

## ZZZZ347 – Validation of the rubbing cables CABLE\_GAINE

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### Summary:

The objective of this test is to validate the modeling of cables of prestressing CABLE\_GAINE.

Modeling A is used to validate the use of DEFI\_CABLE\_BP/CALC\_PRECONT with the elements BAR in the absence of friction in the curved cases, and is used as reference to validate modeling CABLE\_GAINE in the case MEMBER, tested in modeling B.

Modeling C validates modeling CABLE\_GAINE in the case SLIPPING.

Modeling D validates the use of DEFI\_CABLE\_BP/CALC\_PRECONT with the elements BAR in the presence of friction. It is also used as reference to the modeling E, which validates modeling CABLE\_GAINE in the case RUBBING, with taking into account of frictions linear and curve, if there is only one active anchoring or both, and finally, with and without passing of anchoring.

Modelings F and G are copies of modeling E with the concrete modelled in hull (DKT and Q4GG), they make it possible to validate the new procedure of setting in prestressed with elements of hull.

Lastly, modeling H tests kinematics PETIT\_REAC in comparison with the elements BAR.

## 1 Problem of reference

### 1.1 Geometry

#### 1.1.1 Modelings A with G

One considers a concrete half-ring, of square section, with a cable in the center of the section. The half ring is of ray  $r=5m$ , of center the origin, in a plan  $(xy)$  and half of the ring considered is with  $y$  positive. A section of the ring in the plan  $y=0$  is given by the two following points of the diagonal  $(4.5;0;-0.5)$  and  $(5.5;0;0,5)$  (either a surface of  $1m$  by  $1m$ ). The section of the cable is of  $2,5 \times 10^{-3}m$ .

For modelings A with E, the modeling of the concrete is voluminal, for modelings F and G, modeling is plane.

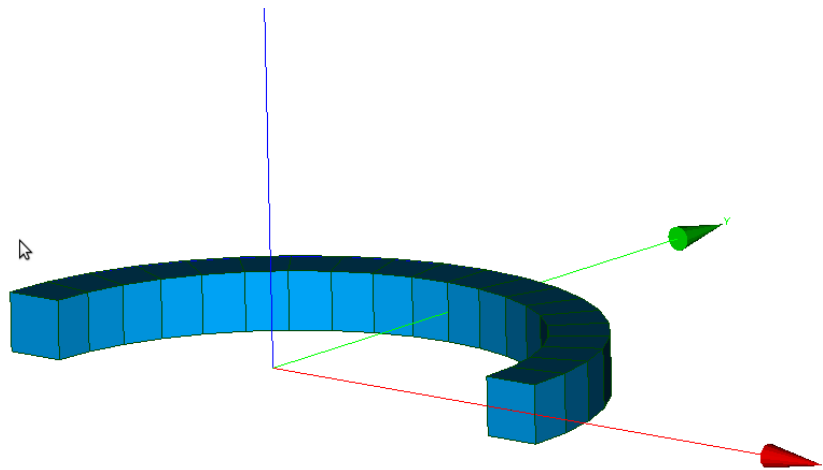


Figure 1-1: sight of the grid concrete used (modelings A with E)

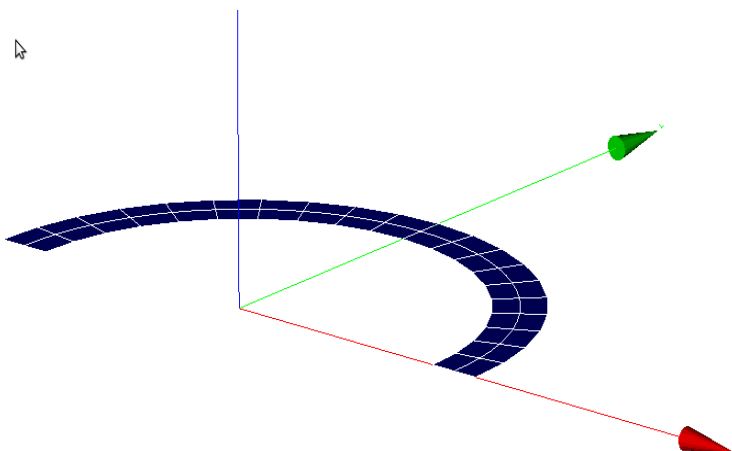


Figure 1-2: sight of the grid concrete used (modelings F and G)

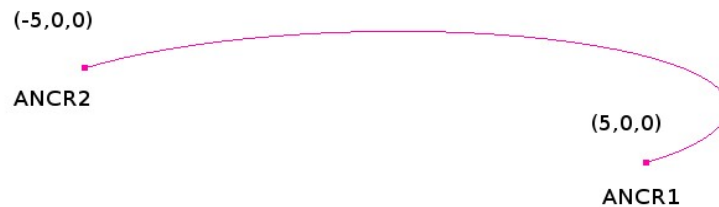


Figure 1-3: sight of the cable of prestressing drowned in the concrete

### 1.1.2 Modeling H

One considers a concrete beam length  $10\text{ m}$ , of square section of  $1\text{ m}$  on side with a cable in the center of the section. The section of the cable is of  $2,5 \times 10^{-3}\text{ m}^2$ .

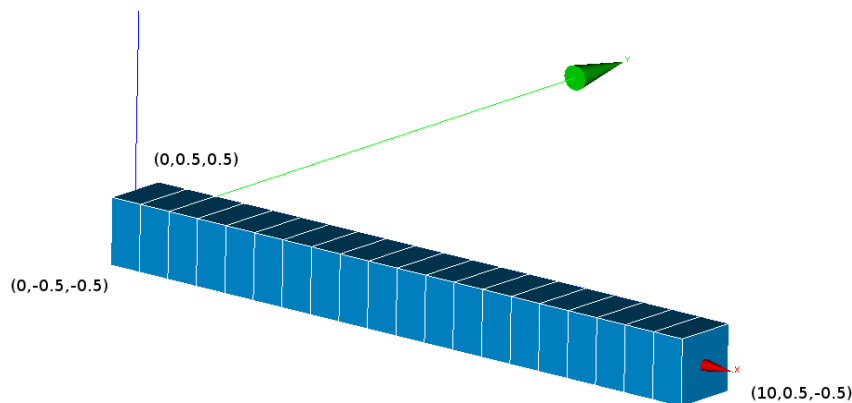


Figure 1-4: sight of the grid of the concrete of modeling H

## 1.2 Properties of material

The concrete is elastic isotropic, its properties are:

- $E = 45\,000\text{ MPa}$
- $\nu = 0$

Steel is elastic isotropic, its properties are:

- $E = 185\,000\text{ MPa}$
- $\nu = 0$

## 1.3 Boundary conditions and loadings

### 1.3.1 Modelings A with G

The section with  $y=0$  and  $x<0$  ring is embedded (face containing ANCR2).

## 1.3.2 Modeling H

The face in the plan  $x=0$  is embedded and one puts pressure distributed on the lower face of the beam ( $z=-0,5$ ) of a value of  $10^5 Pa$ . It does not have there a setting in prestressed in this test.

## 1.4 Initial conditions

Nothing.

## 2 Reference solution

### 2.1 Method of calculating

In the case of a cable slipping without friction (modeling C), with concrete and sheath of the cable embedded (only the slip of the cable is then authorized), one displays the following analytical solution. The imposed slip is noted  $\tilde{g}$ , the length of the cable  $L$ , its section  $A$

The deformation of the cable is uniform (not friction) and is worth then  $\frac{\tilde{g}}{L}$ , the constraint  $E \frac{\tilde{g}}{L}$  and

the tension  $T = A E \frac{\tilde{g}}{L}$ .

The reaction on the whole of the concrete is worth  $R = 2T$ .

On a section of cable, the reaction is worth  $S = T \Delta \alpha$  with  $\Delta \alpha$  the angular deviation.

If the cable is discretized in  $n$  of the same elements cuts, one has  $S = T \frac{\pi}{n}$ .

For calculations of tension BPEL, the references analytical are obtained thanks to the formulas given in [R7.01.02].

### 2.2 Sizes and results of reference

#### 2.2.1 Tension and reactions for modeling C

While taking  $\tilde{g} = 0.1$ ,  $L = r \pi$ ,  $A = 2.5e-3$ ,  $E = 185\,000\text{ MPa}$ , one finds:

- the tension  $T = 2.9443664 \cdot 10^6\text{ N}$
- reaction on the whole of the concrete  $R = 5.888734 \cdot 10^6\text{ N}$  and on a section of cable  $S = 462\,500\text{ N}$  with  $n = 20$ .

#### 2.2.2 Tension BPEL for modelings E, F and G

The points of Gauss tested are the points of Gauss 1 meshes 105 and 96 for modeling E corresponding to the meshes 59 and 50 for modelings F and G. Any point  $P$  belonging to the cable can be defined by the value of the angle  $a = \overrightarrow{(OA_1, OP)}$  or  $b = \overrightarrow{(OA_2, OP)}$  where  $O$  is the center of the half-circle,  $A_1$  is ANCR1 and  $A_2$  is ANCR2.

The first node of the mesh 96 is defined by  $a = 67,5$  or  $b = 112,5$ . The first point of Gauss of the mesh 96 is then defined by  $a_{96} = 67,5 + \frac{4,5}{\sqrt{3}}$  or  $b_{96} = 112,5 - \frac{4,5}{\sqrt{3}}$ .

The first node of the mesh 105 is defined by  $a = 148,5$  or  $b = 31,5$ . The first point of Gauss of the mesh 105 is then defined by  $a_{96} = 148,5 + \frac{4,5}{\sqrt{3}}$  or  $b_{96} = 31,5 - \frac{4,5}{\sqrt{3}}$ .

It is necessary to calculate the cumulated angular deviation  $\alpha$  of these points which will be used then for calculation of the tensions. The cumulated angular deviation used in formula BPEL of the tension must be calculated starting from active anchoring nearest. In modeling E, two calculations are done: one with ANCR1 liability and ANCR2 credit and the other with two active anchorings. The mesh 105 is closer to ANCR2 who is always active, one thus has in both cases:  $\alpha_{105} = b_{105} * \pi / 180$ .

It is noticed that in our case the cumulated angular deviation is equal to the angles  $a$  or  $b$ , one is only satisfied to pass in radians.

The mesh 96 is closer to ANCR1 one thus has two different values:

$$\alpha_{96} = b_{96} * \pi / 180 \text{ for the case PASSIF/ACTIF}$$

$$\alpha_{96} = a_{96} * \pi / 180 \text{ for the case ACTIF/ACTIF}$$

The curvilinear X-coordinates of these points are also necessary to the calculation of the tension, are also given compared to active anchoring nearest. One has then:  $s_{105} = \alpha_{105} * r$  and  $s_{96} = \alpha_{96} * r$ .

For the case without retreat of anchoring, one uses the formula  $F_c = F_0 \exp(-f \alpha - \phi s)$ , with  $F_0 = 10^6 N$ ,  $\phi = 0,01$ ;  $f = 0,03$ , one obtains:

- for the case PASSIF/ACTIF :  $F_{105} = 960448.709086365 N$  and  $F_{96} = 857741.905702382 N$
- for the case ACTIF/ACTIF :  $F_{105} = 960448.709086365 N$ ;  $F_{96} = 906761.8988894981 N$

The field of deformation EPSI\_ELGA is tested in modeling E in the case PASSIF/ACTIF, on the same points of Gauss as the tension NR. Calculation is elastic, therefore:

$$EPXX_{105} = F_{105} / E / A$$

$$EPXX_{96} = F_{96} / E / A$$

For the case with passing of anchoring, with the notations of [R7.01.02], one shows that the distance  $d$  on which acts the retreat of anchoring is worth:

$$d = \frac{-1}{f} \ln(1 - \sqrt{(f * E_a * S_a * \Delta / F_0)})$$

With a passing of anchoring  $\Delta = 5.10^4$ , one obtains here  $d = 3.9222$ . By keeping the notations defined above, that means that point is concerned if  $a < 44,94$  or  $b < 44,94$ . Mesh 105 is thus concerned with the modification due to the retreat of anchoring, but not mesh 96.

While using then  $F_c = \frac{(F(d))^2}{F_0} \exp(-f \alpha - \phi s)$  for mesh 105 and  $F_c = F_0 \exp(-f \alpha - \phi s)$  for mesh 96, one obtains:

$$F_{105} = 918367.3641803192 ; F_{96} = 906761.8988894981$$

## 2.2.3 Reference for modeling H

Taking into account the imposed loading, in DEFORMATION = 'SMALL' there would be no constraints in the cable. On the other hand in DEFORMATION = 'PETIT\_REAC', constraints must appear. The reference solution in this case is obtained by a calculation with elements BAR.

## 2.3 Uncertainties on the solution

Nothing

## 3 Modeling A

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### 3.1 Characteristics of modeling

Modeling is 3D for the concrete ring and BAR for the cable.

The cable is of type PASSIF/ACTIF : LIABILITY with the group of nodes ANCR1 and CREDIT with the group of nodes ANCR2. Linear friction BPEL is taken equal to 0,01 and friction curves with 0,03 .

In a first phase, the cable is put in prestressed with CALC\_PRECONT and a tension of  $10^6 N$  and without retreat of anchoring.

In a second phase, a displacement is imposed  $DY = -0,1$  with the group of nodes ANCR2.

### 3.2 Characteristics of the grid

The grid contains 20 elements of the type HEXA8 and 20 elements of the type SEG2.

### 3.3 Sizes tested and results

The results tested are of standard not-regression to be used as reference in modeling B and relate to displacements and the tension in the cable (see values with the §4.3).

## 4 Modeling B

### 4.1 Characteristics of modeling

Modeling is 3D for the concrete ring and CABLE\_GAINE for the cable. Modeling for the cable is of type 'MEMBER'.

The cable is of type PASSIF/ACTIF : LIABILITY with the group of nodes ANCR1 and CREDIT with the group of nodes ANCR2. Linear friction BPEL is taken equal to 0,01 and friction curves with 0,03 .

In a first phase, the cable is put in prestressed with CALC\_PRECONT and a tension of  $10^6 N$  without retreat of anchoring.

In a second phase, a displacement is imposed  $DY = -0,1$  with the group of nodes ANCR2.

### 4.2 Characteristics of the grid

The grid contains 20 elements of the type HEXA8 and 20 elements of the type SEG3.

### 4.3 Sizes tested and results

One tests the results thanks to the references obtained in modeling A, one checks thus that modelings BAR and CABLE\_GAINE/ADHERENT the same results give.

The sequence number 2 corresponds at the end of the first phase (CALC\_PRECONT) and the sequence number 3 at the end of the second phase (displacement  $DY = -0,1$  with the group of nodes 'ANCR2').

The mesh M89 is the first mesh of the cable on the basis of ANCR1.

Node/Mesh	Component	NUME_ORDRE	Type of reference	Value of reference	Tolerance
ANCR2	$DY$	2	'AUTRE_ASTER'	3.0875640025E-04	0.5%
ANCR2	$DY$	3	'AUTRE_ASTER'	0.0423286048572	2nd-4%
M89	$N$	2	'AUTRE_ASTER'	7.837433596E+05	0,05%
M89	$N$	3	'AUTRE_ASTER'	7.921749893E+05	0,05%



## 5 Modeling C

### 5.1 Characteristics of modeling

Modeling is 3D for the concrete ring and CABLE\_GAINE for the cable. The behavior for the cable is of type 'SLIPPING'.

The cable and the concrete are entirely embedded, only the slip of the cable is authorized. The degree of freedom GLIS is imposed on 0 for the group of nodes 'ANCR1' and to 0.1 for the group of nodes 'ANCR2'.

### 5.2 Characteristics of the grid

The grid contains 20 elements of the type HEXA8 and 20 elements of the type SEG3.

### 5.3 Sizes tested and results

The values tested analytical and are presented to the §2.2.1.

The mesh M95 is defined by  $a=55,06$  for its first node.

The mesh M89 is the first mesh of the cable on the basis of ANCR1.

Identification	Type of reference	Value of reference	Tolerance
Total reaction	'ANALYTICAL'	-5.888734E6	1%
Reaction on the element M95	'ANALYTICAL'	462500	1%
Mesh M89 - point 1 - N	'ANALYTICAL'	2.9443664E6	0.1%

## 6 Modeling D

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### 6.1 Characteristics of modeling

Modeling is 3D for the concrete ring and BAR for the cable.

For the first calculation (EVOLNOLI), the cable is of type PASSIF/ACTIF : LIABILITY with the group of nodes 'ANCR1' and CREDIT with the group of nodes 'ANCR2'. For two other calculations (EVOLNOL2 and EVOLNOL3), the cable is of type ACTIF/ACTIF. In all the cases, linear friction BPEL is taken equal to 0,01 and friction curves with 0,03 .

Calculation consists of only one stage: the cable is put in prestressed with CALC\_PRECONT and a tension of  $10^6 N$  without retreat of anchoring, except in the case EVOLNOL3 where the retreat of anchoring is worth  $5.10^{-4} m$  .

### 6.2 Characteristics of the grid

The grid contains 20 elements of the type HEXA8 and 20 elements of the type SEG2.

### 6.3 Sizes tested and results

The results tested are of standard not-regression to be used as reference in modeling E and concern:

- Following displacement  $x$  and  $y$  with the node N16 at moments 1 and 2;
- Values of constraints in the mesh M193 at the point of integration 1, moments 1 and 2.  
(see the values with the §7.3).

## 7 Modeling E

### 7.1 Characteristics of modeling

Modeling is 3D for the concrete ring and CABLE\_GAINE for the cable.

Three calculations are carried out, in all the cases, linear friction is taken equal to 0,01 and friction curves with 0,03 .

1. For the first calculation (EVOLNOLI), the cable is of type PASSIF/ACTIF : LIABILITY with the group of nodes 'ANCR1' and CREDIT with the group of nodes 'ANCR2'. The loading is carried out in two stages. Initially, the cable is put in prestressed with CALC\_PRECONT and a tension of  $10^6 N$  without retreat of anchoring, in a second, a displacement  $DY = -0,1$  with the group of nodes 'ANCR2' is imposed.
2. For the second calculation (EVOLNOL2) the cable is of type ACTIF/ACTIF. LE cable is put in prestressed with CALC\_PRECONT and a tension of  $10^6 N$  without retreat of anchoring. The parameter ITER\_GLOB\_MAXI am put at 15 (instead of 20 for other calculations) in order to force the automatic subdivision of the moments of calculation at the time of stage 2 of the setting in tension. That makes it possible to validate the construction of the multiplying function associated with the loading with this stage which depends on the force of reaction of the degree of freedom GLIS on the first node of anchoring obtained at the end of stage 1.
3. For the third calculation (EVOLNOL3) the cable is of type ACTIF/ACTIF. The cable is put in prestressed with CALC\_PRECONT and a tension of  $10^6 N$  with a passing of anchoring of  $5 \times 10^{-4} m$ .

### 7.2 Characteristics of the grid

The grid contains 20 elements of the type HEXA8 and 20 elements of the type SEG3.

### 7.3 Sizes tested and results

The values of reference are analytical and is presented to the §2.2.2, that is to say resulting from the comparison with modeling D in BAR.

One specifies here the coordinates of the concrete node N57 : (-3.889, 3.889, 0,5) .

MI93 is the third concrete mesh on the basis of ANCR2.

Identification	Type of reference	Value of reference	Tolerance
EVOLNOLI Mesh MI05 - point 1 - N	'ANALYTICAL'	960448.709086365	1%
EVOLNOLI Mesh M96 - point 1 - N	'ANALYTICAL'	857741.905702382	1%
EVOLNOLI Mesh MI05 - point 1 - EPXX	'ANALYTICAL'	2.07664585748E-3	1%
EVOLNOLI Mesh M96 - point 1 - EPXX	'ANALYTICAL'	1.85457709341E-3	1%
EVOLNOLI Node N57 - DX	'AUTRE_ASTER'	1.75362396368528E-04	1%

EVOLNOLI Node <i>N57</i> - <i>DY</i>	'AUTRE_ASTER'	1.73862669805773E-04	1%
EVOLNOLI Mesh <i>M193</i> - point 1 - <i>SIXX</i>	'AUTRE_ASTER'	-1.4385853954159E+05	1%
EVOLNOLI Mesh <i>M193</i> - point 1 - <i>SIYY</i>	'AUTRE_ASTER'	-8.2927316052597E+05	1%
EVOLNOLI Mesh <i>M193</i> - point 1 - <i>SIXY</i>	'AUTRE_ASTER'	-3.4252241782541E+05	1%
EVOLNOL2 Mesh <i>M105</i> - point 1 - <i>N</i>	'ANALYTICAL'	960448.709086365	1%
EVOLNOL2 Mesh <i>M96</i> - point 1 - <i>N</i>	'ANALYTICAL'	906761.8988894981	1%
EVOLNOL3 Mesh <i>M105</i> - point 1 - <i>N</i>	'ANALYTICAL'	918367.3641803192	1%
EVOLNOL3 Mesh <i>M96</i> - point 1 - <i>N</i>	'ANALYTICAL'	906761.8988894981	1%

One also makes sure using two tests of not-regression, that, on the second calculation, the component *GLIS* force with the node *ANCR1* do not decrease (in absolute value) between the last moment of calculation of the first phase of setting in tension and the first moment of calculation of the second phase of setting in tension (what would produce a retreat of anchoring to the court of this stage inducing on arrival of the false results).

Node <i>ANCR1</i> - FORC_NODA <i>GLIS</i> Moment 0.9	'NON_REGRESSION'	-	-
Node <i>ANCR1</i> - FORC_NODA <i>GLIS</i> Moment 0.90625	'NON_REGRESSION'	-	-

## 8 Modeling F

### 8.1 Characteristics of modeling

Modeling is DKT for the concrete ring and CABLE\_GAINE for the cable.

Three calculations are carried out, in all the cases, linear friction is taken equal to 0,01 and friction curves with 0,03 .

1. For the first calculation (EVOLNOLI), the cable is of type PASSIF/ACTIF : LIABILITY with the group of nodes 'ANCR1' and CREDIT with the group of nodes 'ANCR2'. The loading is carried out in two stages. Initially, the cable is put in prestressed with CALC\_PRECONT and a tension of  $10^6 N$  without retreat of anchoring. In the second time, a displacement  $DY = -0,1$  with the group of nodes 'ANCR2' is then imposed.
2. For the second calculation (EVOLNOL2) the cable is of type ACTIF/ACTIF. The cable is put in prestressed with CALC\_PRECONT and a tension of  $10^6 N$  without retreat of anchoring.
3. For the third calculation (EVOLNOL3) the cable is of type ACTIF/ACTIF. The cable is put in prestressed with CALC\_PRECONT and a tension of  $10^6 N$  with a passing of anchoring of  $5 \times 10^{-4} m$ .

### 8.2 Characteristics of the grid

The grid contains 20 elements of the type QUAD4 and 20 elements of the type SEG3.

### 8.3 Sizes tested and results

The values of reference analytical and are presented to the §2.2.2.

Identification	Type of reference	Value of reference	Tolerance
EVOLNOLI Mesh M59 - point 1 - N	'ANALYTICAL'	960448.709086365	1%
EVOLNOLI Mesh M50 - point 1 - N	'ANALYTICAL'	857741.905702382	1%
EVOLNOL2 Mesh M59 - point 1 - N	'ANALYTICAL'	960448.709086365	1%
EVOLNOL2 Mesh M50 - point 1 - N	'ANALYTICAL'	906761.8988894981	1%
EVOLNOL3 Mesh M59 - point 1 - N	'ANALYTICAL'	918367.3641803192	1%
EVOLNOL3 Mesh M50 - point 1 - N	'ANALYTICAL'	906761.8988894981	1%

## 9 Modeling G

### 9.1 Characteristics of modeling

Modeling is Q4GG for the concrete ring and CABLE\_GAINE for the cable.

Three calculations are carried out, in all the cases, linear friction is taken equal to 0,01 and friction curves with 0,03 .

1. For the first calculation (EVOLNOLI), the cable is of type PASSIF/ACTIF : LIABILITY with the group of nodes 'ANCR1' and CREDIT with the group of nodes 'ANCR2'. The loading is carried out in two stages. Initially, the cable is put in prestressed with CALC\_PRECONT and a tension of  $10^6 N$  without retreat of anchoring. In the second time, a displacement  $DY = -0,1$  with the group of nodes 'ANCR2' is then imposed.
2. For the second calculation (EVOLNOL2) the cable is of type ACTIF/ACTIF . The cable is put in prestressed with CALC\_PRECONT and a tension of  $10^6 N$  without retreat of anchoring.
3. For the third calculation (EVOLNOL3) the cable is of type ACTIF/ACTIF . The cable is put in prestressed with CALC\_PRECONT and a tension of  $10^6 N$  with a passing of anchoring of  $5 \times 10^{-4} m$  .

### 9.2 Characteristics of the grid

The grid contains 20 elements of the type QUAD4 and 20 elements of the type SEG3.

### 9.3 Sizes tested and results

The values of reference analytical and are presented to the §2.2.2.

Identification	Type of reference	Value of reference	Tolerance
EVOLNOLI Mesh M59 - point 1 - N	'ANALYTICAL'	960448.709086365	1%
EVOLNOLI Mesh M50 - point 1 - N	'ANALYTICAL'	857741.905702382	1%
EVOLNOL2 Mesh M59 - point 1 - N	'ANALYTICAL'	960448.709086365	1%
EVOLNOL2 Mesh M50 - point 1 - N	'ANALYTICAL'	906761.8988894981	1%
EVOLNOL3 Mesh M59 - point 1 - N	'ANALYTICAL'	918367.3641803192	1%
EVOLNOL3 Mesh M50 - point 1 - N	'ANALYTICAL'	906761.8988894981	1%

## 10 Modeling H

### 10.1 Characteristics of modeling

The concrete beam is modelled by elements 3D. The cable is modelled in BAR in the first calculation and in CABLE\_GAINE in the second.

### 10.2 Characteristics of the grid

The first grid contains 20 elements of the type HEXA8 and 20 elements of the type SEG2.  
The second grid contains 20 elements of the type HEXA8 and 10 elements of the type SEG3.

### 10.3 Sizes tested and results

It is the first calculation carried out with the elements BAR who is used as reference for the calculation carried out with the elements CABLE\_GAINE. One compares the constraints with the nodes (SIEF\_NOEU) with the node medium (N10) and with the node located at the not embedded end of the beam (N20) and internal forces in DX and DZ with the node end (N20).

Node	Field/Component	Type of reference	Value of reference	Tolerance
N20	SIEF_NOEU / N	'AUTRE_ASTER'	5373.5429318889	1%
N10	SIEF_NOEU / N	'AUTRE_ASTER'	4145.3863764751	1%
N20	FORC_NODA / DX	'AUTRE_ASTER'	5373.5008825388	1%
N20	FORC_NODA / DZ	'AUTRE_ASTER'	21.258085693706	1%

## 11 Summary of the results

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The results show that under the same assumptions, modeling CABLE\_GAINE give the same results as modeling BAR, that is in the adherent case with a curved friction or in the rubbing case. In this last case, one notes that the procedure of setting in tension installation gives the same profiles as those calculated by the formulas of the BPEL, including with taking into account of a retreat of anchoring. One also finds the same results between two modelings with kinematics PETIT\_REAC.

Moreover, modeling CABLE\_GAINE in version SLIPPING is validated by an analytical test on the tension and the reactions in the concrete and the cable.

The new procedure of setting in tension is operational with concrete modelled in 3D or in hull (modeling DKT or Q4GG).