FORMA20 - Mechanical adaptive grid on a beam in inflection

Summary:

In this CAS-test, it is a question of making sure of **not-regression of the TP n°1 associated with Indicating courses the "of error and adaptation of grid; Establishment and state of the art in *Code_Aster* "** formation "Analyzes static non-linear with *Code_Aster* ".

In fact, one distort one **elastic design on a metal beam in inflection** in plane forced modeling. It is done **to converge uniformly** via the tool of refinement-déraffinement LOBSTER encapsulated in `MACR_ADAP_MAIL`, then **freely** by coupling the process with a map of space errors localised on each finite element.

From the point of view of **data-processing validation**, this case test of course makes it possible to test the not-regression of different coupling calculations from map of errors/procedure of refinement-déraffinement in mechanics, but also the options the "pre one and postprocessings" of these calculations (smoothing of the constraints to the nodes, passage of an error per element with an error with the nodes by element).

Each modeling is associated with a question of the TP and one has some **retranscribed the main part of the elements of correction**. Entirety of the text of the TP being available on the website `http://www.code-aster.com/utilisation/formations`.

1 Problem of reference

1.1 Geometry

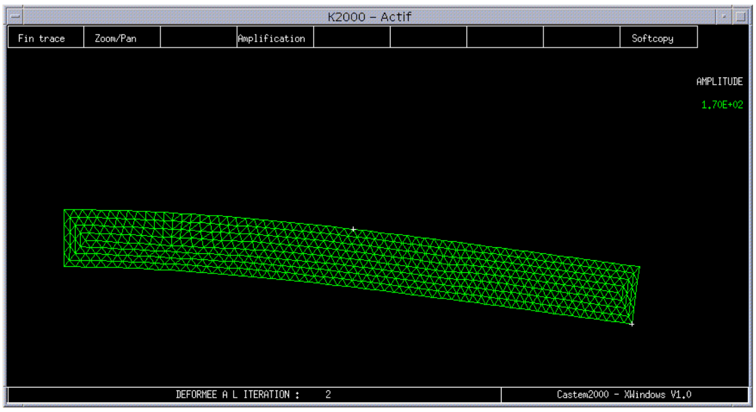

Figure 1.1-a: Deformation of the grid

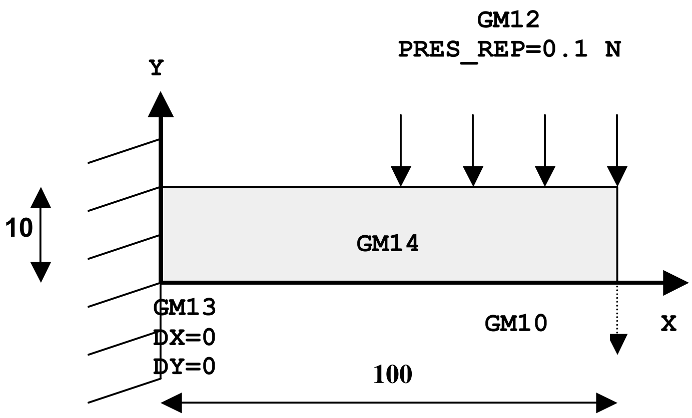

Figure 1.1-b: Diagram of the thermal loadings and the geometry

It is about a metal beam (steel 16MND5, $E=210.10^3\ Mpa$, $\nu=0.2$) in inflection. Elastic design (MECA_STATIQUE or STAT_NON_LINE) in modeling forced plane (C_PLAN). Grids in TRIA3/SEG2 (modeling A) and TRIA6/SEG3 (modelings B and C).

The various key zones of calculation are indicated: GM14 for all the voluminal part in SORTED, GM13 for embedding (DDL_IMPO DX=DY=0 for all the points $(X=0, Y=0 \ldots 10)$), GM12 for the pressure distributed (PRES_REP=0.1N for all the points $(X=50 \ldots 100, Y=10)$) and GM10 (mesh-point $M1=N2$ at the point $(X=100, Y=0)$ on the level of which one will measure the arrow).

1.2 Material properties

On all the structure (GROUP_MA GM14), the characteristics material are applied

$$E=210000 \quad Mpa$$

$$\nu=0.2$$

1.3 Boundary conditions and loadings

One can synthesize the decomposition of the loadings by zone in the shape of the following table:

Geometrical zones (GROUP_NO/GROUP_MA)	Loadings
GM13	DDL_IMPO DX = 0, DY = 0
GM12	PRES_REP = 0.1 NR

2 Reference solution

2.1 Method of calculating used for the reference solutions

On such a case, it is not possible to exhume an analytical solution! The reference solution used for error analyses on the arrow and the potential energy of deformation is in fact an approximate solution obtained after a series of four uniform refinements (on the same grid but in TRIA6).

This procedure of uniform refinement can be controlled by a loop PYTHON and the operator MACR_ADAP_MAIL option UNIFORM. The first two modelings are precisely an illustration of this functionality.

2.2 Result of reference

Potential energy of deformation $= 0.102242\,J$
Arrow $= -0.0614777\,m$

2.3 Uncertainty on the solutions

They acts only of approximate solutions obtained on a “quasi-converged” grid.

2.4 Bibliographical references

1) X. DESROCHES “Estimators of error of Zhu-Zienkiewicz in elasticity 2D”. [R4.10.01], 1994.

2) X. DESROCHES “Estimator of error in residue”. [R4.10.02], 2000.

3) O. BOITEAU “Course and TP Indicateurs of error & Adaptation of grid; Establishment and state of the art in *Code_Aster* ”. http://www.code - aster.com/utilisation/formations, 2002.

4) O. BOITEAU “FORMA05: Thermomechanical adaptive grid on a fissured cylinder head”. [V6.03.120], 2002.

3 Modeling A

3.1 Characteristics of modeling

The grid is carried out with elements of the type TRIA3. Is calculated in linear elasticity with the operator STAT_NON_LINE.

One calculates the cards of space errors of the indicator of Zhu-Zienkiewicz version 1 (ERZ1_ELEM) and of the indicator in pure residue (ERME_ELGA). Beforehand it is necessary to have calculated the stress field to the nodes (SIGM_ELNO) and, post-to treat the map of error (via GIBI), it should be transformed of one CHAM_ELEM by element with one CHAM_ELEM with the nodes by element. One determines also the value of the arrow (POST_RELEVE_T) and of the potential energy of deformation (POST_ELEM).
The whole is placed in a loop PYTHON allowing the installation of a uniform procedure of refinement in nb_calc=4 levels (via MACR_ADAP_MAIL option UNIFORME=' RAFFINEMENT').

One can thus note the convergence of the values of arrow and energy, the increase of their errors relative compared to the errors provided by the indicators (they same into relative and on all the structure), the variations of the indices of effectiveness of the indicators and their good checking of the assumption of saturation.

In order to illustrate advices of “good practice” for the quality of the studies, on the aspects geometry with a grid, grid itself and standard of finite elements, one uses the options adhoc LIRE_MAILLAGE, MACR_ADAP_MAIL and MACR_INFO_MAIL.

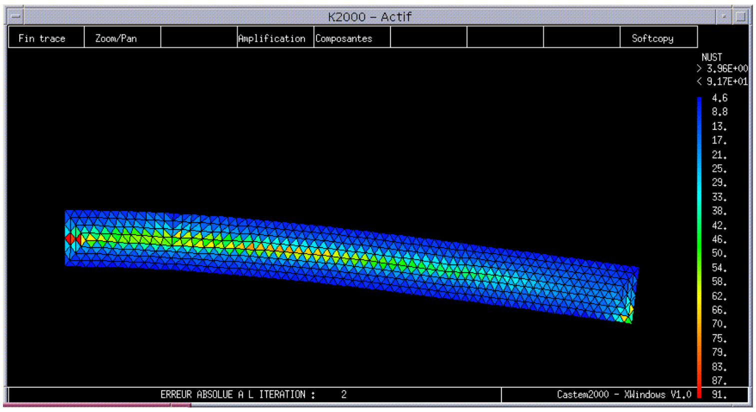

Figure 3.1-a: Isovaleurs of the error in residue (component absolute ERREST) on the initial grid.

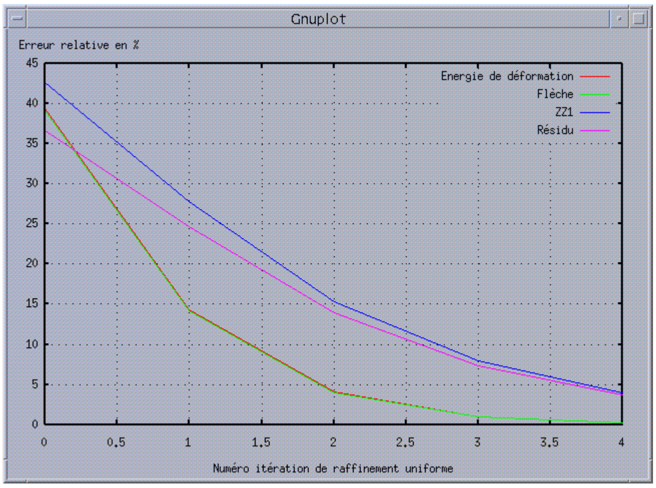

Figure 3.1-b: Decreases of the relative errors of the deformation energy and of the arrow compared with those of the relative total component of the indicators.

3.2 Characteristics of the grid

Initially: 61 `TRIA3`, 15 `SEG2`, 48 nodes
After a uniform refinement: 244 `TRIA3`, 30 `SEG2`, 156 nodes
After two uniform refinements: 976 `TRIA3`, 60 `SEG2`, 555 nodes
After three uniform refinements: 3904 `TRIA3`, 120 `SEG2`, 2085 nodes
After four uniform refinements: 15616 `TRIA3`, 240 `SEG2`, 8073 nodes

3.3 Sizes tested and results

One tests the values of the relative errors out of arrow and potential energy of deformation compared to the reference solutions (cf [§2.2]). And this, on the initial grid and after four uniform refinements. Tests having to be multi-platforms, the relative tolerance, which on the initial errors is fixed at 10^{-6}%, is voluntarily slackened on the errors after four refinements: 10^{-4}%.
These tests are carried out on variables PYTHON (via `TEST_FONCTION`) inserted beforehand in functions ASTER (via `FORMULA`).

Identification	Values *Code_Aster*	Values of reference	Tolerance	Relative variation (in %)	Variable ASTER	Variable PYTHON
E_p (0)	39.406851%	idem	10^{-6}%	$-1.26\ 10^{-12}$ ∣ 0%	`ERREEN0`	`eren0`
E_p (4)	0.274116%	idem	10^{-4}%	$1.5\ 10^{-12}$ ∣ 0%	`ERREEN4`	`eren4`
Arrow (0)	39.244715%	idem	10^{-6}%	$1.09\ 10^{-13}$ ∣ 0%	`ERREFL0`	`erfl0`
Arrow (4)	0.270896%	idem	10^{-4}%	$-2.25\ 10^{-13}$ ∣ 0%	`ERREFL4`	`erfl4`

3.4 What it was necessary to retain of this part of the TP…

MACR_INFO_MAIL is thus complementary to LIRE_MAILLAGE (VERI_MAIL and INFORMATION) and POST_ELEM . Their combined "efforts" can thus allow:

- to check the agreement of the grid with the initial geometry (in mass, dimension, the surface and volume),
- to list them GROUP_MA and GROUP_NO, paramount for a good modeling of the boundary conditions,
- to diagnose possible problems (symmetrization or connexity, elements of outline still present in the model, taken into account of boundary conditions on surfaces or lines of bad dimensions, interpenetration of elements),
- to strictly evaluate the quality of the grid from a point of view finite element.

$$\forall K \in T_h \quad \sigma_K = \frac{h_K}{\rho_K}$$ the possible close relation of 1

For example, an empirical criterion could be:

- at least 50% of the finite elements with a quality standard below 1.5,
- at least 90%, below 2.

The sequence "thermomechanical operators 'UNIFORM' MACR_ADAP_MAIL OPTION" allows to make converge properly, automatically and easily a grid. It is however necessary to take care of the number of generated degrees of freedom which can quickly become prohibitory!

4 Modeling B

4.1 Characteristics of modeling

Identical to modeling A, but in TRIA6.

4.2 Characteristics of the grid

Initially: 61 TRIA6, 15 SEG3, 156 nodes
After a uniform refinement: 244 TRIA6, 30 SEG3, 555 nodes
After two uniform refinements: 976 TRIA6, 60 SEG3, 2085 nodes
After three uniform refinements: 3904 TRIA6, 120 SEG3, 8073 nodes
After four uniform refinements: 15616 TRIA6, 240 SEG3, 31761 nodes

4.3 Sizes tested and results

One tests the values of the relative errors out of arrow and potential energy of deformation compared to the reference solutions (cf [§2.2]). And this, on the initial grid and after four uniform refinements. Tests having to be multi-platforms, the relative tolerance, which on the initial errors is fixed at 10^{-6} %, is voluntarily slackened on the errors after four refinements: 10^{-4}%.
These tests are carried out on variables PYTHON (via TEST_FONCTION) inserted beforehand in functions ASTER (via FORMULA).

Identification	Values *Code_Aster*	Values of reference	Tolerance	Relative variation (in %)	Variable ASTER	Variable PYTHON
$E_p(0)$	0.125637%	idem	10^{-6}%	$-2.65\ 10^{-12}$ | 0%	ERREEN0	eren0
$E_p(4)$	$7.015631\ 10^{-4}$ %	idem	10^{-4} %	$4.71\ 10^{-13}$ | 0%	ERREEN4	eren4
Arrow (0)	0.106929%	idem	10^{-6} %	$1.6\ 10^{-12}$ | 0%	ERREFL0	erfl0
Arrow (4)	$1.546674\ 10^{-4}$ %	idem	10^{-4}%	$-3.33\ 10^{-13}$ | 0%	ERREFL4	erfl4

4.4 What it was necessary to retain of this part of the TP…

Elements P_1 are disadvised in mechanics. **The good practice is rather:** P_1 **lumpé in thermics and** P_2 (possibly under-integrated) **in mechanics** (not artificially not to privilege the thermal component of the field of deformation and to try to avoid space-time oscillations of the field of temperature and its violation of the principle of the maximum).

The choice of **type of finite element bonus on the quality of the meshs** on which rest this element.

5 Modeling C

5.1 Characteristics of modeling

Identical to modeling A with the following modifications:

- grid in TRIA6,
- free refinement-déraffinement (MACR_ADAP_MAIL option LIBRE=' RAFF_DERA') controlled by the component NUEST of ERRE_ELGA_NORE (relative component of the indicator in residue). With like criteria CRIT_RAFF_PE=CRIT_DERA_PE=0.2 (one refines 20% of the worst elements and one déraffine 20% of best).

5.2 Characteristics of the grid

Initially: 61 TRIA6, 15 SEG3, 156 nodes
After a free refinement: 107 TRIA6, 19 SEG3, 256 nodes
After two free refinements: 212 TRIA6, 26 SEG3, 479 nodes
After three free refinements: 404 TRIA6, 33 SEG3, 879 nodes
After four free refinements: 786 TRIA6, 39 SEG3, 1671 nodes

5.3 Sizes tested and results

One tests the values of the relative errors out of arrow and potential energy of deformation compared to the reference solutions (cf [§2.2]). And this, on the initial grid and after four uniform refinements. Tests having to be multi-platforms, the relative tolerance, which on the initial errors is fixed at 10^{-6} %, is voluntarily slackened on the errors after four refinements: 10^{-4}%.
These tests are carried out on variables PYTHON (via TEST_FONCTION) inserted beforehand in functions ASTER (via FORMULA).

Identification	Values *Code_Aster*	Values of reference	Tolerance	Relative variation (in %)	Variable ASTER	Variable PYTHON
$E_p(0)$	0.125637%	idem	10^{-6}%	$-2.65\ 10^{-12}$ | 0%	ERREEN0	eren0
$E_p(4)$	$1.245370\ 10^{-2}$ %	idem	10^{-4}%	$-2.27\ 10^{-12}$ | 0%	ERREEN4	eren4
Arrow (0)	0.106929%	idem	10^{-6}%	$1.6\ 10^{-12}$ | 0%	ERREFL0	erfl0
Arrow (4)	$1.074923\ 10^{-2}$ %	idem	10^{-4} %	$-2.34\ 10^{-12}$ | 0%	ERREFL4	erfl4

5.4 What it was necessary to retain of this part of the TP…

The sequence "thermomechanical operators 'FREE' MACR_ADAP_MAIL OPTION" converge optimalement the grid makes it possible to make.

The quality of the elements is impacted little by the process of refinement/déraffinement. Taking into account the choices operated in LOBSTER, it can even improve in 3D!

The type of indicator and its mode of standardisation affect great the final grid. Taking into account the type of standardisation adopted for the indicators in mechanics,

$$\eta_{rel}(K) = 100 \times \frac{\eta(K)}{\sqrt{\eta(K)^2 + \|\sigma_h\|_{0,K}^{\ 2}}} \text{ (in \%)}$$

On problems with singularities (embedding, discontinuity of curve, returning corner, crack….), it is to better use the absolute component of these indicators. Because as for “our good old fixed beam”:

$$\eta_{rel}(K) \rightarrow 0 \text{ \% when } \|\sigma_h\|_{0,K} \rightarrow \infty \text{ (close to embedding)}$$

$$\eta_{rel}(K) \rightarrow 100 \text{ \% when } \|\sigma_h\|_{0,K} \rightarrow 0 \text{ (close to the arrow)}$$

and this, independently of the true values of the absolute indicator $\eta(K)$!

This does not call at all into question the great utility of these indicators. It is just necessary to take account of these elements to refine its diagnosis and “to possibly juggle” with these two components to refine in the zones of interest.

The problem does not arise in thermics, because the indicator in residue for the thermal problem is standardized differently. One can however compose with the components of the thermal indicator and the limiting conditions, “fictitious” or not, to direct the construction of a grid refined or déraffiné by zones (cf [§6.3] [R4.10.03] and modeling A, _TP21 _, of documentation [V6.03.120]).

6 Summary of the results

In this CAS-test, it is a question of making sure of **not-regression of the TP n°1 associated with Indicating courses the "of error and adaptation of grid; Establishment and state of the art in *Code_Aster* "** formation "Analyzes static non-linear with *Code_Aster* ".

In fact, one "abuses" one **elastic design on a metal beam in inflection** in plane forced modeling. It is done **to converge uniformly** via the tool of refinement-déraffinement LOBSTER encapsulated in MACR_ADAP_MAIL, then **freely** by coupling the process with a map of errors space localised on each finite element.

The objectives of this TP are multiple, it acts:

- to familiarize and put into practice the two dual problems: calculation of map of indicator of error and strategies of adaptation of grid. On standard cases, but also on pathological cases…,
- to detail the various parameter settings of the accused operators (CALC_ERREUR, MACR_ADAP_MAIL) and related operators who can appear particularly interesting for these problems (INFO_MAILLAGE, MACR_INFO_MAIL, PROJ_CHAMP…),
- to hammer advices of "good practice" for the quality of the studies and the use of the tools already available on the subject. One is interested only in the aspects geometry with a grid, grid itself and standard of finite elements. One is not delayed here on the problems of step of time, calibration of digital parameters and on the aspects sensitivity with respect to the data,
- to illustrate the formidable potentialities and facilitated which allows the coupling "language ASTER/PYTHON " in the command file of a study (test, buckles, posting, calculation, personal macro-order, interactivity…). The official CAS-tests being gauged to function in batch, some of these aspects "were thus commentarisés" in the command file.

From a point of view **data-processing validation**, this case test of course makes it possible to test the not-regression of various couplings calculations of map of errors/procedure of refinement-déraffinement in mechanics, but also the options the "pre one and postprocessings" of these calculations (smoothing of the constraints to the nodes, passage of an error per element with an error with the nodes by element).

Each modeling is associated with a question of the TP and one has some **retranscribed "substantial" the marrow of the elements of correction**. Entirety of the text of the TP being available on the website http://www.code-aster.com/utilisation/formations.