Realization of a study civil engineer with cables of prestressing

Summary:

The purpose of this document is to give advices to carry out reinforced concrete studies with cables of prestressing by using the dedicated features (DEFI_CABLE_BP/CALC_PRECONT). He gives information about the precautions of grid, the modes of enforcement of prestressing and the possibilities of phasage.

1 Introduction

The studies of Génie Civil are often rather complex to carry out insofar as they utilize modelings $3D$, hulls, bars and several materials. This document tries to pool the experience gained on the subject by giving advices of methodology for the grid and the phase of modeling, concerning the prestressed structures.

The numeric work implementation of the tension requires some precautions of use, in particular in the case of non-linear calculations, since the chronology of the loadings can impact the results. In this document, we see how to set up the orders to reproduce some examples of possible situations in reality.

For a more visual presentation, supports of the formation “Code_Aster/salome_meca Module 4: Génie Civil “can also be consulted (02-Modeling of the prestressed reinforced structures) and an application in the form of Practical works, accessible via the test FORMA42 .

2 Notice preliminary

In *Code_Aster*, two types of modeling exist to describe prestressing.

- The first method is adapted to describe **adherent prestressing**. In this case, the cables of prestressing are re-pressés by elements $1D$ with modeling BAR. Prestressing perhaps applied in an easy way via the operators DEFI_CABLE_BP and AFFE_CHAR_MECA who allow to consider the profile of initial tension (NR) variable along the cable according to the lawful formulas (BPEL or ETCC) and to transform it into loading.
- The second method (less tested) is adapted to describe **nonadherent prestressing** (typically TGG). In this case, the cables of prestressing are represented by elements $1D$ with modeling CABLE_GAINE. The setting in tension of the cable is obtained by simulating the process of setting in tension of the cable via the operator CALC_PRECONT, by supposing that the cables slip with a friction of type law of Coulomb .

3 First stage: grid

To carry out a calculation on a structure out of prestressed reinforced concrete, it is necessary to net the concrete, the reinforcements as well as the cables of prestressing.

- The grid of the concrete can be carried out with any voluminal element in $3D$ or in $2D$. In $3D$, Lbe elements can be linear or quadratic. If a modeling of type hull is selected, the elements will be linear.

- Reinforcements can be represented:
  - that is to say individually in this case, they will be obligatorily with a grid with $SEG2$ (linear elements) of which nodes are common with those of the concrete. It thus should be thought of it when the concrete is netted. In addition, it is necessary to be vigilant if the concrete is with a grid with elements quadratiques in order to make well correspond all the nodes concrete located along the reinforcement with a node steel: in other words, if the concrete is with a grid with quadratic elements, at the place where a reinforcement, should be defined 2 must pass $SEG2$ steel for a mesh concrete;
  - Shears in a way distributed in the form of a surface whose nodes are the same ones as the nodes of the concrete. The meshs could be indifferently triangles or quadrangles, linear or quadratic. It will thus be necessary to take care to identify this surface with moment of the grid concrete and to duplicate the meshs to define the steel tablecloth (via *Transformation → Nodes Duplication/Elements* in *salome_meca*). If there are several tablecloths of

reinforcements, it will be necessary to duplicate as many times as necessary these elements.

- The cables of prestressed must be with a grid with unidimensional elements. If modeling BAR is used, these elements will be $SEG2$; if modeling CABLE_GAINE is used, these elements will be $SEG3$. Some is modeling, it is not necessary to make coincide the nodes of the cable and the nodes concrete: the order DEFI_CABLE_BP indeed allows to create S connections kinematics which will bind the nodes of the cable with the nodes of the concrete of the surrounding mesh. It is necessary on the other hand to take care to have a level of similar discretization for the concrete and steel, in order to have, as far as possible, a node steel in each concrete mesh (so that all the elements see the cable) and to avoid having several nodes steel in a mesh concrete (to avoid weighing down the problem with multipliers of useless Lagrange).
  Nodes of anchoring having to be defined for each cable, it is necessary to have created groups of nodes for each end DE cableS.

4 Second phase: the setting in fact of the case

One details here the various stages of the setting in data of a standard prestressed concrete problem in *Code_Aster,* for the two types of modeling. For each phase, one specifies the possible questions to be posed and information which should be provided. In the case of modeling BAR, UN example of application is proposed in appendix where one gives the various alternatives for the phase of resolution.

4.1 Reading and possible enrichments of the grid

- To check that the nodes of anchoring are quite accessible (individually) by one GROUP_NO.
- To create the possible groups of nodes or meshs for postprocessing. If one wishes post-to treat the tensions in cables of prestressing, it is necessary to think of ordering the nodes of the group of corresponding nodes (option 'SEGM_DROI_ORDO' or 'NOEUD_ORDO' in DEFI_GROUP/CRÉA_GROUP_NO).
- To direct the groups of meshs correctly where one imposes loadings of type pressure or flow (order ORIE_PEAU_3D (2D)).

4.2 Assignment of a model

- **For the reinforcement**S

In the case of a modeling 3D , the reinforcements will be modelled by elements BAR if they were represented by linear elements or elements GRILLE_MEMBRANE or MEMBRANE) if they were represented by surface elements.
In the case of a modeling of the type plates (DKT , Q4GG), it is necessary to use modeling GRILLE_EXCENTREE .

- **For the cables of prestressing**

For adherent cables, the model BAR (resting on $SEG2$) will be used.
For cables not-members, the model CABLE_GAINE (resting on $SEG3$) will be used..

4.3 Characteristics of the elements of structure

In AFFE_CARA_ELEM, Dto éfinir:

- for the reinforcementS passive, that is to say their section (BAR), that is to say the section and the orientation of the tablecloth (GRID)
- for Lbe cables of prestressing, to define the section (BAR).

4.4 Definition of materials

Various types of laws are available according to the phenomena which one wishes to take into account (elasticity, damage, creep,…). Tables of synthesis giving the main features of each one of them are available in **[U2.03.07]: Panorama of the tools available to carry out structural analyses of concrete Génie Civil** .

The choice of the law determines the keywords to inform under DEFI_MATERIAU [U4.43.01].

In the presence of cables and to be able to use DEFI_CABLE_BP, it is also necessary to have informed besides the parameters dependent on the law of behavior used, the regulation used (BPEL or ETCC) :

- for the concrete, **that is to say** the keyword BPEL_CONCRETE, by informing if necessary the losses by creep PERT_CREPT, and losses due to the withdrawal PERT_RETR **that is to say** the keyword ETCC_BETON();
- for the steel of the cables of prestressing, **that is to say** the keyword BPEL_STEEL, while informing the constraint with rupture F_PRG, the coefficient of friction partly right FROT_LINE and partly curve FROT_COURB, the coefficient of relieving MU0_RELAX, and the relieving of steel at 1000 hours RELAX_1000, **that is to say** the keyword ETCC_ACIER. In this case, the data required are the constraint with rupture F_PRG, the coefficient of friction COEF_FBELCH, the loss ratio on line PERT_LIGNRE, and the relieving of steel at 1000 hours RELAX_1000.

All these parameters are optional.

Note:

1) *The parameter F_PRG does not intervene in a possible nonlinear calculation with the plasticity of the cables, it only allows to calculate the loss by relieving. To allow a calculation with plasticization, it is necessary to state the elastic limit with the selected law of behavior.*
2) *The order DEFI_CABLE_BP cannot consider the case where the elastic characteristics of the concrete crossed by the cable can vary with the temperature.*
3) *The order DEFI_CABLE_BP can support the case where a cable crosses several materials concrete. It is necessary however that all the concretes have the same properties opposite DU BPEL or ETCC, i.e. same properties under the keyword BPEL_BETON or ETCC_BETON.*

Case of the cables not-members:
When modeling is used CABLE_GAINE , the user must also inform the law of friction which must be used via the keyword CABLE_GAINE_FROT . The choice is logically of type ' RUBBING ', implying to inform the coefficients of friction in straight line and curve. However, L' user also has the possibility of choosing the option 'ADHERENT' to easily make comparisons between the two behaviors (results equivalent to modeling BAR) or the option 'SLIPPING' who allows to avoid the possible difficulties of convergence related to friction.

4.5 Definition of the cables

The phase of definition of the cables places by the order DEFI_CABLE_BP. That makes it possible to define which must be the tension in the cables according to the rules of the BPEL/ETCC, according to the tension initial, of the retreat of anchoring (which applies only for active anchorings), of the relieving of steel and the deformations differed from the concrete (creep and withdrawal).
Let us announce that only one DEFI_CABLE_BP can gather several cables provided that they have the same parameters of entry for the calculation of the tension, and that one wishes to tighten all these

cables simultaneously. It is in general preferable from a performance point of view. To facilitate the setting in data and to avoid the recourse to macros pythons, it is possible[1] to define the cables via a table defined in an external file (cf. SSNV229A).

If the user made the choice to model cables not-members (RUBBING or SLIPPING), it is advisable to specify in DEFI_CABLE_BP, ADHERENT=' NON'.

The punching created by anchorings can some time cause digital difficulties of modeling. The origin of this problem is related to the incompatibility of the load pattern (a specific force created by anchoring) compared to the grid of the concrete (2D or 3D). To avoid this problem, the keyword CONE under DEFI_CABLE_BP) allows to define a volume representing the cone of fainding placed at the end of the cables, and thus to distribute the force of punching on a volume of the concrete, and either on one or some nodes. The geometry of this volume corresponds to a cylinder whose dimensions (length and ray) would have ideally to correspond to the cone of fainding really employed. However, it should be noted that if the grid of the concrete in this area is not sufficiently fine, the volume of the conewill not integrate additional nodes and the problem will not be modified. It is also not possible that there is covering of the cones. The option CONE is not activable in the case of nonadherent cables.

Note:

1) *Each end of cable can be declared as being "active" or "passive". If a cable does not comprise any active end, no tension is then applied.*
2) *The use of the option CONE a special attention as for the way requires of imposing the boundary conditions under penalty of seeing appearing conditions superabundant kinematics which prevent the resolution of the problem.*

4.6 Definition of the loadings

4.6.1 Case of the adherent cables

Two alternatives exist to realize setting in tension. The first method consists with to directly apply prestressing in the form of an initial tension in the cables like loading with STAT_NON_LINE. The loading is instantaneous. Its disadvantage is that the tension which results from balance is generally weaker than that required by the user because of the elastic strain of the concrete under the effect of prestressing.

The second method is an improvement of the first and rests on the macro-order CALC_PRECONT who includes a certain number of handling of the model to ensure the setting in tension (cf [R7.01.02]). By using this operator, the tension with balance is exactly that requested (i.e. that calculated by the lawful formulas), but that also the setting in successive tension of the cables allows to recreate the phasage of the setting in prestressed structure. Lastly, LE last interest of this method, it is the possibility of applying the tension of the cable in a gradual way, which can be necessary for behaviors of the non-linear type, in particular in the event of cracking of the concrete during the phase of setting in prestressing.

Basic method: STAT_NON_LINE

Besides the boundary conditions, and various loadings, it is enough to create a loading related to the cables via the operator AFFE_CHAR_MECA by including the loadings related to the tension and those related to the connections kinematics between steel and the concrete is :

```
CHCAB   =AFFE_CHAR_MECA    (MODELE=MO,   RELA_CINE_BP=_F   (CABLE_BP=CAB_BP3,
                      SIGM_BPEL=' YES ', RELA_CINE=' OUI',),).
```

1 Version 15.2.5

However if the user plans to connect several STAT_NON_LINE, it will be necessary to duplicate this loading by including only the connections kinematics (SIGM_BPEL=' NON', RELA_CINE=' OUI'). This loading will be used as of the second call to STAT_NON_LINE.

Advised method: CALC_PRECONT

Besides the boundary conditions, and various loadings, it is necessary to define the loadings related to the cables which should not integrate that the connections kinematics is:

```
CHCAB   =AFFE_CHAR_MECA   (MODELE=MO,   RELA_CINE_BP=_F   (CABLE_BP=CAB_BP3,
                         SIGM_BPEL=' NOT ', RELA_CINE=' OUI',),).
```

These loadings will be used :

- for any calculation with STAT_NON_LINE during phases former to the setting in tension (for example, if a phase of creep is simulated)
- for the posterior phases with the setting in tension (if not calculation stops in fatal error due to matrix not factorisable) that is calculated with STAT_NON_LINE or with CALC_PRECONT .

It is thus necessary to think of defining loading as muchS that different phases of setting in tension.

4.6.2 Case of the nonadherent cables

The instructions are the same ones as for the adherent case with CALC_PRECONT . On the other hand, it is necessary to also envisage to create additional loadings making it possible to block the slip with the nodes of anchoring of the cables once put in tension. That is to say:

```
CGLIS =AFFE_CHAR_MECA (MODELE=MO,
                    DDL_IMPO= (  _F (GROUP_NO= ('PC1D', 'PC1F'),
                                          GLIS=0.0,),)
```

5 The resolution of the mechanical problem

The last stage consists in solving the mechanical problem. It is held differently according to the method employed and the taking into account of the phasage. This chapter details the manner of proceeding for each choice, in precisant the loadingS to include (keyword EXCIT) at the time of the call to CALC_PRECONT or with STAT_NON_LINE.

5.1 Adherent cables put in tension with CALC_PRECONT

Three cases are possible:

1) The user wishes to put in tension **at the same time** all cables of prestressed as well as an instantaneous loading, without other first loadings. In this case, it is enough to call on the macro-order only once CALC_PRECONT. The loading is composed of the boundary conditions and the possible instantaneous loadings (no loading concerning the cables). Under the keyword CABLE_BP, all the concepts will be included DEFI_CABLE_BP (see scenario 3 in appendix).

2) The user wishes to do calculations **front** the setting in tension of the cables. In this case, it is appropriate:

   - that is to say to disable the cables in the model in their affecting the law of behavior RELATION=' SANS' under keyword BEHAVIOR of STAT_NON_LINE. In this case, the rigidity of the cables is worthless. IL is also essential to add in the loadings, the relations kinematics binding cable and concrete (loading obtained while writing AFFE_CHAR_MECA(RELA_CINE_BP=_F (RELA_CINE=' OUI'))) (see scenario 1 and 3 in appendix).
   - that is to say not to include the cables in the model used to do the calculations before the

setting in tension of the cables (what is more tiresome since it is necessary to work with 2 models).

3) The user wishes to put **successively** in tension cables. In this case, it is necessary to call on CALC_PRECONT as many times as necessary.
CABLE_BP will contain the concepts DEFI_CABLE_BP associated with the cables which one is tending during this call to CALC_PRECONT.
CABLE_BP_INACTIF will contain those which one wishes to tighten later on. In this way, it is the macro-order which is given the responsibility to affect a law of behavior WITHOUT with these cables and to include the connections kinematics associated with these same cables.
For the loading, it is a question systematically of including the boundary conditions as well as the possible instantaneous loadings.
From the second call to CALC_PRECONT, it is advisable to include moreover, the connections kinematics related to the cables already put in tension at the preceding stages (see scenario 1 in Appendix).

In all the cases, for STAT_NON_LINE who follow the setting in tension of the cables, it is important not to forget the whole of the connections kinematics related to the cables

5.2 Adherent cables put in tension with STAT_NON_LINE

If the user does not wish to use CALC_PRECONT to put in tension the cables of prestressing, it is possible to resort to the old method of setting in tension of the cables in spite of its disadvantages [R7.01.02].
The setting in tension is carried out simply by including in the loads the concept AFFE_CHAR_MECA defined by RELA_CINE_BP = F (RELA_CINE = 'YES', SIGM_BPEL=' OUI'). At the conclusion of this calculation, the tension in the cables is not equal any more to that prescribed by the BPEL. Nevertheless, it is possible of to determine a multiplicative coefficient (about ten de%) to apply to the initial tensions applied to the cables (on the level of the declaration of the operator DEFI_CABLE_BP) allowing to compensate for L overallbe lossS by instantaneous strain of the structure. Once the command file modified by these coefficients of correction, the modeling of the cables of prestressing is accomplished.

Attention, in the case of sequence of STAT_NON_LINE , it is appropriate starting from the second call, to include in the loading only the relations kinematics and not the tension in the cables, under penalty of adding this tension, with each calculation (see scenario 2 in appendix). That thus requires to create a second AFFE_CHAR_MECA with the operand RELA_CINE_BP = F (RELA_CINE = 'YES', SIGM_BPEL=' NON') (cf scenario 2 in Appendix).

5.3 Cables not members put in tension with CALC_PRECONT

The instructions are identical to the case of the adherent cables. Two specificities to be announced nevertheless.

1. The law of behavior for the cable is not simply any more elastic but:
   RELATION = 'KIT_CG', RELATION_KIT = (' ELAS ', 'CABLE_GAINE_FROT'),
   'ELAS', can be replaced by 'WITHOUT' when the cable should not intervene in calculation.

2. Once the cables were put in tension, it is necessary to add the loading which blocks the slip of the nodes of anchoring (cf § 4.6.2). It is advised to be based on the CAS-test SSNV164D.

6 Typical cases: relieving of the cables and rupture of the cables

6.1 Relieving of the cables

To model the relieving of the cables two options are possible but only in the case of the adherent cables (modeling BAR and not CABLE_GAINE): to use the lawful formulas or to use a viscoelastic law for the cables.

- When you use the lawful formulas (BPEL or ETCC) you calculate the losses by relieving on a given date. It is thus to use with precaution when you to carry out a non-linear calculation.
- For relieving, the formula of the ETCC requires to know the state of tension in the cable after taking into account of the instantaneous losses: calculation must thus be done in 2 stages. To refer to the CAS-test SSNV229B to have an example. The user also has the possibility of using a simplified version: it is the option TYPE_RELAXATION=' ETCC_DIRECT' (in opposition to TYPE_RELAXATION=' ETCC_REPRISE'). The test SSNV229A met of work this option.
- For a completely non-linear calculation, it is enough to assign to the cable of prestressed (modeling BAR), the law of behavior RELAX_ACIER (cf [R5.03.09] and test SSNL143 for more details).

6.2 Rupture of the cables

To simulate the rupture of a cable **member**, it should be taken care that the grid is sufficiently refined so that there is not although a cable by concrete mesh.
If it is supposed that the tension is worthless in all the cable, it is enough to call again on CALC_PRECONT in having defined new DEFI_CABLE_BP with the cables concerned while having defined a worthless tension
If it is supposed that there is réancrage cable, then you have the possibility of returning the profile of your choice. The sequence suggested is the following one:

- realization of the calculation of setting in initial tension
- recovery of the tension in (S) the cable (S) concerned (S): CALC_CHAM/POST_RELEVE_T
- modification of the tensions in the table using a formula defined by the user
- creation of the concept DEFI_CABLE_BP by defining the cable thanks to the keyword factor MODI_CABLE_RUPT
- new setting in prestressed using CALC_PRECONT.

The test SSNV229C allows to have an example.

Caution: taking into account the assumptions of modeling, the answers obtained are rather qualitative and do not have to be looked in manner very local.

7 Postprocessing

For the adherent cases, it is possible to recover the profile of tension in the cable calculated according to the lawful formulas, via the order:

```
TAB_1_I=RECU_TABLE (CO=CAB_BP, NOM_TABLE=' CABLE_BP',)
```

After setting in tension of the cables, it is of course possible to trace the profile of tension at several moments thanks to the orders POST_RELEVE_T/RECU_FONCTION/IMPR_FONCTION. An example is present in test FORMA42.

8 List of the CAS-tests of checking/validation

Name test	Type of structure	Type of validation

SSNV137/ ZZZZ305	Beam $3D$ subjected to inflection-compression by a cable of prestressing	DEFI_CABLE_BP (BPEL) + STAT_NON_LINE in 3D
ZZZZ344	Cylinder $3D$ with 1 cable	Calculation of the angular deviations in DEFI_CABLE_BP
SSNV229	Cylinder $3D$ with 10 cables of prestressing	Validation of the formulas of the ETCC
SSLV115	Elélies of prestressed concrete 3D (BAR or CABLE_GAINE for the cable)	Checking of calculations of pesanteur+validation CALC_PRECONT in 3D
SSNV164/ FORMA42	Twin-boom $3D$ with 5 cables of prestressing	Validation of the phasage of setting into prestressed (comparison CASTEM) + option CONE (SSNV164B)
ZZZZ347	1/2 ring in $3D$ with a cable of prestressing	Validation of the elements CABLE_GAINE to describe the rubbing cables.
ZZZZ111	1/2 rolls with 4 cables of prestressing	Validation of DEFI_CABLE_BP with elements hulls (DKT and Q4GG)
SSNP108	Plate with 1 cable of prestressed (compression)	Validation calculation of balance with STAT_NON_LINE with the hulls
SSNP109	Beam subjected to inflection-compression by a cable of prestressed (DKT)	Validation calculation of balance with STAT_NON_LINE
SSLS137	Plate with 1 cable of prestressed (inflection)	Validation of CALC_PRECONT with the hulls
ARCAD01	Current part of enclosure	Test used for the tool-trade ARCADE

9 Appendix

Here an example of application commented on which is drawn from TP of formation FORMA42 available in the list of the CAS-tests [V6.04.165]. It is about a post crossed by 5 cables, and the loading is composed of:

- gravity
- prestressing in the cables
- a pressure on the higher face (loading nonpresent in the CAS-test)

The setting in data is common, then one shows 3 scenarios to solve the problem. The implementation of the test will make it possible to compare the answers obtained in terms of tension in the cables. According to the scenario chosen, the tension in the cables and the deformations of the concrete are not identical.

first scenario (`FORMA42C`) is most physical and the phasage is the following :

- taking into account of gravity
- setting in tension of cables 1 and 2
- setting in tension of cables 3 and 4
- setting in tension of cable 5
- pressurization

deuxième scenario (`FORMA42B`) is identical to first but it uses the operator `CALC_PRECONT` and thus allows to have directly the lawful tension in the cables of prestressing.

third scenario (`FORMA42A`) is that which one applied before the development of the operator `CALC_PRECONT` (to version 6 of *Code_Aster*) and which is the method which remains recommended if a model is used `DKT` for the concrete

- taking into account of gravity and setting in tension of the 5 cables
- pressurization

The setting in fact of the case

`MY=LIRE_MAILLAGE (...)`
 	
`MA=DEFI_GROUP (...)`
	Reading and enrichment of the grid. The creation of `GROUP_NO` bound to the cables is essential only for one possible postprocessing along those.

`MO=AFFE_MODELE (MAILLAGE=MA,`
`AFFE= (_F (GROUP_MA=' VOLTOT',`
`PHENOMENE=' MECANIQUE',`
`MODELISATION=' 3D',),`
`_F (GROUP_MA= ('CAB1', 'CAB2', 'CAB3', ' CAB4', 'CAB5'),`
`PHENOMENE=' MECANIQUE',`
`MODELISATION=' BARRE',),),)`
	Definition of the models (`3D` for the concrete, `BAR` for the cables)

`CE=AFFE_CARA_ELEM (MODELE=MO,` `BARRE=_F (… ),)`	Geometrical characteristics (section) elements bars

`MBETON=DEFI_MATERIAU (ELAS=_F (...),`
`BPEL_BETON=_F (),);`
 	
`MCABLE=DEFI_MATERIAU (ELAS=_F (… ),`
`BPEL_ACIER=_F (F_PRG=1.94E11,`
`FROT_COURB=0.0,`
`FROT_LINE=1.5E-3,))`
 	
`CMAT=AFFE_MATERIAU (…)`
	Creation and assignment of characteristic materials for the cable and the concrete:
	Concrete: rubber band + given lawful BPEL by default
	Steel: rubber band +données lawful BPEL +

`CAB_BP12=DEFI_CABLE_BP (MODELE=MO,`
`CHAM_MATER=CMAT,`
`CARA_ELEM=CE,`
`GROUP_MA_BETON=' VOLTOT',`
`TYPE_ANCRAGE= ('ACTIVE', 'PASSIVE',),`
`TENSION_INIT=3.75E6,`
`RECUL_ANCRAGE=0.001,`
`DEFI_CABLE= (`
`_F (GROUP_MA=' CAB1',`
`GROUP_NO_ANCRAGE= ('PC1D', 'PC1F',)),`
`_F (GROUP_MA=' CAB2',`
`GROUP_NO_ANCRAGE= ('PC2D', 'PC2F')))`
 	
`CAB_BP34=DEFI_CABLE_BP (MODELE=MO,`
`CHAM_MATER=CMAT,`
`CARA_ELEM=CE,`
`GROUP_MA_BETON=' VOLTOT',`
`TYPE_ANCRAGE= ('ACTIVE', 'PASSIVE',),`
`TENSION_INIT=3.75E6,`
`RECUL_ANCRAGE=0.001,`
`DEFI_CABLE=(`
`_F (GROUP_MA=' CAB3',`
`GROUP_NO_ANCRAGE= ('PC3D', 'PC3F',)),`
`_F (GROUP_MA=' CAB4',`
`GROUP_NO_ANCRAGE= ('PC4D', 'PC4F',)))`
 	
`CAB_BP5=DEFI_CABLE_BP (MODELE=MO,`
`CHAM_MATER=CMAT,`
`CARA_ELEM=CE,`
`GROUP_MA_BETON=' VOLTOT',`
`TYPE_ANCRAGE= ('ACTIVE', 'PASSIVE',),`
`TENSION_INIT=3.75E6,`
`RECUL_ANCRAGE=0.001,`
`DEFI_CABLE=_F (GROUP_MA=' CAB5',`
`GROUP_NO_ANCRAGE= ('PC5D', 'PC5F',)))`
	Definition of the 5 cables of prestressing
	
	It is possible to gather in same : `DEFI_CABLE_BP` cables 1 and 2 on the one hand, and cables 3 and 4 of other share, since they have the same characteristics and are put in tension simultaneously. And in the case where all the cables are simultaneously tightened (scenario 2 and 3), one pourrait to gather all the cables.
	
	Creation of the loadings:

`AIR CONDITIONING =AFFE_CHAR_MECA (MODELE=MO,`
`DDL_IMPO =…,`
`GRAVITY =…)`
	boundary conditions and gravity

`CMCAB12=AFFE_CHAR_MECA (MODELE=MO,`
`RELA_CINE_BP=_F (CABLE_BP=CAB_BP12,`
`SIGM_BPEL=' NON',`
`RELA_CINE=' OUI',),)`
 	
`CMCAB23=AFFE_CHAR_MECA (MODELE=MO,`
`RELA_CINE_BP=_F (CABLE_BP=CAB_BP23,`
`SIGM_BPEL=' NON',`
`RELA_CINE=' OUI',),)`
 	
`CMCAB5=AFFE_CHAR_MECA (MODELE=MO,`
	The connections kinematics connecting the cable to the concrete
	(here `SIGM_BPEL=' NON'` , because one does not want to include in this loading the tension in the cables)

`RELA_CINE_BP=_F (CABLE_BP=CAB_BP5,`
`SIGM_BPEL=' NON',`
`RELA_CINE=' OUI',),);`
 	
`CLOSE =AFFE_CHAR_MECA (MODELE=MO,`
`PRES_REP =_F (GROUP_MA = 'HIGH',`
`CLOSE = 500,),)`
`FUNCTION = DEFI_FONCTION (NOM_PARA = 'INST',`
`VALE = (0. , 0. , 600. , 0. , 1000. ,`
`1.),)`
	Posterior loadings with the setting in tension of the cables (here a pressure)

Scenario 1

`LINST=DEFI_LISTE_REEL (VALE= (0.0, 150. , 300. , 450. , 600. , 1000.),);`
 	
# STAGE 1: effect of gravity 	
 	
`RES1 = STAT_NON_LINE (MODELE=MO, CHAM_MATER=CMAT, CARA_ELEM=CE, COMPORTEMENT= (_F (RELATION = 'ELAS', GROUP_MA=' VOLTOT',), _F (RELATION = 'WITHOUT', GROUP_MA= ('CABLE'),),), EXCIT = (_F (LOAD = AIR CONDITIONING,), _F (LOAD = CMCAB12), _F (LOAD = CMCAB34), _F (LOAD = CMCAB5),), INCREMENT=_F (LIST_INST = LINST, INST_FIN = 150.),)`
	The cables do not intervene: from where `RELATION=' SANS'` , but as they are present in the model, one includes the connections kinematics with regard to them (if not the cables “fall”).

# STAGE 2: setting in tension of cables 1 and 2 #--- `RES1 = CALC_PRECONT (reuse=RES1, ETAT_INIT=_F (EVOL_NOLI=RES1), MODELE=MO, CHAM_MATER=CMAT, CARA_ELEM=CE, COMPORTEMENT= (_F (RELATION = 'ELAS', GROUP_MA=('VOLTOT', 'CABLE')), EXCIT= (_F (LOAD = AIR CONDITIONING,),), CABLE_BP= (CAB_BP12), CABLE_BP_INACTIF = (CAB_BP34, CAB_BP5,), INCREMENT=_F (LIST_INST = LINST, INST_FIN = 300. ,),)`	Whereas the boundary conditions and gravity are maintained, `CALC_PRECONT` , will put in tension cables 1 and 2, while maintaining inactive cables 3.4 and 5. To assign the real law of behavior to the cables. Not to include the connections kinematics binding the cables to the concrete, `CALC_PRECONT` takes care some
# STAGE 3: setting in tension cables 3 and 4 #--- `RES1 = CALC_PRECONT (reuse=RES1, ETAT_INIT=_F (EVOL_NOLI=RES1), MODELE=MO, CHAM_MATER=CMAT, CARA_ELEM=CE, COMPORTEMENT= (_F (RELATION = 'ELAS', GROUP_MA=('VOLTOT', 'CABLE')), EXCIT = (_F (LOAD = AIR CONDITIONING,), _F (LOAD = CMCAB12,)), CABLE_BP = (CAB_BP34), CABLE_BP_INACTIF = (CAB_BP5,), INCREMENT=_F (LIST_INST = LINST, INST_FIN = 450.),)`	This time cables 1 and 2 are already tended and thus are not managed any more by `CALC_PRECONT` , this is why it is necessary to include in the loading besides the boundary conditions, the connections kinematics for these 2 cables. On the other hand nothing to put for cable 5, always inactive, and for cables 3 and 4 that `CALC_PRECONT` will put in tension at this stage
# STAGE 4: setting in tension cables 5 #-- `RES1 = CALC_PRECONT (reuse=RES1, ETAT_INIT=_F (EVOL_NOLI=RES1), MODELE=MO, CHAM_MATER=CMAT, CARA_ELEM=CE, COMPORTEMENT= (_F (RELATION = 'ELAS', GROUP_MA=' VOLTOT',), _F (RELATION = 'VMIS_ISOT_LINE', GROUP_MA = 'CABLE'),), EXCIT = (_F (LOAD = AIR CONDITIONING,), _F (LOAD = CMCAB12,), _F (LOAD = CMCAB34,)), CABLE_BP = (CAB_BP5,), INCREMENT=_F (LIST_INST = LINST, INST_FIN = 600. ,),)`	Only cable 5 is managed by `CALC_PRECONT` , it is thus necessary to include the connections kinematics for the other already tended cables (1,2,3 and 4).

# STAGE 5: pressurization 	
#--
`RES1 = STAT_NON_LINE (reuse=RES1,`
`ETAT_INIT=_F (EVOL_NOLI=RES1),`
`MODELE=MO,`
`CHAM_MATER=CMAT,`
`CARA_ELEM=CE,`
`COMPORTEMENT=_F (RELATION = 'ELAS',`
`GROUP_MA=('VOLTOT',`
`'CABLE)),`
`EXCIT = (_F (LOAD = AIR`
`CONDITIONING,),`
`_F (LOAD = CMCAB12,),`
`_F (LOAD = CMCAB34,),`
`_F (LOAD = CMCAB5,),`
`_F (LOAD = NEAR,`
`FONC_MULT =`
`FUNCTION,)),`
`INCREMENT=_F (LIST_INST = LINST,`
`INST_FIN = 1000.),)`
	All the cables are now active. The loading must understand the boundary conditions, the loadings instantaneous, the connections kinematics for all the cables and the new loadings to be applied (here NEAR).

Scenario 2

```
LINST=DEFI_LISTE_REEL (VALE= (0.0, 600. , 1000.),);

# STAGE 1: effect of gravity + tension of the cables

RES1 = CABLE_PRECONT (MODELE=MO,
                      CHAM_MATER=CMAT,
                      CARA_ELEM=CE,
                      COMPORTEMENT=_F (RELATION = 'ELAS',
                              GROUP_MA=('VOLTOT', 'CABLE)),
                      CABLE_BP = (CAB_BP12,CAB_BP34, CAB_BP5),
                      EXCIT   =_F (LOAD = AIR CONDITIONING,),
                      INCREMENT=_F (LIST_INST = LINST,
                                    INST_FIN = 600.),)
```

The loading is composed of `Air conditioning` and the 5 cables are put in tension simultaneously

```
# STAGE 2: pressurization
#-----------------------------------------------------------
RES1 = STAT_NON_LINE (reuse=RES1,
                       ETAT_INIT=_F (EVOL_NOLI=RES1),
                       MODELE=MO,
                       CHAM_MATER=CMAT,
                       CARA_ELEM=CE,
                      COMPORTEMENT=_F (RELATION = 'ELAS',
                               GROUP_MA=('VOLTOT', 'CABLE)),
                                  EXCIT    =  (_F  (LOAD  =  AIR
CONDITIONING,),
                                 _F (LOAD = CMCAB12,),
                                 _F (LOAD = CMCAB34,),
                                 _F (LOAD = CMCAB5,),
                                 _F (LOAD = NEAR,
                                    FONC_MULT = FUNCTION,)),
                       INCREMENT=_F (LIST_INST = LINST,
                                    INST_FIN = 1000.),)
```

One always maintains the boundary conditions and gravity, one includes the pressure. For the cables, one always needs the connections kinematics with regard to them.

Scenario 3

```
LINST=DEFI_LISTE_REEL (VALE= (0.0, 600. , 1000.),);

CMCAB12B=AFFE_CHAR_MECA (MODELE=MO,
                  RELA_CINE_BP=_F (CABLE_BP=CAB_BP12,
                                   SIGM_BPEL=' OUI',
                                   RELA_CINE=' OUI',),)

CMCAB34B=AFFE_CHAR_MECA (MODELE=MO,
                  RELA_CINE_BP=_F (CABLE_BP=CAB_BP3,
                                    SIGM_BPEL=' OUI',
                                    RELA_CINE=' OUI',),)

CMCAB5B=AFFE_CHAR_MECA (MODELE=MO,
                  RELA_CINE_BP=_F (CABLE_BP=CAB_BP5,
                                   SIGM_BPEL=' OUI',
                                   RELA_CINE=' OUI',),);
```

To directly apply the tension in the cables, one needs to define new loadings containing at the same time the connections kinematics binding cable and concrete, and the value of the tension to be included in the cables (from where `SIGM_BPEL=' OUI'` , contrary to the loadings `CMCABi` defined initially).

```
# STAGE 1: effect of gravity  + tension of the cables

RES1 = STAT_NON_LINE (MODELE=MO,
                      CHAM_MATER=CMAT,
                      CARA_ELEM=CE,
                      COMPORTEMENT=_F (RELATION = 'ELAS',
                                        GROUP_MA=('VOLTOT',
'CABLE)),
                               EXCIT    = (_F  (LOAD  =  AIR
CONDITIONING,),
                                _F (LOAD = CMCAB12B),
                                _F (LOAD = CMCAB34B),
                                _F (LOAD = CMCAB5B),),
                     INCREMENT=_F (LIST_INST = LINST,
                     INST_FIN = 600.),)
```

The loading is composed of `Air conditioning` and of `CMCABIJB` containing the connections kinematics and the tension in the cables

```
# STAGE  2: pressurization
#-----------------------------------------------------------
RES1 =  STAT_NON_LINE (reuse=RES1,
                       ETAT_INIT=_F (EVOL_NOLI=RES1),
                       MODELE=MO,
                       CHAM_MATER=CMAT,
                       CARA_ELEM=CE,
                       COMPORTEMENT=_F (RELATION = 'ELAS',
                                        GROUP_MA=('VOLTOT',
'CABLE)),
                               EXCIT    = (_F  (LOAD  =  AIR
CONDITIONING,),
                                  _F (LOAD = CMCAB12,),
                                  _F (LOAD = CMCAB34,),
                                  _F (LOAD = CMCAB5,),
                                  _F (LOAD = NEAR,
                                          FONC_MULT  =
FUNCTION,)),
                       INCREMENT=_F (LIST_INST = LINST,
                                     INST_FIN = 1000.),)
```

One always maintains the boundary conditions and gravity, one includes the pressure. For the cables, it is well them `CMCABI` because one just wishes to maintain the connections kinematics (if not, one adds once again the tension in the cables)