RCCM01 - Operator POST_RCCM

Summary:

This test is an elementary test of validation of the order POST_RCCM.

The analytical solution is simple, and makes it possible to test postprocessing within the meaning of the RCC-M. The constraints are not calculated but are not extracted from tables.

More precisely, modeling A makes it possible to test L'option PM_PB for results of the type EVOLUTION and of type B3200 with and without earthquake.

modeling B allows to test the option SN for results of the type EVOLUTION and of type B3200 with and without earthquake.

modeling C allows to test the option TIREDNESS for results of the type EVOLUTION and of type B3200 with and without earthquake. The keyword KE_MIXTE fatigue analysis is tested in this modeling. The option EFAT with B3200 is also tested.

Modeling D allows to test again L'option EFAT for results of the type B3200.

Modeling E makes it possible to test the option TIREDNESS for results of the type B3200 with different from types of situations as starter.

1 Problem of reference

1.1 Material properties

The properties material are the following ones:

1) module of Young: $E=2.E+05\,MPa$;
2) Poisson's ratio: $\nu=0.3$;
3) thermal dilation coefficient: $\alpha=1.E-05\,m.°C^{-1}$.

The characteristics suitable for calculation RCC-M are:

1) constant material for the calculation of Ke : $n=0.2$, $m=2$;
2) Young modulus of reference: $E_{REFE}=2.E+05\,MPa$;
3) working stress: $Sm=200\,MPa$.

The curve of Wöhler is analytically defined: $N_{adm}=\frac{5.10^5}{S_{alt}}$

Note:

For the validation of the taking into account of the elastoplastic concentration factor Ke *, certain calculations are carried out with a lower or higher working stress:* $Sm=50\,MPa$ *(modeling C) and* $Sm=2000\,MPa$ *(modeling D and E).*

1.2 Evolution of the constraints

The constraints on the segment of analysis are not calculated but are not read directly in a table. The only nonworthless component of the tensor of the constraints is σ_{yy} . Two transients are considered:

Moment	**Constraints thermic**			**Constraints had with the pressure**			**Mechanical constraints (moments and efforts)**			**Constraints totalbe**		
	X-coordinate			*X-coordinate*			*X-coordinate*			*X-coordinate*		
	0	1	2	0	1	2	0	1	2	0	1	2
1	50	100	150	40	0	40	0	0	-80	90	100	110
2	0	50	-100	0	50	0	0	0	10	0	100	-90
3	0	0	50	10	-10	-200	90	-40	50	100	-50	-100
4	0	0	0	0	0	0	0	0	0	0	0	0

Table 1.2-1 : Definition of the constraints σ_{yy} (in MPa) for the moments of situation 1 according to the curvilinear X-coordinate

Moment	**Constraints thermic**			**Constraints had with the pressure**			**Mechanical constraints (moments and efforts)**			**Constraints totalbe**		
	X-coordinate			*X-coordinate*			*X-coordinate*			*X-coordinate*		
	0	1	2	0	1	2	0	1	2	0	1	2
1,5	50	100	150	40	0	**20**	0	0	-80	90	100	**90**
2,5	0	50	-100	0	50	0	0	0	10	0	100	-90
3,5	0	0	50	10	-10	-200	90	-40	50	100	-50	-100

Table 1.2-2 : Definition of the constraints σ_{yy} (in MPa) for the moments of the situation 2 according to the curvilinear X-coordinate

These transients do not aim representing a specific real transient, but at covering the whole of the possible constraints (constant, linear or non-linear evolution of the constraint in the thickness).

Two other situations are taken into account in this CAS-test. They are provided in the shape of two torques and a tensor of unit constraints.
Situation 3 is made up of a state A which correspond to moment 3 of situation 1 and of a state B which corresponds to moment 2 of situation 1. It also consists of a thermal transient which is that of situation 1.
Situation 4 is made up of a state A which correspond to moment 1.5 of situation 2 and of a state B which corresponds to moment 3.5 of situation 2. It also consists of a thermal transient which is that of situation 2.

State	**Constraints had with the pressure**			**Mechanical constraints (moments and efforts)**			**Constraints mechanics totalbe**		
	X-coordinate			*X-coordinate*			*X-coordinate*		
	0	1	2	0	1	2	0	1	2
With	10	-10	-200	90	-40	50	100	-50	-100
B	0	50	0	0	0	10	0	100	-90

Table 1.2-3 : Definition of the constraints σ_{yy} (in MPa) situation 3 according to the curvilinear X-coordinate

EtaT	**Constraints had with the pressure**			**Mechanical constraints (moments and efforts)**			**Constraints mechanics totalbe**		
	X-coordinate			*X-coordinate*			*X-coordinate*		
	0	1	2	0	1	2	0	1	2
With	40	0	**20**	0	0	-80	90	100	**90**
B	10	-10	-200	90	-40	50	100	-50	-100

Table 1.2-4 : Definition of the constraints σ_{yy} (in MPa) situation 4 according to the curvilinear X-coordinate

2 Reference solution

2.1 Results of reference

2.1.1 Calculation of Pm and Pb

Parameters Pm and Pb represent respectively primary constraint of membrane and the stress bending. Criteria must also be checked on the quantity ($Pm \pm Pb$), at the origin and the end of the segment of analysis.

Each one of these parameters can be calculated analytically starting from the data of the tensor of the constraints on the segment. Only the primary constraints must be taken into account. The user can either only provide directly the mechanical constraints, or to provide the total thermomechanical constraints and the constraints related to the thermal loading only, in which case those are cut off automatically with `'EVOLUTION'` .

One indicates in the tables below the signed value of the parameters Pm and Pb , even if it is the standard of Tresca of these quantities which is to be retained finally.

Situation 1

Moment	Total mechanical constraints (pression+efforts/moments)			Pm	Pb	PmPb (0)	PmPb (L)
	X-coordinate						
	0	1	2				
1	40	0	-40	0	|-40|	40	|-40|
2	0	50	10	27.5	5	22.5	32.5
3	100	-50	-150	|-37.5|	|-125|	87.5	|-162.5|
4	0	0	0	0	0	0	0

For situation 1, $Pm=37,5$ $Pb=125$ $PmPb_0=87,5$ and $PmPb_L=162,5$.

Situation 2

Moment	Total mechanical constraints (pression+efforts/moments)			Pm	Pb	PmPb (0)	PmPb (L)
	X-coordinate						
	0	1	2				
1,5	40	0	-60	|-5|	|-50|	45	|-55|
2,5	0	50	10	27.5	5	22.5	32.5
3,5	100	-50	-150	|-37.5|	|-125|	87.5	|-162.5|

For the situation 2, $Pm=37,5$ $Pb=125$ $PmPb_0=87,5$ and $PmPb_L=162,5$.

SituatioNS 3 and 4

For the situation 3, $Pm=37,5$ $Pb=125$ $PmPb_0=87,5$ and $PmPb_L=162,5$.

For the situation 4, $Pm=37,5$ $Pb=125$ $PmPb_0=87,5$ and $PmPb_L=162,5$.

2.1.2 Calculation of Sn

The parameter Sn represent the amplitude of variation of Contrainte linear (average constraint $\pm$ bending stress) between two moments of the transient considered.

Situation 1

Moment	Total constraints			σ^{moyen}	$\sigma^{flexion}$	σ_0^{lin}	σ_L^{lin}
	X-coordinate						
	0	1	2				
1	90	100	110	100	1 0	90	11 0
2	0	100	-90	27.5	-45	72.5	-17.5
3	100	-50	-100	-25	-100	75	-125
4	0	0	0	0	0	0	0

Moment 1	Moment 2	Sn_0	Sn_L
1	2	17.5	127.5
1	3	15	**235**
1	4	**90**	110
2	3	2.5	107.5
2	4	72.5	17.5
3	4	75	125

For situation 1, $Sn_0=90$ and $Sn_L=235$.

Situation 2

For situation 2, $Sn_0=22,5$ and $Sn_L=220$.

Situation 3

EtaT	Constraints mechanics total			σ^{moyen}	$\sigma^{flexion}$	$\sigma_0^{meca,lin}$	$\sigma_L^{meca,lin}$
	X-coordinate						
	0	1	2				
With	100	-50	-150	-37.5	-125	87.5	-162.5
B	0	50	10	27.5	5	22.5	32.5

EtaT 1	State 2	Sn_0	Sn_L
With	B	65	195

Moment	Constraints thermicsS			σ^{moyen}	$\sigma^{flexion}$	σ_0^{lin}	σ_L^{lin}
	X-coordinate						
	0	1	2				
1	50	100	150	100	5 0	50	1 5 0
2	0	50	-100	0	-50	50	-50
3	0	0	50	12.5	+25	-12.5	37.5
4	0	0	0	0	0	0	0

Moment 1	Moment 2	Sn_0	Sn_L
1	2	0	**200**
1	3	**62.5**	112.5
1	4	50	150
2	3	**62.5**	87.5
2	4	50	50
3	4	12.5	37.5

For situation 3, $Sn_0=65+62,5=127,5$ and $Sn_L=195+200=395$.

Situation 4

For situation 4, $Sn_0=42,5+62,5=105$ and $Sn_L=107,5+200=307,5$.

2.1.3 Calculation of Sn^*

The parameter Sn^* represent the amplitude Sn calculated without taking into account stresses bending thermal. Only the calculation of the size Sn^* for situation 1 is detailed.

Situation 1

Moment	σ^{moyen}	$\sigma^{flexion}$	σ_0^{lin}	σ_L^{lin}	$\sigma_{thermique}^{flexion}$	$\sigma_0^{lin}+\sigma_{thermique}^{flexion}$	$\sigma_L^{lin}-\sigma_{thermique}^{flexion}$
1	100	1 0	90	11 0	5 0	140	60
2	27.5	-45	72.5	-17.5	-50	22.5	32.5
3	-25	-100	75	-125	+25	100	-150
4	0	0	0	0	0	0	0

Moment 1	Moment 2	Sn_0	Sn_L
1	2	117.5	27.5
1	3	40	**210**
1	4	**140**	60
2	3	77.5	182, 5
2	4	22.5	32, 5
3	4	100	150

For situation 1, $Sn*_0=140$ and $Sn*_L=210$.

Calculation is not detailed for the three other situations

For the situation 2, $Sn*_0=122,5$ and $Sn*_L=195$.

For the situation 3, $Sn*_0=165$ and $Sn*_L=295$.

For situation 4, $Sn*_0=142,5$ and $Sn*_L=207,5$ with the method `'TOUT_INST'` and $Sn*_0=130$ and $Sn*_L=207,5$ with the method `'TRESCA'`. Indeed, when method of selection of the moments `'TRESCA'` is selected, one does not recompute the moments which maximize $Sn*$ but one takes those which maximized Sn , which can be nonconservative.

2.1.4 Calculation of the thermal ratchet

Calculation is detailed for situation 1 only.

One calculates initially membrane stress due to the pressure σ_m .

Moment	**Constraints had with the pressure**			σ_m
	X-coordinate			
	0	1	2	
1	40	0	40	20
2	0	50	0	25
3	10	-10	-200	-52.5
4	0	0	0	0

σ_m 52.5 MPa is worth.

According to the equations of the RCC-M, $x=\frac{\sigma_m}{Sy}=\frac{52,5}{200}=0,2625$ and $y'_{LINE}=\frac{1}{x}=\frac{1}{0,2625}$.

Then. $\sigma_{\theta,LINE}=y'_{LINE}*Sy=\frac{1}{0,2625}*200=761,905\ MPa$

According to preceding calculations $Sn_{ther,ORI}^{max}=62,5$ and $Sn_{ther,EXT}^{max}=200$ thus one respects strictly the criterion for situation 1.

2.1.5 Calculation of tiredness for situations 1 and 2 in the same group

Calculation is detailed for combination of situationS 1 and 2 only and **at the origin**.

One seeks to fill out the table of the elementary factors of use.

One calculates initially the sizes by situations then combination.

Situation 1

For situation 1, it is pointed out that $Sn_0=90$ (part 2.1.2). One calculates the Sp size.

Moment 1	Moment 2	Sp_0
1	2	90
1	3	10
1	4	90
2	3	**100**
2	4	0
3	4	**100**

For situation 1, one thus has $Sp_0=100$.

For $Sm=200\,MPa$, one thus has $Ke=1$ and $Salt_0=\frac{1}{2}\frac{E_c}{E}Ke\,Sp_0=50\,MPa$. According to the curve of Wöhler one thus has $Nadm_0=\frac{500000}{Salt_0}=10\,000$ that is to say $FU_0=\frac{1}{10000}=10^{-4}$.

Situation 2

In a similar way for situation 2, one has $Sn_0=22{,}5$, $Sp_0=100$, that is to say $Ke=1$ and $Salt_0=50\,MPa$ that is to say $FU_0=10^{-4}$.

Combination of situations 1 and 2

Moment	Total constraints X-coordinate 0	1	2	σ^{moyen}	$\sigma^{flexion}$	σ_0^{lin}	σ_L^{lin}
1	90	100	110	100	1 0	90	11 0
2	0	100	-90	27.5	-45	72.5	-17.5
3	100	-50	-100	-25	-100	75	-125
4	0	0	0	0	0	**0**	0
1.5	90	100	90	95	0	**95**	95
2.5	0	100	-90	27.5	-45	72.5	-17.5
3.5	100	-50	-100	-25	-100	75	-125

For the combination of situations 1 and 2 one thus has $Sn_0=95-0=95$ for moments 4 and 1.5. Thus $Ke=1$. $Sp_0=100$ (for example by combining moments 2 and 3) that is to say $FU_0=10^{-4}$.

The table of the elementary factors of use with `'B3200'` is thus

	Situation 1	Situation 2

Situation 1	10^{-4}	10^{-4}
Situation 2		10^{-4}

-

In `B3200`, if $Nocc_1=1$ and $Nocc_2=1$ one has $FU_{TOTAL}^{ORI}=2.10^{-4}$.

With `EVOLUTION`, the operator combines every moment together, such of the states of loadings

The table of the elementary factors of use with `'EVOLUTION'` is thus

Moments	1	2	3	4	1.5	2.5	3.5
1		9.10^{-5}	1.10^{-5}	9.10^{-5}	0	9.10^{-5}	1.10^{-5}
2			1.10^{-4}	0	9.10^{-5}	0	1.10^{-4}
3				1.10^{-4}	1.10^{-5}	1.10^{-4}	0
4					9.10^{-5}	0	1.10^{-4}
1.5						9.10^{-5}	1.10^{-5}
2.5							1.10^{-4}
3.5							

ET with `EVOLUTION`, if $Nocc_1=1$ and $Nocc_2=1$ one has $FU_{TOTAL}^{ORI}=2{,}9.10^{-4}$.

2.1.6 Calculation of tiredness for situations 3 and 4 in the same group

Calculation is detailed for combination of situationS 3 and 4 only and **at the end.**

One seeks to fill out the table of the elementary factors of use.

One calculates initially the sizes by situations then combination.

Situation 3

For the situation 3 , it is pointed out that $Sn_L=395$. One calculates the Sp size.

Moment 1	Moment 2	Sp_L^{ther}
1	2	**250**
1	3	100
1	4	150
2	3	150
2	4	100
3	4	50

For the situation 3 , one thus has $Sp_L=Sp_L^{meca}+Sp_L^{ther}=160+250=410$.

For $Sm=200\,MPa$, one has $Ke=1$ and $Salt_L=\frac{1}{2}\frac{E_c}{E}Ke\,Sp_L=205\,MPa$. According to the curve of Wöhler one thus has $Nadm_L=\frac{500000}{Salt_L}=2439$ that is to say $FU_L=\frac{1}{2439}=4{,}1.10^{-4}$.

Situation 4

In a similar way for the situation 4 , one has $Sn_L=307{,}5$ and $Sp_L=Sp_L^{meca}+Sp_L^{ther}=90+250=340$.

Thus $Ke=1$ and $Salt_L=170\,MPa$ that is to say $FU_L=3{,}4.10^{-4}$.

Combination of the situations 3 and 4

For the combination of the situations 3 and 4 one thus has $Sn_L=440$. Thus $Ke=1$, one has $Sp_L^1=410$ and $Sp_L^2=340$ that is to say $FU_L=4{,}1.10^{-4}+3{,}4.10^{-4}=7{,}5.10^{-4}$.

The table of the elementary factors of use with `'B3200'` is thus

	Situation 3	Situation 4
Situation 3	$4{,}1.10^{-4}$	$7{,}5.10^{-4}$
Situation 4		$3{,}4.10^{-4}$

In `B3200`, if $Nocc_3=1$ and $Nocc_4=1$ one has $FU_{TOTAL}^{EXT}=7{,}5.10^{-4}$.

In `B3200`, if $Nocc_3=10$ and $Nocc_4=7$ one has $FU_{TOTAL}^{EXT}=7*7{,}5.10^{-4}+3*4{,}1.10^{-4}=6{,}48.10^{-3}$.

2.1.7 Calculation of environmental tiredness for situations 3 and 4 in the same group

Calculation is detailed for combination of situationS 3 and 4 only and **at the end** with $Nocc_3=1$ and $Nocc_4=1$.

Environmental tiredness is applied only after classical tiredness. One thus takes again the combinations which intervened in fatigue classical to calculate the factor of total use.

In fatigue classical, $FU_{TOTAL}^{EXT}=7{,}5.10^{-4}$ and the combination of situations 3 and 4 utilizes. It is thus necessary to calculate the FEN of this combination.

The increment of constraint $\Delta\sigma$ is easy to calculate because the tensor being uniaxial, it does not need diagonaliser there. Only it thermal intervenes in this increment because the other sizes are not function of time.

When the increment of constraint is negative, it is considered that the environment thus does not have an effect one does not calculate the other sizes.

If not $\Delta\epsilon=\frac{Ke*\Delta\sigma}{E(T)}$. In this example, one returned a constant Young modulus according to the temperature and about 200,000 MPa. And it Ke is that which was useful for the combination of situations 3 and 4, that is to say $Ke=1$.

Then one calculates $\dot{\epsilon}=\frac{\Delta\epsilon}{t_i-t_{i-1}}$. In this case, it is lower than the threshold $\epsilon_{seul,inf}$ thus

$$\dot{\epsilon}*=\ln\left(\frac{\epsilon_{seuilinf}}{\epsilon_{seuilsup}}\right)=\ln\left(\frac{1}{2}\right)$$

$F=\exp[(A+B\dot{\epsilon}*)S*O*T*+C]=\exp[\dot{\epsilon}*T*]$ knowing that T* is a function of T, with $T=\frac{T(t_i)+T(t_{i-1})}{2}$. The user obviously returned the temperature during each situation under the keyword `TABL_TEMP`.

Increment of treated time	$\Delta\sigma$	$\Delta\epsilon$	$\dot{\epsilon}$ (s^{-1})	$\dot{\epsilon}*$	T	T*	F
1-2	-250						
2-3	+150	$7{,}5.10^{-4}$	$7{,}5.10^{-4}$	$\ln\left(\frac{1}{2}\right)$	150	2.2	$\exp\left(2{,}2*\ln\left(\frac{1}{2}\right)\right)$ =0,218
3-4	-50						
1,5-2,5	-250						
2,5-3,5	+150	$7{,}5.10^{-4}$	$7{,}5.10^{-4}$	$\ln\left(\frac{1}{2}\right)$	150	2.2	$\exp\left(2{,}2*\ln\left(\frac{1}{2}\right)\right)$ =0,218

Lastly, $FEN_{EXTREMITE}=\frac{F_{2-3}\Delta\epsilon_{2-3}+F_{2,5-3,5}*\Delta\epsilon_{2,5-3,5}}{\Delta\epsilon_{2-3}+\Delta\epsilon_{2,5-3,5}}=0{,}218$.

One can calculate the factor of use partial as well as the factor of total use with effect of environment

$$FU^{EXT}_{partiel,env}=FEN_{EXTREMITE}*FU_{partiel}=0{,}218*7{,}5*10^{-4}=1{,}6323.10^{-4}$$

$$FU^{EXT}_{TOTAL,env}=N_{occ}\,FU^{EXT}_{partiel,env}=1*1{,}6323.10^{-4}$$

2.2 Uncertainty on the solution

Analytical solution.

3 Modeling A

3.1 Characteristics of modeling

No thermal or mechanical calculation is carried out in this test: the tables of statements of constraints are directly provided to the operator POST_RCCM. Results of the type EVOLUTION and of type B3200 are analyzed for the option PM_PB.

3.2 Sizes tested and results

On this case simple test, the whole of the results tested is in agreement with the reference solution:

- for the calculation of Pm, of Pb and PmPb,
- for a junction of piping,
- with and without earthquake,
- with the option TYPE_RESU=' VALE_MAX' as with the option TYPE_RESU=' DETAILS '.

Analytical solution with a precision lower than 10^{-4} %.

4 Modeling B

4.1 Characteristics of modeling

No thermal or mechanical calculation is carried out in this test: the tables of statements of constraints are directly provided to the operator `POST_RCCM`. Results of the type `EVOLUTION` and of type `B3200` are analyzed for the option `SN`.

4.2 Sizes tested and results

On this case simple test, the whole of the results tested is in agreement with the reference solution:

- for the calculation of Sn, of Sn* and the thermal ratchet,
- for a junction of piping,
- with and without earthquake,
- with the option `TYPE_RESU=' VALE_MAX'` as with the option `TYPE_RESU=' DETAILS` '.

Analytical solution with a precision lower than 10^{-4} %.

5 Modeling C

5.1 Characteristics of modeling

No thermal or mechanical calculation is carried out in this test: the tables of statements of constraints are directly provided to the operator POST_RCCM. Results of the type EVOLUTION and of type B3200 are analyzed for the option TIREDNESS. The option EFAT is analyzed with the type B3200.

5.2 Sizes tested and results

On this case simple test, the whole of the results tested is in agreement with the reference solution:

- for the calculation of Sp, of Salt and the elementary and cumulated damage,
- for a junction of piping,
- with and without earthquake,
- with TYPE_KE = 'QUE_MECA' and 'KE_MIXTE'
- the factor of use with environmental tiredness,
- with the option TYPE_RESU=' VALE_MAX' as with the option TYPE_RESU=' DETAILS '.

Analytical solution with a precision lower than 10^{-4} %.

6 Modeling D

6.1 Characteristics of modeling

No thermal or mechanical calculation is carried out in this test: the tables of statements of constraints are directly provided to the operator POST_RCCM. Results of type B3200 are analyzed for the option EFAT.

6.2 Sizes tested and results

On this case simple test, the whole of the results tested is in agreement with the reference solution:

- for the calculation of Sn, of Sp, the FEN;
- with and without earthquake
- with the option TYPE_RESU=' DETAILS '.

Analytical solution with a precision lower than 10^{-4} %.

7 Modeling E

7.1 Characteristics of modeling

No thermal or mechanical calculation is carried out in this test: the tables of statements of constraints are directly provided to the operator POST_RCCM . Results of type B3200 are analyzed for the option FAT IGUE with situations from which the data input are different.

7.2 Sizes tested and results

On this case simple test, the whole of the results tested is in agreement with the reference solution:

- for the calculation of Sn and of Sp
- with the option TYPE_RESU=' DETAILS ‘.

Analytical solution with a precision lower than 10^{-4} %.

8 Summary of the results

The results are exact and show that the operator POST_RCCM select the quantities correctly to be treated and correctly calculates the integrals (average on the segments) as well for the results of the type EVOLUTION that of type B3200.