ZZZZ111 - Validation of Summarized `operator`

DEFI_CABLE_BP:

The goal of this benchmark is to validate the operator `DEFI_CABLE_BP`, who 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 the anchorages, shrinking and creep of the concrete and relaxation of steel, material constituting the cables.

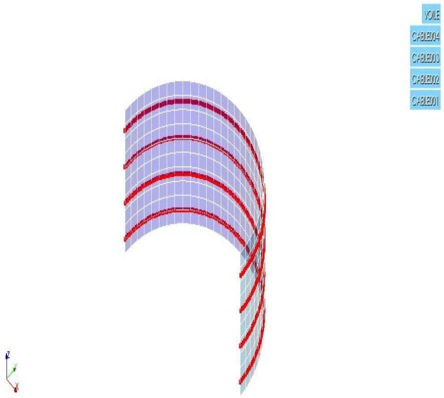
The structure considered is a semi-cylindrical veil, containing in its thickness four cables of prestressing. The cables describe each one a half-circle in a horizontal plane, and thus traverse the veil over its length. Two cables have an eccentricity compared to the average radius of the veil.

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 the anchorages. This calculation is done for modelizations `DKT` (modelization A) and `Q4GG` (modelization B).

A second modelization is added to cover routine `PROJKN` used in certain cases for the projection of the nodes of cables on meshes of concrete.

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 planes 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 area of the straight section of each cable is worth $S_a=1,5.10^{-4}\,m^2$.

1.2 Properties of the materials

1.2.1 Concrete material 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:

Relaxation of steel at 1000 hours	$\rho_{1000} = 2\%$
adimensional Coefficient of relaxation of prestressed steel	$\mu_0 = 0{,}3$
Stress yield stress of steel	$f_{prg} = 1{,}77 . 10^9 \, Pa$
Coefficient of kinetic friction in curve	$f = 0{,}2 \, rad^{-1}$
Ratio loss 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 force of tension. The value of the tension applied is $F_0 = 2.10^5 \, N$.

To evaluate the losses of tension by relaxation 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	time of evaluating, in equivalent
r_m	average radius day, cm

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

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

Note:

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

2 Cumulated angular deviation

2.1 and reference solution Curvilinear abscisse

the cables describe each one a trajectory in the form of half-circle in a horizontal plane. Consequently, the curvilinear abscisse s and the cumulated angular deviation α are expressed very simply:

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

where R_c the radius of the half-circle indicates described by the cable, and θ the azimuth in cylindrical coordinates.
The values of reference for the tests are estimated using these statements.

2.2 Normal force in the cables

One considers a cable describing a horizontal half-circle of radius R_c. One notes θ_0 the azimuth locating the end of the zone where the losses of tension by retreat apply to the first anchorage; $\pi-\theta_0$ locate the beginning of the zone where the losses of tension by retreat apply to the second anchorage.
Taking into account the preceding statements of the curvilinear abscisse and cumulated angular deviation, the profile of tension along the cable can be parameterized by the azimuth θ, out of zones where the losses by retreat apply to the anchorages:

$$\begin{aligned} F(\theta)=&-F_0(x_{flu}+x_{ret}) \\ &+F_0\left[1+r(j)\times\frac{5}{100}\rho_{1000}\times\mu_0\right]\exp(-(f+\varphi R_c)\theta) \\ &-F_0\times r(j)\times\frac{5}{100}\rho_{1000}\times\frac{F_0}{S_a f_{prg}}\times\exp(-2(f+\varphi R_c)\theta) \end{aligned}$$ 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 statements, which define a symmetric 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 of 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 edge $[N1;N2]$, $[N2;N3]$ or $[N3;N1]$;
$IPROJ=2$	if there is coincidence of the point project with a top node.

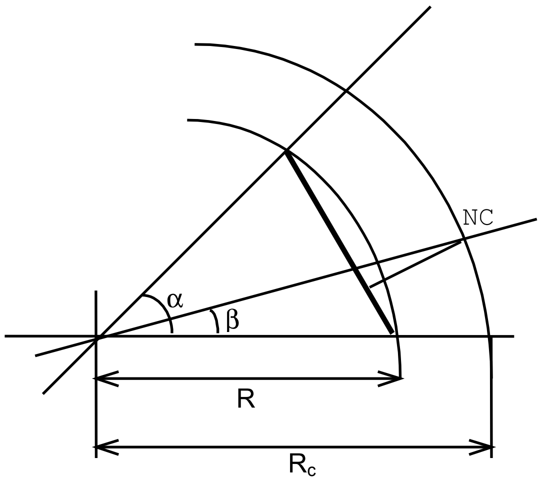
Projection on a mesh quadrangle of nodes tops $N1, N2\ N3$ and $N4$:

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

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 meshes 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 rope on the half-circle of radius R . One notes α the angular sector covered by the mesh. The node of the cable, noted NC , is located on the half-circle of radius R_c . Its relative position compared to the mesh is located by the azimuth β .



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

The equation of the rope 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 plane, 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.

The node NC belonging to 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 statement.

3 Modelization A and B

3.1 Characteristic of the modelizations

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

All that follows is common to the modelizations A and B.

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

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

An area of cross-section $S_a=1{,}5.10^{-4}m^2$ is assigned to all meshes cables, as well as a material steel for which behaviors ELAS and BPEL_ACIER are defined: 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 stress yield stress, for stranded cables of prestressing. The evaluating of the losses of tension by relaxation and retreat with the anchorages 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 the anchorages, the profiles of tension obtained must be symmetric compared to the nodes mediums of the cables.

Taking into account the geometrical characteristics and mesh, the nodes of the cables n°1 and n°2 and the project on the nodes tops edges of meshes 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 edges and inside meshes 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 mesh, eccentricities of the nodes of the cables are evaluated using the statement 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 Quantities tested and Curvilinear abscisse

3.2.1 results

the component tested is ABS_CURV.

Identification (node)	Standard of reference	Value of reference [m]	Tolerance ($\%$)
NC001032	"ANALYTIQUE"	7,608545.100	0.10%
NC001033	"ANALYTIQUE"	7,853982.100	0.10%
NC001034	"ANALYTIQUE"	8,099419.100	0.10%
NC001064	"ANALYTIQUE"	1,546253.101	0.10%
NC001065	"ANALYTIQUE"	1,570796.101	0.10%
NC001066	"ANALYTIQUE"	1,595340.101	0.10%
NC001096	"ANALYTIQUE"	2,331651.101	0.10%
NC001097	"ANALYTIQUE"	2,356194.101	0.10%
NC001098	"ANALYTIQUE"	2,380738.101	0.10%
NC002032	"ANALYTIQUE"	7,608545.100	0.10%
NC002033	"ANALYTIQUE"	7,853982.100	0.10%
NC002034	"ANALYTIQUE"	8,099419.100	0.10%
NC002064	"ANALYTIQUE"	1,546253.101	0.10%
NC002065	"ANALYTIQUE"	1,570796.101	0.10%
NC002066	"ANALYTIQUE"	1,595340.101	0.10%
NC002096	"ANALYTIQUE"	2,331651.101	0.10%
NC002097	"ANALYTIQUE"	2,356194.101	0.10%
NC002098	"ANALYTIQUE"	2,380738.101	0.10%
NC003032	"ANALYTIQUE"	7,646587.100	0.10%
NC003033	"ANALYTIQUE"	7,893252.100	0.10%
NC003034	"ANALYTIQUE"	8,139916.100	0.10%
NC003064	"ANALYTIQUE"	1,553984.101	0.10%
NC003065	"ANALYTIQUE"	1,578650.101	0.10%
NC003066	"ANALYTIQUE"	1,603317.101	0.10%
NC003096	"ANALYTIQUE"	2,343309.101	0.10%
NC003097	"ANALYTIQUE"	2,367975.101	0.10%
NC003098	"ANALYTIQUE"	2,392642.101	0.10%
NC004032	"ANALYTIQUE"	7,684630.100	0.10%
NC004033	"ANALYTIQUE"	7,932521.100	0.10%

NC004034	"ANALYTIQUE"	8,180413.100	0.10%
NC004064	"ANALYTIQUE"	1,561715.101	0.10%
NC004065	"ANALYTIQUE"	1,586504.101	0.10%
NC004066	"ANALYTIQUE"	1,611293.101	0.10%
NC004096	"ANALYTIQUE"	2,354967.101	0.10%
NC004097	"ANALYTIQUE"	2,379756.101	0.10%
NC004098	"ANALYTIQUE"	2,404546.101	0.10%

3.2.2 cumulated angular Deviation

the component tested are ALPHA.

Identification (node)	Standard of reference	Value of reference [rad]	Tolerance ($\%$)
NC001032	"ANALYTIQUE"	7,608545.10-1	1.00%
NC001033	"ANALYTIQUE"	7,853982.10-1	1.00%
NC001034	"ANALYTIQUE"	8,099419.10-1	1.00%
NC001064	"ANALYTIQUE"	1,546253.100	1.00%
NC001065	"ANALYTIQUE"	1,570796.100	1.00%
NC001066	"ANALYTIQUE"	1,595340.100	1.00%
NC001096	"ANALYTIQUE"	2,331651.100	1.00%
NC001097	"ANALYTIQUE"	2,356194.100	1.00%
NC001098	"ANALYTIQUE"	2,380738.100	1.00%
NC002032	"ANALYTIQUE"	7,608545.10-1	1.00%
NC002033	"ANALYTIQUE"	7,853982.10-1	1.00%
NC002034	"ANALYTIQUE"	8,099419.10-1	1.00%
NC002064	"ANALYTIQUE"	1,546253.100	1.00%
NC002065	"ANALYTIQUE"	1,570796.100	1.00%
NC002066	"ANALYTIQUE"	1,595340.100	1.00%
NC002096	"ANALYTIQUE"	2,331651.100	1.00%
NC002097	"ANALYTIQUE"	2,356194.100	1.00%
NC002098	"ANALYTIQUE"	2,380738.100	1.00%
NC003032	"ANALYTIQUE"	7,608545.10-1	1.00%
NC003033	"ANALYTIQUE"	7,853982.10-1	1.00%
NC003034	"ANALYTIQUE"	8,099419.10-1	1.00%
NC003064	"ANALYTIQUE"	1,546253.100	1.00%
NC003065	"ANALYTIQUE"	1,570796.100	1.00%

NC003066	"ANALYTIQUE"	1,595340.100	1.00%
NC003096	"ANALYTIQUE"	2,331651.100	1.00%
NC003097	"ANALYTIQUE"	2,356194.100	1.00%
NC003098	"ANALYTIQUE"	2,380738.100	1.00%
NC004032	"ANALYTIQUE"	7,608545.10-1	1.00%
NC004033	"ANALYTIQUE"	7,853982.10-1	1.00%
NC004034	"ANALYTIQUE"	8,099419.10-1	1.00%
NC004064	"ANALYTIQUE"	1,546253.100	1.00%
NC004065	"ANALYTIQUE"	1,570796.100	1.00%
NC004066	"ANALYTIQUE"	1,595340.100	1.00%
NC004096	"ANALYTIQUE"	2,331651.100	1.00%
NC004097	"ANALYTIQUE"	2,356194.100	1.00%
NC004098	"ANALYTIQUE"	2,380738.100	1.00%

3.2.3 normal Force in the cables

the component tested are TENSION.

Identification (node)	Standard of reference	Value of reference [N]	Tolerance (%)
NC001032	"ANALYTIQUE"	1,334446.105	0.50%
NC001033	"ANALYTIQUE"	1,325720.105	0.50%
NC001034	"ANALYTIQUE"	1,317036.105	0.50%
NC001064	"ANALYTIQUE"	1,076002.105	0.50%
NC001065	"ANALYTIQUE"	1,068586.105	0.50%
NC001066	"ANALYTIQUE"	1,076002.105	0.50%
NC001096	"ANALYTIQUE"	1,317036.105	0.50%
NC001097	"ANALYTIQUE"	1,325720.105	0.50%
NC001098	"ANALYTIQUE"	1,334446.105	0.50%
NC002032	"ANALYTIQUE"	1,334446.105	0.50%
NC002033	"ANALYTIQUE"	1,325720.105	0.50%
NC002034	"ANALYTIQUE"	1,317036.105	0.50%
NC002064	"ANALYTIQUE"	1,076002.105	0.50%
NC002065	"ANALYTIQUE"	1,068586.105	0.50%
NC002066	"ANALYTIQUE"	1,076002.105	0.50%
NC002096	"ANALYTIQUE"	1,317036.105	0.50%
NC002097	"ANALYTIQUE"	1,325720.105	0.50%

NC002098	"ANALYTIQUE"	1,334446.105	0.50%
NC003032	"ANALYTIQUE"	1,334270.105	0.50%
NC003033	"ANALYTIQUE"	1,325538.105	0.50%
NC003034	"ANALYTIQUE"	1,316850.105	0.50%
NC003064	"ANALYTIQUE"	1,075696.105	0.50%
NC003065	"ANALYTIQUE"	1,068278.105	0.50%
NC003066	"ANALYTIQUE"	1,075696.105	0.50%
NC003096	"ANALYTIQUE"	1,316850.105	0.50%
NC003097	"ANALYTIQUE"	1,325538.105	0.50%
NC003098	"ANALYTIQUE"	1,334270.105	0.50%
NC004032	"ANALYTIQUE"	1,334093.105	0.50%
NC004033	"ANALYTIQUE"	1,325356.105	0.50%
NC004034	"ANALYTIQUE"	1,316664.105	0.50%
NC004064	"ANALYTIQUE"	1,075391.105	0.50%
NC004065	"ANALYTIQUE"	1,067969.105	0.50%
NC004066	"ANALYTIQUE"	1,075391.105	0.50%
NC004096	"ANALYTIQUE"	1,316664.105	0.50%
NC004097	"ANALYTIQUE"	1,325356.105	0.50%
NC004098	"ANALYTIQUE"	1,334093.105	0.50%

3.2.4 Index of projection

the component tested is `INDICE_PROJECTION`.

Identification (node)	Standard of reference	Value of reference	Tolerance
NC001032	"ANALYTIQUE"	13	1.00E-003
NC001033	"ANALYTIQUE"	2	1.00E-003
NC001034	"ANALYTIQUE"	13	1.00E-003
NC001064	"ANALYTIQUE"	13	1.00E-003
NC001065	"ANALYTIQUE"	2	1.00E-003
NC001066	"ANALYTIQUE"	13	1.00E-003
NC001096	"ANALYTIQUE"	13	1.00E-003
NC001097	"ANALYTIQUE"	2	1.00E-003
NC001098	"ANALYTIQUE"	13	1.00E-003
NC002032	"ANALYTIQUE"	0	1.00E-003
NC002033	"ANALYTIQUE"	12	1.00E-003

NC002034	"ANALYTIQUE"	0	1.00E-003
NC002064	"ANALYTIQUE"	0	1.00E-003
NC002065	"ANALYTIQUE"	12	1.00E-003
NC002066	"ANALYTIQUE"	0	1.00E-003
NC002096	"ANALYTIQUE"	0	1.00E-003
NC002097	"ANALYTIQUE"	12	1.00E-003
NC002098	"ANALYTIQUE"	0	1.00E-003
NC003032	"ANALYTIQUE"	13	1.00E-003
NC003033	"ANALYTIQUE"	2	1.00E-003
NC003034	"ANALYTIQUE"	13	1.00E-003
NC003064	"ANALYTIQUE"	13	1.00E-003
NC003065	"ANALYTIQUE"	2	1.00E-003
NC003066	"ANALYTIQUE"	13	1.00E-003
NC003096	"ANALYTIQUE"	13	1.00E-003
NC003097	"ANALYTIQUE"	2	1.00E-003
NC003098	"ANALYTIQUE"	13	1.00E-003
NC004032	"ANALYTIQUE"	0	1.00E-003
NC004033	"ANALYTIQUE"	12	1.00E-003
NC004034	"ANALYTIQUE"	0	1.00E-003
NC004064	"ANALYTIQUE"	0	1.00E-003
NC004065	"ANALYTIQUE"	12	1.00E-003
NC004066	"ANALYTIQUE"	0	1.00E-003
NC004096	"ANALYTIQUE"	0	1.00E-003
NC004097	"ANALYTIQUE"	12	1.00E-003
NC004098	"ANALYTIQUE"	0	1.00E-003

3.2.5 Eccentricity

the component tested is `ECCENTRICITY`.

Identification (node)	Standard of reference	Value of reference [m]	Tolerance
NC001032	"ANALYTIQUE"	9,033625.10-3	0.10%
NC001033	"ANALYTIQUE"	0	1.00E-003
NC001034	"ANALYTIQUE"	9,033625.10-3	0.10%
NC001064	"ANALYTIQUE"	9,033625.10-3	0.10%
NC001065	"ANALYTIQUE"	0	1.00E-003

NC001066	"ANALYTIQUE"	9,033625.10-3	0.10%
NC001096	"ANALYTIQUE"	9,033625.10-3	0.10%
NC001097	"ANALYTIQUE"	0	1.00E-003
NC001098	"ANALYTIQUE"	9,033625.10-3	0.10%
NC002032	"ANALYTIQUE"	9,033625.10-3	0.10%
NC002033	"ANALYTIQUE"	0	1.00E-003
NC002034	"ANALYTIQUE"	9,033625.10-3	0.10%
NC002064	"ANALYTIQUE"	9,033625.10-3	0.10%
NC002065	"ANALYTIQUE"	0	1.00E-003
NC002066	"ANALYTIQUE"	9,033625.10-3	0.10%
NC002096	"ANALYTIQUE"	9,033625.10-3	0.10%
NC002097	"ANALYTIQUE"	0	1.00E-003
NC002098	"ANALYTIQUE"	9,033625.10-3	0.10%
NC003032	"ANALYTIQUE"	5,901857.10-2	0.10%
NC003033	"ANALYTIQUE"	5.10-2	0.10%
NC003034	"ANALYTIQUE"	5,901857.10-2	0.10%
NC003064	"ANALYTIQUE"	5,901857.10-2	0.10%
NC003065	"ANALYTIQUE"	5.10-2	0.10%
NC003066	"ANALYTIQUE"	5,901857.10-2	0.10%
NC003096	"ANALYTIQUE"	5,901857.10-2	0.10%
NC003097	"ANALYTIQUE"	5.10-2	0.10%
NC003098	"ANALYTIQUE"	5,901857.10-2	0.10%
NC004032	"ANALYTIQUE"	1,090035.10-1	0.10%
NC004033	"ANALYTIQUE"	10-1	0.10%
NC004034	"ANALYTIQUE"	1,090035.10-1	0.10%
NC004064	"ANALYTIQUE"	1,090035.10-1	0.10%
NC004065	"ANALYTIQUE"	10-1	0.10%
NC004066	"ANALYTIQUE"	1,090035.10-1	0.10%
NC004096	"ANALYTIQUE"	1,090035.10-1	0.10%
NC004097	"ANALYTIQUE"	10-1	0.10%
NC004098	"ANALYTIQUE"	1,090035.10-1	0.10%

3.3 Remarks

One obtain relative variations for the cumulated angular deviation of an order of magnitude definitely higher than those obtained for the curvilinear abscisse, which is calculated with a very good accuracy.

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 derivatives first and second derivative at the boundaries of the subintervals. The interpolation of a circular trajectory, - orbit by polynomials of order 3 is in is an approximation, of which the effects are more sensitive on second derivative than on derivatives first.

This is why the accuracy obtained for the curvilinear abscisse, calculated using derivatives first of the trajectory, is definitely better than that obtained for the cumulated angular deviation, calculated using products crossed between derivatives first and the second derivative. To improve the accuracy on the cumulated angular deviation, it would appreciably be necessary to refine mesh: this approach is not valid a priori, because it would lead to very consequent overcosts of computation for a weak gain of accuracy.

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

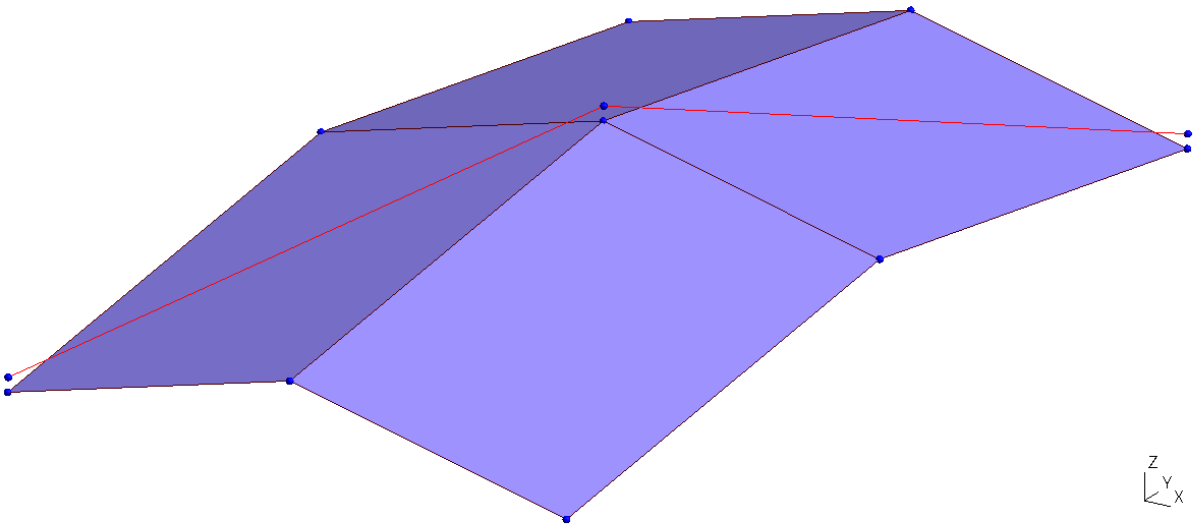
The indices of projection obtained are in conformity with those expected, and the eccentricities are calculated with a very good accuracy: this validates the operations of projection.

4 Modelization C

the purpose of this modelization is to validate routine PROJKN.

4.1 Characteristics of the modelization and mesh

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



Appear 4.1-a: seen mesh zzzz111b

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

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

4.2 Quantities 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 routine PROJKN.

Standard	identification of reference	Value of reference	N101
Tolerance - INDICE_PROJECTION	"ANALYTIQUE"		0.1.0E-03
N105 - INDICE_PROJECTION	"ANALYTIQUE"		2.1.0E-03
N109 - INDICE_PROJECTION	"ANALYTIQUE"		0.1.0E-03
N105 - ECCENTRICITY	"ANALYTIQUE"		0.1.1.0E-10

5 Summary of the results

the got results are validated by comparison with those theoretically expected with a good accuracy.

The particular features tested are the following ones:

- operator DEFI_MATERIAU [U4.23.01]: definition of the parameters characteristic of the materials steel and concrete allowing computation of the tension along the cables of prestressing, the rules of the BPEL;
- operator DEFI_CABLE_BP [U4.23.06]: computation of the tension along the cables; projection of the nodes of the cables on meshes representing structure of concrete, preliminary to the computation of the coefficients of the kinematic relations between the degrees of freedom of the nodes of the cables and the degrees of freedom of the nodes “close” to structure of concrete.