

Note of use of the static under-structuring

Summary

This document is an introduction to the use of the static under-structuring.

While being based on a detailed example, the case test SSLP100B:

- paragraphs 1,2,3,4 will be read;
- one will refer to the description of the specific orders:
MACR_ELEM_STAT [U4.44.01]
DEFI_MAILLAGE [U4.12.04] and,
DEPL_INTERNE [U4.65.01],
- one will return to the detailed comments of the command file [§6].

1 General information

The static under-structuring established in *Aster* is usable in **linear mechanics** and in **nonlinear mechanics on linear parts of a model**. It can be done a priori with **several levels** : a substructure can contain others under - structures of lower level. All types of elements of the phenomenon "MECHANICAL" are accepted thus that all the loadings supported by these elements.

The under-structuring is currently established within the framework of the ordinary orders [U4.4 -] and [U4.5-]. It is however not established within the framework of the total orders: MECA_STATIQUE, CALC_CHAMP, POST_ELEM,...

An exception exists: orders STAT_NON_LINE and DYNA_NON_LINE accept macro - static elements (see [§2]).

The static under-structuring consists in "condensing" statically the problem to be treated: a certain number of unknown factors are eliminated (internal). There then remain the unknown factors known as "external" in less great number.

It is a method which reduces the size of the problem. One can thus expect from them savings of time CPU and occupation of the discs. This static condensation applies naturally to the matrix of rigidity and mass and with the second members representing the various loadings. In this case, the method of condensation can be interpreted algebraically like a resolution of the linear system by the method "of elimination". The solution of a linear problem of statics is thus not modified by the under-structuring. On the other hand, it is possible to statically condense the matrix of mass (condensation of Guyan) but in this case the research of the clean modes of the condensed structure **is faded** by the method of under-structuring (see for example IMBERT [bib1]). There exist other methods of under-structuring for the problems of dynamics in *Aster* [U4.55].

The theoretical principles of the static under-structuring are well explained in the book of IMBERT [bib1] and handbooks PERMAS [bib2].

The use of the static under-structuring into nonlinear is approached in a first distinct chapter.

In the continuation of this document, one will suppose known these theoretical principles and one will be interested only in the aspects "user". For that, one will make use much of an example: the case test SSLP100 of the handbook of validation *Aster*. We tested, through this case test, to illustrate a large number of possibilities of the software, by complicating voluntarily the test:

- under-structuring on several levels (2),
- use of a macronutrient to generate by successive rotations several substructures,
- boundary conditions and loadings on several levels,
- mixture of substructures and ordinary finite elements,
- "following" loading or not.

The command file of this case test which one numbered the lines is given in appendix of this document. When one wants to refer to line N of this file, one will write {line N}.

2 Use of macronutrients in STAT_NON_LINE (or DYNA_NON_LINE)

One can do a nonlinear calculation with `STAT_NON_LINE` [U4.51.03] on a model containing of the macronutrients. The interest of this kind of calculation is a possible performance profit (memory and/or CPU).

So that calculation with macronutrients is more economic, it is necessary that the model has broad linear elastic zones (possibly repetitive). It is necessary also that these elastic zones (that one will condense in macronutrients) have a border as small as possible. A favorable situation will be for example the case of an entirely elastic structure with a small zone of confined plasticity [Figure 2-a].

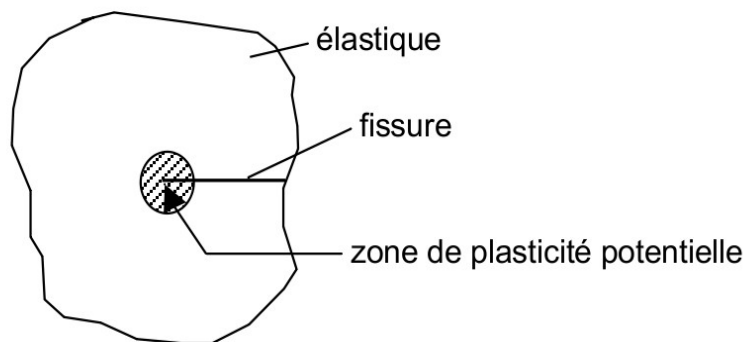


Figure 2-a

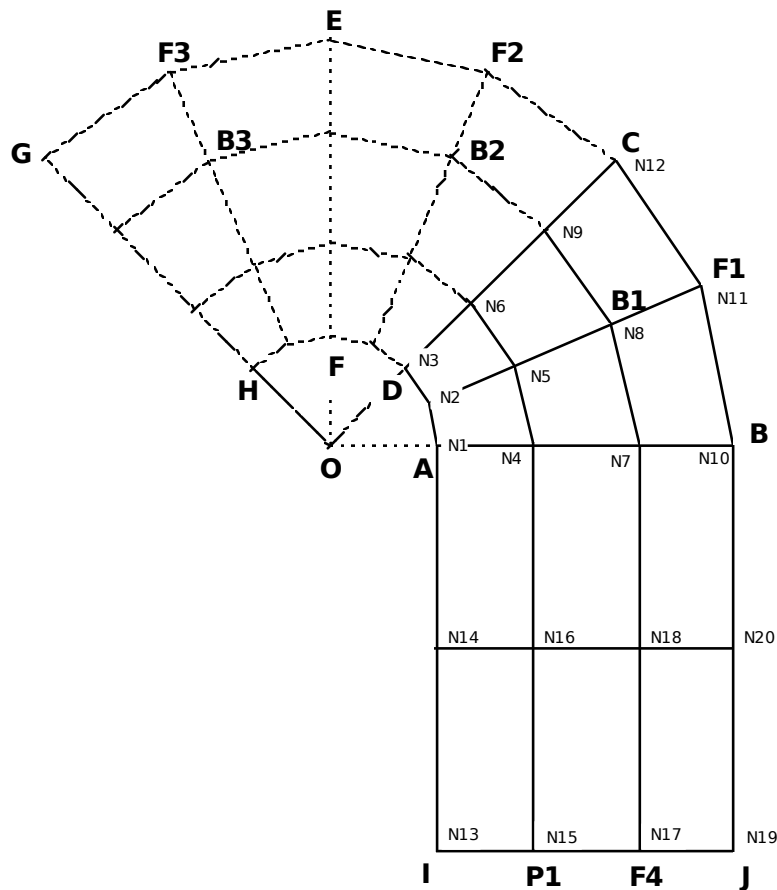
One will then condense all the elastic part on the only nodes of the interface with the zone of potential plasticity.

The use of macronutrients in `STAT_NON_LINE` (see case tests SSLP100C and D) is conditioned by the following requirements:

- 1) each macronutrient must be elastic linear, its temperature should not vary in the course of time,
- 2) there cannot be contact with macronutrients,
- 3) the loadings assigned to the macronutrients "constant" (are not multiplied by "FONC_MULT"),
- 4) the macronutrients should not undergo great rotations,
- 5) "linear research" is not possible.

Once calculation makes with `STAT_NON_LINE`, usual postprocessings (`CALC_CHAMP`, `POST_ELEM`) will not have an effect that on the ordinary finite elements of the model (the macronutrients are ignored). If one wants to examine for example the state of stress inside a macronutrient, the basic commands should be used: `CREA_CHAMP/EXTR`, `DEPL_INTERNE`,... (see [§4.3] and [§4.4]).

3 Presentation of the case test SSLP100B being used as example



It is about a plane structure subjected to the boundary conditions following:

- on the side $[GH]$: $u+v=0$ (slipping support)
- nodes $B1$, $B2$, $u=v=0$
 $B3$:
- node J : $u=2.0$
- loading case 1: chf1 : pressure distributed on $ADFH$ $p=10.0$
- loading case 2: chf2 : specific forces on the nodes $F1$, $F2$, $F3$, $F4$ and $P1$
: $Fy=-20.0$

4 Treatment of the case test by the method of under - structuring

- the initial grid contains only the meshes (and the nodes) of the polygon *IJB CDA* ,
- one defines a macronutrient (*S_1*) corresponding to the polygon *ABCD* ,
- the macronutrient (*S_1*) 2 times per rotation are repeated around *O* ,
- one obtains the macronutrient then (*S_123*) corresponding to the polygon *ABCEGHFD* ,
- the final model (on which one makes the resolution) is obtained while adding to the macronutrient (*S_123*) finite elements of the quadrilateral *IJBA* .

5 General organization of calculations and definitions

5.1 Construction of the total model

The principle of the establishment of the static under-structuring in *Code_Aster* is that of an ascending approach:

one **model** having been defined, it is condensed (operator *MACR_ELEM_STAT*) on some of its nodes. One then is obtained **macronutrient** who, functionally resembles much a new finite element "larger". This macronutrient can then be integrated in one **model** of higher level (operators *DEFI_MAILLAGE* and *AFFE_MODELE*). This new model can then be condensed in its turn and so on without limitation a priori amongst levels.

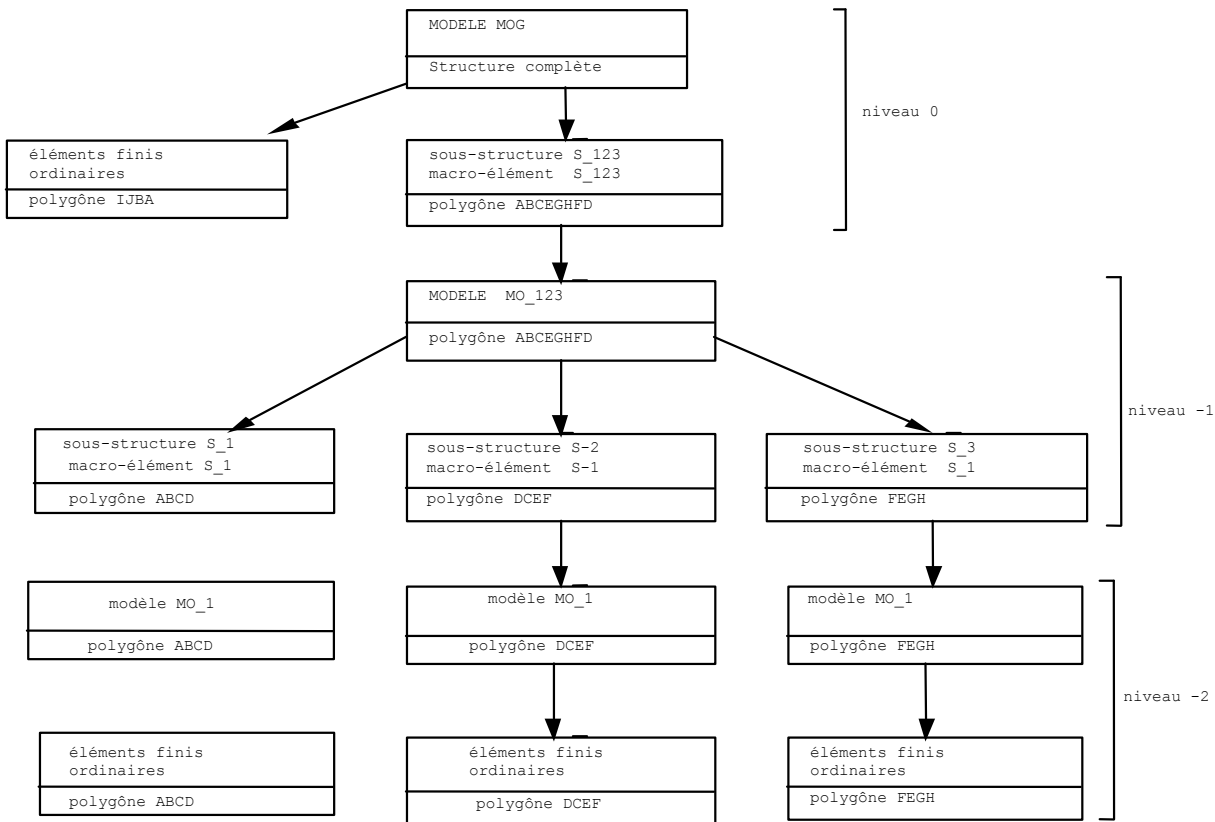
Definition :

- the nodes on which a macronutrient is condensed are known as "external"(the others are "interns"),
- **level** : it is a notion useful for comprehension of the text of orders; any level describes the relations of structuring between the various models and the various macronutrients. For us, it is an entirety. The operation of condensation increases the level of $+1$: a model of level n give by condensation a macro - element of level $n + 1$ who will be integrated into a model of level $n + 1$,
- the operator *MACR_ELEM_STAT* is the only operator allowing to create a macro - element in static under-structuring,
- the operator *DEFI_MAILLAGE* is the only operator using the macronutrients under - static structuring.

For our example:

- *MO_1* {line 22} is the model moreover low level (- 2),
- *S_1* {lines 45.59} is the intermediate macronutrient of level (- 1),
- *MA_123* and *MO_123* {lines 68.87} represent the grid and the intermediate model of level (- 1),
- *S_123* {line 104} is the macronutrient moreover high level (0),
- *MAG0*, *MAG* and *MOG* {lines 120,125,129} represent grids and a model moreover high level (0): the distinction enters the grids *MAG0* and *MAG* will be explained to [§6.6] and [§6.7].

The structuring of the model moreover high level *MOG* can present itself graphically by one **tree structure**, distinction between macronutrient and substructure being explained in the following paragraph.



5.2 macronutrient and substructure

One calls **macronutrient** the result of the operator `MACR_ELEM_STAT` : it is a model condensed on its external nodes.

One calls **substructure** one **occurrence** of a macronutrient in of a the same model level. A substructure is a macronutrient put in position in physical space. The position of a substructure is given by the coordinates of the nodes of the super-mesh which is associated for him.

The same macronutrient can give rise to several substructures by defining several positions: in our example, the macronutrient `S_1` generate 3 substructures `S_1`, `S_2` and `S_3` by suitable rotations.

A substructure is to some extent a new "finite element". The macronutrient is the "type" of this element: one affects a macronutrient on a super-mesh to form a substructure.

One calls **super-mesh**, the geometrical support of a substructure. It is an object **named** included in one **grid**. A super-mesh, like an ordinary mesh, is only one ordered list of names of nodes.

Like an ordinary finite element, a substructure has:

- an "elementary" matrix of rigidity (and/or of mass, damping,...),
- "elementary" vectors of loading,
- a mesh support (one will speak about super-mesh),
- nodes carrying of the degrees of freedom.

Unlike an ordinary finite element, a substructure has several limitations:

- the mesh support is not a simple type: TRIA3, ..., HEXA20 : some post - treatments are thus not possible,
- it does not have type_élément, not functions of form,...
- the only options of calculation available are RIGI_MECA, MASS_MECA and CHAR_MECA,
- the nodes can be nodes of LAGRANGE coming from the dualisation of the internal conditions kinematics.

Identification of the substructures and the macronutrients:

The macronutrients are concepts named by the user.

Substructures (as the ordinary finite elements) are identified by the name of the super - meshes which supports them.

In our example:

- S_1 and S_123 are the two macronutrients defined by the user {lines 45 and 104},
- S_1, S_2, S_3, S_123 are the names of the super-meshes (and thus of under - structures) that the user gives during the construction of the grids MA_123 and MAG0.

Note:

There is no possible confusion (by the program) between a substructure and a macro - of the same element name (here S_1 and S_123 although that does not facilitate the reading of the command file!).

5.3 Redescende in the substructures

The approach **ascending**, that we have just detailed, allows to build the model total, or final, (mog) on which one carries out the resolution:

- CALC_MATR_ELEM
 - CALC_VECT_ELEM
 - ASSE_MATRICE
 - ...
 - TO SOLVE
- {lines 151-184}

This resolution has as a result the field of displacements of the nodes of the total model. These nodes are:

- nodes of the ordinary finite elements of the model (here the quadrilateral IJBA),
- nodes **external** substructures of the model: (here only one substructure: S_123).

To find the field of displacements on the internal nodes of the substructures, it is necessary then “**to go down again**” the tree structure of the substructures thanks to the operator DEPL_INTERNE.

This operator calculates the field of displacements on **all** nodes of the substructure starting from the data of the field of displacements on its external nodes.

For our example and load 1:

- U1S_123 {line 193} is displacement on the substructure S_123
- U1S_1 {line 197} is displacement on the substructure S_1
- U1S_2 {line 199} is displacement on the substructure S_2
- U1S_3 {line 201} is displacement on the substructure S_3

5.4 Postprocessings

Usual postprocessings: calculation of the deformations, of the constraints,... cannot be made that by the ordinary finite elements which only know the concept of function of interpolation.

One will be able to thus calculate the constraints in a given point of the structure only with the model containing the ordinary finite element containing this point. Before that, it will have been necessary to calculate the field of displacements on this model:

Example:

- to calculate the constraints on the quadrilateral IJBA the model will be used: MOG and displacements: U1
- to calculate the constraints on the polygon DCEF the model will be used: MO_1 and them displacements: U1S_2

Note:

It is necessary to use `CALC_CHAMP` but for that, one is obliged to create a SD `evol_elas` by the order `CREA_RESU`.

6 Some comments on the command file

The purpose of the few comments which follow are to illustrate the orders which intervene in static under-structuring. The comprehension of these comments supposes obviously the preliminary reading of the notes of use of the orders concerned:

- Orders specific to the static under-structuring:
 - `MACR_ELEM_STAT` [U4.44.01]
 - `DEFI_MAILLAGE` [U4.12.04]
 - `DEPL_INTERNE` [U4.65.01]
- Orders modified for the static under-structuring:
 - `AFFE_MODELE` [U4.22.01]
 - `CAL_VECT_ELEM` [U4.41.02]
- Orders useful for the static under-structuring:
 - `ASSE_MAILLAGE` [U4.12.02]
 - `DEFI_GROUP` [U4.12.03]

6.1 Operator `AFFE_MODELE` {line 22}

Since one wants to build a macronutrient starting from the polygon ABCD and that grid `my` contains all the elements of IJBCDA, one cannot employ the assignment: `ALL: 'YES'`.

It is necessary to affect only the group of mesh ABCD (`grsd2`) and not to forget to affect the elements of the edge AD (`grma14`) because of loading of pressure.

6.2 Operator `MACR_ELEM_STAT` {lines 45-59}

- The example illustrates the fact that one can define the macronutrient in several successive stages (use of the operator `MACR_ELEM_STAT` 3 times: {lines 45.50 and 56} with the symbol of enrichment &).

With the first call, truly the macronutrient is defined:

- its "volume": the model `mo_1`
- its external nodes {line 48}
- the material field and the conditions kinematics which to him are applied {line 47}.

At the time of the 2 following calls {line 50 and 56}, one enriches the structure of data of the macro - element:

- calculation of the matrix of condensed rigidity {line 52}
- calculation of two "loading cases" {lines 53 and 58}.

This possibility of enriching the macronutrient makes it possible "to repair a lapse of memory" without setting out again to zero:

- addition of a new loading case,
 - calculation of the mass condensed for a method of Guyan.
- Definition of the loading case 1: CHF1 {line 53}
This loading case is following (SUIV = 'YES') because the pressure is a loading which always acts according to the normal at the edge.
The fact of having specified like load CHBL_1, is not used for nothing here because the conditions kinematics are worthless $DX = 0.0$ $DY = 0.0$ {line 29}.

6.3 Operator DEFI_MALLAGE {lines 68.84}

- {line 70}: one defines a substructure (and the super-mesh support) by giving him the same name as the macronutrient that one affects to him. It is not prohibited.
- {line 74}
All the geometrically confused nodes "are unified":
the side CD of S_1 merges with the side AB of S_2,
the side CD of S_2 merges with the side AB of S_3.
- {line 76}
 - the node C, who has as a name N12 in the initial grid MY, will have as a name NN112 in the grid MA_123,
 - the node E, who is the image of C grid MY in the substructure S_2 will have as a name NN212.
This node E can also be regarded as the image of the node B under - structure S_3 it could thus have had the name NN310 but the convention of sticking together of the super-meshes [U4.12.04] chooses the first denomination.
- {line 77}
The node with (N1), which had been named NN11 with line 76, is famous in N1. It is the same for the nodes N4, N7 and N10.
This renaming is necessary for the assembly of the grids which one will make {line 125} because this assembly is made by pooling of the same nodes name.
- {line 82}
The group of nodes is defined GH who will serve {line 107} for the definition of the outside of the macronutrient S_123.

6.4 Operators AFFE_MODELE and AFFE_CHAR_MECA {lines 86.89}

- {line 87}
All super-meshes MA_123 "are activated": the macro - element is affected to them S_1.
- {line 91}
The node NN33 who is the node N3 substructure S_3 is subjected to a condition of slipping support.

6.5 Operator MACR_ELEM_STAT {lines 104.111}

- {line 109}
The kinematic load CHBL_123 who corresponds to the support slipping on GH is introduced into the macronutrient S_123. It is advised in the note [U4.44.01] to introduce this condition at the highest level: one could have done it at the total level because GH fact part of the outside of S_123.

- {line 109}
For the macronutrient S_{123} , one gives the same name of loading case $CHF1$ that for the macronutrient S_1 because the convention of definition of a loading case results in adding:
 - loadings defined by the keyword $LOAD$ (here: $chb1_{123}$ who is not used for nothing because imposed displacements are worthless),
 - loading cases possibly present on the substructures included in the model: here $chf1$ who is present in S_1, S_2, S_3 .

6.6 Operator $DEFI_MAILLAGE$ {line 120}

- {line 123} nodes of $MAG0$ will have the same name as the nodes of the macro - elements being used for its definition (S_{123}).

Nodes of $MAG0$ will be thus:

side AB : $N1, N4, N7, N10$

side GH : $NN33, NN36, NN39, NN312$

Grid $MAG0$ contains only one super-mesh and not ordinary mesh.

6.7 Operator $ASSE_MAILLAGE$ {line 125}

The grid final (or total) contains:

- all meshes $QUAD4$ initial grid MY ,
- the super-mesh S_{123} grid $MAG0$

The super-mesh is connected to the meshes $QUAD4$ thanks to the identity of the names of the nodes $N1, N2, N7, N10$ in the grids MY and $MAG0$

6.8 Calculation at the total level {lines 129-184}

- {line 130} in the total grid, which contains all the meshes of my , one affects only those of the quadrilateral $IJBA$.
- {line 131} one affects the substructure S_{123} ; the model thus contains: under - structure (S_{123}) and of the ordinary finite elements ($IJBA$).
- {line 165} one should not forget to indicate the loading case $CHF1$ who was defined in line 32 and who forwards by the two macronutrients S_1 and S_{123} via the name $CHF1$.

6.9 Operator $DEPL_INTERNE$

- {line 193} $U1S_{123}$ is the field of displacements on the nodes of the model MO_{123} (it is - with-to say the nodes of AB, CD, EF, GH). This field of displacements corresponds to the loading case $CHF1$.
- {line 199} $U1S_2$ is the field of displacements on the nodes of the model MO_1 (it is - with - to say the nodes of $ABCD$). It should be noticed that one asked for the field of displacement on the mesh S_2 , but there does not exist grid "finite elements" of this part of the structure. This is why, the field of displacement is restored in the "local" reference mark of the macro - element S_1 (rotation of -45°). This reference mark is the only one which allows the calculation of the constraints thanks to the model MO_1 .

7 Bibliography

- 1) J.F. IMBERT: "Analysis of the structures by finite elements". Editions CEPADUES (1979)
- 2) E. SCHREM: "Handbook for linear analysis". INTES Publication UM 404 REVC. STUTTGART (1989)