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. Les forced are not calculated but are not extracted from tables.

More precisely, modeling A makes it possible to test the options `PM_PB`, `SN` and `FATIGUE_ZH210` for results of the type `EVOLUTION`.

Modeling B makes it possible to test the options `PM_PB`, `SN` and `TIREDNESS` for results of the type `UNIT`.

The keyword `KE_MIXTE` fatigue analysis is tested in these two modelings.

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 working stress:* $Sm=50\,MPa$ *.*

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} . Three transients are considered, with or without thermal stresses:

Moment	**Mechanical constraints**			**Thermal stresses**			**Total constraints**		
	X-coordinate			*X-coordinate*			*X-coordinate*		
	0	*1*	*2*	*0*	*1*	*2*	*0*	*1*	*2*
1	100	50	0	200	250	300	300	300	300
2	100	100	100	0	100	0	100	200	100
3	100	150	200	100	- 50	-100	200	100	100
4	100	200	300	0	0	0	100	200	300

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	**Mechanical constraints**		
	X-coordinate		
	0	*1*	*2*
1	0	0	0
2	200	50	-100

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

Moment	**Mechanical constraints**			**Thermal stresses**			**Total constraints**		
	X-coordinate			*X-coordinate*			*X-coordinate*		
	0	*1*	*2*	*0*	*1*	*2*	*0*	*1*	*2*
1	0	0	0	50	50	50	50	50	50
2	200	50	-100	0	50	100	200	100	0

Table 1.2-3 **:** Definition of the constraints σ_{yy} (in MPa) for the moments of situation 3 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).

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 is to only provide directly the mechanical constraints (situation 2 below); that is to say to provide the total thermomechanical constraints and the constraints related to the thermal loading only, in which case those are automatically cut off (situations 1 and 3).

One indicates in the tables below the signed value of the parameters Pm and Pb , even if it is the standard of these quantities which is to be retained finally. That makes it possible to distinguish the origin and the end in calculation from $Pm \pm Pb$, and to facilitate the calculation of Sn in the following paragraph.

Situation 1 :

Moment	Pm	Pb	$Pm-Pb$ **(origin)**	$Pm+Pb$ **(end)**
1	50.	-50.	+100.	0.
2	100.	0.	100.	100.
3	150.	50.	100.	200.
4	200.	100.	100.	300.

Situation 2 and **Situation 3** :

Moment	Pm	Pb	$Pm-Pb$ **(origin)**	$Pm+Pb$ **(end)**
1	0.	0.	0.	0.
2	50.	-150.	200.	-100.

2.1.2 Calculation of Sn and Sn^* (modeling A)

The parameter Sn represent the amplitude of variation of Contrainte linear (average constraint ± bending stress) between two moments of the transient considered. The parameter Sn^* represent the amplitude Sn calculated without taking into account stresses bending thermal.

The tables below present the values of Sn and Sn^* for the various combinations of moments of each situation, within the framework of modeling A (`TYPE_RESU_MECA = 'EVOLUTION'`).

Situation 1 :

Sn *at the origin:*

Moment	1	2	3	4
1	0	150	125	200
2		0	25	50
3			0	75
4				0

Sn *at the end:*

Moment	1	2	3	4
1	0	150	225	0
2		0	75	150
3			0	225
4				0

Sn^* at the origin:

Moment	1	2	3	4
1	0	200	275	250
2		0	75	50
3			0	25
4				0

Sn^* at the end:

Moment	1	2	3	4
1	0	100	75	50
2		0	25	150
3			0	125
4				0

Situation 2 :

Sn at the origin:

Moment	2
1	200

Sn at the end:

Moment	2
1	100

Situation 3 :

Sn at the origin:

Moment	2
1	250

Sn at the end:

Moment	2
1	150

Sn^* at the origin:

Moment	2
1	200

Sn^* at the end:

Moment	2
1	100

2.1.3 Principle of the calculation of the elementary factors of use (modeling B)

One illustrates below the calculation of the factors of use within the framework of modeling B (`TYPE_RESU_MECA = 'UNIT'`). One considers the combination of situations 1 and 3. One detail the procedure of calculation of the sizes Sn and Sp , for the origin of the segment only (the procedure is exactly the same one at the end and for the other combinations of situations).

One indicates by A and B the stabilized mechanical states of each situation and one thus notes σ_1^A and σ_1^B mechanical constraints associated with the two stabilized states of situation 1; one makes in the same way for situation 3.

The thermal stresses are used only via their extrema (within the meaning of a standard of Tresca signed). One notes $\sigma_{p,min}^{ther}$ (resp. $\sigma_{p,max}^{ther}$) the minimal constraint (resp. maximum) of the thermal transient associated with the situation p .

Calculation of Sn : for the six possible combinations of states $pi-qj$ ($1A-3B, 1B-3B, 1B-1B$ …), 4 sizes are calculated: $\left|\sigma_p^i-\sigma_q^j+\sigma_{p,max}^{ther,lin}-\sigma_{q,min}^{ther,lin}\right|$, $\left|-\sigma_p^i+\sigma_q^j+\sigma_{p,max}^{ther,lin}-\sigma_{q,min}^{ther,lin}\right|$, $\left|\sigma_p^i-\sigma_q^j+\sigma_{q,max}^{ther,lin}-\sigma_{p,min}^{ther,lin}\right|$ and $\left|-\sigma_p^i+\sigma_q^j+\sigma_{q,max}^{ther,lin}-\sigma_{p,min}^{ther,lin}\right|$. Sn corresponds to the maximum of all these quantities.

For the combination of situations 1 and 3, there is for example the following table:

Combination	1A-3A	1A-3B	1B-3A	1B-3B	1A-1B	3A-3B

σ_p^I	100	100	100	100	100	0
σ_Q^j	0	200	0	200	100	200
$\sigma_{p,max}^{ther,lin}$	200	200	200	200	200	-
$\sigma_{p,min}^{ther,lin}$	50	50	50	50	50	-
$\sigma_{q,max}^{ther,lin}$	50	50	50	50	-	50
$\sigma_{q,min}^{ther,lin}$	0	0	0	0	-	0
$Méca+pMax-qMin$	300	100	300	100	150	250
$-Méca+pMax-qMin$	100	300	100	300	150	150
$Méca+qMax-pMin$	100	100	100	100	-	-
$-Méca+qMax-pMin$	100	100	100	100	-	-

Sn for the combination of situations 1 and 3 is worth thus 300. The elastoplastic concentration factor Ke 1 is worth then.

<u>Calculation of S_p:</u> one takes again the same approach while being based this time on the not linearized thermal stresses. One initially determines, for each combination, the maximum enters $\left|\sigma_p^i-\sigma_q^j+\sigma_{p,max}^{ther}-\sigma_{q,min}^{ther}\right|$ and $\left|-\sigma_p^i+\sigma_q^j+\sigma_{p,max}^{ther}-\sigma_{q,min}^{ther}\right|$, that one notes $Sp1$; then that enters $\left|\sigma_p^i-\sigma_q^j+\sigma_{q,max}^{ther}-\sigma_{p,min}^{ther}\right|$ and $\left|-\sigma_p^i+\sigma_q^j+\sigma_{q,max}^{ther}-\sigma_{p,min}^{ther}\right|$ that one notes $Sp2$.

Then one selects the maximum of each one of these sizes on the whole of the combinations, which one names again $Sp1$ and $Sp2$. The factor of use associated with the combination of situations is equal to the sum of the factors of uses associated with $Sp1$ and $Sp2$.

Combination	Méca +pM - qm	- Méca +pM - qm	Méca +qM - pm	- Méca +qM - pm	S_p 1	S_p 2	S_p 1_max	S_p 2_max	S_{alt}	FU
1a-3a	300	100	150	50	300	150	**300**	**150**	225	4.5E-4
1a-3b	100	300	50	150	300	150				
1b-3a	300	100	150	50	300	150				
1b-3b	100	300	50	150	300	150				
1a-1b	200	200	-	-	200	-	250	200		
3a-3b	250	150	-	-	250	-				

2.1.4 Calculation of the factor of total use

For modeling A, one builds a matrix of factors of use which gives the elementary factors of use for all the combinations of moments of all the situations, obtained thanks to the values of Sp corresponding and to the curve of tiredness. The factor of total use is calculated by successively summoning the maximum elementary factors of use until exhaustion of the numbers of occurrences of the situations.

By noting {1,2,3,4} the four moments of situation 1 and {5.6} the two moments of situation 2, one presents below the significant values of the matrix which makes it possible to obtain the factor of total use for the combination of situations 1 and 2, at the origin and the end of the segment.

<u>Situation 1 + Situation 2</u> : origin

Instant_1	**Instant_2**	Sn	$S p$	$S alt$	$N adm$	**TOO BAD**	**DOMMAGE_CUMU**
1	5	300	300	150	3.3E3	3 E-4	3rd-4
2	3	25	100	50	1E4	1E-4	4th-4
5	6	200	200	100	5E3	2nd-4	**5th-4**

Situation 1 + Situation 2 : end

Instant_1	**Instant_2**	$S n$	$S p$	$S alt$	$N adm$	**TOO BAD**	**DOMMAGE_CUMU**
1	6	400	400	200	2. 5E3	4th-4	4th-4
4	5	300	300	1 50	3.3 E3	3rd-4	**7th-4**

With `TYPE_KE=QUE_MIXTE`, one must obtain:

Situation 1 + Situation 2 : origin

Instant_1	**Instant_2**	$S n$	$S p_{meca}$	$S p_{ther}$	$K e_{meca}$	$K e_{ther}$	$S alt$	**TOO BAD**	**DOMMAGE_CUMU**
1	5	300	1 00	200	1	1.27	1.77E2	3.54E-4	3.54E-4
3	6	25	100	100	1	1	1E2	2E-4	**5.54E-4**

Situation 1 + Situation 2 : end

Instant_1	**Instant_2**	$S n$	$S p_{meca}$	$S p_{ther}$	$K e_{meca}$	$K e_{ther}$	$S alt$	**TOO BAD**	**DOMMAGE_CUMU**
1	3	225	200	4 00	1	1.19	3 .38E2	6.77E-4	6.77E-4
4	6	400	400	0	1	1.35	2E2	4 E-4	1.08E-3
2	5	150	100	0	1	1.09	5E1	1E-4	**1.18E-3**

For modeling B and with the curve of tiredness simplified, the results of the analysis to tiredness according to RCCM_B3200 and TIREDNESS must be (for 1 cycle of loading for the two situations):

Place	**Situation_1**	**Situation_2**	$S n$	$S p$	$K e$	$S alt$	**TOO BAD**
origin	1	2	250	400	1	200	4th-4
end	1	2	825	1200	2.5	1500	3rd-3

With `TYPE_KE=QUE_MIXTE`, one must obtain, at the same moments:

Place	$S n$	$S p_{meca}$	$S p_{ther}$	$K e_{meca}$	$K e_{ther}$	$S alt$	**TOO BAD**
origin	250	200	200	1	1.2208	222.08	4.4416E-4
end	825	700	400	2.5	1.5385	1182.7	2.3654E-3

2.1.5 Calculation of the thermal ratchet

The criterion of the thermal ratchet gives the acceptable maximum value of the amplitude of variation of the thermal stresses σ_θ , starting from the data of the maximum of the membrane stress due to the pressure σ_m . It is supposed here that the constraint due to the pressure is that of transient 1.

Two relations of the form $\sigma_\theta = f(\sigma_m, S_y)$ are proposed according to whether the temperature variation in the wall is supposed to be linear or parabolic. The two values are calculated.

Moment	σ_m	σ_θ - Linear law	σ_θ - Parabolic law

1	100.	400.	540.
2	150.	200.	260.
3	100.	400.	540.
4	200.	0.	0.

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` .

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 and PB ;
- for the calculation of SN and $SN*$;
- for the fatigue analysis with `KE_MIXTE` and `KE_MECA` ;
- with the option `TYPE_RESU=' VALE_MAX'` as with the option `TYPE_RESU=' DETAILS` ‘.

4 Modeling B

4.1 Characteristics of modeling

No thermal or mechanical calculation is carried out in this test: tables of statements of contraintes is provided to the operator `POST_RCCM` . The various moments of the problem of reference are built by linear combination starting from unit constraints in the beginning, the medium and the end of the segment.

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 PM and PB ;
- for the calculation of SN and $SN*$;
- for the fatigue analysis with `KE_MIXTE` and `KE_MECA` ;
- with the option `TYPE_RESU=' VALE_MAX'` as with the option `TYPE_RESU=' DETAILS` ‘.

5 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 `UNIT`.