# ZZZZ111 - Validation of the operator DEFI_CABLE_BP

**Summary:**

The goal of this CAS-test is to validate the operator DEFI_CABLE_BP, which calculates the profiles of tension in the cables of prestressed of a structure of concrete, in accordance with the rules of the BPEL: those make it possible to take account of the losses of tension per contact between the cables and the concrete, by retreat with anchorings, shrinking and creep of the concrete and relieving of steel, material constituting the cables.

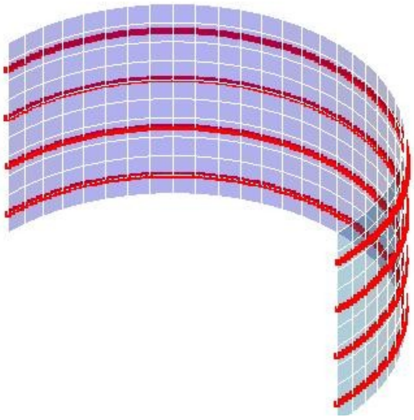
For modelings A and B, the structure considered is a semi-cylindrical veil, containing in its thickness four cables of prestressing. The cables describe each one a half-circle in a horizontal plane, and thus traverse the veil over its length. Two cables have an eccentricity compared to the average radius of the veil.

The got results are validated by comparison with those theoretically expected. The profiles of tension can be clarified analytically out of zones where the losses by retreat apply to anchorings. This calculation is done for modelings DKT (modeling A) and Q4GG (modeling B).

Modelings C and D make it possible to validate the operation of the routine PROJKM in the cases for which projection can be done only on one node.

# 1 Problem of reference

## 1.1 Geometry



The concrete veil has a semi-cylindrical form: the height is $H=10\,m$ and the average radius is worth $R=10\ m$.

The thickness of the veil is worth $e=0{,}6\,m$. The "equivalent average radius", within the meaning of the BPEL on the vertical section of the veil is thus worth $r_m=0{,}283\,m$, knowing that:

$$r_m=\frac{eH}{2(e+H)}$$ (reference BPEL 2.1,5)

The cables describe each one a half-circle in a horizontal plane, and thus traverse the veil over its length. The dimensions of the plans containing the cables are:

- for the cable n°1: $z_1=1\,m$ ;
- for the cable n°2: $z_2=3{,}5\,m$ ;
- for the cable n°3: $z_3=6\,m$ ;
- for the cable n°4: $z_4=8{,}5\,m$ .

Cables 3 and 4 have an eccentricity compared to the average radius of the veil, being worth respectively:

- $ex_3=0{,}05\,m$ ;
- $ex_4=0{,}1\,m$ .

The surface of the cross-section of each cable is worth $S_a=1{,}5.10^{-4}\,m^2$ .

## 1.2 Properties of materials

### 1.2.1 Material concrete constituting the veil

Elastic properties:

| | |
|---|---|
| Young modulus | $E_b=3.10^{10}\,Pa$ |
| Poisson's ratio | $\nu_b=0{,}2$ |

Parameters characteristic for estimate of the losses of tension:

| | |
|---|---|
| Standard rate of loss of tension by creep of the concrete | $x_{flu}=0{,}07$ |
| Standard rate of loss of tension by shrinking of the concrete | $x_{ret}=0{,}08$ |

### 1.2.2 Material steel constituting the cables

Elastic properties:

| | |
|---|---|
| Young modulus | $E_a=2{,}1.10^{11}Pa$ |
| Poisson's ratio | $\nu_a=0{,}3$ |

Parameters characteristic for estimate of the losses of tension:

| | |
|---|---|
| Relieving of steel at 1000 hours | $\rho_{1000}=2\%$ |
| Adimensional coefficient of relieving of prestressed steel | $\mu_0=0{,}3$ |
| Elastic ultimate stress of steel | $f_{prg}=1{,}77.10^9 Pa$ |
| Coefficient of friction in curve | $f=0{,}2\,rad^{-1}$ |
| Loss ratio of tension per unit of length | $\varphi=3.10^{-3}m^{-1}$ |

## 1.3 Loading

One applies at the two ends of each cable a normal effort of traction. The value of the tension applied is $F_0=2.10^5 N$ .

To evaluate the losses of tension by relieving of the cables in time, the following relations are used:

$$\Delta\sigma_{pj}=\Delta\sigma_p(x)r(j)$$ (reference BPEL 3.3,24)

$$\Delta\sigma_p=\frac{6}{100}\rho_{1000}\left(\frac{\sigma_{pi}(x)}{f_{prg}}-\mu_0\right)\sigma_{pi}(x)$$ (reference BPEL 3.3,23)

$$r(j)=\frac{j}{j+9\times r_m}$$ (reference BPEL 3.3,24 and 2.1,51)

| | |
|---|---|
| $\sigma_{pi}(x)$ | called initial tension, the tension at the point of X-coordinate $x$ , after instantaneous losses of tension. |
| $j$ | moment of evaluation, in day |
| $r_m$ | equivalent average radius, in $cm$ |

The characteristics are evaluated at the day $j=10$ .

To evaluate the losses of tension in the vicinity of anchorings, one takes account of a retreat with anchorings $\Delta=5.10^{-4}m$ .

**Note:**

*This problem disregards resolution of the balance of the structure supplements steel-concrete and is limited to the determination according to the BPEL of prestressing in the cables.*

# 2 Reference solution

## 2.1 Curvilinear X-coordinate and cumulated angular deviation

The cables describe each one a trajectory in the form of half-circle in a horizontal plane. Consequently, the curvilinear X-coordinate $s$ and the cumulated angular deviation $\alpha$ express themselves very simply:

$$\begin{cases} s=R_c\theta \\ \alpha=\theta \end{cases}$$

where $R_c$ indicate the ray of the half-circle described by the cable, and $\theta$ the azimuth in cylindrical coordinates.
The values of reference for the tests are estimated using these expressions.

## 2.2 Normal effort in the cables

One considers a cable describing a horizontal half-circle of ray $R_c$. One notes $\theta_0$ the azimuth locating the end of the zone where the losses of tension by retreat apply to the first anchoring; $\pi-\theta_0$ reference mark the beginning of the zone where the losses of tension by retreat apply to the second anchoring.
Taking into account the preceding expressions of the curvilinear X-coordinate and cumulated angular deviation, the profile of tension along the cable can be parameterized by the azimuth $\theta$, out of zones where the losses by retreat apply to anchorings:

$$\begin{aligned} F(\theta)=&-F_0(x_{flu}+x_{ret}) \\ &+F_0\left[1+r(j)\times\frac{5}{100}\rho_{1000}\times\mu_0\right]\exp(-(f+\varphi R_c)\theta) \\ &-F_0\times r(j)\times\frac{5}{100}\rho_{1000}\times\frac{F_0}{S_a f_{prg}}\times\exp(-2(f+\varphi R_c)\theta) \end{aligned}$$ on the interval $\left[\theta_0;\frac{\pi}{2}\right]$

$$\begin{aligned} F(\theta)=&-F_0(x_{flu}+x_{ret}) \\ &+F_0\left[1+r(j)\times\frac{5}{100}\rho_{1000}\times\mu_0\right]\exp(-(f+\varphi R_c)(\pi-\theta)) \\ &-F_0\times r(j)\times\frac{5}{100}\rho_{1000}\times\frac{F_0}{S_a f_{prg}}\times\exp(-2(f+\varphi R_c)(\pi-\theta)) \end{aligned}$$ on the interval $\left[\frac{\pi}{2};\pi-\theta_0\right]$

The values of reference for the tests are estimated using these expressions, which define a symmetrical profile of tension compared to the central node.

## 2.3 Index of projection

The projection of a node pertaining to the one of the cables on a mesh of the concrete veil causes the assignment of an index of projection $IPROJ$ in accordance with the following rule:

**Projection on a mesh triangle** nodes tops $N1$, $N2$ and $N3$:

| | |
|---|---|
| $IPROJ=0$ | if the point project is inside the triangle; |
| $IPROJ=11,12$ or $13$ | if the point project belongs respectively to the edge $[N1;N2]$, $[N2;N3]$ or $[N3;N1]$; |
| $IPROJ=2$ | if there is coincidence of the point project with a node top. |

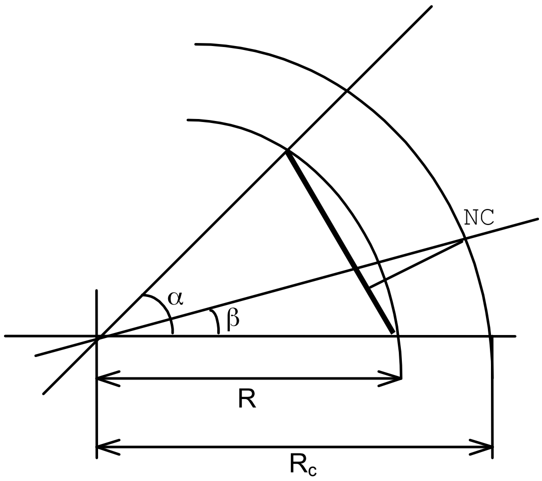
**Projection on a mesh quadrangle** nodes tops $N1, N2\ N3$ and $N4$ :

| | |
|---|---|
| $IPROJ=0$ | if the point project is inside the quadrangle; |
| $IPROJ=11, 12, 13$ or $14$ | if the point project belongs respectively to the edge $[N1; N2]$, $[N2; N3]$, $[N3; N4]$ or $[N4; N1]$; |
| $IPROJ=2$ | if there is coincidence of the point project with a node top. |

The values of reference for the tests are estimated by predicting the places of projection of the cables, taking into account their situation compared to the veil and of the provision of the meshs on this one.

## 2.4 Eccentricity

The eccentricity of a node pertaining to the one of the cables is defined as the distance from this node to the mesh of the concrete veil on which it is projected.
Seen in a horizontal plane, the trace of the mesh is a cord on the half-circle of ray $R$ . One notes $\alpha$ the angular sector covered by the mesh. The node of the cable, noted $NC$ , is located on the half-circle of ray $R_c$ . Its relative position compared to the mesh is located by the azimuth $\beta$ .




The vector $\left(\cos\frac{\alpha}{2}; \sin\frac{\alpha}{2}\right)$ is normal with the cord, which passes by the point $(R; 0)$ .

The equation of the cord is thus $\cos\frac{\alpha}{2}x+\sin\frac{\alpha}{2}y-R\cos\frac{\alpha}{2}=0$

The distance from a point on a line, in the plan, is given by:

$$d=\frac{|a\,x_0+b\,x_0+c|}{\sqrt{a^2+b^2}}$$

where $(x_0 ; y_0)$ are the coordinates of the point and $ax+by+c=0$ is the equation of the right-hand side.

The node $NC$ belonging to the cable has as coordinates $\left(R_c\cos\beta ; R_c\sin\beta\right)$ . Its eccentricity compared to the mesh of the veil on which it is projected is thus worth:

$$ex_c=\left|R_c\cos\left(\frac{\alpha}{2}-\beta\right)-R\cos\frac{\alpha}{2}\right|$$

The values of reference for the tests are estimated using this expression.

# 3 Modeling A and B

## 3.1 Characteristics of modelings

The concrete veil is represented by elements DKT for modeling A and by the elements Q4GG for modeling B, supported in both cases by meshs quadrangles with 4 nodes: one counts 10 meshs on a vertical generator and 32 on a horizontal half-circle. With this provision, the meshs have dimensions close to those of a square of $1\,m$ on side.

All that follows is common to modelings A and B.

A thickness $e=0,6\,m$ is assigned to all the meshs of the veil, as well as a material concrete for which the behaviors are defined ELAS and BPEL_BETON : the parameters take the values given previously in paragraph [§ 2.2.1].

Each cable is represented by 128 elements MECA_BARRE, supported by meshs segments with 2 nodes. On a horizontal half-circle, one thus counts 4 times more meshs on a cable than on the concrete veil.

A surface of cross-section $S_a=1,5.10^{-4}\,m^2$ is assigned to all the meshs of the cables, as well as a material steel for which the behaviors are defined ELAS and BPEL_ACIER : the parameters take the values given previously in paragraph [§ 2.2.2].

The tension $F_0=2.10^5\,N$ is applied to the two nodes ends of each cable. The value of this tension is coherent with the values of section and elastic ultimate stress, for stranded cables of prestressing. The evaluation of the losses of tension by relieving and retreat with anchorings is carried out in accordance with the rules of the BPEL; the parameters take the values given previously in paragraph [§ 2.2.3].

As one applies the same tension at the two ends of each cable, and as one imposes the same retreat on anchorings, the profiles of tension obtained must be symmetrical compared to the nodes mediums of the cables.

Taking into account the geometrical characteristics and grid, the nodes of the cables n°1 and n°2 are projected on the nodes tops and the edges of the meshs of the concrete veil. For the nodes of these two cables, the indices of projection obtained must be in conformity with the following sequence: 2 for the first node, then $13-13-13-2$ until the last node.

The nodes of the cables n°3 and n°4 are projected as for them on the edges and inside the meshs of the concrete veil. For the nodes of these two cables, the indices of projection obtained must be in conformity with the following sequence: 14 for the first node, then $0-0-0-12$ until the last node.

The rule of assignment of the index of projection is previously defined in paragraph [§ 3.3].

Taking into account the characteristics of the grid, the eccentricities of the nodes of the cables are evaluated using the expression of the paragraph [§ 3.4] with $\alpha=\frac{\pi}{32}$ and $\beta=0,\frac{\alpha}{4},\frac{\alpha}{2},\frac{3\alpha}{4}$ .

## 3.2 Sizes tested and results

### 3.2.1 Curvilinear X-coordinate

The component tested is ABS_CURV.

| Identification (node) | Type of reference | Value of reference [ $m$ ] | Tolerance ( $\%$ ) |
|---|---|---|---|
| NC001032 | 'ANALYTICAL' | $7{,}608545.10^{0}$ | 0,10% |
| NC001033 | 'ANALYTICAL' | $7{,}853982.10^{0}$ | 0,10% |
| NC001034 | 'ANALYTICAL' | $8{,}099419.10^{0}$ | 0,10% |
| NC001064 | 'ANALYTICAL' | $1{,}546253.10^{1}$ | 0,10% |
| NC001065 | 'ANALYTICAL' | $1{,}570796.10^{1}$ | 0,10% |
| NC001066 | 'ANALYTICAL' | $1{,}595340.10^{1}$ | 0,10% |
| NC001096 | 'ANALYTICAL' | $2{,}331651.10^{1}$ | 0,10% |
| NC001097 | 'ANALYTICAL' | $2{,}356194.10^{1}$ | 0,10% |
| NC001098 | 'ANALYTICAL' | $2{,}380738.10^{1}$ | 0,10% |
| | | | |
| NC002032 | 'ANALYTICAL' | $7{,}608545.10^{0}$ | 0,10% |
| NC002033 | 'ANALYTICAL' | $7{,}853982.10^{0}$ | 0,10% |
| NC002034 | 'ANALYTICAL' | $8{,}099419.10^{0}$ | 0,10% |
| NC002064 | 'ANALYTICAL' | $1{,}546253.10^{1}$ | 0,10% |
| NC002065 | 'ANALYTICAL' | $1{,}570796.10^{1}$ | 0,10% |
| NC002066 | 'ANALYTICAL' | $1{,}595340.10^{1}$ | 0,10% |
| NC002096 | 'ANALYTICAL' | $2{,}331651.10^{1}$ | 0,10% |
| NC002097 | 'ANALYTICAL' | $2{,}356194.10^{1}$ | 0,10% |
| NC002098 | 'ANALYTICAL' | $2{,}380738.10^{1}$ | 0,10% |
| | | | |
| NC003032 | 'ANALYTICAL' | $7{,}646587.10^{0}$ | 0,10% |
| NC003033 | 'ANALYTICAL' | $7{,}893252.10^{0}$ | 0,10% |
| NC003034 | 'ANALYTICAL' | $8{,}139916.10^{0}$ | 0,10% |
| NC003064 | 'ANALYTICAL' | $1{,}553984.10^{1}$ | 0,10% |
| NC003065 | 'ANALYTICAL' | $1{,}578650.10^{1}$ | 0,10% |
| NC003066 | 'ANALYTICAL' | $1{,}603317.10^{1}$ | 0,10% |
| NC003096 | 'ANALYTICAL' | $2{,}343309.10^{1}$ | 0,10% |
| NC003097 | 'ANALYTICAL' | $2{,}367975.10^{1}$ | 0,10% |
| NC003098 | 'ANALYTICAL' | $2{,}392642.10^{1}$ | 0,10% |
| | | | |
| NC004032 | 'ANALYTICAL' | $7{,}684630.10^{0}$ | 0,10% |
| NC004033 | 'ANALYTICAL' | $7{,}932521.10^{0}$ | 0,10% |

| | | | |
|---|---|---|---|
| NC004034 | 'ANALYTICAL' | $8{,}180413.10^{0}$ | 0,10% |
| NC004064 | 'ANALYTICAL' | $1{,}561715.10^{1}$ | 0,10% |
| NC004065 | 'ANALYTICAL' | $1{,}586504.10^{1}$ | 0,10% |
| NC004066 | 'ANALYTICAL' | $1{,}611293.10^{1}$ | 0,10% |
| NC004096 | 'ANALYTICAL' | $2{,}354967.10^{1}$ | 0,10% |
| NC004097 | 'ANALYTICAL' | $2{,}379756.10^{1}$ | 0,10% |
| NC004098 | 'ANALYTICAL' | $2{,}404546.10^{1}$ | 0,10% |

### 3.2.2 Cumulated angular deviation

The component tested is ALPHA.

| Identification (node) | Type of reference | Value of reference [ $rad$ ] | Tolerance ( $\%$ ) |
|---|---|---|---|
| NC001032 | 'ANALYTICAL' | $7{,}608545.10^{-1}$ | 1,00% |
| NC001033 | 'ANALYTICAL' | $7{,}853982.10^{-1}$ | 1,00% |
| NC001034 | 'ANALYTICAL' | $8{,}099419.10^{-1}$ | 1,00% |
| NC001064 | 'ANALYTICAL' | $1{,}546253.10^{0}$ | 1,00% |
| NC001065 | 'ANALYTICAL' | $1{,}570796.10^{0}$ | 1,00% |
| NC001066 | 'ANALYTICAL' | $1{,}595340.10^{0}$ | 1,00% |
| NC001096 | 'ANALYTICAL' | $2{,}331651.10^{0}$ | 1,00% |
| NC001097 | 'ANALYTICAL' | $2{,}356194.10^{0}$ | 1,00% |
| NC001098 | 'ANALYTICAL' | $2{,}380738.10^{0}$ | 1,00% |
| | | | |
| NC002032 | 'ANALYTICAL' | $7{,}608545.10^{-1}$ | 1,00% |
| NC002033 | 'ANALYTICAL' | $7{,}853982.10^{-1}$ | 1,00% |
| NC002034 | 'ANALYTICAL' | $8{,}099419.10^{-1}$ | 1,00% |
| NC002064 | 'ANALYTICAL' | $1{,}546253.10^{0}$ | 1,00% |
| NC002065 | 'ANALYTICAL' | $1{,}570796.10^{0}$ | 1,00% |
| NC002066 | 'ANALYTICAL' | $1{,}595340.10^{0}$ | 1,00% |
| NC002096 | 'ANALYTICAL' | $2{,}331651.10^{0}$ | 1,00% |
| NC002097 | 'ANALYTICAL' | $2{,}356194.10^{0}$ | 1,00% |
| NC002098 | 'ANALYTICAL' | $2{,}380738.10^{0}$ | 1,00% |
| | | | |
| NC003032 | 'ANALYTICAL' | $7{,}608545.10^{-1}$ | 1,00% |
| NC003033 | 'ANALYTICAL' | $7{,}853982.10^{-1}$ | 1,00% |
| NC003034 | 'ANALYTICAL' | $8{,}099419.10^{-1}$ | 1,00% |
| NC003064 | 'ANALYTICAL' | $1{,}546253.10^{0}$ | 1,00% |
| NC003065 | 'ANALYTICAL' | $1{,}570796.10^{0}$ | 1,00% |

| | | | |
|---|---|---|---|
| NC003066 | 'ANALYTICAL' | $1,595340.10^{0}$ | 1,00% |
| NC003096 | 'ANALYTICAL' | $2,331651.10^{0}$ | 1,00% |
| NC003097 | 'ANALYTICAL' | $2,356194.10^{0}$ | 1,00% |
| NC003098 | 'ANALYTICAL' | $2,380738.10^{0}$ | 1,00% |
| | | | |
| NC004032 | 'ANALYTICAL' | $7,608545.10^{-1}$ | 1,00% |
| NC004033 | 'ANALYTICAL' | $7,853982.10^{-1}$ | 1,00% |
| NC004034 | 'ANALYTICAL' | $8,099419.10^{-1}$ | 1,00% |
| NC004064 | 'ANALYTICAL' | $1,546253.10^{0}$ | 1,00% |
| NC004065 | 'ANALYTICAL' | $1,570796.10^{0}$ | 1,00% |
| NC004066 | 'ANALYTICAL' | $1,595340.10^{0}$ | 1,00% |
| NC004096 | 'ANALYTICAL' | $2,331651.10^{0}$ | 1,00% |
| NC004097 | 'ANALYTICAL' | $2,356194.10^{0}$ | 1,00% |
| NC004098 | 'ANALYTICAL' | $2,380738.10^{0}$ | 1,00% |

### 3.2.3 Normal effort in the cables

The component tested is TENSION.

| Identification (node) | Type of reference | Value of reference [ $N$ ] | Tolerance (%) |
|---|---|---|---|
| NC001032 | 'ANALYTICAL' | $1,334446.10^{5}$ | 0,50% |
| NC001033 | 'ANALYTICAL' | $1,325720.10^{5}$ | 0,50% |
| NC001034 | 'ANALYTICAL' | $1,317036.10^{5}$ | 0,50% |
| NC001064 | 'ANALYTICAL' | $1,076002.10^{5}$ | 0,50% |
| NC001065 | 'ANALYTICAL' | $1,068586.10^{5}$ | 0,50% |
| NC001066 | 'ANALYTICAL' | $1,076002.10^{5}$ | 0,50% |
| NC001096 | 'ANALYTICAL' | $1,317036.10^{5}$ | 0,50% |
| NC001097 | 'ANALYTICAL' | $1,325720.10^{5}$ | 0,50% |
| NC001098 | 'ANALYTICAL' | $1,334446.10^{5}$ | 0,50% |
| | | | |
| NC002032 | 'ANALYTICAL' | $1,334446.10^{5}$ | 0,50% |
| NC002033 | 'ANALYTICAL' | $1,325720.10^{5}$ | 0,50% |
| NC002034 | 'ANALYTICAL' | $1,317036.10^{5}$ | 0,50% |
| NC002064 | 'ANALYTICAL' | $1,076002.10^{5}$ | 0,50% |
| NC002065 | 'ANALYTICAL' | $1,068586.10^{5}$ | 0,50% |
| NC002066 | 'ANALYTICAL' | $1,076002.10^{5}$ | 0,50% |
| NC002096 | 'ANALYTICAL' | $1,317036.10^{5}$ | 0,50% |
| NC002097 | 'ANALYTICAL' | $1,325720.10^{5}$ | 0,50% |

| | | | |
|---|---|---|---|
| NC002098 | 'ANALYTICAL' | $1,334446.10^5$ | 0,50% |
| | | | |
| NC003032 | 'ANALYTICAL' | $1,334270.10^5$ | 0,50% |
| NC003033 | 'ANALYTICAL' | $1,325538.10^5$ | 0,50% |
| NC003034 | 'ANALYTICAL' | $1,316850.10^5$ | 0,50% |
| NC003064 | 'ANALYTICAL' | $1,075696.10^5$ | 0,50% |
| NC003065 | 'ANALYTICAL' | $1,068278.10^5$ | 0,50% |
| NC003066 | 'ANALYTICAL' | $1,075696.10^5$ | 0,50% |
| NC003096 | 'ANALYTICAL' | $1,316850.10^5$ | 0,50% |
| NC003097 | 'ANALYTICAL' | $1,325538.10^5$ | 0,50% |
| NC003098 | 'ANALYTICAL' | $1,334270.10^5$ | 0,50% |
| | | | |
| NC004032 | 'ANALYTICAL' | $1,334093.10^5$ | 0,50% |
| NC004033 | 'ANALYTICAL' | $1,325356.10^5$ | 0,50% |
| NC004034 | 'ANALYTICAL' | $1,316664.10^5$ | 0,50% |
| NC004064 | 'ANALYTICAL' | $1,075391.10^5$ | 0,50% |
| NC004065 | 'ANALYTICAL' | $1,067969.10^5$ | 0,50% |
| NC004066 | 'ANALYTICAL' | $1,075391.10^5$ | 0,50% |
| NC004096 | 'ANALYTICAL' | $1,316664.10^5$ | 0,50% |
| NC004097 | 'ANALYTICAL' | $1,325356.10^5$ | 0,50% |
| NC004098 | 'ANALYTICAL' | $1,334093.10^5$ | 0,50% |

### 3.2.4 Index of projection

The component tested is INDICE_PROJECTION.

| Identification (node) | Type of reference | Value of reference | Tolerance |
|---|---|---|---|
| NC001032 | 'ANALYTICAL' | 13 | 1,00E-003 |
| NC001033 | 'ANALYTICAL' | 2 | 1,00E-003 |
| NC001034 | 'ANALYTICAL' | 13 | 1,00E-003 |
| NC001064 | 'ANALYTICAL' | 13 | 1,00E-003 |
| NC001065 | 'ANALYTICAL' | 2 | 1,00E-003 |
| NC001066 | 'ANALYTICAL' | 13 | 1,00E-003 |
| NC001096 | 'ANALYTICAL' | 13 | 1,00E-003 |
| NC001097 | 'ANALYTICAL' | 2 | 1,00E-003 |
| NC001098 | 'ANALYTICAL' | 13 | 1,00E-003 |
| | | | |
| NC002032 | 'ANALYTICAL' | 0 | 1,00E-003 |
| NC002033 | 'ANALYTICAL' | 12 | 1,00E-003 |

| | | | |
|---|---|---|---|
| NC002034 | 'ANALYTICAL' | 0 | 1,00E-003 |
| NC002064 | 'ANALYTICAL' | 0 | 1,00E-003 |
| NC002065 | 'ANALYTICAL' | 12 | 1,00E-003 |
| NC002066 | 'ANALYTICAL' | 0 | 1,00E-003 |
| NC002096 | 'ANALYTICAL' | 0 | 1,00E-003 |
| NC002097 | 'ANALYTICAL' | 12 | 1,00E-003 |
| NC002098 | 'ANALYTICAL' | 0 | 1,00E-003 |
| | | | |
| NC003032 | 'ANALYTICAL' | 13 | 1,00E-003 |
| NC003033 | 'ANALYTICAL' | 2 | 1,00E-003 |
| NC003034 | 'ANALYTICAL' | 13 | 1,00E-003 |
| NC003064 | 'ANALYTICAL' | 13 | 1,00E-003 |
| NC003065 | 'ANALYTICAL' | 2 | 1,00E-003 |
| NC003066 | 'ANALYTICAL' | 13 | 1,00E-003 |
| NC003096 | 'ANALYTICAL' | 13 | 1,00E-003 |
| NC003097 | 'ANALYTICAL' | 2 | 1,00E-003 |
| NC003098 | 'ANALYTICAL' | 13 | 1,00E-003 |
| | | | |
| NC004032 | 'ANALYTICAL' | 0 | 1,00E-003 |
| NC004033 | 'ANALYTICAL' | 12 | 1,00E-003 |
| NC004034 | 'ANALYTICAL' | 0 | 1,00E-003 |
| NC004064 | 'ANALYTICAL' | 0 | 1,00E-003 |
| NC004065 | 'ANALYTICAL' | 12 | 1,00E-003 |
| NC004066 | 'ANALYTICAL' | 0 | 1,00E-003 |
| NC004096 | 'ANALYTICAL' | 0 | 1,00E-003 |
| NC004097 | 'ANALYTICAL' | 12 | 1,00E-003 |
| NC004098 | 'ANALYTICAL' | 0 | 1,00E-003 |

### 3.2.5 Eccentricity

The component tested is ECCENTRICITY.

| Identification (node) | Type of reference | Value of reference [ $m$ ] | Tolerance |
|---|---|---|---|
| NC001032 | 'ANALYTICAL' | $9{,}033625.10^{-3}$ | 0,10% |
| NC001033 | 'ANALYTICAL' | 0 | 1,00E-003 |
| NC001034 | 'ANALYTICAL' | $9{,}033625.10^{-3}$ | 0,10% |
| NC001064 | 'ANALYTICAL' | $9{,}033625.10^{-3}$ | 0,10% |
| NC001065 | 'ANALYTICAL' | 0 | 1,00E-003 |

| | | | |
|---|---|---|---|
| NC001066 | 'ANALYTICAL' | $9{,}033625.10^{-3}$ | 0,10% |
| NC001096 | 'ANALYTICAL' | $9{,}033625.10^{-3}$ | 0,10% |
| NC001097 | 'ANALYTICAL' | 0 | 1,00E-003 |
| NC001098 | 'ANALYTICAL' | $9{,}033625.10^{-3}$ | 0,10% |
| | | | |
| NC002032 | 'ANALYTICAL' | $9{,}033625.10^{-3}$ | 0,10% |
| NC002033 | 'ANALYTICAL' | 0 | 1,00E-003 |
| NC002034 | 'ANALYTICAL' | $9{,}033625.10^{-3}$ | 0,10% |
| NC002064 | 'ANALYTICAL' | $9{,}033625.10^{-3}$ | 0,10% |
| NC002065 | 'ANALYTICAL' | 0 | 1,00E-003 |
| NC002066 | 'ANALYTICAL' | $9{,}033625.10^{-3}$ | 0,10% |
| NC002096 | 'ANALYTICAL' | $9{,}033625.10^{-3}$ | 0,10% |
| NC002097 | 'ANALYTICAL' | 0 | 1,00E-003 |
| NC002098 | 'ANALYTICAL' | $9{,}033625.10^{-3}$ | 0,10% |
| | | | |
| NC003032 | 'ANALYTICAL' | $5{,}901857.10^{-2}$ | 0,10% |
| NC003033 | 'ANALYTICAL' | $5.10^{-2}$ | 0,10% |
| NC003034 | 'ANALYTICAL' | $5{,}901857.10^{-2}$ | 0,10% |
| NC003064 | 'ANALYTICAL' | $5{,}901857.10^{-2}$ | 0,10% |
| NC003065 | 'ANALYTICAL' | $5.10^{-2}$ | 0,10% |
| NC003066 | 'ANALYTICAL' | $5{,}901857.10^{-2}$ | 0,10% |
| NC003096 | 'ANALYTICAL' | $5{,}901857.10^{-2}$ | 0,10% |
| NC003097 | 'ANALYTICAL' | $5.10^{-2}$ | 0,10% |
| NC003098 | 'ANALYTICAL' | $5{,}901857.10^{-2}$ | 0,10% |
| | | | |
| NC004032 | 'ANALYTICAL' | $1{,}090035.10^{-1}$ | 0,10% |
| NC004033 | 'ANALYTICAL' | $10^{-1}$ | 0,10% |
| NC004034 | 'ANALYTICAL' | $1{,}090035.10^{-1}$ | 0,10% |
| NC004064 | 'ANALYTICAL' | $1{,}090035.10^{-1}$ | 0,10% |
| NC004065 | 'ANALYTICAL' | $10^{-1}$ | 0,10% |
| NC004066 | 'ANALYTICAL' | $1{,}090035.10^{-1}$ | 0,10% |
| NC004096 | 'ANALYTICAL' | $1{,}090035.10^{-1}$ | 0,10% |
| NC004097 | 'ANALYTICAL' | $10^{-1}$ | 0,10% |
| NC004098 | 'ANALYTICAL' | $1{,}090035.10^{-1}$ | 0,10% |

## 3.3 Remarks

One obtains relative variations for the cumulated angular deviation of an order of magnitude definitely higher than those obtained for the curvilinear X-coordinate, which is calculated with a very good precision.
The cause is inherent in the method of interpolation spline cubic used to interpolate the trajectories of the cables. This method consists in interpolating the trajectory on each subinterval by a polynomial of order 3, by guaranteeing the continuity of the derivative first and the derivative second at the boundaries of the subintervals. The interpolation of a circular trajectory by polynomials of order 3 is in is an approximation, of which the effects are more sensitive on the derivative second than on the derivative first.

This is why the precision obtained for the curvilinear X-coordinate, calculated using the derivative first of the trajectory, is definitely better than that obtained for the cumulated angular deviation, calculated using products crossed between the derivative first and the derivative second. To improve the precision on the cumulated angular deviation, the grid would have appreciably to be refined: this approach is not valid a priori, because it would lead to very consequent overcosts of calculation for a weak profit of precision.

One obtains indeed symmetrical profiles of tension compared to the nodes mediums of the cables. The variations by default on the curvilinear X-coordinate and the cumulated angular deviation induce variations by excess on the calculated values of tension, but the precision remains satisfactory: this validates the method of calculating.

The indices of projection obtained are in conformity with those expected, and the eccentricities are calculated with a very good precision: this validates the operations of projection.

# 4 Modeling C

The objective of this modeling is to validate the routine PROJKM in the case or projections on the meshs then on the sides are impossible.

## 4.1 Characteristics of modeling and grid

One uses for the concrete a geometry having a S curve of type "cupola". The grid is composed of four meshs QUAD4 of concrete and two meshs SEG2 for the cable.

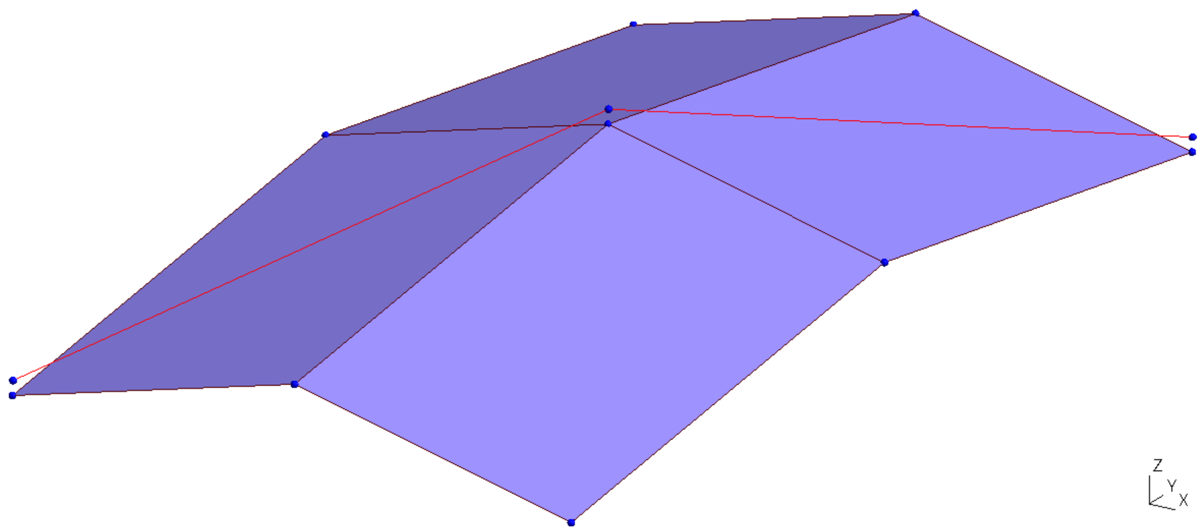



**Figure 4.1-a: sight of the grid zzzz111b**

The S curve of the concrete creates a zone where projections on the surface meshs and the edges of the concrete meshs fail. The point medium of the cable is located in this zone so that the routine PROJKN that is to say called.

The command file is based on that of modeling A with a minimum of modification to adapt it to the grid and tests of this modeling; all the other parameters are identical: modeling, materials, loadings,…

## 4.2 Sizes tested and results

One tests the index of projection for the 3 nodes of the cable and the eccentricity of the central point whose projection was calculated by the routine PROJKN.

| Identification | Type of reference | Value of reference | Tolerance |
|---|---|---|---|
| N101 - INDICE_PROJECTION | 'ANALYTICAL' | 0 | 1.0E-03 |
| N105 - INDICE_PROJECTION | 'ANALYTICAL' | 2 | 1.0E-03 |
| N109 - INDICE_PROJECTION | 'ANALYTICAL' | 0 | 1.0E-03 |
| N105 - ECCENTRICITY | 'ANALYTICAL' | 0.1 | 1.0E-10 |

# 5 Modeling D

This modeling is the same one as modeling C. One simply replaced meshs QUAD4 by TRIA3 by separating them into two so that the node top belongs to the 8 surface meshs of the grid.

# 6 Summary of the results

The got results are validated by comparison with those theoretically expected with a good precision.

The particular features tested are the following ones:

- operator DEFI_MATERIAU [U4.23.01]: définition of the parameters characteristic of the materials steel and concrete allowing calculation of the tension along the cables of prestressing, the rules of the BPEL;
- operator DEFI_CABLE_BP [U4.23.06]: calculation of the tension along the cables; projection of the nodes of the cables on meshs representing the structure of concrete, preliminary to the calculation of the coefficients of the relations kinematics between the degrees of freedom of the nodes of the cables and the degrees of freedom of the nodes "close" to the structure of concrete.