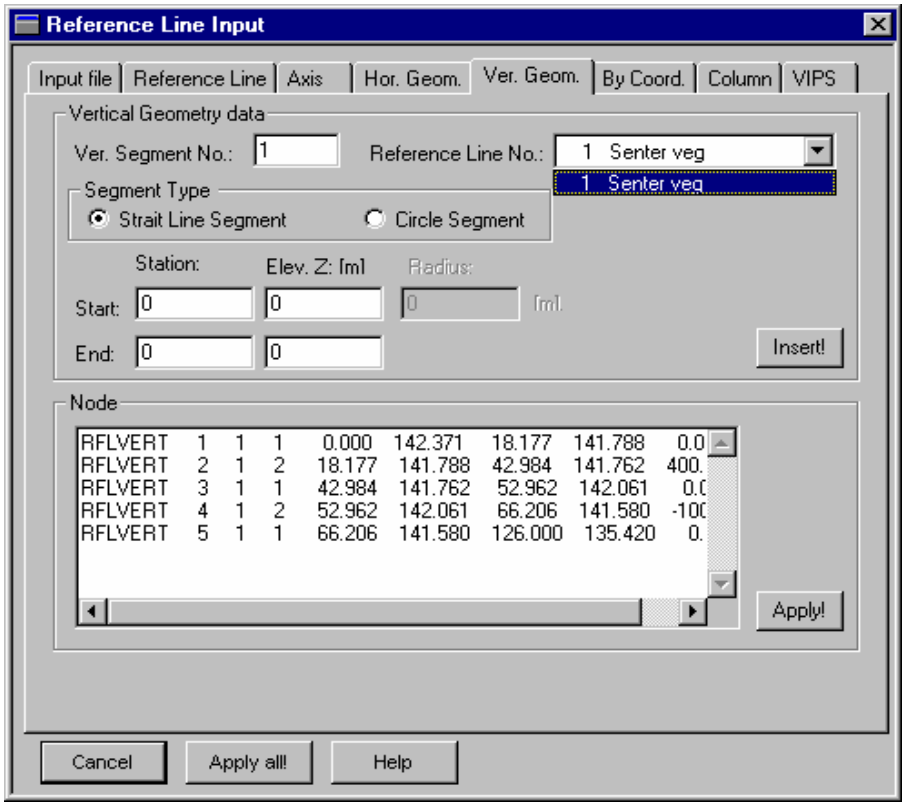


Fig.: 2.6-1 Input page for defining vertical segments

Available segment types for defining vertical curvature:

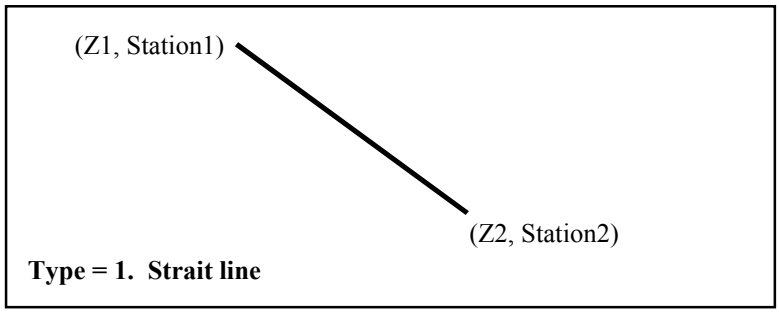


Fig.: 2.6-2 Vertical segment type= 1.

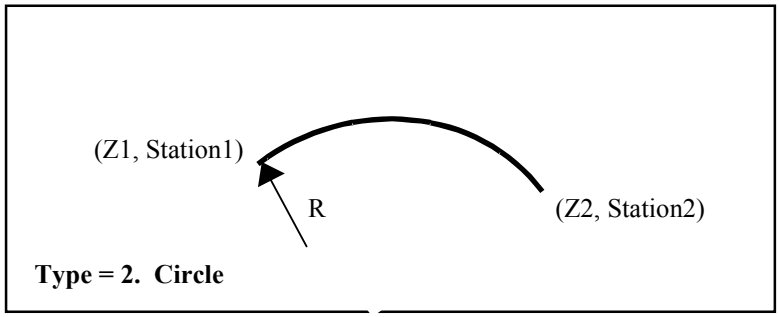


Fig.: 2.6-3 Vertical segment type= 2.

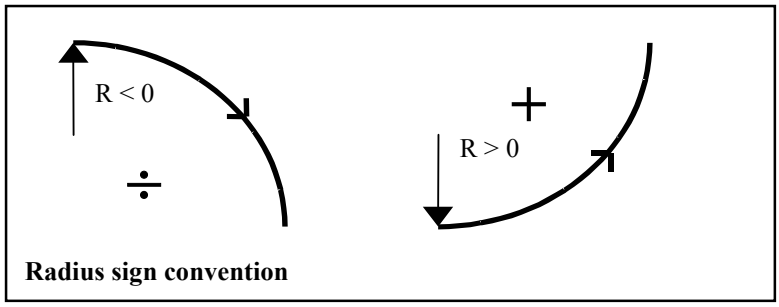


Fig.: 2.6-4 Vertical segments, sign conventions.

2.7 Defining geometry by a sequence of coordinates

Using coordinates defines a line, which is the linear interpolation between the defined coordinates. Stations are calculated as the length along this line or a projection of the line. This method can be used for defining general lines.

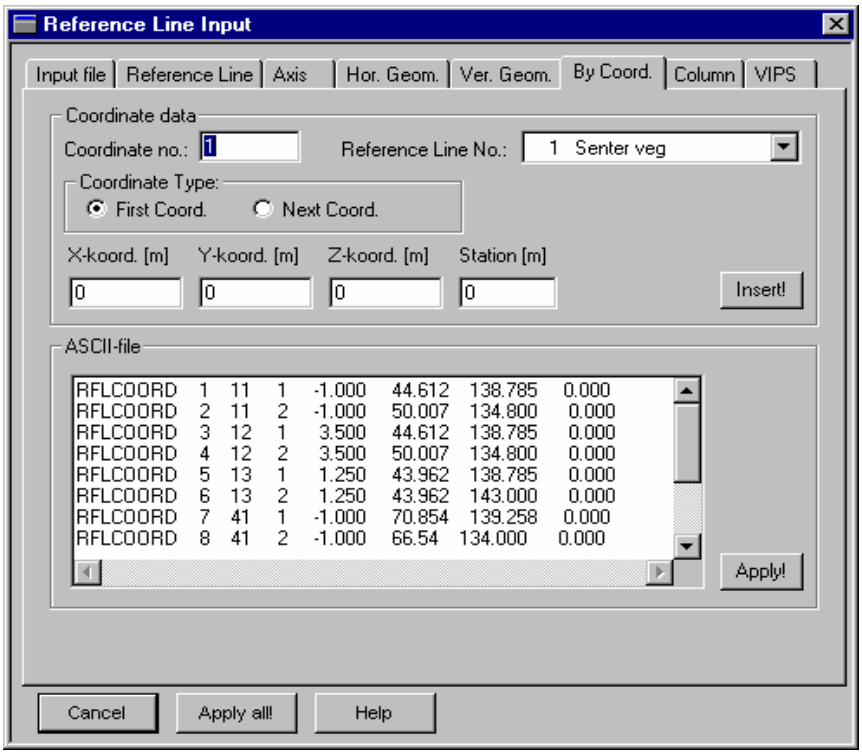


Fig.: 2.7-1 Input page for defining coordinates

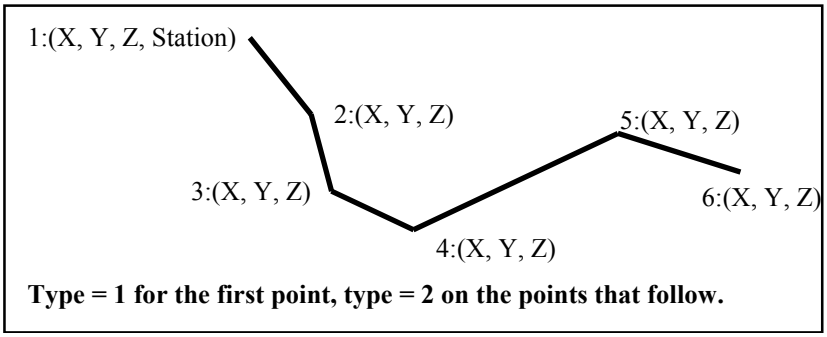


Fig.: 2.7-2 Sequence of coordinates.

2.8 Defining columns in NovaFrame;

Columns can be defined in NovaFrame. The column definition consists of connecting a reference line with vertical projection at a specific station of reference line with projection in the XY-plane. The coordinate at the specified station or axis is calculated and the geometry of the column reference line is automatically calculated.

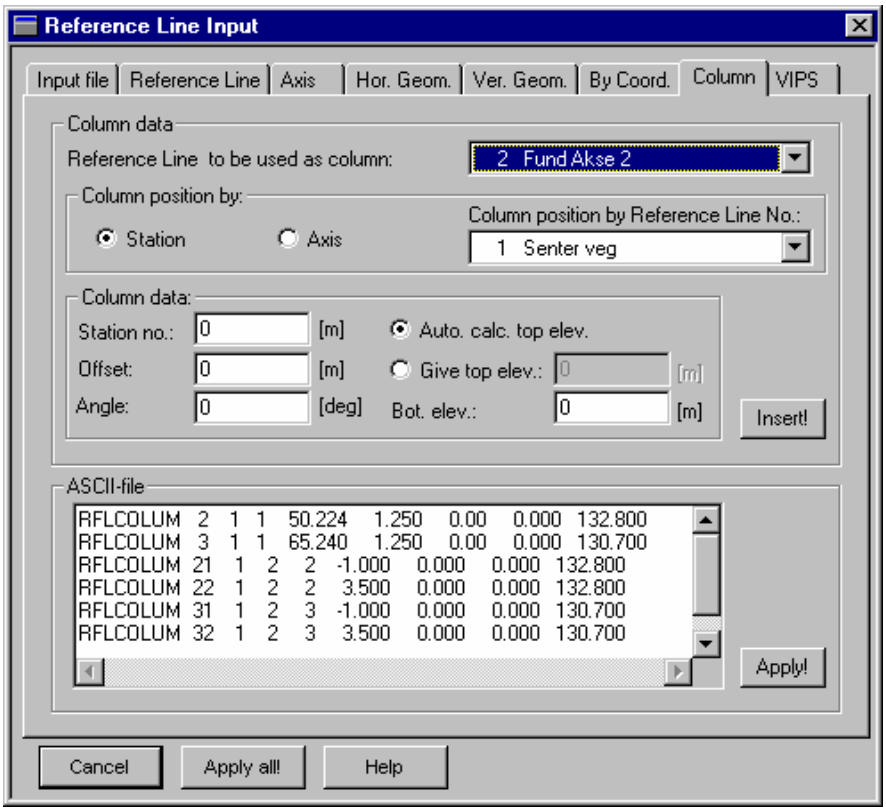


Fig.: 2.8-1 Input page for defining columns.

The column does not need to be located directly on the reference line. An offset and an angle can be specified to get the column positioned. This is described on the figure below:

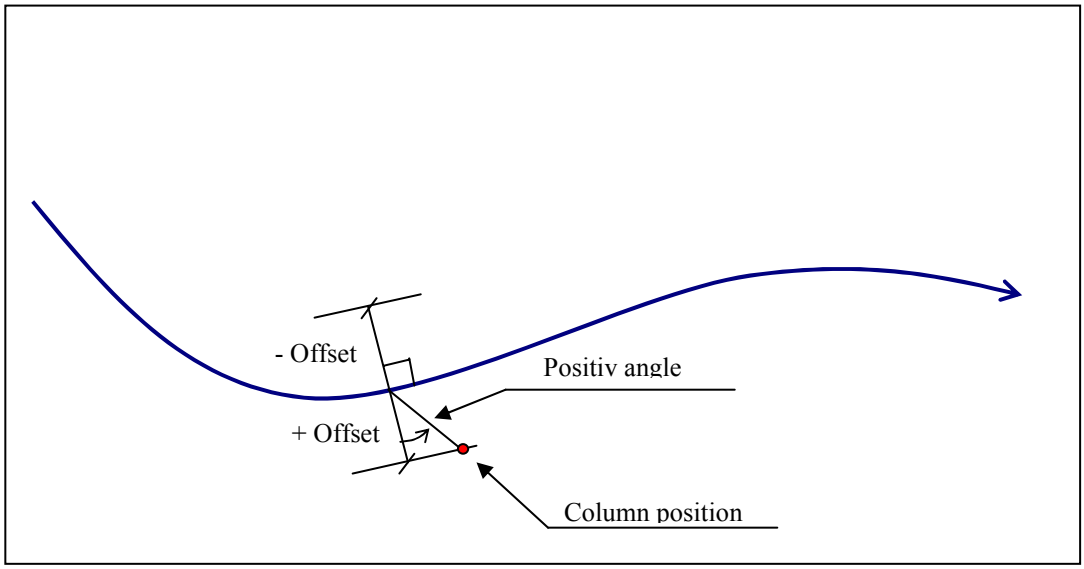


Fig.: 2.8-2 Offset and angle when positioning columns.

The user specifies the column bottom elevation. Top of elevation can be specified geometry or automatically calculated. Automatically calculated top elevation is top the z elevation of the reference line in the specified station.

What happens?
When defining a column the column reference line will get its geometry defined. The geometry definition consists of two coordinates, see section 2.7. The first coordinate is at the bottom elevation and the second is at the top elevation. See figure 2.8.3.
In addition two labeled axes are defined. One at the bottom and one at the top. They are numbered as axis 1 and 2.

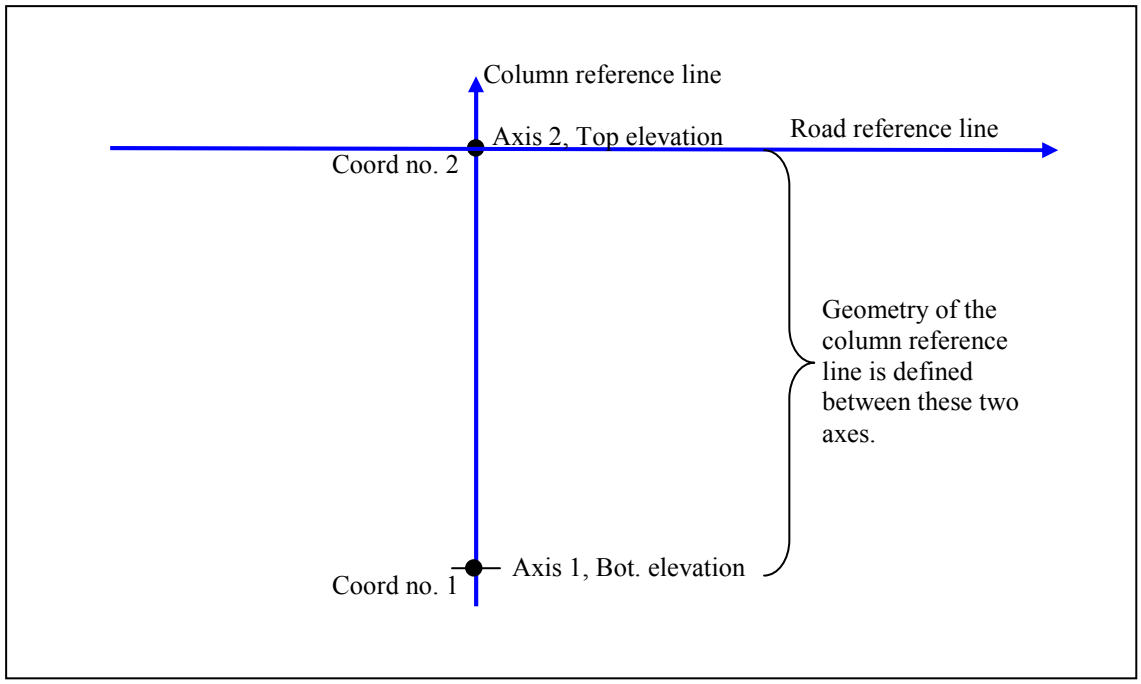


Fig.: 2.8-3 Vertical reference line with data generated by column command.

Local axis direction for columns:
Automatically the local L-axis of the column will point in the direction of the road at the specified station. The user can override this.

3 Nodes on reference lines

One of the main objectives of all the definitions and input is now to be assembled. Defining nodes are done by using the ***Nodes*** card, found when selecting **Build Model…** from the **Preprocess** menu:

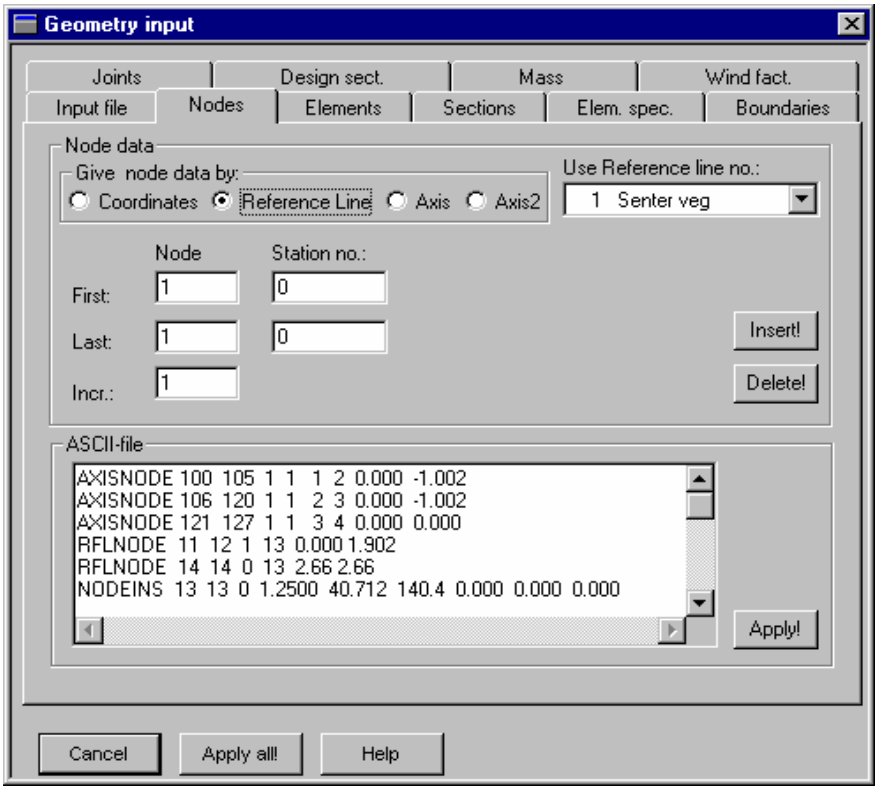


Fig.: 3-1 Input page for defining nodes.

The reference line geometry and the section connected to the reference line are used to calculate the coordinate of the reference line and the distance from the reference line to COG where the node is to be positioned.

Typical nodes generated for a cantilever bridge is shown on figure 3.2.

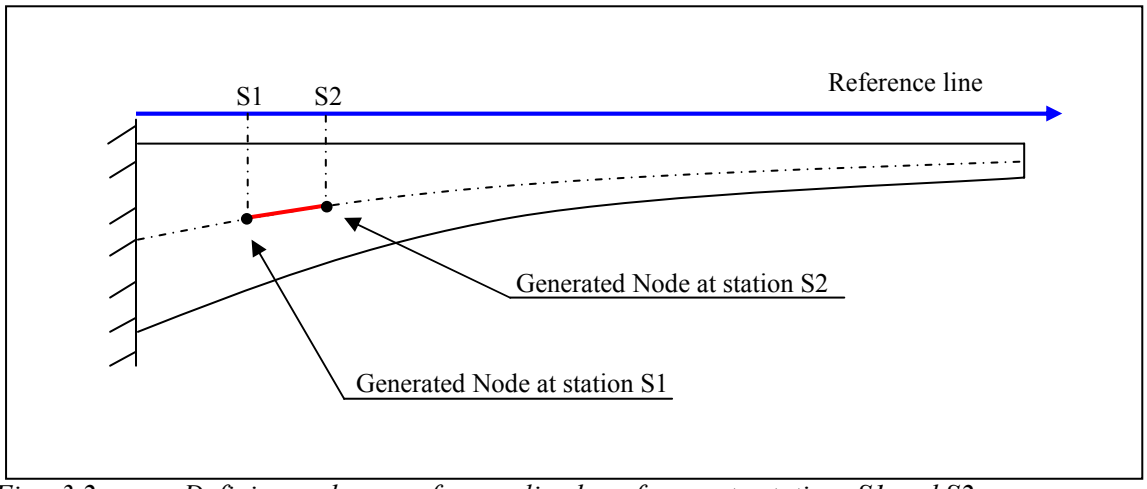


Fig.: 3.2 Defining nodes on reference line by reference to stations S1 and S2.

The sequence of calculations:

- The cross section in station no. S1 and S2 are calculated.
- COG is computed
- The coordinate of the reference line in station S1 and S2 are calculated.
- Offsets from COG to reference line are added.

The alternatives for defining nodes on reference lines are presented below:

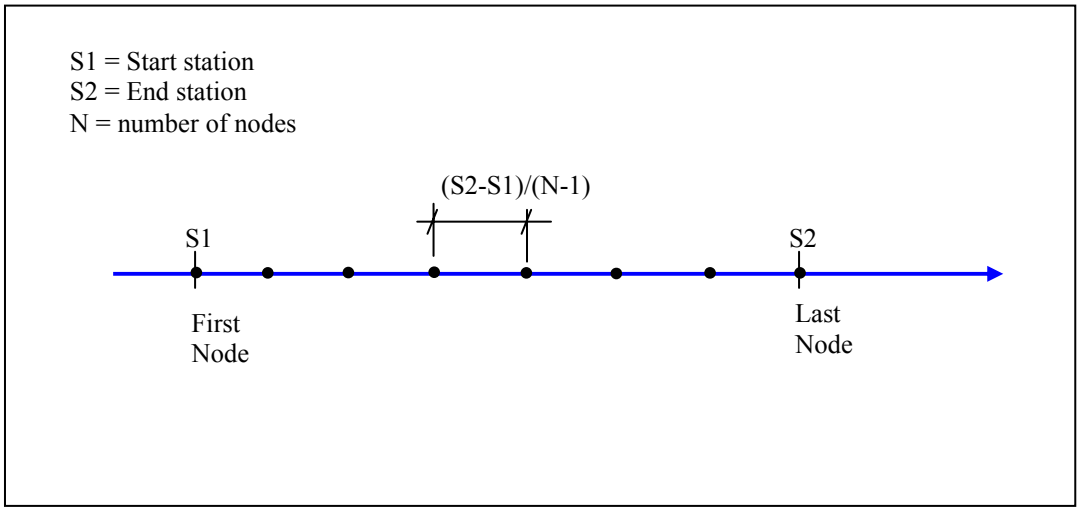


Fig.: 3.3 Defining nodes on reference line by reference to stations S1 and S2.

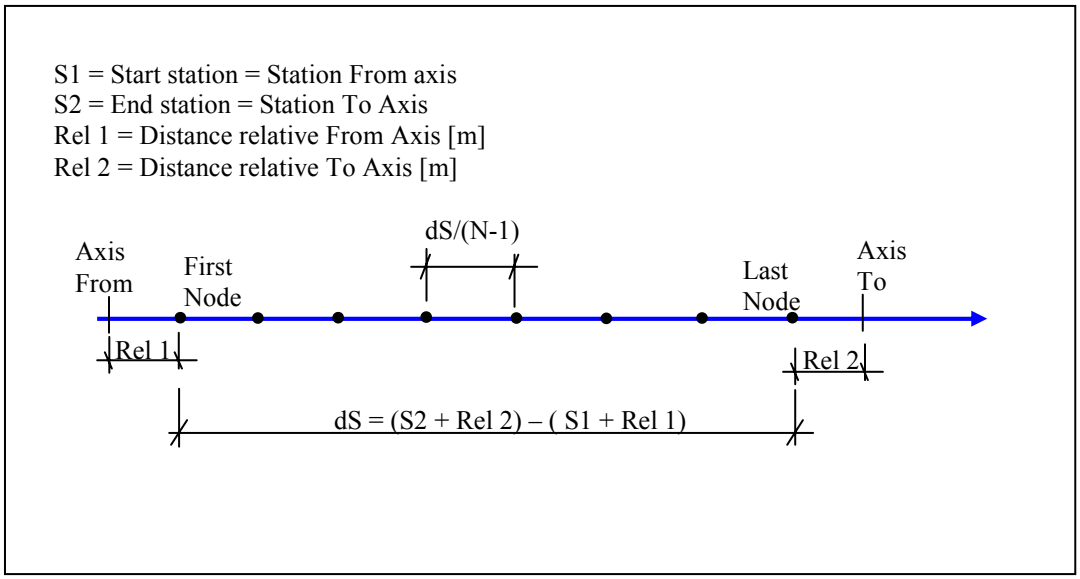


Fig.: 3.4 Defining nodes on reference line by axes alternative 1.

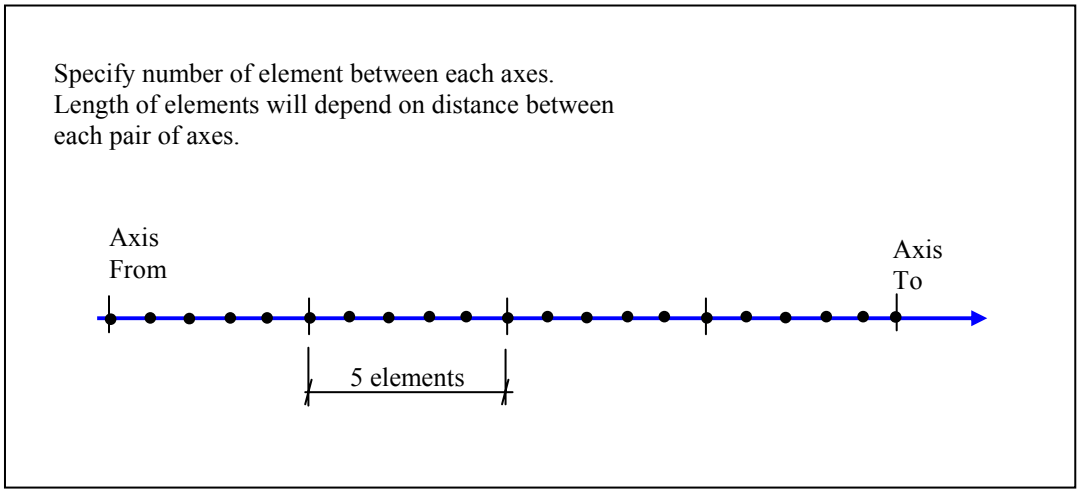


Fig.: 3.5 Defining nodes on reference line by axes alternative 2.

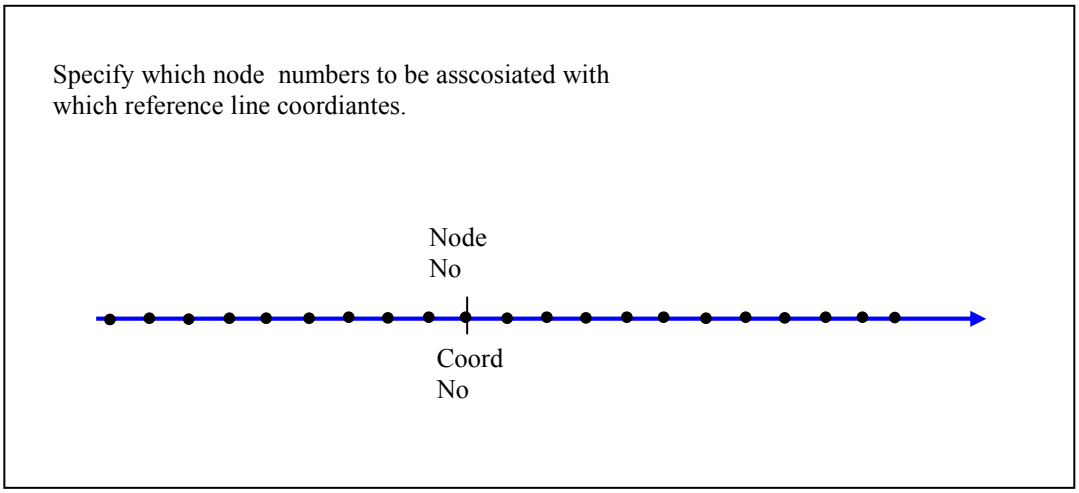


Fig.: 3.6 Defining nodes directly on coordinates which describe the reference line.

4 Element properties

Elements are defined as usual by assignment of nodes to each end of the element. It is the nodes who are defined by the reference lines. This chapter intends to clearify how the properties of an element between two nodes are calulated.

The two simplest situations are:

A1: Both node 1 and node 2 are on the same reference line. Element area and stiffness parameters are the average stiffness of cross section in node 1 and node 2 of the element.

A2: Neither node 1 or node 2 are connected to a reference line. Element area and stiffness parameters cannot be calculated. Properties of the element must be made using a section number from reference line 0 and by specifying an ELSPINScommand in NovaFrame.

Further, if neither A1 or A2 is valid then:
The unit direction vector of the reference line asscociated with node 1 and node 2 are calculated. Also the the unit direction vector of the element M-axis, (=lenghth axis), is calculated.

Nodes are asscosiated with different reference lines (or only one of them is):

B1: Element M-axis is parallell to the reference line in node 1 and not parallell to the reference line in node 2:
Element properties are calculated based on section properties in node 1. In addition section properties at node 2 are calculated for the same reference line by using the station number at node 1 corrected for the element length.
Element area and stiffness parameters are the average stiffness of cross section in node 1 and node 2 of the element.

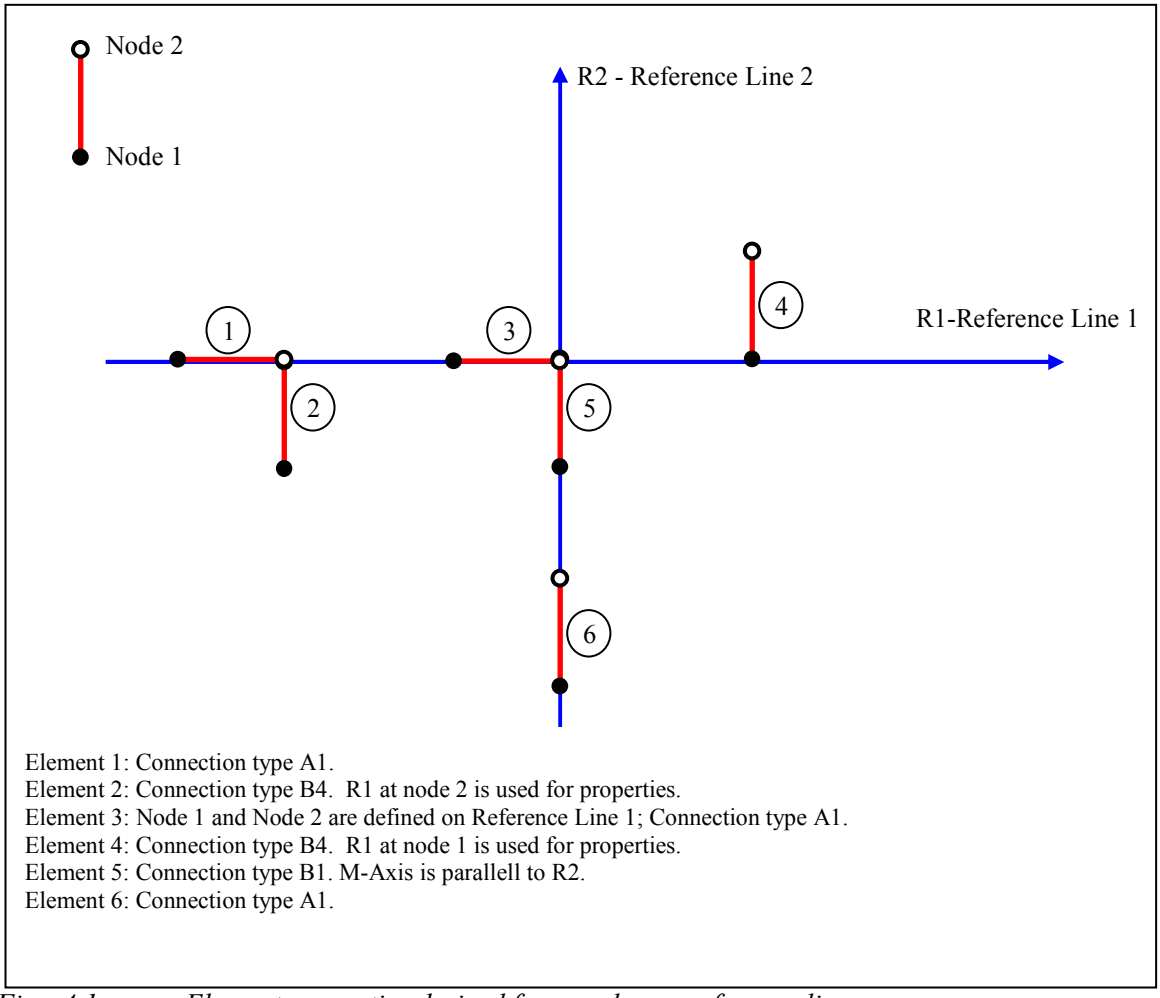
B2: Element M-axis is parallell to the reference line in node 2 and not parallell to the reference line in node 1:
Element properties are calculated based on section properties in node 2. In addition section properties at node 1 is calculated for the same reference line using the station number at node 2 corrected for the element length.
Element area and stiffness parameters are the average stiffness of cross section in node 1 and node 2 of the element.

B3: Element M-axis is parallell to the reference line in node 1 and also parallell to the reference line in node 2:
Element properties are calculated based on section properties in node 1.

B4: None of the reference lines are parallell to the element M-axis:
The reference line and station number at node 1 are used if found. Otherwise the reference line and station number at node 2 are used

Some specific rules:

- Young's modulus, Poisson ratio and f_{cck} for partial creep factor calculations are all based on the properties found in node 1.
- When calculating partial creep the partial creep factor is calculated fully for both ends 1 and 2 before an average is made.
- If cross section is specified by the ELEMSPEC command then this section will override the properties found according to reference lines.
- The tolerance on parallell is 18 degres.



Element 1: Connection type A1.
Element 2: Connection type B4. R1 at node 2 is used for properties.
Element 3: Node 1 and Node 2 are defined on Reference Line 1; Connection type A1.
Element 4: Connection type B4. R1 at node 1 is used for properties.
Element 5: Connection type B1. M-Axis is parallell to R2.
Element 6: Connection type A1.

Fig.: 4.1 Element properties derived from nodes on reference line.

Note!
Inclination between COG line and the reference line; The user must ensure that geometry is as intended.

Note!
Default local axis orientation can be overridden for elements with properties based on reference lines. This is done by using ELEMSPEC command and referring to section no. 0. By doing this the section definition from reference lines will not be affected/overridden.

Note!
Section properties are based on homogeneous concrete sections. The amount of prestressing and reinforcement are not included in the calculation of stiffness properties. If other stiffness properties than homogeneous are to be used in an analysis then this can be done by using appropriate parameters for a NovaFrame cross section on reference line 0.

Note!
Reasons for why the calculation of element properties fail;

- If calculation of a section at a specific station will attempt to interpolate between two sections with different number of section points.
- No section at the specific station number is found.

5 Methods

There are several methods of assigning element properties:
1. Using NovaFrame sections on reference line = 0.
2. Using NovaDesign sections on reference line = 0.
3. Using NovaDesign sections on reference lines. (Nodes are calculated by reference line!)
4. Specify nodes to be calculated by reference lines but overriding some of the section calculated by the reference line by specifying section directly on the element, sections from reference line = 0.

5.1 NovaFrame sections (Reference line = 0)

This is the traditional method and does not require any interaction with NovaDesign. The sections are defined in NovaFrame in the **Section input card.** These sections are not available in NovaDesign for the purpose of design calculations.

5.2 NovaDesign sections (Reference line = 0)

This is the first step using interaction between the two applications. The sections are defined in NovaDesign in the ***Section Design Dialog***. The sections are assigned to specific elements on the structural model by using the ***Element specification page***. The stiffness properties of the section will now be used in the analyses of the structure.

Design of the section is performed for all results associated with the section. These results are the section forces in all design sections of all elements, which uses the section.

Consider the examples below:

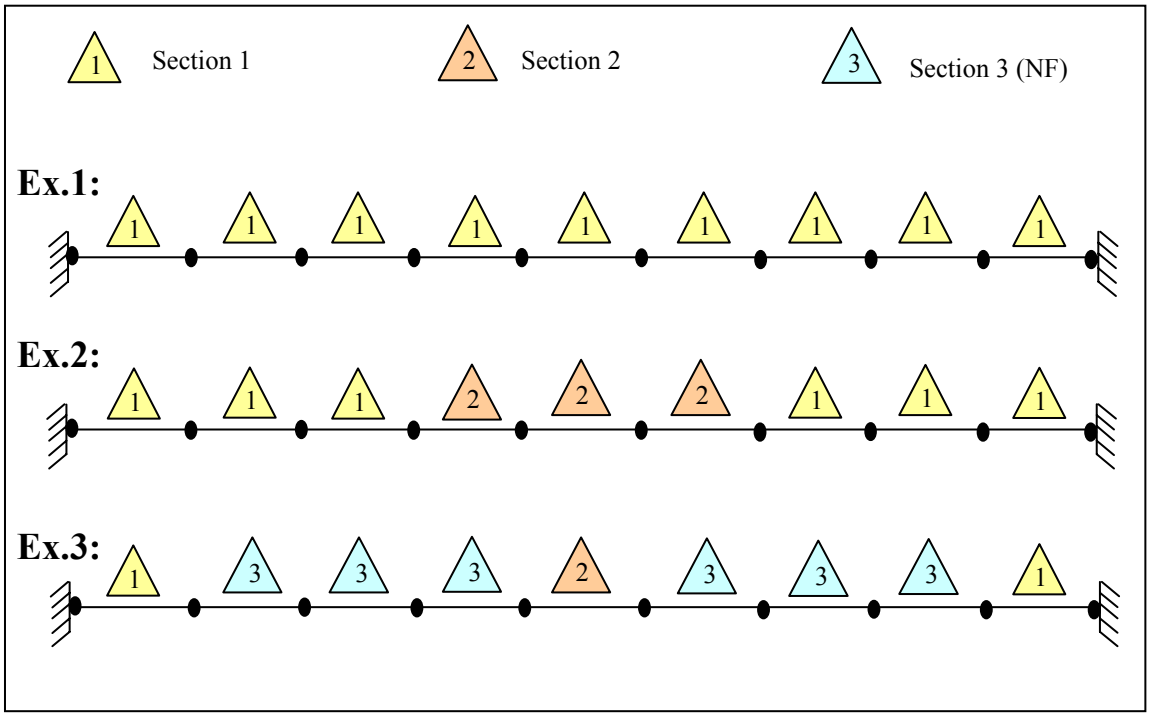


Fig.: 5.1 Elements and sections by their numbers.

Example 1:
The NovaDesign cross-section no. 1 will be used for all elements. After an analysis a design of this cross section will be performed for the design sections of all the elements.

Example 2:
The NovaDesign cross section no. 1 is used for the elements close to support and section no 2 is used in the field. Design of section 1 and 2 will be performed for the design sections of all the elements to which they are used.
Section 1 will be designed for typically negative moments and section 2 for typically positive moments.

Example 3:
The NovaDesign cross section no. 1 is used for the elements at support and section no 2 is used in the mid field. Cross section 3 is used for the rest of the elements. Design is only performed for the results of the elements that has either section 1 or 2.
Section 1 will be designed for support negative moments and section 2 for maximum field moment. Section no 3 is not used in the design, only as a section with stiffness properties in the analysis.

5.3 NovaDesign sections by reference lines

This is the most efficient way to achieve a full design of cross sections along a line.

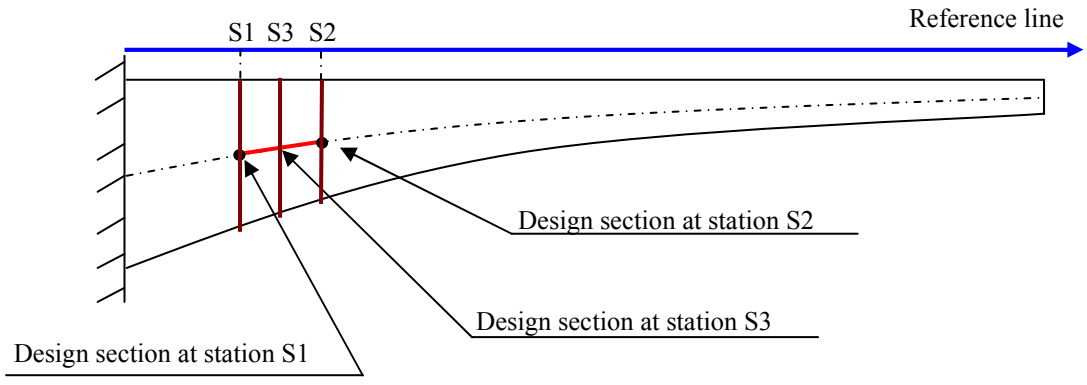
The Nodes must be generated along the reference line in order to get the correct node coordinates and in order to find the element section properties from the interpolation along the reference line.

In the analysis the element section properties are calculated based on the station along the reference line at each end of the element.

When starting the design calculation the cross section is calculated at each element design section and a design calculation is performed for this cross. For a description of element design sections see section 3.7 of the manual.
(Each element design section has an unique station number on the reference line.)

Note on reinforcement:
The reinforcement definition and step criteria for a section are valid from the station it is defined until a new cross section is defined on the reference line.
However the calculated utilization and reinforcement amounts will be unique for all the element design sections. Reinforcement stepping will be used for each of the design sections in order to achieve an optimal design.

Note on prestressing:
The prestressing definition is valid from the station it is defined until a new cross section is defined on the reference line. For sections with variable position of the cable along the reference line this imply that a number of sections needs to be defined in order to give the cable a reasonable accurate position along the line. The cable positions are not interpolated between two sections. The cable position will however vary according to the variation of the sides of the section to which they are connected.



The element is between station S1 and S2 on the reference line. Section forces are calculated for all the design sections of the element. The design sections are in this example in S1, S3 and S2. The cross section is calculated in each of the design sections by the help of the station number associated with each of the design sections. A design calculation can then be performed for each of the cross sections.

5.4 Overriding NovaDesign sections by reference lines

This method can be used for:

- Performing limited design
- Speed up the calculation process
- Reduce the amount of results

The first approach is as described in section 5.3, but an additional step is made by overriding the section calculated according to the reference line. This overriding is made by specifying sections by their number on specific elements using the ***Element spec. Page***.