SSNV164 - Setting in tension of cables of prestressed in a beam 3D

Summary

One considers a reinforced concrete beam of section square, made up of two 10 meters length sections, having respectively one and four square meters of section. The beam is vertical, the weakest section in bottom. It is embedded at its base, and contains 5 rectilinear cables of prestressing.
One tests here the phasage of the setting in prestressing, i.e. the setting in successive tension of the various cables.
The features particular to test are the following ones:

- the operator DEFI_CABLE_BP : determination of the relations kinematics between the degrees of freedom of the nodes of a cable and the degrees of freedom of the nodes “close” to a concrete structure modelled by elements $3D$ and calculation of the tensions in a cable under the friction effect and of the retreat of anchoring,
- the operator AFFE_CHAR_MECA associated with the keyword RELA_CINE_BP,
- the operator CALC_PRECONT : setting in tension of the cables of prestressed with the method of NEWTON classic or with the method IMPLEX.
- the operator CALC_PRECONT : setting in tension of the cables of prestressing modelled by elements BAR with presence of elements CABLE_GAINE in the model and conversely (modeling C and D).

The got results are validated by comparison with the computer code CASTEM 2000.
Modeling B allows more specifically to validate the use of the keyword CONE in DEFI_CABLE_BP.

1 Problem of reference

1.1 Geometry

One considers a reinforced concrete beam of section square, made up of two 10 meters length sections, having respectively one and four square meters of section. The beam is vertical, the weakest section in bottom. It is embedded at its base, and contains 5 rectilinear cables of prestressing.
The five cables which cross all the length of the beam are located as on the plan below:

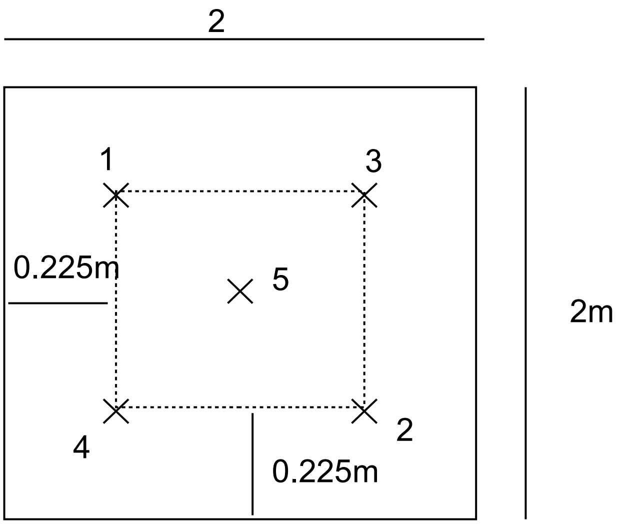

Figure 1.1-a: Positioning of the cables in the beam

The section of each cable is of $25\,cm^2$.

1.2 Properties of materials

Material concrete constituting the beam:

- Young modulus: $E_b = 4.\,10^5\,MPa$
- Poisson's ratio: $\nu = 0{,}2$
- density: $\rho = 2500\,kg/m^3$
- limit in traction $\sigma_Y = 3\text{MPa}$
- module of work hardening $E_{bT} = -10000\,MPa$

Material steel constituting the cable:

- Young modulus: $E_c = 1{,}93\,10^5\,MPa$
- Poisson's ratio: $\nu = 0{,}3$
- density: $\rho = 7850\,kg/m^3$
- limit in traction $\sigma_Y = 19400\text{MPa}$
- module of work hardening $E_{bT} = 10\text{E-3}\,MPa$

Characteristic concerning the setting in tension of the cables:

- retreat of anchoring: $1\,mm$
- linear coefficient of friction: $0{,}0015\,m^{-1}$

- force of tension at the end of a cable: $3{,}75\,10^{6}\,N$
- age of dismantling 150 days
- old of setting in tension of the first cable: 300 days

1.3 Boundary conditions and loadings

The base of the beam is blocked in the direction Z. Two translatory movements compared to OX and OY are blocked as well as the rotation movement around OZ.
The sequence of loading is the following one:

- at 300 days, put in tension of 2 cables (1 and 2) by their lower end,
- at 450 days, put in tension of 2 additional cables (3 and 4) always by their lower end,
- at 600 days, put in tension of the last cable (5) by its two ends.

The beam is obviously subjected to gravity.

2 Reference solution

The reference solution was obtained by the ECA with CASTEM 2000, a grid containing 2080 cubic elements with 20 nodes and 100 elements of cable.

3 Modeling A

3.1 Characteristics of modeling

The concrete beam is represented by 2080 elements MECA_HEXA8, supported per as many meshs hexahedrons to 8 nodes. The 5 cables are represented using 20 elements MECA_BARRE each one supported per as many segments with 2 nodes. The figure below watch grid of the beam.

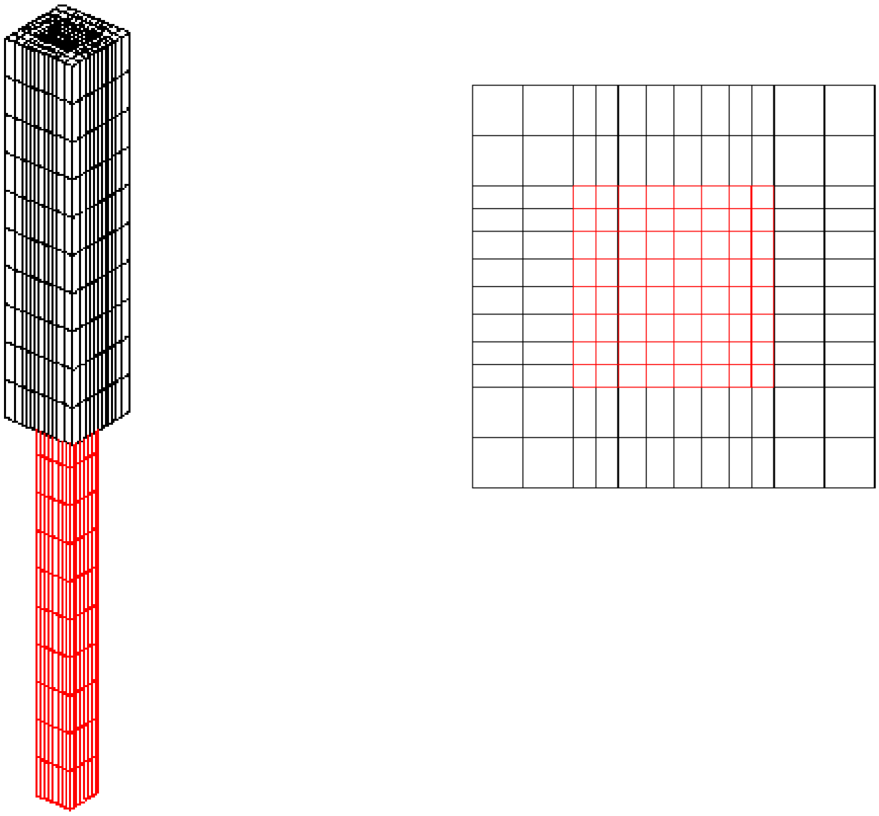

Figure 3.1-a: Description of the grid

The material concrete is defined by the behaviors ELAS and BPEL_BETON : the parameters characteristic of this relation are fixed at 0 because one does not wish to include the losses of tension due to the shrinking and the creep of the concrete.
The material steel for the cables is defined by the behaviors ELAS and BPEL_ACIER. Nonworthless values for BPEL_ACIER relate to friction ($FROT\_LINE=1{,}5\,10^{-3}m^{-1}$) and elastic limit since a zero value is illicit ($SY=1{,}94\,10^{11}\,Pa$). The ray of the cables is of $2{,}8209\,10^{-2}\,m$.

The blocked degrees of freedom are the following:
DZ for the lower face
DX and DY for the points located on the axis of symmetry of the beam
DX for the point $(0.5\,0.\,0.)$ and DY for the point $(-0.5\,0.\,0.)$

The tension $F_0=3{,}75\,10^{6}\,N$ is applied to the lower nodes of cables 1,2,3 and 4 and at the two ends for cable 5.

The loading is carried out in 6 pas de time:

- $t=50\,\mathrm{et}\,100\,s$, two first steps in elasticity with the method IMPLEX : this is used to test the convergence of the method in the elastic range in only one step as time
- $t=150\,s$, taken into account of gravity: STAT_NON_LINE with the boundary conditions, gravity and the relations kinematics for all the cables. The cables not contributing to the rigidity of the model, one affects a law of behavior to them 'WITHOUT' (forced worthless),
- $t=300\,s$, put in tension of cables 1 and 2: CALC_PRECONT with the boundary conditions, cables 1 and 2 being cables to be put in tension, cables 3.4 and 5 being inactive,
- $t=450\,s$, put in tension of cables 3 and 4: CALC_PRECONT with the boundary conditions, the relations kinematics for cables 1 and 2, cables 3 and 4 being cables to be put in tension, cable 5 being inactive,
- $t=600\,s$, put in tension of cable 5: CALC_PRECONT with the boundary conditions, the relations kinematics for cables 1,2,3 and 4, cable 5 being the cable to be put in tension.

3.2 Stages of calculation

The principal stages of calculation correspond to the features which one wishes to validate:

- operator DEFI_MATERIAU : definition of the relations of behavior BPEL_BETON with the values by default and BPEL_ACIER, in the case of loss by linear friction,
- operator DEFI_CABLE_BP : determination of a profile of tension along the cable of prestressing, by taking of account losses by linear friction and losses by retreat of anchoring; calculation of the coefficients of the relations kinematics between the degrees of freedom of the nodes of the cable and the degrees of freedom of the nodes "close" to the beam out of concrete, in the case of a beam modelled by elements $3\mathrm{D}$,
- operator AFFE_CHAR_MECA : definition of a loading of the type RELA_CINE_BP (RELA_CINE = ' OUI'),
- operator STAT_NON_LINE, option BEHAVIOR : calculation of the state of balance by taking account of the loading of the type RELA_CINE_BP, in the case of a beam modelled by elements $3\mathrm{D}$,
- law of behavior WITHOUT,
- macro-order CALC_PRECONT with a nonvirgin initial state, that there are or not inactive cables, that there are one or more cables to put in tension.

Moreover, one tests calculation with the exact iterative method of Newton and the approximate method IMPLEX. In this case test, one remains in elasticity; the results got by the two methods of resolution must thus be identical.

3.3 Results of modeling A

One compares the value extracted the field SIEF_ELNO with the value of reference obtained with CASTEM
and this for the various characteristic moments (nonworthless tension) and for nodes équirépartis along the cables.
The component to which the test relates is the tension in the cables N.
The tests are carried out 2 times, once when the problem is solved into implicit (METHODE=' NEWTON') and once when the problem is solved with the method IMPLEX (METHODE=' IMPLEX'). In both cases, the tolerances are identical.

3.3.1 Tension in cable 1

$T=150\,s$
tests of not-regression for the method IMPLEX for the global value of the constraints and displacements.

$T=300\,s$

Identification (node/mesh)	Type of reference	Value of reference (N)	Tolerance ($\%$)
N1 - M5655	'SOURCE_EXTERNE'	$3,648.10^6$ NR	0,10%
N6 - M5660	'SOURCE_EXTERNE'	$3,675.10^6$ NR	0,10%
N11 - M5664	'SOURCE_EXTERNE'	$3,693.10^6$ NR	0,10%
N16 - M5670	'SOURCE_EXTERNE'	$3,667.10^6$ NR	0,10%
N101 - M5674	'SOURCE_EXTERNE'	$3,640.10^6$ NR	0,10%

$T=450\,s$

Identification (node/mesh)	Type of reference	Value of reference (N)	Tolerance ($\%$)
N1 - M5655	'SOURCE_EXTERNE'	$3,561.10^6$ NR	1,00%
N6 - M5660	'SOURCE_EXTERNE'	$3,588.10^6$ NR	1,00%
N11 - M5664	'SOURCE_EXTERNE'	$3,628.10^6$ NR	1,00%
N16 - M5670	'SOURCE_EXTERNE'	$3,645.10^6$ NR	1,00%
N101 - M5674	'SOURCE_EXTERNE'	$3,629.10^6$ NR	1,00%

$T=600\,s$

Identification (node/mesh)	Type of reference	Value of reference (N)	Tolerance ($\%$)
N1 - M5655	'SOURCE_EXTERNE'	$3,519.10^6$ NR	1,00%
N6 - M5660	'SOURCE_EXTERNE'	$3,546.10^6$ NR	1,00%
N11 - M5664	'SOURCE_EXTERNE'	$3,597.10^6$ NR	1,00%

N16 - M5670	'SOURCE_EXTERNE'	$3{,}635.10^6$ NR	1,00%
N101 - M5674	'SOURCE_EXTERNE'	$3{,}614.10^6$ NR	1,00%

3.3.2 Tension in cable 3

$T=450\,s$

Identification (node/mesh)	Type of reference	Value of reference (N)	Tolerance ($\%$)
N41 - M5695	'SOURCE_EXTERNE'	$3{,}647.10^6$ NR	0,10%
N46 - M5700	'SOURCE_EXTERNE'	$3{,}675.10^6$ NR	0,10%
N51 - M5705	'SOURCE_EXTERNE'	$3{,}695.10^6$ NR	0,10%
N56 - M5710	'SOURCE_EXTERNE'	$3{,}667.10^6$ NR	0,10%
N103 - M5714	'SOURCE_EXTERNE'	$3{,}640.10^6$ NR	0,10%

$T=600\,s$

Identification (node/mesh)	Type of reference	Value of reference (N)	Tolerance ($\%$)
N41 - M5695	'SOURCE_EXTERNE'	$3{,}6075.10^6$ NR	1,00%
N46 - M5700	'SOURCE_EXTERNE'	$3{,}6346.10^6$ NR	1,00%
N51 - M5705	'SOURCE_EXTERNE'	$3{,}6720.10^6$ NR	1,00%
N56 - M5710	'SOURCE_EXTERNE'	$3{,}6529.10^6$ NR	1,00%
N103 - M5714	'SOURCE_EXTERNE'	$3{,}6241.10^6$ NR	1,00%

3.3.3 Tension in cable 5

$T=600\,s$

Identification (node/mesh)	Type of reference	Value of reference (N)	Tolerance ($\%$)
N81 - M5735	'SOURCE_EXTERNE'	$3{,}647.10^6$ NR	0,10%
N86 - M5740	'SOURCE_EXTERNE'	$3{,}674.10^6$ NR	0,10%
N91 - M5745	'SOURCE_EXTERNE'	$3{,}695.10^6$ NR	0,10%
N96 - M5750	'SOURCE_EXTERNE'	$3{,}674.10^6$ NR	0,10%
N105 - M5754	'SOURCE_EXTERNE'	$3{,}647.10^6$ NR	0,10%

4 Modeling B

4.1 Characteristics of modeling

The grid is identical to modeling A.

The loading is also identical.
One includes simply a cone of diffusion at the final end of cable 1: the definite cone has a length of $1{,}5\,m$ and a ray of $20\,cm$, to validate the use of the functionality CONE of DEFI_CABLE_BP.

4.2 Results of modeling B

The results on the level of the tension of the cables are very only slightly modified, the tolerances are identical to modeling A.

5 Modeling C

5.1 Characteristics of modeling

The problem is identical to modeling A with the difference which cables 3 and 4 are modelled by elements CABLE_GAINE of adherent type.

5.2 Results of modeling C

The results on the level of the tension of the cables are very only slightly modified, the tolerances are identical to modeling A except for the first two tests on cable 3 at the moment $600 s$ where the tolerance passed to 2.5%.

5.2.1 Tension in cable 1

$T=300 s$

Identification (node/mesh)	Type of reference	Value of reference (N)	Tolerance ($\%$)
N1 - M5655	'SOURCE_EXTERNE'	3,648.10^6 NR	0,10%
N6 - M5660	'SOURCE_EXTERNE'	3,675.10^6 NR	0,10%
N11 - M5664	'SOURCE_EXTERNE'	3,693.10^6 NR	0,10%
N16 - M5670	'SOURCE_EXTERNE'	3,667.10^6 NR	0,10%
N101 - M5674	'SOURCE_EXTERNE'	3,640.10^6 NR	0,10%

$T=450 s$

Identification (node/mesh)	Type of reference	Value of reference (N)	Tolerance ($\%$)
N1 - M5655	'SOURCE_EXTERNE'	3,561.10^6 NR	1,00%
N6 - M5660	'SOURCE_EXTERNE'	3,588.10^6 NR	1,00%
N11 - M5664	'SOURCE_EXTERNE'	3,628.10^6 NR	1,00%
N16 - M5670	'SOURCE_EXTERNE'	3,645.10^6 NR	1,00%
N101 - M5674	'SOURCE_EXTERNE'	3,629.10^6 NR	1,00%

$T=600 s$

Identification (node/mesh)	Type of reference	Value of reference (N)	Tolerance ($\%$)
N1 - M5655	'SOURCE_EXTERNE'	3,519.10^6 NR	1,00%
N6 - M5660	'SOURCE_EXTERNE'	3,546.10^6 NR	1,00%
N11 - M5664	'SOURCE_EXTERNE'	3,597.10^6 NR	1,00%

N16 - M5670	'SOURCE_EXTERNE'	$3,635.10^6$ NR	1,00%
N101 - M5674	'SOURCE_EXTERNE'	$3,614.10^6$ NR	1,00%

5.2.2 Tension in cable 3

$T=450\,s$

Identification (node/mesh)	Type of reference	Value of reference (N)	Tolerance ($\%$)
N41 - M5695	'SOURCE_EXTERNE'	$3,647.10^6$ NR	0,10%
N46 - M5700	'SOURCE_EXTERNE'	$3,675.10^6$ NR	0,10%
N51 - M5705	'SOURCE_EXTERNE'	$3,695.10^6$ NR	0,10%
N56 - M5710	'SOURCE_EXTERNE'	$3,667.10^6$ NR	0,10%
N103 - M5714	'SOURCE_EXTERNE'	$3,640.10^6$ NR	0,10%

$T=600\,s$

Identification (node/mesh)	Type of reference	Value of reference (N)	Tolerance ($\%$)
N41 - M5695	'SOURCE_EXTERNE'	$3,6075.10^6$ NR	2,50%
N46 - M5700	'SOURCE_EXTERNE'	$3,6346.10^6$ NR	2,50%
N51 - M5705	'SOURCE_EXTERNE'	$3,6720.10^6$ NR	1,00%
N56 - M5710	'SOURCE_EXTERNE'	$3,6529.10^6$ NR	1,00%
N103 - M5714	'SOURCE_EXTERNE'	$3,6241.10^6$ NR	1,00%

5.2.3 Tension in cable 5

$T=600\,s$

Identification (node/mesh)	Type of reference	Value of reference (N)	Tolerance ($\%$)
N81 - M5735	'SOURCE_EXTERNE'	$3,647.10^6$ NR	0,10%
N86 - M5740	'SOURCE_EXTERNE'	$3,674.10^6$ NR	0,10%
N91 - M5745	'SOURCE_EXTERNE'	$3,695.10^6$ NR	0,10%
N96 - M5750	'SOURCE_EXTERNE'	$3,674.10^6$ NR	0,10%
N105 - M5754	'SOURCE_EXTERNE'	$3,647.10^6$ NR	0,10%

6 Modeling D

6.1 Characteristics of modeling

The problem is identical to modeling A with the difference which cables 3 and 4 are modelled by elements CABLE_GAINE of rubbing type.

6.2 Results of modeling D

The results on the level of the tension of the cables are very only slightly modified, the tolerances are identical to modeling A .

7 Summary of the results

It is noted that the macro-order makes it possible to obtain the tension given by the BPEL (guaranteed by the procedure put in work by CASTEM) with a very good precision since the variation is lower than 0.1% , as well with the method of Newton as with the method IMPLEX. In addition, the effect of the setting in tension of the cables on the rest of the structure and in particular on the already tended cables, is completely satisfactory since the difference between the reference solution and calculation Aster is lower than 1% , whereas the grid of reference was quadratic and calculation carried out here used linear meshs.
The results are identical that calculation is solved using the algorithm of Newton or with the method IMPLEX.
The introduction of a cone of diffusion does not modify the quality of calculations.
It is also noted that it is possible to make successive settings in tension with modelled cables with 2 modelings available BAR and CABLE_GAINE.