Macro-order DEFI_CABLE_BP

Summary

The objective of this order is to calculate the initial profiles of tension along the cables of prestressed of a structure concrete. The data of calculation are the tension applied at the ends and other parameters characteristic of anchorings and materials. The relations used are those prescribed by the BPEL 91 or the ETCC. It also makes it possible to create relations kinematics between the nodes of cable and the concrete nodes in which it is immersed.

The concept cabl_precont product can then be used:

- maybe by the operator AFFE_CHAR_MECA [U4.44.01] operand RELA_CINE_BP to define them mechanical loadings related to the presence of the cable (relations kinematics and/or tension in the cables). These loadings will be taken into account by the operator STAT_NON_LINE [U4.51.03].

– maybe by the operator CALC_PRECONT [U4.42.05] for a setting in progressive tension of the cables and the possibility of making phasage.

– maybe by the operator DEFI_GROUP (CREA_GROUP_NO/OPTION = 'RELA_CINE_BP') to create groups of nodes corresponding to the connections created and to allow a visual checking of these relations kinematics.

Product a Structure of Data of the type cabl_precont.

1 Syntax

```
cabl_pr [cabl_precont] = DEFI_CABLE_BP  (

    ♦  MODEL            =       model,                    [model]
    ♦  CHAM_MATER    =       chmat,                       [cham_mater]
    ♦  CARA_ELEM        =       caelem,                   [cara_elem]
    ♦  GROUP_MA_BETON   =       grmabe,                   [gr_maille]

    ♦  DEFI_CABLE    =   _F  (
           ♦  GROUP_MA          =  grmaca,                [gr_maille]
           ♦  GROUP_NO_ANCRAGE  =  l_gnoa,                [l_gr_noeud]
           ◊     TENSION_CT     =  table                  [table_*])
   ♦   MEMBER        =        / 'YES'                     [DEFECT]
                                / 'NOT'
   ♦   TYPE_ANCRAGE     =       l_tya,                    [l_tx]
   ♦   TENSION_INIT     =       f0,                       [R]
   ♦   RECUL_ANCRAGE    =       delta,                    [R]

 # So ADHERENT = 'YES',
       ◊   TYPE_RELAX       =        / 'WITHOUT'                [DEFECT]
                                     / 'BPEL'
                                     / 'ETCC_DIRECT'
                                     / 'ETCC_REPRISE'

       ◊   CONE             =   _F  (
               ♦   RAY    =            ray,               [R]
               ♦   LENGTH =            length,            [R]
               ♦   PRESENT    =           l_pre,          [l_tx])

   ◊   TITLE            =            l_titr,              [l_tx]

# If TYPE_RELAX=' BPEL',
   ♦      R_J    =             rj,                        [R]
# If TYPE_RELAX=' ETCC_DIRECT' or 'ETCC_REPRISE',
   ♦      NBH_RELAX  =            nbh,                    [R]
)
```

2 Operands

2.1 Operand MODEL

♦ MODEL = model
Concept produced by the operator AFFE_MODELE [U4.41.01] allowing to define the types of finite elements assigned to the meshs of the grid.

2.2 Operand CHAM_MATER

♦ CHAM_MATER = chmat
Concept produced by the operator AFFE_MATERIAU [U4.43.02] allowing to assign materials to the meshs of the grid.

2.3 Operand CARA_ELEM

♦ CARA_ELEM = caelem
Concept produced by the operator AFFE_CARA_ELEM [U4.42.01] allowing to assign mechanical and geometrical characteristics to the elements of the studied structure.

2.4 Operand GROUP_MA_BETON

♦ GROUP_MA_BETON = grmabe
Name of (or of) the groups of meshs of the grid representing the structure concrete. One thus precisely defines the locus of projection of the cables, preliminary stage to the determination of the relations kinematics between the degrees of freedom of the nodes of the cables and the degrees of freedom of the nodes of the structure concrete.

Note:

1- It is possible to provide here a list of group of meshs, in particular for the case where all the meshs concrete surrounding the cable do not have the same behavior. However, it is essential that all the meshs concretes concerned have the same characteristics BPEL_BETON*.*
*2- The meshs modelling the concrete can be only meshs 3D or meshs 2D in the case of a modeling of plate (*DKT, Q4GG*).*

2.5 Keyword DEFI_CABLE

♦ DEFI_CABLE
Keyword factor allowing the definition of a cable by designation of the topological entities of the grid which represent it. The multiple occurrences are authorized, in order to be able to define several cables.

♦ GROUP_MA = grmaca
Name of the group of meshs of the grid representing the cable.

♦ GROUP_NO_ANCRAGE = l_gnoa
List of groups of nodes defining anchorings. The cardinal of this list must be lower or equal to 2. In each group of node, one will retain like anchoring only the first node of the group.

◊ TENSION_CT = table
Table containing the tension in the cable for all the curvilinear X-coordinates (table with 2 columns). This table is used to calculate the losses by relieving of steel if the user chose the option TYPE_RELAX = 'ETCC_REPRISE'. This table is obtained via one POST_RELEVE_T on the nodes of the cable studied, after the first static calculation.

2.6 Operand MEMBER

♦ MEMBER = / 'YES' [DEFECT]

/ 'NOT'

This keyword makes it possible to indicate if one wishes to model adherent cables with the concrete or slipping or rubbing cables. It is necessary to inform MEMBER = 'NOT' if one models the cables with modeling CABLE_GAINE and the law of behavior CABLE_GAINE_FROT, in the cases SLIPPING and RUBBING. In Lbe other case (case MEMBER for the law CABLE_GAINE_FROT or modeling BAR), in fact the case by default must be used either MEMBER = 'YES' .

Note:

In the case MEMBER = 'NOT' , the profile of tension is calculated even if it is not used thereafter (nor in AFFE_CHAR_MECA/RELA_CINE_BP, nor in CALC_PRECONT).

2.7 Operand TYPE_ANCRAGE

♦ TYPE_ANCRAGE = l_tya

List of arguments of type text characterizing anchorings of the cable: 'ACTIVE' or 'PASSIVE' (only licit arguments). This list must comprise 2 arguments, neither more nor less, and must be ordered compared to the list of the nodes defining anchorings (operand GROUP_NO_ANCRAGE above). To note that if several cables are defined in DEFI_CABLE then the first argument of TYPE_ANCRAGE applies to all the first nodes which define anchorings. *Idem* for the second argument.

Note:

1- The operator reconstitutes the driving related way of the first to the second anchoring of the cable by traversing the meshs which represent it. The non-existence of a related way between two anchorings causes a program stop in fatal error.
2- Active anchorings are those where an initial tension is applied.

2.8 Operand TENSION_INIT

♦ TENSION_INIT = f0

Value of the initial force applied to active anchorings of the cables.
This value must be positive.

2.9 Operand RECUL_ANCRAGE

♦ RECUL_ANCRAGE = delta

Value of the retreat to active anchorings of the cables.
This value must be positive.

2.10 Choice of the type of calculation for the taking into account of the relieving of steels

Keyword factor allowing to determine whether one takes into account or not, losses of tension by relieving of steel by the lawful method, and so yes which (ETCC or BPEL). This keyword factor being optional, by defaults the losses of tension by relieving of steel are not taken into account.

2.10.1TYPE_RELAX=' SANS'

It is the value by default. In this case, one does not take into account this kind of loss by a lawful method. On the other hand, one can to take into account while using the viscoelastic law of behavior RELAX_ACIER for the cable (cf [R5.03.09]).

2.10.2 TYPE_RELAX=' BPEL'

In this case, the formula of the BPEL is applied, and the keyword `R_J` must be well informed (cf §2.11 for the detail).

2.10.3 TYPE_RELAX=' ETCC_DIRECT'

In this case, the formula of the ETCC is applied, but the effort used takes into account only the losses by friction and retreat of anchoring (cf § 4).
It is necessary to inform the keyword `NBH_RELAX` (cf §2.12).

2.10.4 TYPE_RELAX=' ETCC_REPRISE'

In this case, the formula of the ETCC is applied. The effort used is that provided by the user under the keyword factor `DEFI_CABLE/TENSION_CT= counts`. The tension thus taken into account can take account of the elastic losses if the cables were put in prestressed in 2 families.
It is necessary to inform the keyword `NBH_RELAX` (cf §2.12).

2.11 Operand R_J

◊ `R_J =` rj

Parameter to be informed only if `TYPE_RELAX=' BPEL'`.
Value of the adimensional function $r(j)$ characterizing the evolution of the relieving of steel in time and only of steel (this coefficient does not apply to the losses by creep or shrinking of the concrete indicated under `BPEL_BETON` in `DEFI_MATERIAU`); for example the BPEL 91 recommends:

$r(j)=\frac{j}{j+9\times r_m}$ with j in days

and $r_m=\frac{\text{aire de la section de béton}}{\text{périmètre de la section de béton}}\equiv\text{rayon moyen}$

This value must be positive or worthless.

j corresponds to the date (in days) for which one wants to estimate the state of stress in the structure. For the case where, in the structural analysis, the bars would be modelled with a behaviour of type creep, one should not inform this keyword in `DEFI_CABLE_BP`.

2.12 Operand NBH_RELAX

◊ `NBH_RELAX =` nh

Parameter to be informed only if `TYPE_RELAX=' ETCC_DIRECT'` or `'ETCC_REPRISE'`.
Time considered for the taking into account of the losses by relieving of steel in the ETCC (used if `TYPE_RELAX=' ETCC_DIRECT'` or '`ETCC_REPRISE`'), expressed of number D' hours.
The formula applied is the following one:

$$\Delta F_{pr}=0,66.\rho_{1000}.e^{9,1\frac{\tilde{F}(s)}{P_{pk}}}.\left(\frac{nh}{1000}\right)^{0,75(1-\tilde{F}(s)/P_{pk})}.10^{-5}\tilde{F}(s)$$

where:

ρ_{1000} is the value of the coefficient of relieving of steel at 1000 hours in %, well informed under `ETCC_ACIER`.

P_{pk} is the maximum tension of steel with rupture, calculated starting from the data of `F_PRG` under `ETCC_ACIER`.

$\tilde{F}$ is equal to the tension calculated according to the ETCC by taking of account the losses by friction and retreat of anchoring if `TYPE_RELAX=' ETCC_DIRECT'` or the power provided by the user under DEFI_CABLE/TENSION_CT if TYPE_RELAX=' ETCC_REPRISE'.

2.13 Keyword CONE

♦ CONE

This keyword factor makes it possible to define a geometrical volume around anchorings, and to affect, at exit AFFE_CHAR_MECA keyword RELA_CINE_BP, with all the nodes (concrete and cable) contained in this volume, a kinematic relation of type LIAISON_SOLIDE (rigid body). The definition of this volume makes it possible to attenuate the constraints which the tensions at the ends of the cables generate on the concrete. In reality, this phenomenon is avoided thanks to the installation of a cone of diffusion of constraint (material harder than the concrete) which distributes the force of prestressed on a large surface of the concrete. In practice, the cone being practically right, one defines a cylindrical volume.

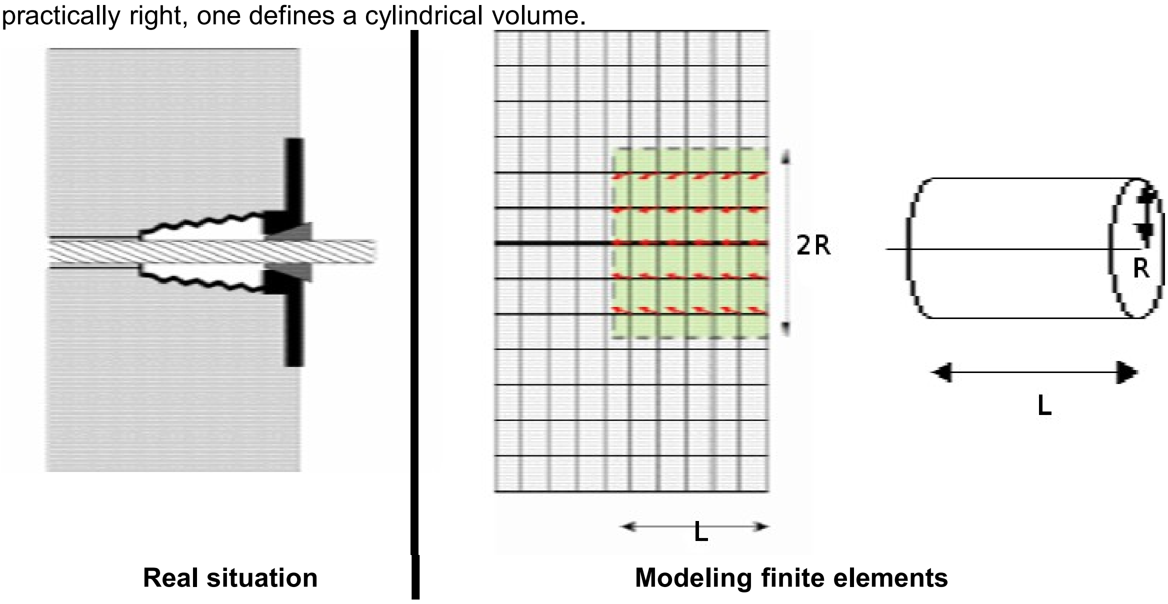

Figure 1: use of a cone of diffusion: real situation and modeling

To note that several rigid cones and thus several blocks are defined if the keyword PRESENT contains two 'YES' (a block per end of the cable) or if several cables are defined under DEFI_CABLE.

Note:

In practice, the cylinder is defined by the order DEFI_GROUP option TUNNEL. The methodology of extraction of the nodes contained in the cone is described in the document [U4.22.01] (order DEFI_GROUP).

♦ RAY = ray

Ray of the cone.

♦ LENGTH = length

Length of the cone, with the curvilinear direction X-coordinate on the cable. One defines the cone as a succession of cylinder while stopping when the overall length of the cylinders is equal to the parameter length.

♦ PRESENT = l_pre

This list must comprise 2 arguments, neither more nor less, and must be ordered compared to the list of the nodes defining anchorings (operand GROUP_NO_ANCRAGE above).

The only valid arguments are 'YES' or 'NOT'; they allow to define the cone on two anchorings (PRESENT = ('YES', 'YES',)), on the first anchoring (PRESENT = ('YES', 'NOT',)) or on the second anchoring (PRESENT = ('NOT', 'YES',)). It should be noted that if several cables are defined in DEFI_CABLE then the first argument of PRESENT applies to all the first nodes which define anchorings. Idem for the second argument.

2.14 Operand `TITLE`

◊ `TITLE = l_titr`

List of arguments of type text defining a title attached to the concept `[cabl_precont]`.

3 Theoretical complement: estimate of the losses of tension in a cable of prestressed according to the regulations of the BPEL

If the user defined characteristic materials `BPEL_BETON` and `BPEL_ACIER`, the evolution of the tension (in Newton) along a cable of prestressing is calculated by using the relations prescribed by the BPEL. These relations are the following ones:

3.1 Évolution of the tension in the vicinity of anchoring

$$F(s)=\tilde{F}(s)-\{x_{flu}\times F_0+x_{ret}\times F_0+r(j)\times\frac{5}{100}\times\rho_{1000}\left[\frac{\tilde{F}(s)}{S_a\times\sigma_y}-\mu_0\right]\times\tilde{F}(s)\}$$

where s indicate the curvilinear X-coordinate along the cable. The parameters introduced into this expression are:

- F_0 initial tension (NR);
- x_{flu} standard rate of loss of tension by creep of the concrete, compared to the initial tension;
- x_{ret} standard rate of loss of tension by shrinking of the concrete, compared to the initial tension;
- ρ_{1000} relieving of steel at 1000 hours, expressed in %;
- S_a surface of the cross-section of the cable defined in `AFFE_CARA_ELEM` ;
- σ_y elastic ultimate stress of steel;
- μ_0 adimensional coefficient of relieving of prestressed steel.

$r(j)$ is an adimensional function characterizing the evolution of relieving in time:

$$r(j)=\frac{j}{j+9\times r_m} \text{ with J in days and } r_m=\frac{\text{aire de la section de béton}}{\text{périmètre de la section de béton}}\equiv\text{rayon moyen}$$

The function $r(j)$ depending on the geometry of the structure, the value used is defined in the operator `DEFI_CABLE_BP`.

$\tilde{F}(s)$ is the evolution of the tension in the vicinity of anchoring after taking into account of the loss by retreat of anchoring and the losses by contact between the cable and the concrete.

$\tilde{F}(s)$ is defined by the relation: $F_c(s)\times\tilde{F}(s)=[F_c(d)]^2$

$F_c(s)$ indicate the evolution of the tension along the cable after taking into account of the losses by contact between the cable and the concrete: $F_c(s)=F_0\exp(-f\alpha-\varphi s)$

α indicate the cumulated angular deviation and the parameters introduced into the expression of its $F_c(s)$ T:

f coefficient of friction enters the cable and the partly curved sheath, in rad^{-1} ;

φ coefficient of friction enters the cable and the sheath in m^{-1}.

Note:

- *Coefficients* $f, \varphi, \rho_{1000,} \sigma_y, \mu_0$ *are to be informed in the operator* `DEFI_MATERIAU` *under the keyword* `BPEL_ACIER`*,*
- x_{flu} *and* x_{ret} *are to be informed in the operator* `DEFI_MATERIAU` *under the keyword* `BPEL_BETON`*.*

The length d intervening in the expression of $\tilde{F}(s)$ is the length to which the loss of tension by retreat applies to anchoring. This length is estimated using the relation:

$$E_a S_a \Delta = \int_0^d \left(F_c(s) - \tilde{F}(s) \right) ds$$

where E_a is the Young modulus of steel and Δ the value of the retreat to anchoring. Thus $E_a S_a \Delta$ represent the deformation energy (cable) due to the retreat with anchoring.

3.2 Évolution of the tension beyond the length where the losses of tension by retreat apply to anchoring

$$F(s) = F_c(s) - \{ x_{flu} \times F_0 + x_{ret} \times F_0 + r(j) \times \frac{5}{100} \times \rho_{1000} \left[\frac{\tilde{F}(s)}{S_a \times \sigma_y} - \mu_0 \right] \times \tilde{F}(s) \}$$

with the same notations as those introduced in the preceding paragraph.

4 Theoretical complement: estimate of the losses of tension in a cable of prestressed according to the regulations of the ETCC

If the user defined characteristic materials `ETCC_BETON` and `ETCC_ACIER`, the evolution of the tension (in Newton) along a cable of prestressing is calculated by using the relations prescribed by the ETCC. However the losses due to the elastic strain of the concrete and the deformations due to the shrinking and the creep of the concrete are not taken into account in calculation. It is appropriate if one wants to take them into account:

- of tightening the cables in 2 families to recover the losses due to the elastic strain of the concrete
- to impose on the concrete the deformations withdrawal and of creep, after the setting in tension of the cables.

The established relations are the following ones.

4.1 Évolution of the tension in the vicinity of anchoring

$$F(s) = \tilde{F}(s) - 0{,}8 \Delta F_{pr}(s)$$

with

$\tilde{F}(s)$ is the evolution of the tension in the vicinity of anchoring after taking into account of the loss by retreat of anchoring and the losses by contact between the cable and the concrete.

$\tilde{F}(s)$ is defined by the relation: $F_c(s) \times \tilde{F}(s) = [F_c(d)]^2$

$F_c(s)$ indicate the evolution of the tension along the cable after taking into account of the losses by contact between the cable and the concrete: $F_c(s) = F_0 \exp^{-\mu(\alpha + k s)}$

α indicate the cumulated angular deviation and the parameters introduced into the expression of its $F_c(s)$ are:

$\mu[rad^{-1}]$ the coefficient of friction enters the cable and the sheath;

$k[rad^{-1}.m^{-1}]$ the loss ratio on line.

The length d intervening in the expression of $\tilde{F}(s)$ is the length to which the loss of tension by retreat applies to anchoring. This length is estimated using the relation:

$$E_a S_a \Delta = \int_0^d \left(F_c(s) - \tilde{F}(s)\right) ds$$

where

E_a is the Young modulus of steel and Δ the value of the retreat to anchoring. Thus $E_a S_a \Delta$ represent the deformation energy (cable) due to the retreat with anchoring.

ΔF_{pr} are the losses due to the relieving of the cables, estimated by the following formula

$$\Delta F_{pr}(s) = 0{,}66 \,.\, \rho_{1000} \,.\, e^{9{,}1 \frac{\tilde{F}(s)}{P_{pk}}} \,.\, \left(\frac{nh}{1000}\right)^{0{,}75(1-\tilde{F}(s)/P_{pk})} .\, 10^{-5} \tilde{F}_{(s)}$$

s indicate the curvilinear X-coordinate along the cable. The parameters introduced into this expression are:

- ρ_{1000} Relaxation of steel at 1000 hours, expressed in %.
- P_{pk} Force with rupture in steel (calculated starting from the parameter `F_PRG` informed in `DEFI_MATERIAU/ETCC_ACIER`)
- nh The number of hours after the setting into prestressed to which the losses are calculated.

Note:

- *Coefficients $\mu, k, \rho_{1000}, F_{prg}$ are to be informed in the operator `DEFI_MATERIAU` under the keyword `BPEL_ACIER`,*
- *nh is to be informed in the operator `DEFI_CABLE_BP`.*

4.2 Evolution of the tension beyond the length where the losses of tension by retreat apply to anchoring

$$F(s) = F_c(s) - 0{,}8 * 0{,}66\, \rho_{1000} \,.\, \exp^{9{,}1 F_c(s)/F_{prg}} \,.\, \left(\frac{nh}{1000}\right)^{0{,}75(1-F_c(s))/F_{prg}} .\, 10^{-5} F_c(s)$$

With the same notations as those introduced in the preceding paragraph.

5 Example

See the test `SSNV164` for an application, and the documents [U2.03.06] and [U4.42.05] to know more precisely how to put in tension the cables of prestressing.
See the test `SSNV229` for an example of taking into account of the relieving of steel according to the ETCC.
See the test `ZZZZ347` for an example of use with modeling `CABLE_GAINE`.