TTLL01 - Thermal shock on a Summarized infinite

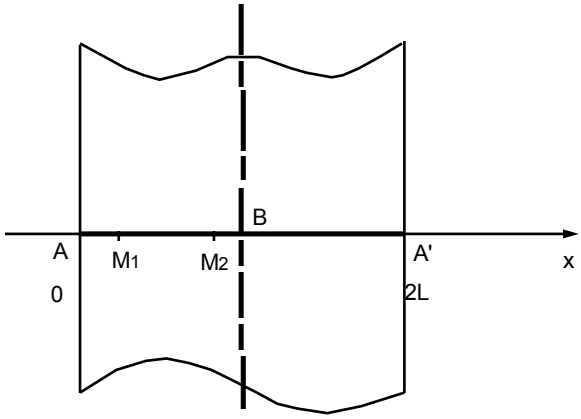
wall:

Transitory linear thermal,
elements 2D and 3D (7 modelizations),
interests of the test:
•test the algorithm of linear thermal transitory with change of time step,
•imposed temperature (with discontinuity),
•archivage of some time step.

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



$\bar{A}A' = 2\mathrm{L} = 2\,m$
$x(M1) = 0.2\,m$
$x(M2) = 0.8\,m$

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 $t > 0$

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

1.4 Initial conditions

$T(x,0) = 0°C$ for all x

1.5 Precise details concerning the modelizations

Discretization in time (t) :

The thermal shock requires a “fine” discretization in time close to $t = 0$.

The goal of the test being validating the various elements (various modelizations), we chose a single discretization in time:

10	steps for	$[0., 1.\mathrm{E}-3]$	either	$\Delta t = 10^{-4}\,s$
9	steps for	$[1.\mathrm{E}-3, 1.\mathrm{E}-2]$	or	$\Delta t = 10^{-3}\,s$
9	steps for	$[1.\mathrm{E}-2, 1.\mathrm{E}-1]$	or	$\Delta t = 10^{-2}\,s$
9	steps for	$[1.\mathrm{E}-1, 1.]$	or	$\Delta t = 10^{-1}\,s$
10	steps for	$[1., 2.]$	or	$\Delta t = 10^{-1}\,s$

the shock are defined in two different ways:

•for the modelization B, it is about a true shock (T_p is discontinuous):

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

•for the modelizations A, C, D, E, F, G, it is about a linear slope:

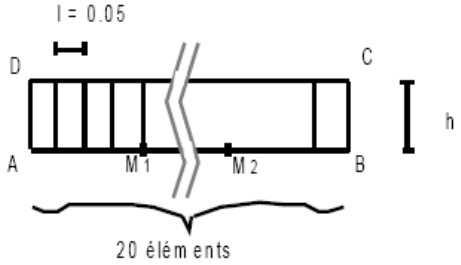
$$\begin{cases} T_p(A)_{t=0}=0. \\ T_p(A)_{t=10^{-3}}=100. \end{cases}$$

2 Reference solution

2.1 Method of calculating used for the reference solution

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

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



points	nœuds
M1	N9
M2	N33

initial Temperature
$T_p=$ imposed Temperature
$n=$ $1,3,5,...$

2.2 Results of reference

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

2.3 Uncertainty on the numerical

solution Series.

2.4 Bibliographical references

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

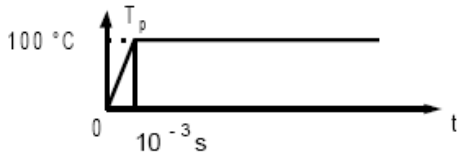
3 Modelization A

3.1 Characteristic of modelization

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

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

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



3.2 Characteristics of the mesh

Many nodes: 103
Number of meshes and types: 20 QUAD8

4 Results of the modelization A

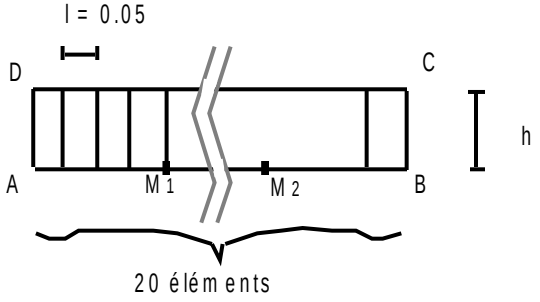
4.1 Values tested

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 Modelization B

5.1 Characteristic of modelization

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

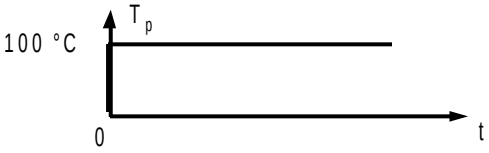


points	nœuds
M1	N9
M2	N33

Conditions limites

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

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



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

5.2 Characteristics of the mesh

Many nodes: 103
Number of meshes and types: 20 QUAD8

6 Results of the modelization B

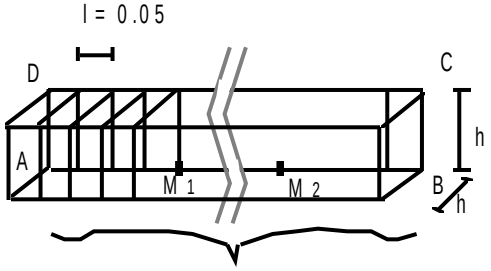
6.1 Values tested

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 Modelization C

7.1 Characteristic of modelization

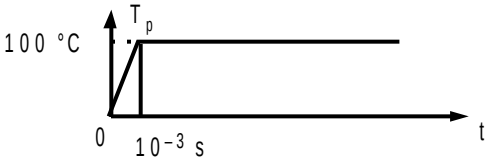
HEXA8
One net only half of the thickness of the wall by reason of symmetry; the modelization is made under a height and a thickness $h=1.0$ with only one layer of elements.



Conditions limites

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

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.

7.2 Characteristics of the mesh

Many nodes: 84
Number of meshes and types: 20 HEXA8

8 Results of the modelization C

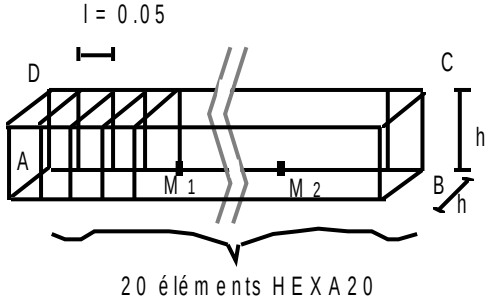
8.1 Values tested

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 Modelization D

9.1 Characteristic of modelization

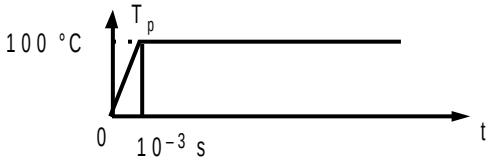
HEXA20
One nets only half of the thickness of the wall by reason of symmetry; the modelization is made under a height and a thickness $h=1.0$ with only one layer of elements.



Conditions limites

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

sur [AD] : T_p est imposée



points	nœuds
M1	N57 à N64
M2	N201 à N208

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

9.2 Characteristics of the mesh

Many nodes: 248
Number of meshes and types: 20 HEXA20

10 Results of the modelization D

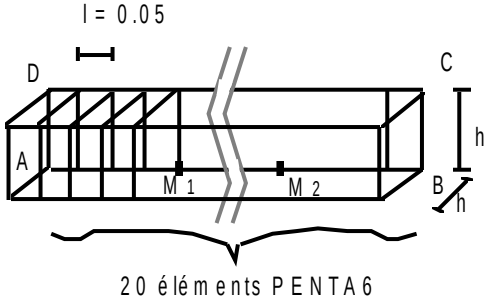
10.1 Values tested

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 Modelization E

11.1 Characteristic of modelization

PENTA6
One nets only half of the thickness of the wall by reason of symmetry; the modelization is made under a height and a thickness H = 1.0 with only one layer of elements. Each cube is cut out in 2 pentahedrons.

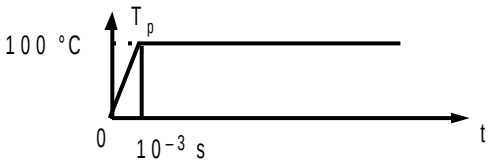


points	nœuds
M 1	N21 à N24
M 2	N69 à N72

Conditions limites

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

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 mesh

Many nodes: 84
Number of meshes and types: 40 PENTA6

12 Results of the modelization E

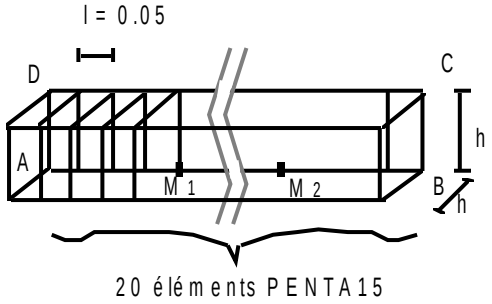
12.1 Values tested

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 Modelization F

13.1 Characteristic of modelization

PENTA15
One nets only half of the thickness of the wall by reason of symmetry; the modelization is made under a height and a thickness H = 1.0 with only one layer of elements. Each cube is cut out in 2 pentahedrons.

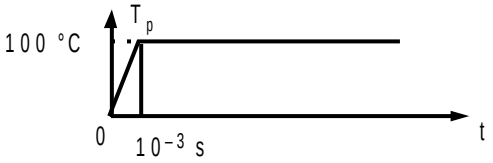


points	nœuds
M1	N62 à N70
M2	N218 à N226

Conditions limites

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

sur [AD] : T_p est imposée



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

13.2 Characteristics of the mesh

Many nodes: 269
Number of meshes and types: 40 PENTA15

14 Results of the modelization F

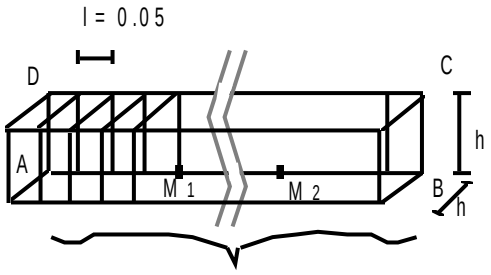
14.1 Values tested

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 Modelization G

15.1 Characteristic of modelization

TETRA4
One nets only half of the thickness of the wall by reason of symmetry; the modelization is made under a height and a thickness $h=1.0$ with only one layer of elements. Each cube is cut out in 5 tetrahedrons.



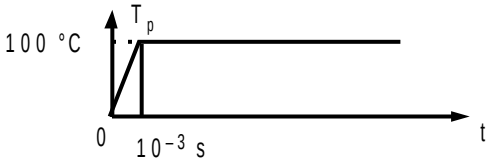
20 éléments TETRA4

points	nœuds
M1	N12, N17
M2	N48, N53

Conditions limites

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

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 mesh

Many nodes: 84
Number of meshes and types: 100 TETRA4

16 Results of the modelization G

16.1 Values tested

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

16.2 Remarks

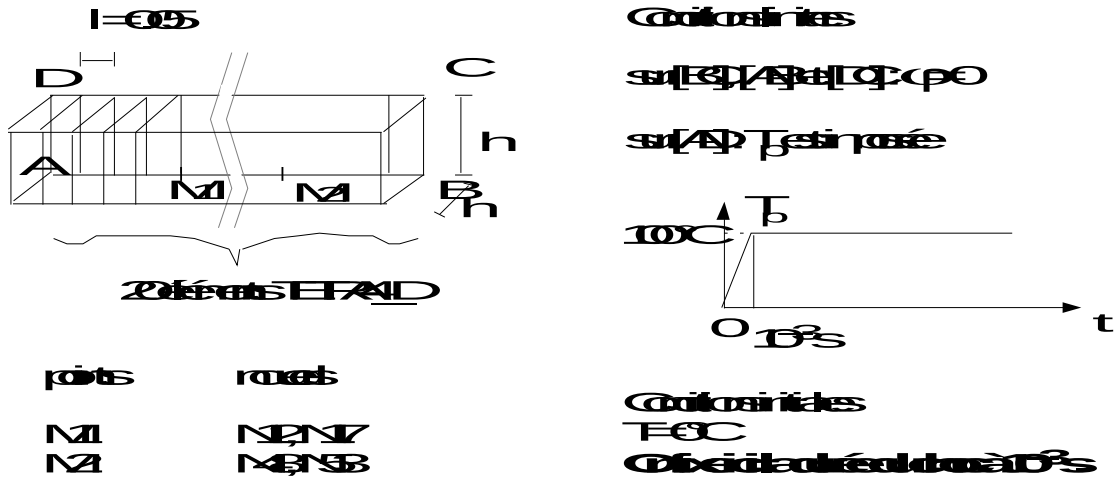
At the beginning of transient, one observe slightly different values between the nodes located in a plane $x=constante$ (<3 pour 1000). This anomaly seems to be due to the modelization in

tetrahedrons with 4 nodes. The results remain nevertheless correct 3D compared to the other elements.

17 Modelization J

17.1 Characteristic of modelization

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



17.2 Characteristics of the mesh

Many nodes: 84
Number of meshes and types: 100 TETRA4

18 Results of the modelization J

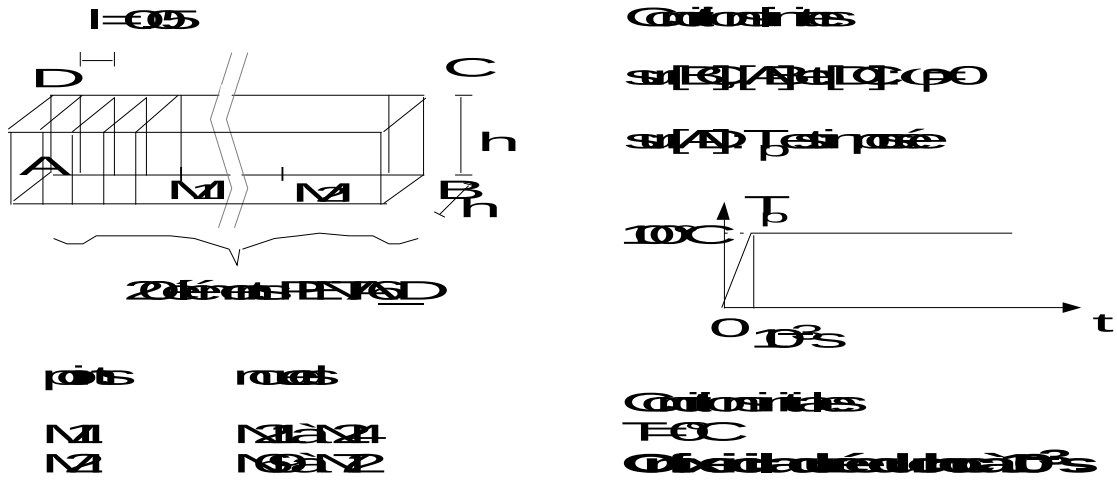
18.1 Values tested

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

19 Modelization K

19.1 Characteristic of modelization

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



19.2 Characteristics of the mesh

Many nodes: 84
Number of meshes and types: 40 PENTA6

20 Results of the modelization K

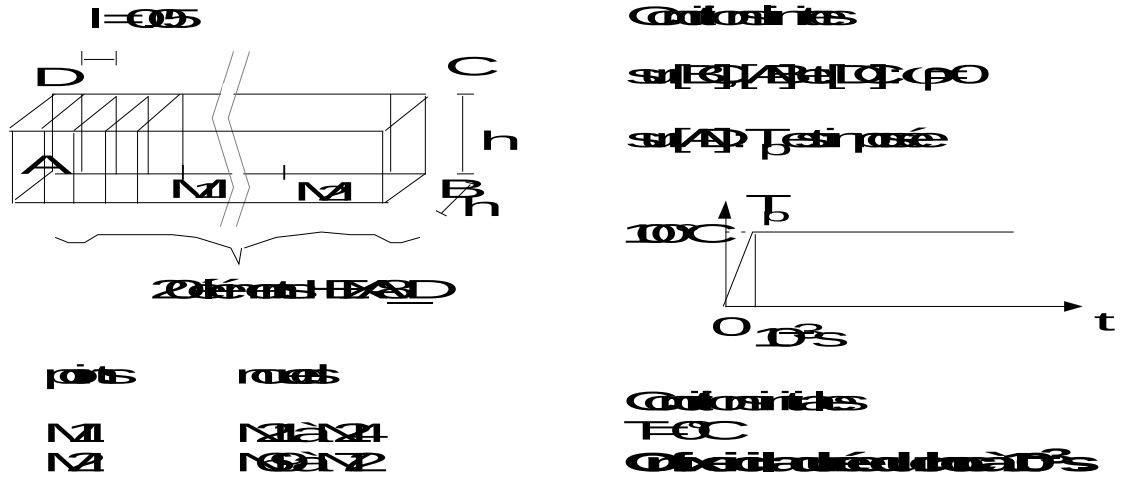
20.1 Values tested

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 Modelization L

21.1 Characteristic of modelization

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



21.2 Characteristics of the mesh

Many nodes: 84
Number of meshes and types: 20 HEXA8

22 Results of the modelization 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 result numerical one.

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