TTLL01 - Thermal shock on an infinite wall

Summary:

Transitory linear thermics,
elements 2D and 3D (7 modelings),
interests of the test:

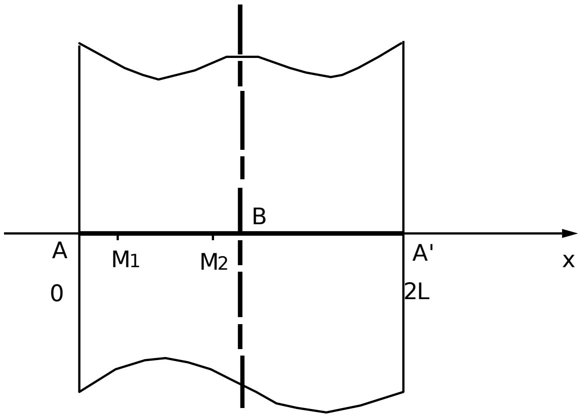
- test the algorithm of linear thermics transitory with change of step of time,
- imposed temperature (with discontinuity),
- filing of some not of time.

The shock is modelled in 2 different ways:

- by a linear slope: $\Delta T=100.$ in 10^{-3} second,
- by true a discontinuity of imposed temperature.

1 Problem of reference

1.1 Geometry



$\overline{AA'}=2\text{L}=2\,m$
$x(M1)=0.2\,m$
$x(M2)=0.8\,m$

1.2 Material properties

$\lambda=1\,W/m\,°C$
$\rho\,C_P=1\,J/m^3\,°C$

1.3 Boundary conditions and loadings

- $A: T(0,t)=T_p=100\,°C$
  for $t>0$
- $A': T(2\text{L},t)=T_p=100\,°C$

1.4 Initial conditions

$T(x,0)=0\,°C$ for all x

1.5 Precise details concerning modelings

Discretization in time (t) :
The thermal shock requires a "fine" discretization in time close to $t=0$.
The goal of the test being to validate the various elements (various modelings), we chose a single discretization in time:

10	not for	$[0.,1.\text{E}-3]$	that is to say	$\Delta t=10^{-4}s$
9	not for	$[1.\text{E}-3,1.\text{E}-2]$	that is to say	$\Delta t=10^{-3}s$
9	not for	$[1.\text{E}-2,1.\text{E}-1]$	that is to say	$\Delta t=10^{-2}s$
9	not for	$[1.\text{E}-1,1.]$	that is to say	$\Delta t=10^{-1}s$
10	not for	$[1.,2.]$	that is to say	$\Delta t=10^{-1}s$

The shock is defined in two different ways:

- for modeling B, it is about a true shock (T_p is discontinuous):

$$\begin{cases} T_p^-(A)=0. \\ T_p^+(A)=100. \end{cases}$$

- for modelings A, C, D, E, F, G , it is about a linear slope:

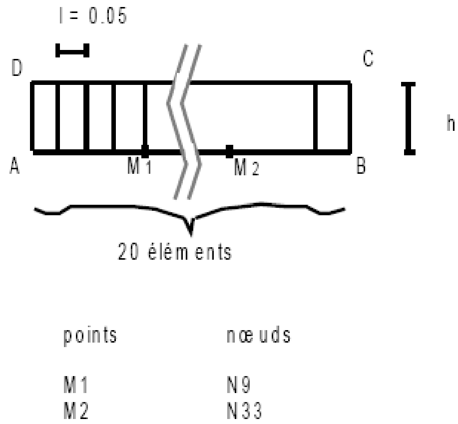
$$\begin{cases} T_p(A)_{t=0}=0. \\ T_p(A)_{t=10^{-3}}=100. \end{cases}$$

2 Reference solution

2.1 Method of calculating used for the reference solution

$$\frac{T(x,t)-T_p}{T_0-T_p}=\frac{4}{\pi}\sum_{n=1}^{\infty}\frac{1}{n}\sin\left(\frac{n\pi x}{2L}\right)\exp\left\{-\left(\frac{n\pi}{2L}\right)^2 \cdot \frac{\lambda}{\rho C_p} . t\right\}$$

$x=$ X-coordinate
$t=$ Time
$T_0=$



Initial temperature
$T_p=$ Imposed temperature
$n=$ $1,3,5,...$

2.2 Results of reference

Temperatures at the points $M1$ ($x=0.2$) and $M2$ ($x=0.8$), and at various moments ($t=0.1, 0.2, 0.7$ and 2.0).
The values of reference are those given in guide VPCS.

2.3 Uncertainty on the solution

Digital series.

2.4 Bibliographical references

• J.F. SACCADURA: Initiation with the heat transfers, Paris, Technique and documentation (1982).

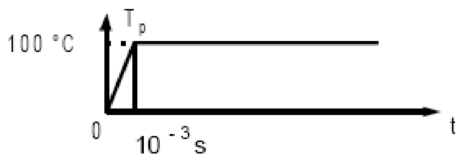
3 Modeling A

3.1 Characteristics of modeling

QUAD8
One nets only half the thickness of the wall by reason of symmetry; modeling is made under a height $h=1.0$ with only one elements sleep.

Limiting conditions:
On $[BC]$, $[AB]$ and $[DC]$: $j=0$
on $[AD]$: T_p is imposed

Initial conditions:
$T=0.°C$
One fixes here the duration of the shock at $10.^{-3} s$



3.2 Characteristics of the grid

Many nodes: 103
Many meshs and types: 20 QUAD8

4 Results of modeling A

4.1 Values tested

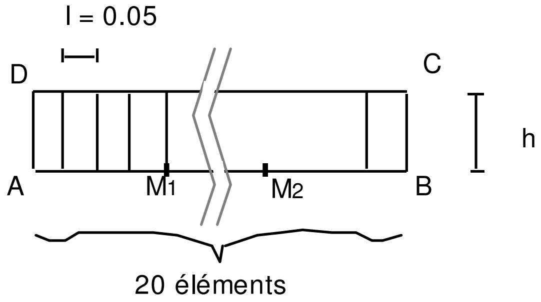
Identification	Reference	% difference
$M1(x=0.2)N9$		
$t=0.1$	65.48	– 0.28
$t=0.2$	75.58	+0.31
$t=0.7$	93.01	– 0.15
$t=2.0$	99.72	– 0.02
$M2(x=0.8)N33$		
$t=0.1$	8.09	– 0.67
$t=0.2$	26.37	– 2.20
$t=0.7$	78.47	– 0.54
$t=2.0$	99.13	– 0.05

5 Modeling B

5.1 Characteristics of modeling

QUAD8

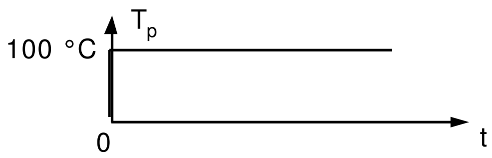
One nets only half the thickness of the wall by reason of symmetry; modeling is made under a height $h=1.0$ with only one elements sleep.



Conditions limites

sur [BC], [AB] et [DC] $\phi = 0$

sur [AD] : T_p est imposée $T_p = 100°C$



points	nœuds
M1	N9
M2	N33

Conditions initiales
On affecte directement la température de 100°C à l'instant 0.

5.2 Characteristics of the grid

Many nodes: 103
Many meshs and types: 20 QUAD8

6 Results of modeling B

6.1 Values tested

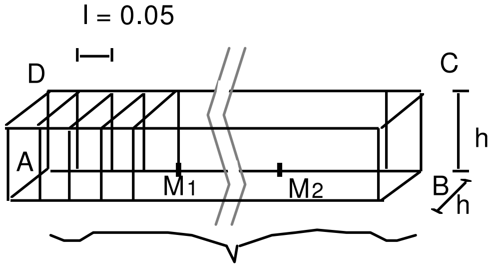
Identification	Reference	% difference
$M1(x=0.2)N9$		
$t=0.1$	65.48	– 0.17
$t=0.2$	75.58	0.35
$t=0.7$	93.01	– 0.14
$t=2.0$	99.72	– 0.02
$M2(x=0.8)N33$		
$t=0.1$	8.09	0.28
$t=0.2$	26.37	– 1.89
$t=0.7$	78.47	– 0.51
$t=2.0$	99.13	– 0.05

7 Modeling C

7.1 Characteristics of modeling

HEXA8

One nets only half the thickness of the wall by reason of symmetry; modeling is made under a height and a thickness $h=1.0$ with only one elements sleep.



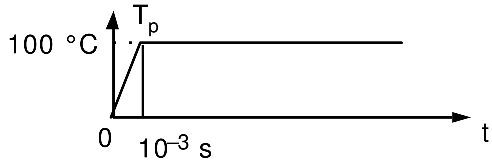
20 éléments HEXA8

points	nœuds
M1	N21 à N24
M2	N69 à N72

Conditions limites

sur [BC], [AB] et [DC] : ϕ = 0

sur [AD] : T_p est imposée



Conditions initiales

T = 0°C

On fixe ici la durée du choc à 10^{-3} s.

7.2 Characteristics of the grid

Many nodes: 84

Many meshs and types: 20 HEXA8

8 Results of modeling C

8.1 Values tested

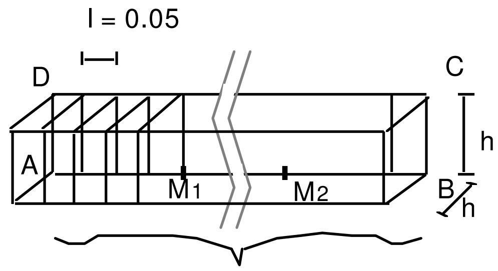
Identification	Reference	% difference
$M1(x=0.2)\,N21$		
$t=0.1$	65.48	– 0.26
$t=0.2$	75.58	+0.31
$t=0.7$	93.01	– 0.15
$t=2.0$	99.72	– 0.02
$M2(x=0.8)\,N69$		
$t=0.1$	8.09	– 1.31
$t=0.2$	26.37	– 2.30
$t=0.7$	78.47	– 0.53
$t=2.0$	99.13	– 0.05

9 Modeling D

9.1 Characteristics of modeling

HEXA20

One nets only half the thickness of the wall by reason of symmetry; modeling is made under a height and a thickness $h=1.0$ with only one lay down elements.



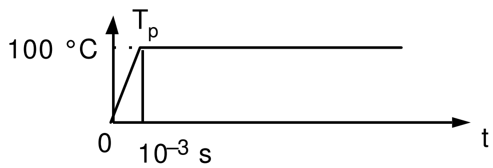
20 éléments HEXA20

points	nœuds
M1	N57 à N64
M2	N201 à N208

Conditions limites

sur [BC], [AB] et [DC] : $\phi = 0$

sur [AD] : T_p est imposée



Conditions initiales
T = 0°C
On fixe ici la durée du choc à 10^{-3} s.

9.2 Characteristics of the grid

Many nodes: 248
Many meshs and types: 20 HEXA20

10 Results of modeling D

10.1 Values tested

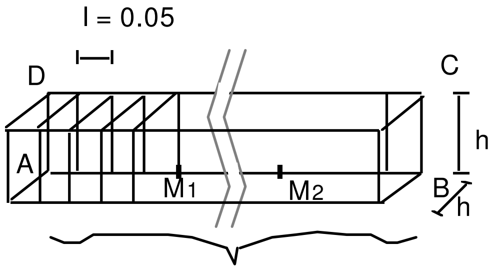
Identification	Reference	% difference
$M1(x=0.2)N57$		
$t=0.1$	65.48	– 0.28
$t=0.2$	75.58	+0.31
$t=0.7$	93.01	– 0.15
$t=2.0$	99.72	– 0.02
$M2(x=0.8)N201$		
$t=0.1$	8.09	– 0.67
$t=0.2$	26.37	– 2.20
$t=0.7$	78.47	– 0.54
$t=2.0$	99.13	– 0.05

11 Modeling E

11.1 Characteristics of modeling

PENTA6

One nets only half the thickness of the wall by reason of symmetry; modeling is made under a height and a thickness H = 1.0 with only one lay down elements. Each cube is cut out in 2 pentahedrons.



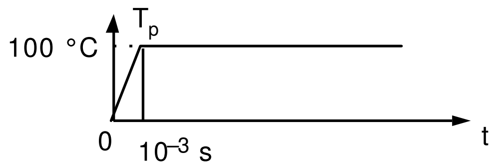
20 éléments PENTA6

points	nœuds
M1	N21 à N24
M2	N69 à N72

Conditions limites

sur [BC], [AB] et [DC] : $\phi = 0$

sur [AD] : T_p est imposée



Conditions initiales

T = 0 °C

On fixe ici la durée du choc à 10^{-3} s.

11.2 Characteristics of the grid

Many nodes: 84

Many meshs and types: 40 PENTA6

12 Results of modeling E

12.1 Values tested

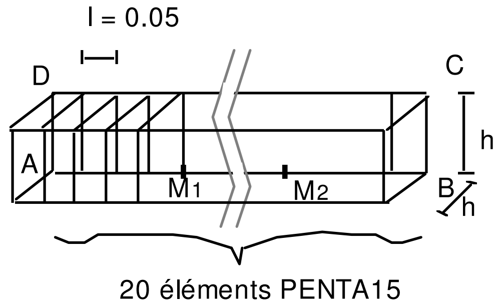
Identification	Reference	% difference
$M1(x=0.2)N21$		
$t=0.1$	65.48	– 0.26
$t=0.2$	75.58	+0.31
$t=0.7$	93.01	– 0.15
$t=2.0$	99.72	– 0.02
$M2(x=0.8)N69$		
$t=0.1$	8.09	– 1.31
$t=0.2$	26.37	– 2.30
$t=0.7$	78.47	– 0.53
$t=2.0$	99.13	– 0.05

13 Modeling F

13.1 Characteristics of modeling

PENTA15

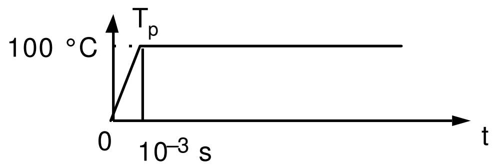
One nets only half the thickness of the wall by reason of symmetry; modeling is made under a height and a thickness H = 1.0 with only one lay down elements. Each cube is cut out in 2 pentahedrons.



Conditions limites

sur [BC], [AB] et [DC] : $\phi = 0$

sur [AD] : T_p est imposée



points	nœuds
M1	N62 à N70
M2	N218 à N226

Conditions initiales

T = 0 °C

On fixe ici la durée du choc à 10^{-3} s.

13.2 Characteristics of the grid

Many nodes: 269

Many meshs and types: 40 PENTA15

14 Results of modeling F

14.1 Values tested

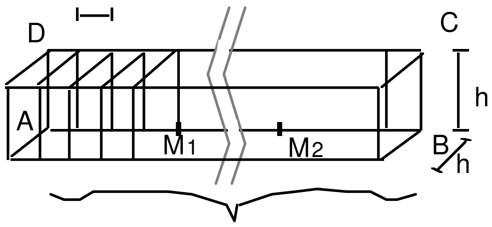
Identification	Reference	% difference
$M1(x=0.2)\,N62$		
$t=0.1$	65.48	– 0.28
$t=0.2$	75.58	+0.31
$t=0.7$	93.01	– 0.15
$t=2.0$	99.72	– 0.02
$M2(x=0.8)\,N218$		
$t=0.1$	8.09	– 0.67
$t=0.2$	26.37	– 2.20
$t=0.7$	78.47	– 0.54
$t=2.0$	99.13	– 0.05

15 Modeling G

15.1 Characteristics of modeling

TETRA4

One nets only half the thickness of the wall by reason of symmetry; modeling is made under a height and a thickness $h=1.0$ with only one elements sleep. Each cube is cut out in 5 tetrahedrons.



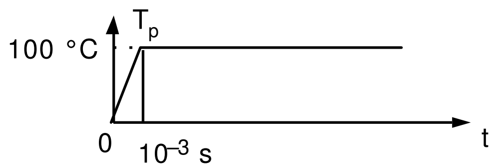
20 éléments TETRA4

points	nœuds
M1	N12, N17
M2	N48, N53

Conditions limites

sur [BC], [AB] et [DC] : $\phi = 0$

sur [AD] : T_p est imposée



Conditions initiales
T = 0 °C
On fixe ici la durée du choc à 10^{-3} s.

15.2 Characteristics of the grid

Many nodes: 84
Many meshs and types: 100 TETRA4

16 Results of modeling G

16.1 Values tested

Identification		Reference	% difference
$M1(x=0.2)$			
T = 0.1	N12	65.48	– 0.17
	N17	65.49	– 0.33
T = 0.2	N12	75.58	+0.34
	N17	75.58	+0.29
T = 0.7	N12	93.01	– 0.14
	N17	93.01	– 0.16
T = 2.0	N12	99.72	– 0.02
	N17	99.72	– 0.02
$M2(x=0.8)$			
T = 0.1	N48	8.09	– 0.11
	N53	8.09	– 1.43
T = 0.2	N48	26.37	– 1.96
	N53	26.37	– 2.39
T = 0.7	N48	78.47	– 0.51
	N53	78.47	– 0.55
T = 2.0	N48	99.13	– 0.05
	N53	99.13	– 0.05

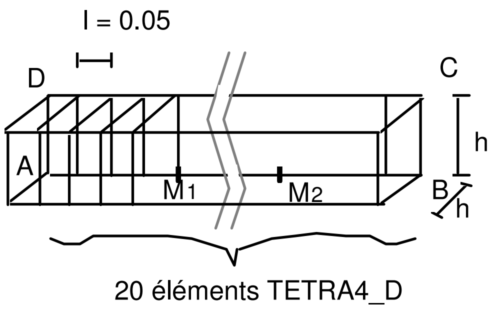
16.2 Remarks

At the beginning of transient, one observes slightly different values between the nodes located in a plan $x=constante$ ($<3 \text{ pour } 1000$). This anomaly seems to be due to modeling in tetrahedrons with 4 nodes. The results remain nevertheless correct compared to the other elements 3D.

17 Modeling J

17.1 Characteristics of modeling

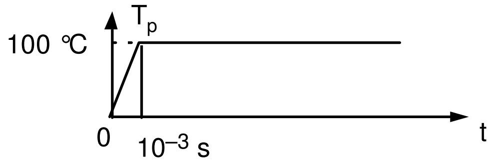
TETRA4_D
One nets only half the thickness of the wall by reason of symmetry; modeling is made under a height and a thickness $h=1.0$ with only one elements sleep. Each cube is cut out in 5 tetrahedrons.
Modeling is used `3D_DIAG` applied to TETRA4, which corresponds to the lumpage of the matrix of thermal mass.



Conditions limites

sur [BC], [AB] et [DC] : $\phi = 0$

sur [AD] : T_p est imposée



points	nœuds
M1	N12, N17
M2	N48, N53

Conditions initiales
T = 0°C
On fixe ici la durée du choc à 10^{-3} s.

17.2 Characteristics of the grid

Many nodes: 84
Many meshs and types: 100 TETRA4

18 Results of modeling J

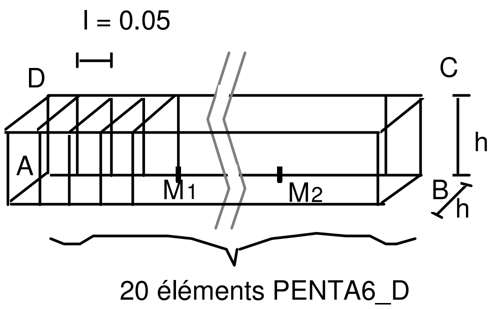
18.1 Values tested

Identification		Reference	% difference
$M1(x=0.2)$			
T = 0.1	N12	65.48	– 0.21
	N17	65.49	– 0.36
T = 0.2	N12	75.58	+0.34
	N17	75.58	+0.29
T = 0.7	N12	93.01	– 0.15
	N17	93.01	– 0.16
T = 2.0	N12	99.72	– 0.02
	N17	99.72	– 0.02
$M2(x=0.8)$			
T = 0.1	N48	8.09	+1.16
	N53	8.09	– 0.15
T = 0.2	N48	26.37	– 1.77
	N53	26.37	– 2.20
T = 0.7	N48	78.47	– 0.52
	N53	78.47	– 0.57
T = 2.0	N48	99.13	– 0.05
	N53	99.13	– 0.05

19 Modeling K

19.1 Characteristics of modeling

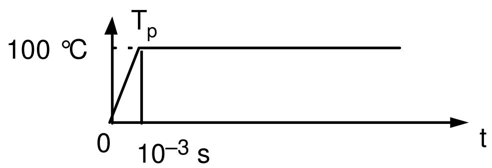
PENTA6_D
One nets only half the thickness of the wall by reason of symmetry; modeling is made under a height and a thickness $h=1.0$ with only one elements sleep. Each cube is cut out in 2 pentahedrons.
Modeling is used `3D_DIAG` applied to PENTA6, which corresponds to the lumpage of the matrix of thermal mass.



Conditions limites

sur [BC], [AB] et [DC] : $\phi = 0$

sur [AD] : T_p est imposée



points	nœuds
M1	N21 à N24
M2	N69 à N72

Conditions initiales
T = 0°C
On fixe ici la durée du choc à 10^{-3} s.

19.2 Characteristics of the grid

Many nodes: 84
Many meshs and types: 40 PENTA6

20 Results of modeling K

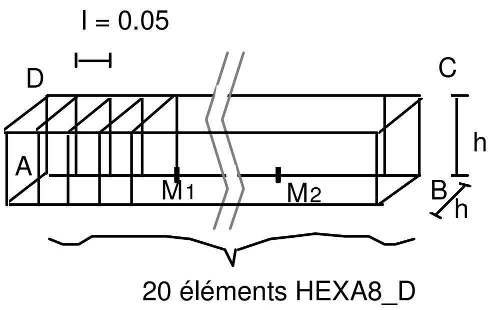
20.1 Values tested

Identification	Reference	% difference
$M1(x=0.2)$		
$t=0.1$	65.48	– 0.30
$t=0.2$	75.58	+0.31
$t=0.7$	93.01	– 0.15
$t=2.0$	99.72	– 0.02
$M2(x=0.8)$		
$t=0.1$	8.09	– 0.03
$t=0.2$	26.37	– 2.14
$t=0.7$	78.47	– 0.55
$t=2.0$	99.13	– 0.05

21 Modeling L

21.1 Characteristics of modeling

HEXA8_D
One nets only half the thickness of the wall by reason of symmetry; modeling is made under a height and a thickness $h=1.0$ with only one elements sleep.
Modeling is used `3D_DIAG` applied to HEXA8, which corresponds to the lumpage of the matrix of thermal mass.

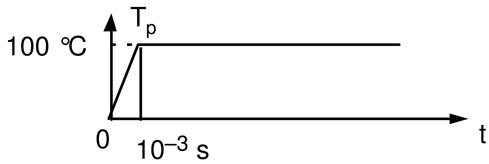


points	nœuds
M1	N21 à N24
M2	N69 à N72

Conditions limites

sur [BC], [AB] et [DC] : $\phi = 0$

sur [AD] : T_p est imposée



Conditions initiales
T = 0°C
On fixe ici la durée du choc à 10^{-3} s.

21.2 Characteristics of the grid

Many nodes: 84
Many meshs and types: 20 HEXA8

22 Results of modeling L

22.1 Values tested

Identification	Reference	% difference
$M1(x=0.2)$		
$t=0.1$	65.48	– 0.30
$t=0.2$	75.58	+0.31
$t=0.7$	93.01	– 0.15
$t=2.0$	99.72	– 0.02

$M2(x=0.8)$		
$t=0.1$	8.09	– 0.03
$t=0.2$	26.37	– 2.10
$t=0.7$	78.47	– 0.55
$t=2.0$	99.13	– 0.05

23 Summary of the results

At the end of 0.7 S the error is definitely lower than 1% for the various thermal elements 2D (QUAD8) and 3D (HEXA8 - HEXA20 - PENTA6 - PENTA15 - TETRA4) used.

It does not seem that the lumpage improves the digital result.

It would be advisable to test the elements lumpés with a true jump as in modeling B.