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USER'S MANUAL FOR SAFIR (version 2022)

A COMPUTER PROGRAM FOR ANALYSIS OF STRUCTURES SUBJECTED TO FIRE

Part 2: thermal calculations

by

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This document explains the introduction of data for thermal calculation with the software SAFIR developed at the University of Liege and Jonhs Hopkins University for the simulation of building structures subjected to fire.

Table of content

1. Detailed description of the input file for thermal analyses

SERIES 1: COMMENTS

A. Multiple cards (can be 0)

As many lines as required may be introduced by the user at the beginning of the file to comment the content of the file. These comments will not influence in any manner the results of the calculation. They will help understand what the file is about, which may be particularly useful if the file is found and opened several years after it has been created. Experience shows that the users tend to neglect the comments, relying on the characters that are used in [filename] to differentiate several calculations made for a project. Using extensively the possibility of introducing detailed comments in the file is nevertheless highly preferable because it allows reporting much more information.

B. 1 card

1 blank line to indicate that the comments are finished.

SERIES 2: QUANTITY OF NODES

1 card

`NNODE`, *nnode*

- `NNODE`

  Command.

- *nnode*

  Quantity of nodes of the model. Minimum value is 3. There is no maximum value.

```
This file has been created as an example for the users manual of SAFIR
Date: 01/02/2022
Author: Jean-Marc Franssen
This model has 16 nodes

     NNODE   16
```

SERIES 3: QUANTITY OF DIMENSIONS

1 card

NDIM, *ndim*

- NDIM

  Command.

- *ndim*

  Quantity of dimensions of the model.
  - *ndim* = 2 for 2D models.
  - *ndim* = 3 for 3D models.

SERIES 4: DEGREES OF FREEDOM

1 card

NDOFMAX, *1*

- NDOFMAX

  Command.

- *1*

  This card indicates that the maximum quantity of degrees of freedom for the nodes is 1 in a thermal analysis. The degree of freedom is the temperature of the node.

SERIES 5 (optional): CORES OF THE CPU

1 card (optional)

NCORES, *ncores*

- NCORES

  Command.

- *ncores*

  Quantity of cores of the CPU of the computer used by matrix solver. The default value is 1, in which case this card may be omitted.

This card can be used to force SAFIR to use more than 1 core if present on the computer. Experience has shown that using more than 1 core hardly reduces the duration of the runs with the present versions of Pardiso and Windows. This card can thus be omitted as a common practice. The possibility of using the card has nevertheless been given to allow users to perform their own tests on their particular system, and to offer the possibility of working with more than 1 core in the future if new releases of Pardiso and/or Windows show a difference of sun time as a function of the number of cores mentioned in this card.

SERIES 6: THERMAL CALCULATION

A. 1 card, choice between two possible settings.
`COMMAND`

- `COMMAND` = `TEMPERAT`

  is used for a normal thermal calculation from time $t = 0$ to a final time to be defined by the user (see *uptime* in SERIES 21).

- `COMMAND` = `RESTARTT`

  is used if a previous thermal analysis has been made and a new thermal analysis must be restarted from a restart time t_i (to be defined by the user) up to a final time. The temperature field at time t_i is taken from the previous analysis. The new analysis can be performed either on the same structure as the previous analysis or on a new structure that is only one part of the previous structure.

  The first possibility is used if the structural analysis shows that the thermal analysis had been stopped too early.

  The second possibility is used, for example, to consider the fact that some layers of concrete or of protective material have fallen off the structure (what part has fallen off and at what time has to be decided by the user).

The next 3 cards, B, C and D are present only if `RESTARTT` has been entered in card A.
If `TEMPERAT` has been entered in card A, then go directly to card E.

B. 1 card
`FIRSTFILE`, *filename*

- `FIRSTFILE`

  Command.

- *filename*

  Name (comprising the file name and the file type) of the ".OUT" file where the results of the previous thermal analysis have been written. This file must be present in the same folder as the input file of the thermal analysis.

C. 1 card
`FIRSTTIME`, *time*

- `FIRSTTIME`

  Command.

- *time*

  Time (in seconds) when the second analysis will start. The temperatures will be read from the first analysis and used as initial values for the second analysis.

D. 1 card, choice between two possible settings.
COMMAND

- COMMAND = MATCHNODES

  is used if the second structure is exactly the same as the first one or if its nodes were the first nodes of the first structure. In that case, the initial temperature at each node in the second structure is taken as the temperature at the same node in the first structure.

- COMMAND = MATCHCOORD

  allows considering that the initial temperature at each node in the second structure is taken as the temperature of the node of the first structure with same coordinates. This possibility is used if some among the first nodes of the first structure have been deleted when creating the second structure.

E. 1 card
TETA, *teta*

- TETA

  Command.

- *teta*

  Parameter for the time integration. $0 < teta \leq 1$. Values of *teta* close to 0 will force SAFIR to perform the time integration in a nearly explicit manner, whereas *teta* = 1 will lead to a fully implicit integration. *teta* = 0.9 has been used consistently by the developers in their own applications.

F. 1 card
TINITIAL, *tinitial*

- TINITIAL

  Command.

- *tinitial*

  Temperature (in degree Celsius) in the model at time t = 0, usually taken as 20°C.

SERIES 7: CONVERGENCE STRATEGY

1 card, optional, choice between two possible settings.

- `COMEBACK`, *timestepmin*

  `COMEBACK`

  Command.

  timestepmin

  Minimum value for the time step in case of comeback.

- `NOCOMEBACK`

  Command.

Notes :

1) If `NOCOMEBACK` is chosen, the simulation is stopped if convergence is not reached after 18 iterations.
   If `COMEBACK` is chosen, when the convergence is not reached after 6 iterations, time is reset at the last converged step and the simulation restarts from there with a time step divided by 2. The division of the time step goes on until the time step is smaller than *timestepmin*
2) This card is optional. If it is not present, `NOCOMEBACK` will be applied

SERIES 8: DIAGONAL CAPACITY

1 card (optional)

`DIAG_CAPA`

Command.

If this card is present, the capacity matrix of the finite elements is made diagonal. This reduces skin effects which can appear in the direction of non-linear temperature gradients.
If this optional card is not present, the full capacity matrix is used (as was the case in all versions of SAFIR until and including SAFIR 2019).
Utilisation of this capability is recommended and the diagonalised version may become the default setting in the future.

SERIES 9: STORAGE OF RESULTS

A. 1 card (optional), choice between 8 possible settings.
COMMAND

- COMMAND = MAKE.TEM
  stores the average temperature of the elements for a subsequent structural analysis. The section analysed here is the cross section of a beam.
- COMMAND = MAKE.TEMHA
  is similar to MAKE.TEM, but the fire is a localized fire as described in Annex C of EN 1991-1-2 (equation C.4, flame impacting the ceiling – Hasemi fire), see Section 2. The sections analysed here are the cross section of a beam.
- COMMAND = MAKE.TEMLF
  is similar to MAKE.TEM, but the fire is a localized fire as described in the RFCS research report LOCAFI, see Section 2. The sections analysed here are the cross section of a beam.
- COMMAND = MAKE.TEMCD
  is similar to MAKE.TEM, but the effects of the fire are described in a transfer file computed by a CFD analysis (made, for example, with FDS). The sections analysed here are the cross section of a beam.
- COMMAND = MAKE.TEMTR
  is similar to MAKE.TEM, but the fire is a travelling fire described as “simple analytical model” in the RFCS research report TRAFIR, see section 3. The sections analysed here are the cross section of a beam.

- COMMAND = MAKE.TSH
  stores the temperature of the first *nnode*/2 nodes for a subsequent structural analysis. The section analysed describes the temperature evolution across the thickness of a shell element.
- COMMAND = MAKE.TSHHA
  is similar to MAKE.TSH, but the fire is a localized fire as described in Annex C of EN 1991-1-2 (equation C.4, flame impacting the ceiling – Hasemi fire), see Section 2. The sections analysed describe the temperature evolution across the thickness of shell elements.
- COMMAND = MAKE.TSHCD
  is similar to MAKE.TSH, but the effects of the fire are described in a transfer file computed by a CFD analysis (made, for example, with FDS). The sections analysed describe the temperature evolution across the thickness of shell elements.

If MAKE.TEM or MAKE.TSH has been entered in card A, then

The next 2 cards, B and C are omitted

else

A file called "*hasemi.txt"* (for MAKE.TEMHA[1] or MAKE.TSHHA), a file called "*locafi.txt"* (for MAKE.TEMLF), a file called "*cfd.txt*" (for MAKE.TEMCD or MAKE.TSHCD), or a file called "*trafir.txt*" (for MAKE.TEMTR) must be present in the same folder as the input file. This file describes the position of the fire in the structure and its thermal characteristics, such as the rate of heat release. The structure of these files is described in Section 2.

B. 1 card (optional)

filename

This is the complete name of the input file of the structural analysis (maximum 20 characters).

> Note: the input file describing the structural analysis must be present in the same folder as the input file for the thermal analysis when the thermal analysis is run. If the structural analysis is 2D, gravity must be pointing downward the **y** axis (i.e. Y is vertical upward). If the structural analysis is 3D, gravity must be pointing downward the **z** axis (i.e. Z is vertical upward).

C. 1 card (optional)

COMMAND, *ielemtype*

- COMMAND, choice between two possible settings.

  COMMAND = BEAM_TYPE if the temperatures are determined in a beam section.

  COMMAND = SHELL_TYPE if the temperatures are determined in a shell section.

- *ielemtype*

  The number in the structural input file of the section type (beam or shell) treated in this thermal analysis.

[1] The name of the file is "*hasemi.txt"*, even if the function HASEMI_FR is used in series 16.

SERIES 10: MATERIALS

A. 1 card
`NMAT`, *nmat*

- `NMAT`
  Command.
- *nmat*
  Quantity of different materials. If two materials have the same name but different thermal properties (such as, e.g., the emissivity) or different mechanical properties (such as, e.g., the yield strength), this makes two different materials.

SERIES 11: ELEMENTS

A. 1 card
`ELEMENTS`
Command.

B. 1 card
`SOLID`, *nsolid*

- `SOLID`
  Command.
- *nsolid*
  Quantity of SOLID elements in the model. Thermal calculations are based on SOLID elements.

C. 1 card
`NG`, *ng*

- `NG`
  Command.
- *ng*
  Quantity of integration points in each direction in the elements. Not less than 1, not greater than 3. 2 has been used consistently by the developers in their own applications.

D. 1 card (to be omitted if *ndim* = 3)
`NVOID`, *nvoid*

- `NVOID`
  Command.
- *nvoid*

Quantity of internal voids, also called internal cavities, i.e., areas in the section where there is no material but there is heat transfer between the walls that make the cavity by convection and by radiation. 0 must be typed if there is no cavity in the model. In the present version of SAFIR (2022), internal cavities can be present only in 2D models.

E. 1 card (optional)

This card is present only if *nvoid* ≠ 0

FRTIERVOID, *nfrontiervoid*

- FRTIERVOID
  Command.
- *nfrontiervoid*
  Maximum (for all the voids of the section) quantity of surfaces (i.e. sides of finite elements) enclosing the internal voids.
  For example, if a section has 2 cavities and one of them is enclosed by 50 surfaces, whereas the second one is enclosed by 30 surfaces, then *nfrontiervoid* is equal to 50.
  If one finite element has two of its sides that define a void, this makes two different frontiers.

F. 1 card

END_ELEM
Command.

The input file, starting after the blank line that follows the comments, may now look like this.

```
    NNODE   16
     NDIM    2
  NDOFMAX    1
TEMPERAT
     TETA       0.9
TINITIAL      20.0
     NMAT    2
ELEMENTS
    SOLID    9
       NG    2
    NVOID    0
END_ELEM
```

SERIES 12: NODES

A. 1 card

`COMMAND`, choice between two possible settings.

- `COMMAND` = `NODES`

  The position of the nodes will be given in a Cartesian system of coordinates, see Figure 1.

- `COMMAND = NODES_CYL`

  The position of the nodes will be given in a cylindrical system of coordinates. Cylindrical coordinates are transformed for the internal solution process by the following equations:

  if *ndim* = 2 (r,θ) => X = r cos(θ); Y = r sin(θ)

  if *ndim* = 3 (r,θ,Z) => X = r cos(θ); Y = r sin(θ); Z

  Note that θ must be introduced in degrees. The transformation is made after all nodes have been read and the automatic generation and repeat have been made, see card C and D.

Several cards are then written, following the format of B, C or D, until all *nnode* nodes have been given their position.

B. 1 card giving the position of 1 node

`NODE`, *nno*, *rcoordg*(1,*nno*), *rcoordg*(2,*nno*), *rcoordg*(3,*nno*)

- `NODE`

  Command.

- *nno*

  Number of the node.

- *rcoordg*(*1,nno*)

  First coordinate (in meter) of node *nno*.

- *rcoordg*(*2,nno*)

  Second coordinate (in meter or in degree) of node *nno*.

- *rcoordg*(*3,nno*)

  Third coordinate (in meter) of node *nno*. Present only if *ndim* = 3.

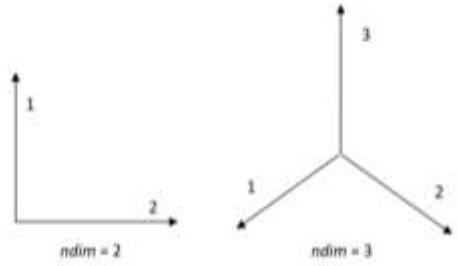

Figure 1: global axes in a Cartesian system of coordinates

C. 1 card (optional) for automatic generation

`GNODE`, *nno*, *rcoordg*(1,*nno*), *rcoordg*(2,*nno*), *rcoordg*(3,*nno*)

- `GNODE`

  This command is used for automatic equidistant generation of nodes between the previously defined node and the node *nno*.
- *nno*

  Number of the node.
- *rcoordg*(*1,nno*)

  First coordinate (in meter) of node *nno*.
- *rcoordg*(*2,nno*)

  Second coordinate (in meter or in degree) of node *nno*.
- *rcoordg*(*3,nno*)

  Third coordinate (in meter) of node *nno*. Present only if *ndim* = 3.

D. 1 card (optional) for repeating a series of nodes

`REPEAT`, *nno*, *delta(1), delta(2), delta(3), kgene*

- `REPEAT`

  This command is used to repeat the definition of the *nno* previously defined nodes with an increment in each coordinate.
- *nno*

  Quantity of nodes to be repeated.
- *delta(1)*

  Increment for the first coordinate (in meters).
- *delta(2)*

  Increment for the second coordinate (in meters or in degrees).
- *delta(3)*

  Increment for the third coordinate (in meters). Present only if *ndim* = 3.
- *kgene*

  Quantity of times that the previous *nno* defined nodes have to be repeated.

For example, the following series of cards:

```
      NODES
       NODE     1      0.000      0.000
       GNODE    4      0.000      0.120
      REPEAT    4      0.025      0.010     3
```

is equivalent to:

```
      NODES
       NODE     1      0.000      0.000
       NODE     2      0.000      0.040
       NODE     3      0.000      0.080
       NODE     4      0.000      0.120
       NODE     5      0.025      0.010
       NODE     6      0.025      0.050
       NODE     7      0.025      0.090
       NODE     8      0.025      0.130
       NODE     9      0.050      0.020
       NODE    10      0.050      0.060
       NODE    11      0.050      0.100
       NODE    12      0.050      0.140
       NODE    13      0.075      0.030
       NODE    14      0.075      0.070
       NODE    15      0.075      0.110
       NODE    16      0.075      0.150
```

The nodes that have been generated are shown on Figure 2.

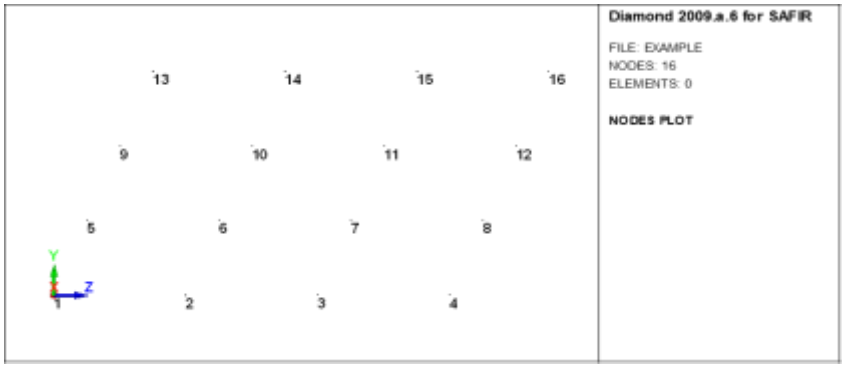

Figure 2: nodes created by GNODE and REPEAT commands

Note: If *ndim* = 2 and the results of a thermal analysis are to be used in the structural analysis of beam elements, then the first coordinate corresponds to the local **y** axis of the beam element and the second coordinate corresponds to the local **z** axis of the beam element.

SERIES 13: NODE LINE

This series is only present if `MAKE.TEM`, `MAKE.TEMHA`, `MAKE.TEMLF`, `MAKE.TEMCD` or `MAKE.TEMTR` has been given in series 9, A.

The values entered in this series will not influence the values of the temperatures that will be calculated. They are relevant only for the structural calculation using the beam elements the section of which is described in the discretization made for the thermal analysis[2].

A. 1 card

`NODELINE`, Y_0, Z_0

- `NODELINE`
  Command.
- Y_0
  First coordinate of the node line in the section of the BEAM finite element.
- Z_0
  Second coordinate of the node line in the section of the BEAM finite element.

B. 1 card

`YC_ZC`, Y_C, Z_C

- `YC_ZC`
  Command.
- Y_C
  First coordinate of the centre of rotation in the section of the BEAM finite element.
- Z_C
  Second coordinate of the centre of rotation in the section of the BEAM finite element.

[2] See Part 3

SERIES 14: IMPOSED TEMPERATURES

A. 1 card

`FIXATIONS`

Command.

B. 1 card (optional) at each node where the evolution of the temperature as a function of time is imposed by the user.

`BLOCK`, *nno*, *cblock*(*nno*)

- `BLOCK`

  Command.
- *nno*

  Number of the node where the evolution of the temperature is imposed.
- *cblock*(*nno*)

  Name of the function[3] describing the evolution of the temperature at this node (not longer than 10 characters).

C. 1 card (optional) for each master-slave relationship

`SAME`, *nno1*, *nno2*, `YES`

- `SAME`

  Command.
- *nno1*

  Number of the slave node (its temperature is forced to be equal to the temperature of the master node).
- *nno2*

  Number of the master node (a master node can have several slave nodes. A `SAME` card must be introduced for each slave).
- `YES`

  Command.

D. 1 card (optional) to repeat the previous `SAME` command

`REPEAT`, *n*, *incr*, `YES`

- `REPEAT`

  Command.
- *n*

  Quantity of times that the previous `SAME` command has to be repeated.
- *incr*

  Increment on the node numbers *nno1* and *nno2* of the previous `SAME` command.
- `YES`

[3] See Part 1, Section 5.5

Command.

E. 1 card (optional) to create master-slave relationship between all nodes that have the same coordinates

`SAMEALL, YES`

- `SAMEALL`

  Command. All the nodes of the model that have the same coordinates (with a precision of 10^{-8} m) will automatically be attributed a master-slave relationship.

- `YES`

  Command.

F. 1 card

`END_FIX`

Command indicating the end of the series.

SERIES 15: SOLID ELEMENTS

A. 1 card

`NODOFSOLID`

Command.

Several cards are then written, following the format of B, C or D, until all *nsolid* elements have been described.

B. 1 card for 1 element

`ELEM`, *nsol, NodesOfSolid*(1,*nsol*), *NodesOfSolid*(2,*nsol*), … ,
NodesOfSolid(*NumberOfNodesInSolid*,*nno*), *matsolid*(*nsol*), *epsrsolid*(*nsol*)

- `ELEM`

  Command.

- *nsol*

  Number of the element.

- *NodesOfSolid*(*1*,*nsol*)

  First node of element *nsol*.

- *NodesOfSolid*(*2*,*nsol*)

  Second node of element *nsol*.

…

- *NodesOfSolid*(*NumberOfNodesInSolid*,*nsol*)

  Last node of element *nsol*.

- *matsolid*(*nsol*)

Material number of the element *nsol.* The materials are numbered from 1 to nmat according to the order appearing in series 20.

- *epsrsolid(nsol)*

  Residual stress (in Pa or N/m²) in element *nsol*. The values entered for *epsrsolid* will not influence the values of the temperatures that will be calculated. They are relevant only for the structural calculation using the beam elements the section of which is described in the discretization made for the thermal analysis[4]. Residual stresses are relevant when *ndim* = 2 and `MAKE.TEM`, `MAKE.TEMHA`, `MAKE.TEMLF`, `MAKE.TEMCD` or `MAKE.TEMTR` have been given in Series 9-A. In other cases, any value can be specified, preferably 0.

If *ndim* = 2, *NumberOfNodesInSolid* = 4.

For triangular elements, *NodesOfSolid*(4,*nsol*) = 0

If *ndim* = 3, *NumberOfNodesInSolid* = 8.

For elements which have a triangular base:

- *NodesOfSolid*(7,*nsol*) and *NodesOfSolid*(8,*nsol*) = 0 for prismatic elements (6 nodes)
- *NodesOfSolid*(5,*nsol*) to *NodesOfSolid*(8,*nsol*) = 0 for tetrahedral elements (4 nodes)

In 2D elements, the nodes must be given in counterclockwise order, see Figure 3. The order of the nodes defines the order of the faces, which will be used to allocate boundary conditions in Series 16 and to define internal cavities in Series 17.

[4] See User's manual for SAFIR 2022, Part 3

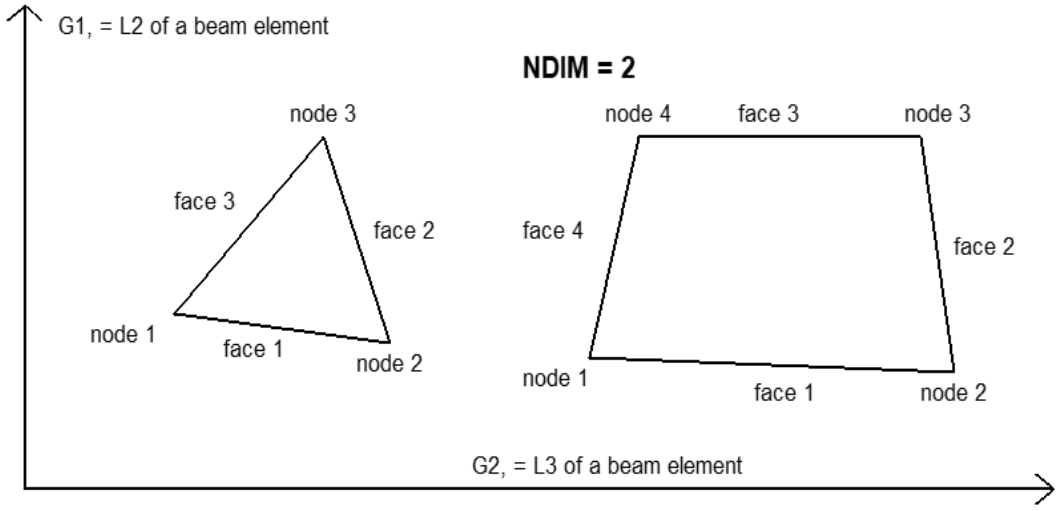

Figure 3: nodes and faces of elements for 2D analyses

In 3D elements with 6 nodes, nodes 1, 2, 3 must belong to one of the triangular faces and nodes 4, 5, 6 to the other one, with the order 1, 2, 3 drilling into the element and 4, 5, 6 drilling out of the element. Node 4 must be on the same edge as node 1, and thus 5 with 2 and 6 with 3, see Figure 4.

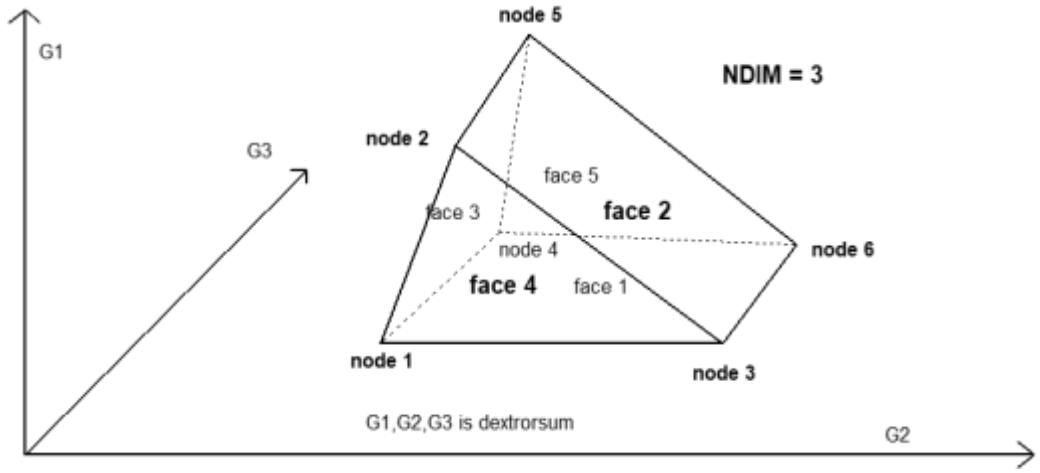

Figure 4: nodes and faces of elements with 6 nodes for 3D analyses

In 3D elements with 8 nodes, nodes 1, 2, 3, 4 must belong to one frontier and nodes 5, 6, 7, 8 to the opposite one, with the order 1, 2, 3, 4 drilling into the element 5, 6, 7, 8 drilling out of the element, see Figure 5. Node 5 must be on the same edge as node 1, and thus 6 with 2, etc.

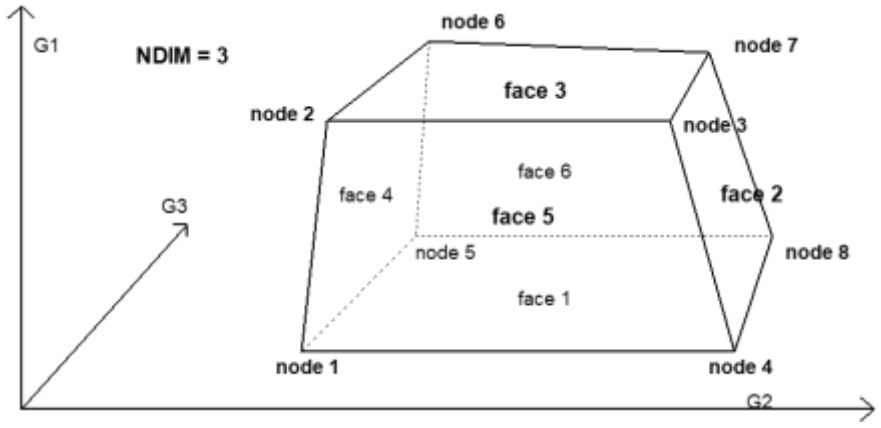

Figure 5: nodes and faces of elements with 8 nodes for 3D analyses

In 3D elements with 4 nodes, nodes 1-2-3 in that order drill into the element; see Figure 6.

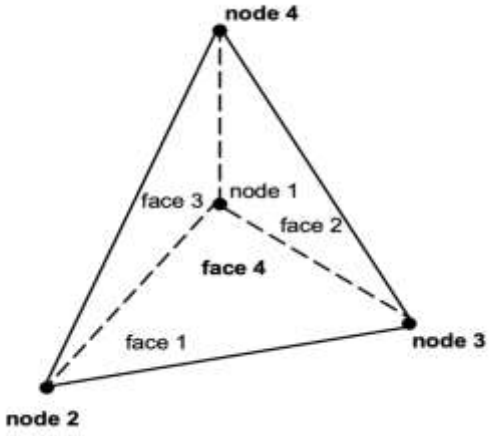

Figure 6: nodes and faces of elements with 4 nodes for 3D analyses

.

Note: Only hexahedral and octahedral elements can be used in a 3D mechanical analysis. Tetrahedral elements are not supported.

C. <u>1 card (optional) for automatic generation</u>

`GELEM`, *nsol*, *NodesOfSolid*(1,*nsol*), *NodesOfSolid*(2,*nsol*), … , *NodesOfSolid*(*NumberOfNodesInSolid*,*nno*), *matsolid*(*nsol*), *epsrsolid*(*nsol*), *kgene*

- `GELEM`

Command.

- *nsol*
  Number of the element.
- *NodesOfSolid*(*1*,*nsol*)
  First node of element *nsol*.
- *NodesOfSolid*(*2*,*nsol*)
  Second node of element *nsol*.

…

- *NodesOfSolid*(*NumberOfNodesInSolid*,*nsol*)
  Last node of element *nsol*.
- *matsolid*(*nsol*)
  Material number of the element *nsol.* The materials are numbered from 1 to nmat according to the order appearing in series 20.
- *epsrsolid(nsol)*
  Residual stress (in Pa or N/m²) in element *nsol*.
- *kgene*
  The elements from the previously defined one up to this one will be generated automatically. *kgene* is the increment of the nodes from one element to the next one.

D. 1 card (optional) for repeating a series of elements

`REPEAT`, *n*, *incr*, *kgene*

- `REPEAT`
  Command.
- *n*
  Quantity of elements to be repeated.
- *incr*
  Increment in the node numbers.
- *kgene*
  Number of times that the *n* elements have to be repeated.

For example, the following series of cards:

```
 FIXATIONS
   END_FIX
NODOFSOLID
      ELEM    1    1    2    6    5    1    0
     GELEM    3    9   10   14   13    1    0    4
    REPEAT    3    1    2
```

is equivalent to:

```
 FIXATIONS
   END_FIX
NODOFSOLID
      ELEM    1    1    2    6    5    1   0.0000E+00
      ELEM    2    5    6   10    9    1   0.0000E+00
      ELEM    3    9   10   14   13    1   0.0000E+00
      ELEM    4    2    3    7    6    1   0.0000E+00
      ELEM    5    6    7   11   10    1   0.0000E+00
      ELEM    6   10   11   15   14    1   0.0000E+00
      ELEM    7    3    4    8    7    1   0.0000E+00
      ELEM    8    7    8   12   11    1   0.0000E+00
      ELEM    9   11   12   16   15    1   0.0000E+00
```

It will generate the elements shown on Figure 7.

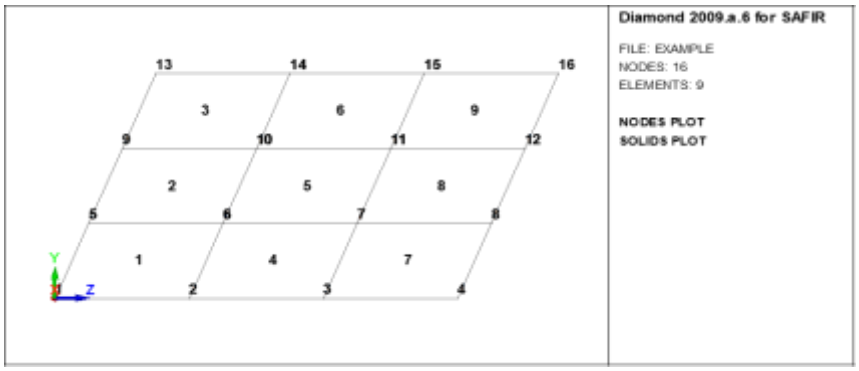

Figure 7: elements created by GELEM and REPEAT

When all elements have been defined, it is possible to change the material of one or several elements. This can be useful if the input file has been created with a text editor and extensive utilization has been made of the `GELEM` and `REPEAT` commands[5].

E. <u>1 card (optional) for each element in which the material has to be changed</u>
`NEW_MAT`, *nsol*, *matsolid*(*nsol*)

- `NEW_MAT`
  Command.
- *nsol*
  Number of the element in which the material must be changed.
- *matsolid*(*nsol*)
  Number of the material to be given to the element *nsol.*

[5] `NEW_MAT` is typically used to create a steel rebar in a concrete section.

For example, the following series of cards:

```
NODOFSOLID
      ELEM    1    1    2    6    5    1    0
     GELEM    3    9   10   14   13    1    0    4
    REPEAT    3    1    2
   NEW_MAT    5    2
```

will allocate the materials to the elements as shown on **Erreur ! Source du renvoi introuvable.** if `STEELEC3EN` is the first material name and `CALCONC_EN`[6] is the second one, see series 20. Without the `NEW_MAT` command, the description of the elements with the appropriate materials would require 7 cards, instead of 4 cards in the example shown here. The utilisation of the `REPEAT` command would indeed not be possible.

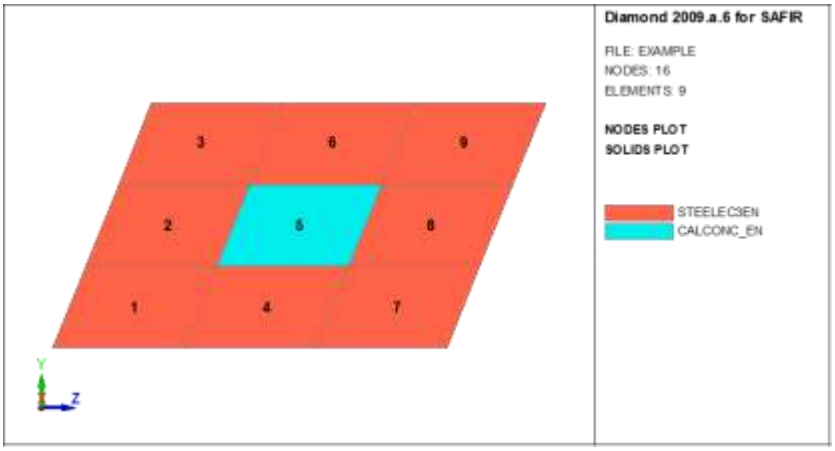

Figure 8: new material assigned

SERIES 16: FRONTIERS

Different cards can be used to allocate boundary conditions to selected surfaces of some elements. Two different boundary conditions can be used:

- either a time-temperature fire curve T_g describes the environment around the model (commands `F` and `GF`). The heat flux q at the boundary will be calculated

[6] This material is now obsolete and should be replaced by `CONCEN2020`

from the temperature of the fire curve T_g and the temperature on the surface T_s according to Eq. (1):

$$q = h(T_g - T_s) + \sigma\varepsilon(T_g^4 - T_S^4) \quad (1)$$

in which the coefficient of convection *h* for surfaces exposed to fire (see Series 20 C) will be considered if T_g > 20°C+*precision* (see series 19). If this condition is not fulfilled, the coefficient for surfaces not exposed to fire will be considered. σ is the Stefan-Boltzmann constant (5.67 x 10^{-8} $Wm^{-2}K^{-4}$) and ε is the relative emissivity of the material at the surface, see Series 20 C.

- or the incipient flux on the model is prescribed (commands `FLUX` and `GFLUX`), either with a value defined by the user, or computed by one of the local fire models (HASEMI, LOCAFI, CFD and TRAFIR).

A. 1 card

`FRONTIER`

Command

B. 1 card for each element that has at least one surface exposed to a fire curve

`F`, *nsol, cfrontiersolid*(1,*nsol*), … ,*cfrontiersolid*(*NumberOfFrontier*,*nsol*),

- `F`

  Command.
- *nsol*

  Number of the element.
- *cfrontiersolid*(*1*,*nsol*)

  Function describing the fire curve on frontier 1 of element *nsol*.

…

- *cfrontiersolid(NumberOfFrontier,nsol)*

  Function describing the fire curve on the last frontier of element *nsol*.

If *ndim* = 2, *NumberOfFrontier* = 4.

For triangular elements, *cfrontiersolid*(4,*nsol*) = `NO`

If *ndim* = 3, *NumberOfFrontier* = 6.

cfrontiersolid(6,*nsol*) = `NO` for prismatic elements which have a triangular base

cfrontiersolid(5,*nsol*) = `NO`, *cfrontiersolid*(6,*nsol*) = `NO` for tetrahedral elements

The order of the surfaces on the elements is linked to the node numbers.

In triangular elements, see Figure 3,

frontier 1 is from node 1 to node 2,
frontier 2 is from node 2 to node 3,
frontier 3 is from node 3 to node 1.

In quadrangular elements, see Figure 3,

frontier 1 is from node 1 to node 2,
frontier 2 is from node 2 to node 3,
frontier 3 is from node 3 to node 4,
frontier 4 is from node 4 to node 1.

In 3D elements with 6 nodes, see Figure 4,

frontier 1 comprises is defined by the nodes 1, 4, 6, 3,
frontier 2 comprises is defined by the nodes 2, 5, 6, 3,
frontier 3 comprises is defined by the nodes 1, 2, 5, 4,
frontier 4 comprises is defined by the nodes 1, 2, 3,
frontier 5 comprises is defined by the nodes 4, 5, 6.

In 3D elements with 8 nodes, see Figure 5,

frontier 1 comprises is defined by the nodes 1, 5, 8, 4,
frontier 2 comprises is defined by the nodes 4, 3, 7, 8,
frontier 3 comprises is defined by the nodes 2, 6, 7, 3,
frontier 4 comprises is defined by the nodes 1, 2, 6, 5,
frontier 5 comprises is defined by the nodes 1, 2, 3, 4,
frontier 6 comprises is defined by the nodes 5, 6, 7, 8.

In 3D elements with 4 nodes, see Figure 6,

frontier 1 comprises is defined by the nodes 1, 2, 3,
frontier 2 comprises is defined by the nodes 1, 3, 4,
frontier 3 comprises is defined by the nodes 1, 2, 4,
frontier 4 comprises is defined by the nodes 2, 3, 4.

The function describing the fire curve can be

- one of the SAFIR defined function (e.g. `FISO` or `F20`)[7],
- or a user defined function (not longer than 10 characters) located in a file[8],
- or the command `NO` if no fire curve is applied on a particular surface. The meaning of `NO` is not “remove any previously fire curve”; it is more to be understood as “disregard this information”. For example:

```
          F    5      FISO      FISO   NO   NO
```

is equivalent to

```
          F    5      FISO        NO   NO   NO
          F    5        NO      FISO   NO   NO
```

[7] Section 5.5.2 in User’s manual for SAFIR 2022, Part 1
[8] *Ibid.*, Section 5.5.3

C. 1 card for automatic generation of frontiers from the previously defined element to this one

`GF`, *nsol, cfrontiersolid*(1,*nsol*), … ,*cfrontiersolid*(*NumberOfFrontier*,*nsol*), *kgene*

- `GF`
  Command.
- *nsol*
  Number of the element.
- *cfrontiersolid*(*1*,*nsol*)
  Function describing the fire curve on frontier 1 of element *nsol*.

…

- *cfrontiersolid*(*NumberOfFrontier,nsol*)
  Function describing the fire curve on the last frontier of element *nsol*.
- *kgene*
  Increment on the element numbers.

For example

```
         F    1      FISO        NO        NO        NO
        GF    7      FISO        NO        NO        NO    3
         F    1        NO        NO        NO       F20
        GF    3        NO        NO        NO       F20    1
```

is equivalent to

```
         F    1      FISO        NO        NO        NO
         F    4      FISO        NO        NO        NO
         F    7      FISO        NO        NO        NO
         F    1        NO        NO        NO       F20
         F    2        NO        NO        NO       F20
         F    3        NO        NO        NO       F20
```

Figure 9 shows the boundary conditions created by these cards applied on the section that was shown on Figure 7.

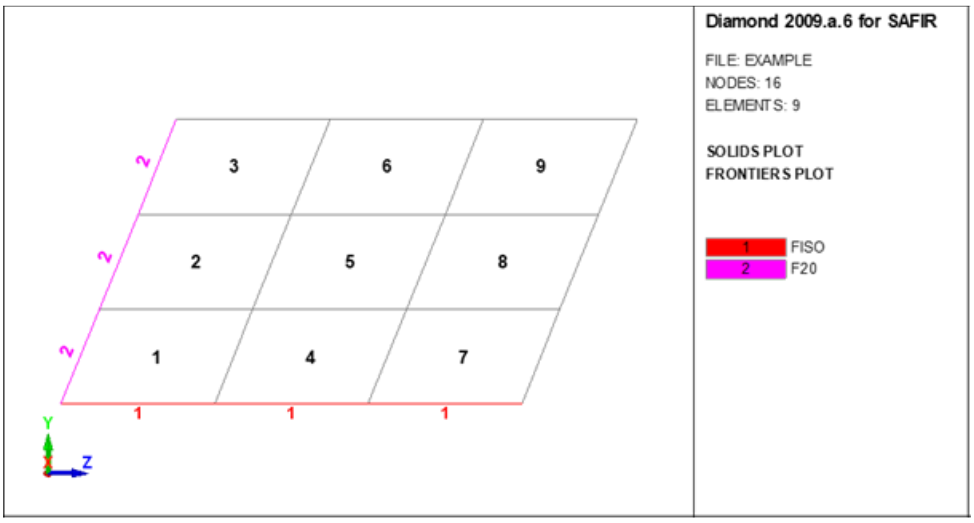

Figure 9: Boundary conditions

D. <u>1 card for each element that has at least one surface exposed to a defined heat flux</u>
`FLUX`, *nsol, cfrontiersolid*(1,*nsol*), … ,*cfrontiersolid*(*NumberOfFrontier*,*nsol*)

- `FLUX`
  Command.
- *nsol*
  Number of the element.
- *cfrontiersolid*(*1*,*nsol*)
  Function describing the flux (in W/m²) on frontier 1 of element *nsol*.

…

- *cfrontiersolid*(*NumberOfFrontier*,*nsol*)
  Function describing the flux (in W/m²) on the last frontier of element *nsol*.

The function describing the flux can be:

- ✓ either one of the SAFIR defined function[9] (e.g. `F1000`) or a user defined function (not longer than 10 characters) located in a file (e.g. [myflux.txt]),
- ✓ or the command `NO` if no flux is applied on a particular surface.

A positive flux means energy introduced in the section.
It is possible to have a flux condition and a fire curve on the same surface.

Each surface of the model heated by a HASEMI local fire must have a `FLUX` command and the function `HASEMI` where appropriate. For example:

```
FLUX    5    NO    NO    HASEMI    NO
```

[9] See section 5.5 in "Users manual of SAFIR 2022 – Part 1 General considerations

There is no need to add a frontier F20 on a surface heated by a HASEMI flux (for reemitting energy); it will be automatically added by SAFIR.

Notes:

1) If the function HASEMI_FR is used in the FLUX command, the flux as given by the Equations of EN 1991-1-2 is multiplied by 0.85, as indicated in the French National Application Document to EN 1991-1-2..
2) A common error made by several users is that they enter the chain of character "HASEMI.TXT" whereas only "HASEMI" is needed in the FLUX command.

Each surface of the model heated by a LOCAFI local fire must have a FLUX command and the function LOCAFI where appropriate. For example:

```
       FLUX     5    NO    NO     LOCAFI    NO
```

There is no need to add a frontier F20 on a surface heated by a LOCAFI flux (for reemitting energy). This effect is included in the model.

Each surface of the model heated by a CFD fire described in a transfer file must have a FLUX command and the function CFD where appropriate. For example:

```
       FLUX     5    NO    NO     CFD    NO
```

There is no need to add a frontier F20 on a surface heated by a CFD flux (for reemitting energy). This effect is included in the model.

E. 1 card for automatic generation from the previously defined element.
`GFLUX`, *nsol, cfrontiersolid*(1,*nsol*), … ,*cfrontiersolid*(*NumberOfFrontier*,*nsol*), *kgene*

- `GFLUX`
  Command.
- *nsol*
  Number of the element.
- *cfrontiersolid*(*1*,*nsol*)
  Function describing the flux (in W/m²) on frontier 1 of element *nsol*.

…

- *cfrontiersolid*(*NumberOfFrontier,nsol)*
  Function describing the flux (in W/m²) on the last frontier of element *nsol*.
- *kgene*
  increment on the element numbers.

F. 1 card
`END_FRONT`
Command indicating the end of the series.

SERIES 17: VOIDS

The following cards A, B, C and D are repeated *nvoid* times, see series 11-D. If *nvoid* = 0 or *ndim* = 3, this series is skipped.

A. 1 card
`VOID`
Command.

B. 1 card for each surface of an element that is adjacent to an internal cavity.
`ELEM`, *nsol, frontiersolid*

- `ELEM`
  Command.
- *nsol*
  Number of the element.
- *frontiersolid*
  Number of the frontier of this element that is adjacent to a cavity (can only be 1, 2, 3 or 4).

If one element has two surfaces that define a void, two cards must be entered. For example:

```
      ELEM     5     2
      ELEM     5     3
```

C. 1 card for automatic generation from the previously defined element.
`GELEM`, *nsol, frontiersolid, kgene*

- `GELEM`
  Command.
- *nsol*
  Number of the element.
- *frontiersolid*
  Number of the frontier of this element that is adjacent to a cavity, see Figure 10.
- *kgene*
  Increment on the element numbers. Can be positive or negative.

D. 1 card
`END_VOID`
Command indicating the end of the cards defining this cavity.

The elements surrounding a cavity can be listed in any order.

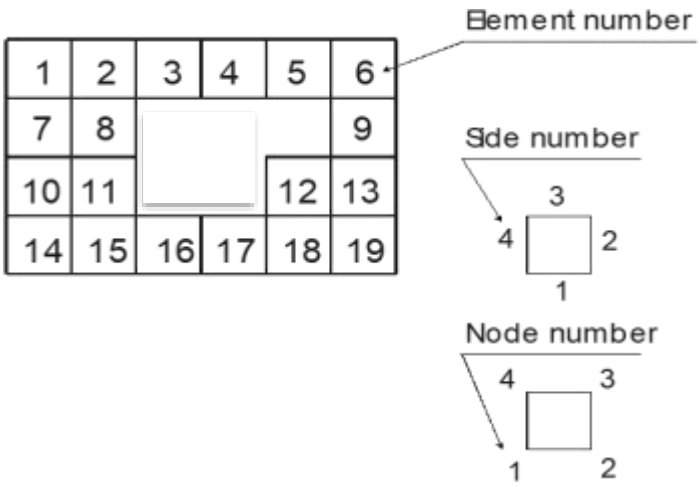

Figure 10; Description of a cavity

For example, **Erreur ! Source du renvoi introuvable.** shows a model with 19 rectangular finite e lements and an internal cavity. The cavity can be described by the following cards[10]:

[10] In this case, *nfrontiervoid* = 10, see series 11-E.

```
     VOID
     ELEM   16    3
     ELEM   17    3
     ELEM   12    4
     ELEM   12    3
     ELEM    9    4
     ELEM    5    1
    GELEM    3    1   -1
     ELEM    8    2
     ELEM   11    2
END_VOID
```

Note: For convection inside the cavity, the coefficient of convection on unexposed surfaces is used, irrespective of the temperature of the air in the cavity. This is to account for the low level of turbulence expected to take place in the cavity.

SERIES 18: SYMMETRIES

A. 1 card

`SYMMETRY`

Command.

The following cards B, C and D are optional. If no symmetry is used when creating the model, only cards A and E are present. Symmetries can only be used in 2D models but this card is nevertheless needed also in 3D models.

B. 1 card for each real axis of symmetry in the section

`REALSYM`, *nno1, nno2*

- `REALSYM`

  Command.
- *nno1*

  Number of the first node defining the axis of symmetry.
- *nno2*

  Number of the second node defining the axis of symmetry.

The line passing through nodes *nno1* and *nno2* is a real axis of symmetry for the model. This possibility is used when the 2D model represents part of a beam section. When creating the ".TEM" file, the fibres located on the other side of the axis of symmetry are created, with the same sectional area, same material number and same temperature.

This card can be repeated several times with different successive axes of symmetry. If it is used *n* times, the section represented in the ".TEM" file will be 2^n times bigger than the one modelled for the thermal analysis.

C. 1 card if the **y** axis is an axis of symmetry in the section.

`YSYM`

Command.

This card is used if the first axis of coordinate of the model, i.e., the local **y** axis for the beam element, is a thermal and structural axis of symmetry. When creating the ".TEM" file, the area of all fibres is simply multiplied by 2.

This card can only be used when the structural model is a 2D model. Another possible option is not to use the `YSYM` command and divide the loads applied on the structure by a factor of two[11].

The `YSYM` command can be used simultaneously with one or several `REALSYM` commands.

D. 1 card if it is desired to analyse a section of 1 meter width.

`WIDTH`, *width*

- `WIDTH`

  Command.

- *width*

  Width of the section. If this command is used, the area of all fibres is divided by *width*. As a result, the section is representative of a section with a width of 1 meter. This command is used essentially for sheet piles of for retaining walls; it allows applying, in the structural analysis, loads on the wall defined per square meter, even if the width of the section represented in the thermal analysis is different from 1 meter.

[11] It is even simpler to model the complete section and not to bother about symmetries. This will nevertheless slightly increase the run times and could be an issue when local fire models are used.

E. 1 card for each axis of symmetry in a cavity.

`SYMVOID`, *nno1, nno2, nvoid*

- `SYMVOID`
  Command.
- *nno1*
  Number of the first node defining the axis of symmetry.
- *nno2*
  Number of the second node defining the axis of symmetry.
- *nvoid*
  Number of the cavity in which this axis of symmetry must be considered.

This card influences the calculation of the view factors in the cavity; the model as described by the user (and by the eventual previous SYMVOID commands) is copied virtually on the other side of the SYMVOID axis when computing the view factors.. It is theoretically possible to have as much as 4 different SYMVOID in a cavity, but the validity of the procedure has been verified only with 2 axes of symmetry in a cavity.

If a SYMVOID axis is also a real axis of symmetry, a `REALSYM` command must also be defined for this axis to modify the quantity of fibres in the TEM file, see series 18-B..

F. 1 card

`END_SYM`

Command to indicate the end of this series.

SERIES 19: PRECISION

A. 1 card

`PRECISION`, *precision*

- `PRECISION`
  Command.
- *precision*
  Small value which must be reached to have convergence.

The value of *precision* is used as a small number at different locations in SAFIR. A good value depends on the type of model that is being analysed and the experience of the user is useful to choose a good value. 2×10^{-3} is normally acceptable for thermal calculations.

SERIES 20: MATERIALS

A. 1 card

`MATERIALS`

Command

All *nmat* materials (see Series 10) must be described here. A material is described by:

- a number, from 1 to *nmat*. The number is defined automatically by the order of appearance in the input file, from 1 for the first material to *nmat* for the last one;
- a name, given in cards B. Different materials in a model can have the same name (with the exception of `USERx`, see below). This will be the case if similar materials have different thermal and/or mechanical properties.
- materials properties which depend on the type of material. They are given in cards C.

The descriptions hereafter give the content of cards B and C for the materials that can be used in a thermal analysis.

> Note: Many materials require two coefficients of convection, one for heated surfaces, and one for unheated surfaces. For SAFIR, a surface is heated if a FRONTIER condition is applied (see SERIES 16) and the temperature of the gas is greater than 20°C. If one of these two conditions is not met, the coefficient on unheated surface is used.
> This can cause unexpected discontinuous behaviour if a physically based fire curve cools down to 20°C, as the coefficient of convection will suddenly change at this time. This can be avoided by either choosing the same value for both coefficients of convection, or cooling the fire down to 21°C.

INSULATION: material with constant thermal properties

B. 1 card

`INSULATION`

Name of the material.

C. 1 card

k, c, rho, w, Tstart, Tend, h_h, h_c, ε

- *k*

  Thermal conductivity, in W/mK.

- *c*

  Specific heat, in J/kg K.

- *rho*

  Specific mass of the dry material, in kg/m³.

- *w*

  Water content, in kg/m³.

- *Tstart*

  Temperature at which evaporation starts.

- *Tend*

  Temperature at which evaporation ends.

- h_h

  Coefficient of convection on heated surfaces, in W/m²K.

- h_u

  Coefficient of convection on unheated surfaces, in W/m²K.

- ε

  Emissivity (no dimension).

Note: *Tstart* and Tend may be taken as, for example, 100°C and 120°C. Reducing the spread between *Tstart* and *Tend* leads to more pronounced plateau in the evolution of the temperature but slows down convergence.

USERx: material with some thermal properties that vary with temperature.

B. 1 card

`USERx`, *ntemperature*

- `USERx`

  Name of the material. Ten different materials are possible, namely `USER1`, `USER2`, … `USER10`. As an exception to all other material types, only one material number can have the name `USER1`, only one material can have the name `USER2`, etc.

- *ntemperature*

  Quantity of temperatures at which the thermal properties are given. Properties are given at a certain quantity of temperatures, given in increasing order. Linear interpolation is made for intermediate temperatures.
  The value of *ntemperature* cannot be smaller than 2.

C. *ntemperature* cards

Card 1

T, k, c, rho, w, Tstart, Tend, h_h, h_c, ε, *r*

- *T*

  First temperature (in degree Celsius) at which thermal properties are given.

- *k*

  Thermal conductivity at *T*, in W/mK.

- *c*

  Specific heat at *T*, in J/kg K.

- *rho*

  Specific mass of the dry material at *T*, in kg/m³.

- *w*

  Water content, in kg/m³.

- *Tstart*

  Temperature at which evaporation starts.

- *Tend*

  Temperature at which evaporation ends.

- h_h

  Coefficient of convection on heated surfaces, in W/m²K.

- h_u

  Coefficient of convection on unheated surfaces, in W/m²K.

- ε

  Emissivity (no dimension).

- *r*

  Any positive value (and 0) will force *k, c, rho* to be non reversible. This means that, during cooling from a maximum temperature T_{max}, these properties will keep the value that was valid for T_{max}. Any negative value will force these properties to be reversible, which means that the value of the property only depends on its current temperature, be it during heating or during cooling.

Card 2 to *ntemperature*

T, k, c, rho

- *T*

  Temperature (in degree Celsius) at which thermal properties are given.

- *k*

  Thermal conductivity at *T*, in W/mK.

- *c*

  Specific heat at *T*, in J/kg K.

- *rho*

  Specific mass of the dry material at *T*, in kg/m³.

Take care that the temperatures calculated at the nodes of the model during the iteration process do not go outside the interval of temperatures given by the card N°1 and the card N°*ntemperature*.

As an example, the following 12 cards have been used to represent concrete of EN 1992-1-2, according to the French National Application document[12].

```
USER1   12
   0.    2.0000      900.     2300.      34.5      100.      120.  25.   4.       0.7   1.
  50.    1.8801      900.     2300.
 100.    1.7656      900.     2300.
 115.    1.7323      915.     2300.
 140.    1.6778      940.     2286.
 160.    1.1570      960.     2276.
 200.    1.1108     1000.     2254.
 400.    0.9072     1100.     2185.
 600.    0.7492     1100.     2145.
 800.    0.6368     1100.     2105.
1000.    0.5700     1100.     2064.
1200.    0.5488     1100.     2024.
```

[12] Equivalent to the material CONCEN2020

GYPSUM: Gypsum plaster boards

B. 1 card

`X_GYPSUM or C_GYPSUM`

Name of the material.

C. 1 card

h_h, h_c, ε

- h_h

  Coefficient of convection on heated surfaces, in W/m²K.

- h_u

  Coefficient of convection on unheated surfaces, in W/m²K.

- ε

  Emissivity (no dimension).

C_GYPSUM has a 20°C density of 732 kg/m³, whereas X_GYPSUM has a 20°C density of 648kg/m³.

Gypsum type materials lead to a slow convergence of the iterations during the time integration process because of the various peaks in the curve of equivalent specific heat. A time step as small as 1 second may be required.

Sprayed Fire Resistive Material with adjustable thermal properties

SFRM_PROBA is an insulation material with temperature-dependent thermal properties. The thermal properties are based on a probabilistic model calibrated on a NIST study of 3 sprayed fire resistive materials. The details of the probabilistic formulation are taken from: Khorasani N.E., Gardoni P., Garlock M. (2015). "Probabilistic fire analysis: material models and evaluation of steel structural members". *JSE*, *141*(12).

A. 1 card

SFRM_PROBA

Name of the material.

B. 1 card

eps_k, eps_c, eps_rho, w, Tstart, Tend, h_h, h_c, ε

- *eps_k*

  Value of the standard normal parameter ε for the probabilistic evaluation of the temperature-dependent thermal conductivity. A positive (resp. negative) value leads to a conductivity higher (resp. lower) than the average measured experimentally[13].

- *eps_c*

  Value of the standard normal parameter ε for the probabilistic evaluation of the temperature-dependent specific heat. A positive (resp. negative) value leads to a specific heat higher (resp. lower) than the average measured experimentally.

- *eps_rho*

  Value of the standard normal parameter ε for the probabilistic evaluation of the temperature-dependent specific mass of the dry material. A positive (resp. negative) value leads to a specific mass higher (resp. lower) than the average measured experimentally.

- *w*

  Water content, in kg/m³.

- *Tstart*

  Temperature at which evaporation starts.

- *Tend*

  Temperature at which evaporation ends.

- h_h

  Coefficient of convection on heated surfaces, in W/m²K.

- h_u

  Coefficient of convection on unheated surfaces, in W/m²K.

- ε

  Emissivity (no dimension).

[13] See Users manual of SAFIR 2022, Part 5.

CONCRETE of EN 1992-1-2, new generation published in 2020[14]:

A. 1 card
CONCEN2020
Name of the material.

B. 1 card
rho, w, h_h, h_c, ε
- *rho*
  Specific mass of concrete (including moisture content), in kg/m³.
- *w*
  Water content, in kg/m³.
- h_h
  Coefficient of convection on heated surfaces, in W/m²K.
- h_u
  Coefficient of convection on unheated surfaces, in W/m²K.
- ε
  Emissivity (no dimension).

LIGHT WEIGTH CONCRETE of EN 1994-1-2: 2004

B. 1 card
LWCONC_EN
Name of the material.

C. 1 card
rho, w, h_h, h_c, ε
- *rho*
  Specific mass of concrete (including moisture content), in kg/m³.
- *w*
  Water content, in kg/m³.
- h_h
  Coefficient of convection on heated surfaces, in W/m²K.
- h_u
  Coefficient of convection on unheated surfaces, in W/m²K.
- ε
  Emissivity (no dimension).

[14] Latest version : prEN 1992-1-2:2021-09

CONCRETE of EN 1992-1-2: 2004

A. 1 card

`CALCONC_EN` or `SILCONC_EN`

Name of the material.

B. 1 card

rho, w, h_h, h_c, ε, *k*

- *rho*

  Specific mass of concrete (including moisture content), in kg/m³.

- *w*

  Water content, in kg/m³.

- h_h

  Coefficient of convection on heated surfaces, in W/m²K.

- h_u

  Coefficient of convection on unheated surfaces, in W/m²K.

- ε

  Emissivity (no dimension).

- *k*

  Parameter that dictates the thermal conductivity λ_c according to the following equation:

  $$\lambda_c = \lambda_l + k(\lambda_u - \lambda_l)$$

  with

  λ_l the lower limit corresponding to curve 2 in Figure 3.7 of EN 1992-1-2;

  λ_u the upper limit corresponding to curve 1 in Figure 3.7 of EN 1992-1-2.

CARBON STEEL of EN 1993-1-2: 2005 or EN 1992-1-2: 2004

B. 1 card

`STEELEC3EN or STEELEC2EN`

Name of the material.

C. 1 card

h_h, h_c, ε

- h_h

  Coefficient of convection on heated surfaces, in W/m²K.

- h_u

  Coefficient of convection on unheated surfaces, in W/m²K.

- ε

  Emissivity (no dimension).

STAINLESS STEEL of EN 1993-1-2: 2005

B. 1 card

`STAINLESS`

Name of the material.

C. 1 card

h_h, h_c, ε

- h_h

  Coefficient of convection on heated surfaces, in W/m²K.

- h_u

  Coefficient of convection on unheated surfaces, in W/m²K.

- ε

  Emissivity (no dimension).

STAINLESS STEEL of FprEN 1993-1-2: 2023-05

B. 1 card

'SS1.4301', 'SS1.4307', 'SS1.4318', 'SS1.4420', 'SS1.4401', 'SS1.4404', 'SS1.4541', 'SS1.4571' for austenitic stainless steels,

'SS1.4362', 'SS1.4062', 'SS1.4482', 'SS1.4462', 'SS1.4162', 'SS1.4662' for duplex stainless steels,

'SS1.4509', 'SS1.4521', 'SS1.4621', 'SS1.4003', 'SS1.4016' for ferritic stainless steels.

Name of the material.

C. 1 card

h_h, h_c, ε

- h_h

  Coefficient of convection on heated surfaces, in W/m²K.

- h_u

  Coefficient of convection on unheated surfaces, in W/m²K.

- ε

  Emissivity (no dimension, 0.4 is the recommended value).

GALVANIZED STEEL:

B. 1 card

GALVASTEEL

Name of the material.

C. 1 card

h_h, h_c

- h_h

  Coefficient of convection on heated surfaces, in W/m²K.

- h_u

  Coefficient of convection on unheated surfaces, in W/m²K.

The behaviour of GALVASTEEL is the same as that of STEELEC3EN from EN1993-1-2 except that the emissivity is set to 0.35 up to 500°C and then 0.7 for T > 500°C.

ALUMINUM of EN 1999-1-2: 2007

B. 1 card

`AL6061_T6, AL6063_T6, AL5083_O, AL5083_H12`

Name of the material.

C. 1 card

h_h, h_c, ε

- h_h

  Coefficient of convection on heated surfaces, in W/m²K.

- h_u

  Coefficient of convection on unheated surfaces, in W/m²K.

- ε

  Emissivity (no dimension).

WOOD of EN 1995-1-2: 2004

A. 1 card

WOODEC5

Name of the material.

B. 1 card

rho, w, h_h, h_c, ε, *r, l, m, n*

- *rho*

  Specific mass of wood (including moisture content), in kg/m³.

- *w*

  Water content, in % of the dry mass.
  If, for example, *rho* = 450 kg/m³ and *w* = 12, the density of dry wood is 450 / (1+12/100) = 401.7 kg/m³

- h_h

  Coefficient of convection on heated surfaces, in W/m²K.

- h_u

  Coefficient of convection on unheated surfaces, in W/m²K.

- ε

  Emissivity (no dimension).

- *r*

  Ratio of conductivity along the grain by conductivity perpendicular to the grain (no dimension), usually greater than 1.

- *l, m, n*

  The vector < *l* ; *m* ; *n* > gives the direction of the grain. It does not have to be a length of 1 because it will be normalised to 1 by SAFIR. Direction of the grain is essential for 3D analyses.

  Vector components for 2D analysis are given in the order < y ; z ; x > with *y* vertical upward and *z* horizontal to the right, see Figure 1. Most 2D analyses are performed on the section of a beam or a column and the grain is perpendicular to the section, with a vector < 0 ; 0; 1 >. If grain direction is parallel to **z**-axis, for example, then the vector should be < 0 ; 1 ; 0 >.
  In 2D models, two different possibilities are thus possible to define an isotropic material:

  - ✓ specifying a vector < 0 ; 0 ; 1 >
  - ✓ specify r = 1

  In 3D models, vector components *l, m* and *n* correspond to the axes of the global system of coordinates X, Y and Z

WOOD of prEN 1995-1-2: 2020

A. 1 card
`WOOD2020`
Name of the material.

B. 1 card
Same as for `WOODEC5`

SERIES 21: TIME DISCRETIZATION

A. 1 card
`TIME`
Command.

B. 1 card
Two cases are possible:
1) In an **analysis with** `COMEBACK`, see series 7, a single line must be used because the program adjusts itself the time steps during calculation.
timestep, *uptime*, *timestepmax*
- *timestep*
  Initial time step in seconds.
- *uptime*
  Time for end of the calculation.
- *timestepmax*
  Maximum value of the time step.

```
   TIME
     2.     3600.       16.
ENDTIME
```

In the example above, the simulation will start with a time step of 2 seconds, and it will vary automatically between a minimum given in the COMEBACK command and a maximum of 16 seconds, depending on the number of iterations that are requested in the successive time steps. The simulation will stop after 1 hour of fire.

2) In an **analysis with** `NOCOMEBACK`, several lines can be given (maximum of *idimtimestep* lines, = 100 in SAFIR2022).
One line added for each time frame added.
timestep, *uptime*

- *timestep*
  Time step in seconds.
- *uptime*
  Limit of validity of this time step

```
    TIME
     12.     3600.
     20.     7200.
ENDTIME
```

The example above leads to a time step of 12 seconds being used during the first hour, then 20 seconds up to 2 hours, time when the simulation will be stopped.

C. 1 card, time last line
One line, end of time discretization series.
`ENDTIME`
Command.

SERIES 22: OUTPUT RESULTS

A. 1 card
`OUTPUT`
Command.

B. 1 card
`TIMEPRINT`
Command.

C. at least 1 card, maximum 16 cards
dt, t

- *dt*
  Time step (in seconds) used for writing the calculated temperatures in the ".OUT" file and in the eventual ".TEM" or ".TSH" files.
- *t*
  Time (in seconds) until which *dt* is used.

D. 1 card

`END_TIMEPR`

Command to indicate the end of the `TIMEPRINT` cards.

The following example leads to a time step of 1 minutes being used for writing the temperatures during the first hour, then 15 minutes up 2 hours:

```
    OUTPUT
 TIMEPRINT
                60.     3600.
               900.     7200.
END_TIMEPR
```

It is recommended to choose the values of *dt* in accordance with the values of the time steps chosen in series 21 in such a way that the time steps are divisors of the timeprint. The example given above is adequate for the time steps of 12 and 20 seconds mentioned in series 21. The values of 2 and 16 seconds

E. 1 card (optional)

`PRINTDEPL`,*Tstart*

- `PRINTDEPL`

  Writes the increment of temperatures at each iteration of each time step of the time integration, see series 21. This command is used only for debugging convergence problems or to decide of an appropriate time step for the time integration. It is not used for usual calculations because it slightly increases the run time but, first of all, it increases significantly the size of the ".OUT" file.

- *Tstart*

  Time (in seconds) from which the increments of temperature will be written.

F. 1 card (optional)

`PRINTFHE`,*Tstart*

- `PRINTFHE`

  Writes the out of balance thermal loads at the nodes at each iteration of each time step of the time integration, see series 21. This command is used only for debugging convergence problems or to decide of an appropriate time step for the time integration. It is not used for usual calculations because it slightly increases the run time and it increases significantly the size of the ".OUT" file.

- *Tstart*

  Time (in seconds) from which the increments of temperature will be written.

G. 1 card

1 blank line to indicate that the input file is finished.

The example input file given hereafter yields the temperatures calculated after 2 hours shown on Figure 11.

```
This file has been created as an example for the users manual of SAFIR
Author: Jean-Marc Franssen

     NNODE   16
      NDIM    2
   NDOFMAX    1

  TEMPERAT
      TETA       0.9
  TINITIAL      20.0

      NMAT    2
  ELEMENTS
     SOLID    9
        NG    2
     NVOID    0
  END_ELEM

     NODES
      NODE    1     0.000     0.000
     GNODE    4     0.000     0.120
    REPEAT    4     0.025     0.010    3

 FIXATIONS
   END_FIX

NODOFSOLID
      ELEM    1    1    2    6    5    1    0.
     GELEM    3    9   10   14   13    1    0.    4
    REPEAT    3    1    2
   NEW_MAT    5    2

  FRONTIER
         F    1      FISO   NO   NO   NO
        GF    7      FISO   NO   NO   NO    3
         F    1        NO   NO   NO  F20
        GF    3        NO   NO   NO  F20    1
 END_FRONT

  SYMMETRY
   END_SYM

 PRECISION     0.002
```

```
      TIME
                  12.      3600.
                  20.      7200.
  END_TIME

    OUTPUT
 TIMEPRINT
                  60.      3600.
                 900.      7200.
END_TIMEPR
```

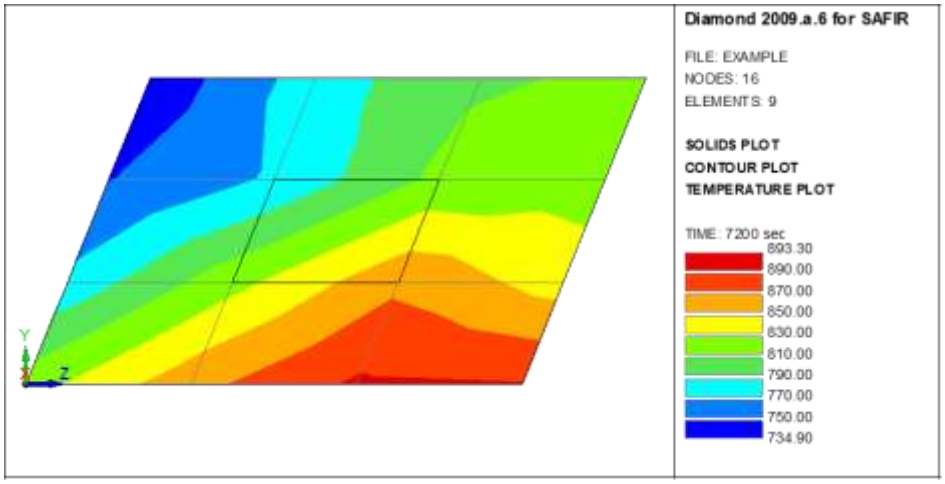

Figure 11: calculated temperatures

2. Detailed description of the file describing the HASEMI fire(s)

If a `HASEMI` function is used in a `FLUX` command of the input file, see series 16, a file called "*hasemi.txt"* must be present in the same folder as the input file. This file gives the position and the characteristics of the local HASEMI fire(s).
The format of this is described in this section.

SERIES 1: COMMENTS

A. Multiple cards (can be 0)
As many lines as required may be introduced by the user at the beginning of the file to comment the content of the file. These comments will not influence in any manner the results of the calculation. They will help understand what the file is about, which may be particularly useful if the file is found and opened several years after it has been created.

B. 1 card
1 blank line to indicate that the comments are finished.

SERIES 2: QUANTITY OF FIRE(S)

1 card
`NFIRE`*, nfire*

- `NFIRE`
  Command.
- *nfire*
  Quantity of localised fires that will influence the model in the thermal analysis.

The following series 3 to 6 must be written *nfire* times, once for each localised fire.

SERIES 3: POSITION OF THE FIRE

1 card

`FIRE_POS`, *posi1, posi2, [posi3]*

- `FIRE_POS`
  Command.
- *posi1*
  Position of the fire along the first axis of coordinates of the structural model.
- *posi2*
  Position of the fire along the second axis of coordinates of the structural model.
- *posi3*
  Position of the fire along the third axis of coordinates of the structural model.

SERIES 4: CEILING HEIGHT

1 card

`HEIGHT`, *hc*

- `HEIGHT`
  Command.
- *hc*
  Vertical distance from the fire source to the ceiling.
  Only this value is present in the local fire model of EN 1991-1-2. It allows detecting whether the flame of the fire touches the ceiling or not. It will thus influence the severity of the attack of the fire on the structure.
  The vertical position of the fire given in Series 3 *posi3* is in fact not used in the HASEMI model.

SERIES 5: DIAMETER

A. 1 card
`DIAMETER`
Command.

B. at least 2 cards, maximum 100 cards
t, diameter
- *t*
  Time (in seconds) when the diameter is given. The evolution of the diameter as a function of time will be linearly interpolated between the values given in this series.
- *diameter*
  Value of the diameter (in meters) of the fire at time *t.*

C. 1 card
`END_DIAM`
Command.

SERIES 6: RATE OF HEAT RELEASE

A. 1 card
`RHR`
Command.

B. at least 2 cards, maximum 100 cards
t, rhr
- *t*
  Time when the rate of heat release is given. The evolution of the rate of heat release as a function of time will be linearly interpolated between the values given in this series.
- *rhr*
  Value of the rate of heat release of the fire at time *t.*

C. 1 card
`END_RHR`
Command.

Hereafter is given an example of a "*hasemi.txt"* file.

```
Description of the local fire by the Hasemi method.
There are 2 local fires.
This file has been used with the structure described in the file TEST.in

    NFIRE    2                    Quantity of localised fires
  FIRE_POS        0.        0.  0.5
    HEIGHT       2.5               Distance between the fire and the ceiling
  DIAMETER
                  0.        0.     Time (s) - Fire source diameter (m)
                300.        3.
                600.        4.
  END_DIAM
       RHR
                  0.        0.     Time (s) - Rate of heat release (W)
                600.   900000.
   END_RHR
  FIRE_POS       1.5        0.  0.5
    HEIGHT       2.5
  DIAMETER
                  0.        0.
                100.        0.
                400.        3.
                600.        4.
  END_DIAM
       RHR
                  0.        0.
                100.        0.
                500.   900000.
                600.   900000.
   END_RHR
```

3. Detailed description of the file describing the LOCAFI fire(s)

If a `LOCAFI` function is used in a `FLUX` command of the input file, a file called "*locafi.txt"* must be present in the same folder as the input file. This file gives the position and the characteristics of the local LOCAFI fire(s).
The format of this is described in this section.

SERIES 1: COMMENTS

A. Multiple cards (can be 0)

As many lines as required may be introduced by the user at the beginning of the file to comment the content of the file. These comments will not influence in any manner the results of the calculation. They will help understand what the file is about, which may be particularly useful if the file is found and opened several years after it has been created.

B. 1 card

1 blank line to indicate that the comments are finished.

SERIES 2: QUANTITY OF FIRE(S)

1 card

`NFIRE`, *nfire*

- `NFIRE`

  Command.
- *nfire*

  Quantity of localised fires that will influence the model in the thermal analysis.

The following series 3 to 6 must be written *nfire* times, once for each localised fire.

SERIES 3: POSITION OF THE FIRE

1 card

`FIRE_POS`, *posi1, posi2, [posi3]*

- `FIRE_POS`
  Command.
- *posi1*
  Position of the fire along the first axis of coordinates of the structural model.
- *posi2*
  Position of the fire along the second axis of coordinates of the structural model.
- *posi3*
  Position of the fire along the third axis of coordinates of the structural model.

SERIES 4: CEILING HEIGHT

1 card

`Z_CEILING`, *Zc*

- `Z_CEILING`
  Command.
- *Zc*
  Vertical coordinate of the ceiling.
  This value allows detecting whether the flame of the fire touches the ceiling or not. It will thus influence the severity of the attack of the fire on the structure.

SERIES 5: TYPE OF PLUME

1 card

`PLUME_TYPE`, *plume_type*

- `PLUME_TYPE`
  Command.
- *plume_type*
  Gives the type of plume. Can have one of the two following values:
  - ✓ “CYLINDRIC” if the solid flame is a cylinder
  - ✓ “CONIC” if the solid flame is a cone.

SERIES 6: DIAMETER

A. 1 card

`DIAMETER`

Command.

B. at least 2 cards, maximum 100 cards

t, diameter

- *t*

  Time (when the diameter is given. The evolution of the diameter as a function of time will be linearly interpolated between the values given in this series.

- *diameter*

  Value of the diameter of the fire at time *t.*

C. 1 card

`END_DIAM`

Command.

SERIES 7: RATE OF HEAT RELEASE

A. 1 card

`RHR`

Command.

B. at least 2 cards, maximum 100 cards

t, rhr

- *t*

  Time when the rate of heat release is given. The evolution of the rate of heat release as a function of time will be linearly interpolated between the values given in this series.

- *rhr*

  Value of the rate of heat release of the fire at time *t.*

C. 1 card

`END_RHR`

Command.

Hereafter is given an example of a "*locafi.txt*" file.

```
Description of a local fire following the LOCAFI model.
There is only 1 local fire

     NFIRE    1                    Quantity of localised fires.
  FIRE_POS        0.        0.  0.2
    HEIGHT       3.0
 DIAMETER
                 0.        0.     Time (s) - Fire source diameter (m)
               600.        3.
              3600.        3.
  END_DIAM
      RHR
                 0.        0.     Time (s) - Rate of heat release (W)
               600.  3534000.     (corresponds to 500 kW/m²)
              3600.  3534000.
   END_RHR
```

4. Detailed structure of the file that describes the TRAFIR compartment.