SAFIR®
A software for modelling the behaviour of structures subjected to fire

Jean-Marc Franssen
jm.franssen@uliege.be

Liege University

SAFIR®

Hasemi model for localised fires
Annex C of EN 1991-1-2

Three steps in the structural fire design:

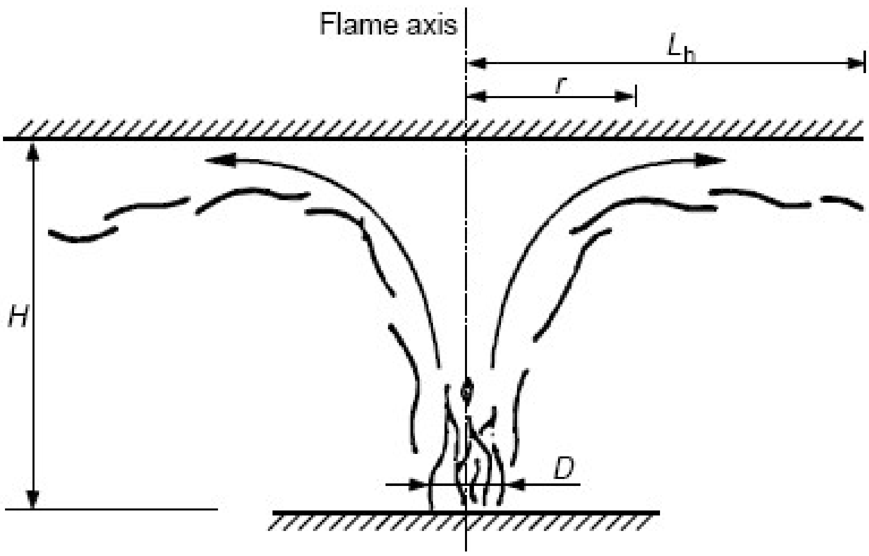
1. Define the fire.

2. Calculate the temperatures in the structure.

3. Calculate the mechanical behaviour.

When calculating temperatures in a structure based on a Hasemi fire:

- we made a choice for step 1,
- we are in step 2,
- and we will need some information coming from step 3.



Localised fire: model introduced in EN 1991-1-2 (based on experimental tests made in Japan by Yuji Hasemi)

Basic equations of the model

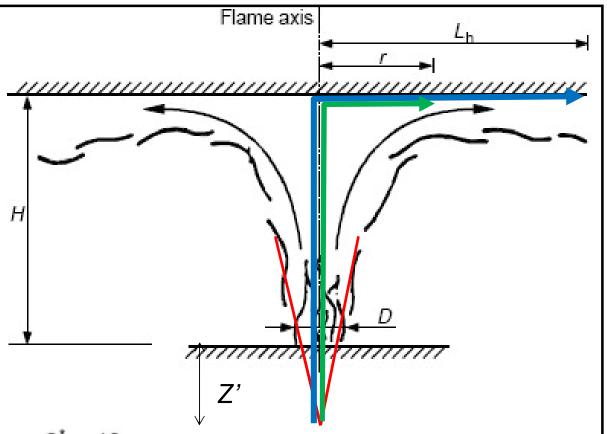
$$Q_H^* = Q / (1{,}11 \cdot 10^6 \cdot H^{2{,}5})$$

$$L_h = \left(2{,}9\ H\ (Q_H^*)^{0{,}33}\right) - H$$

$$Q_D^* = Q / (1{,}11 \cdot 10^6 \cdot D^{2{,}5})$$

$$z' = 2{,}4\, D(Q_D^{*\,2/5} - Q_D^{*\,2/3}) \quad \text{when} \quad Q_D^* < 1{,}0$$

$$z' = 2{,}4\, D(1{,}0 - Q_D^{*\,2/5}) \quad \text{when} \quad Q_D^* \geq 1{,}0$$

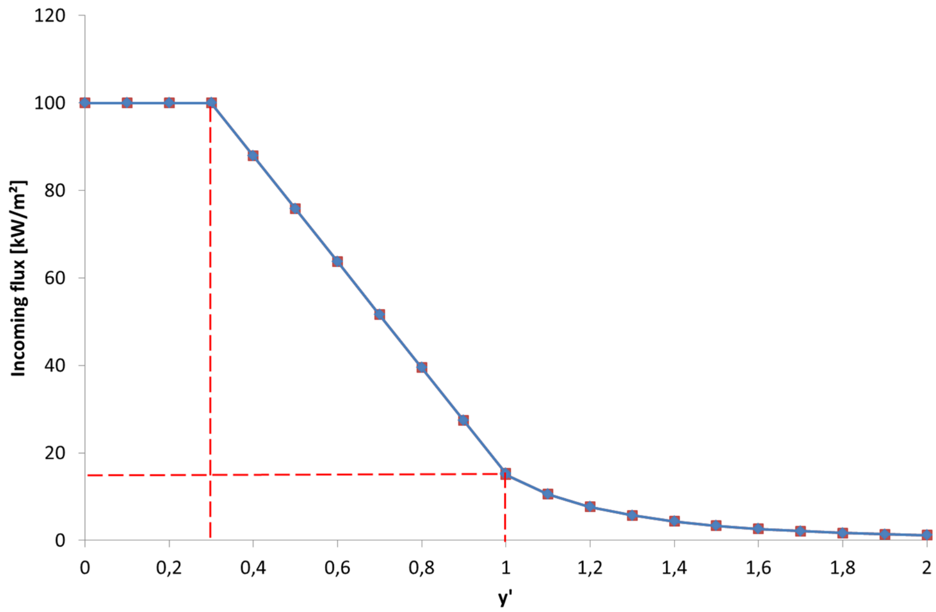


Vertical position of the virtual heat source

$$y = \frac{r + H + z'}{L_h + H + z'}$$

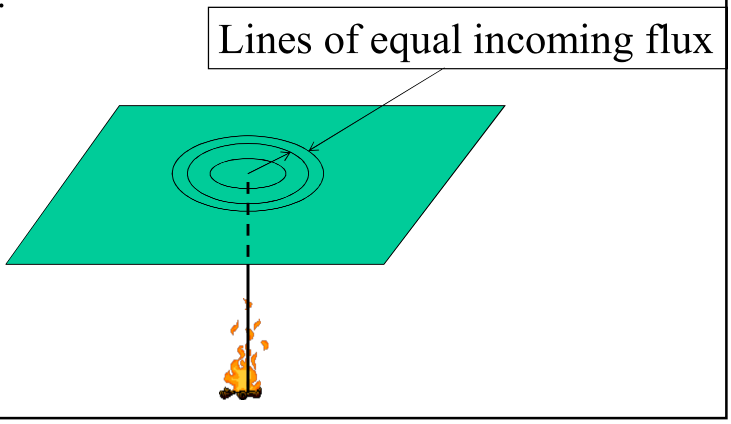
$\dot{h} = 100\,000$	if $y \leq 0{,}30$
$\dot{h} = 136\,300$ to $121\,000\, y$	if $0{,}30 < y < 1{,}0$
$\dot{h} = 15\,000\, y^{3{,}7}$	if $y \geq 1{,}0$

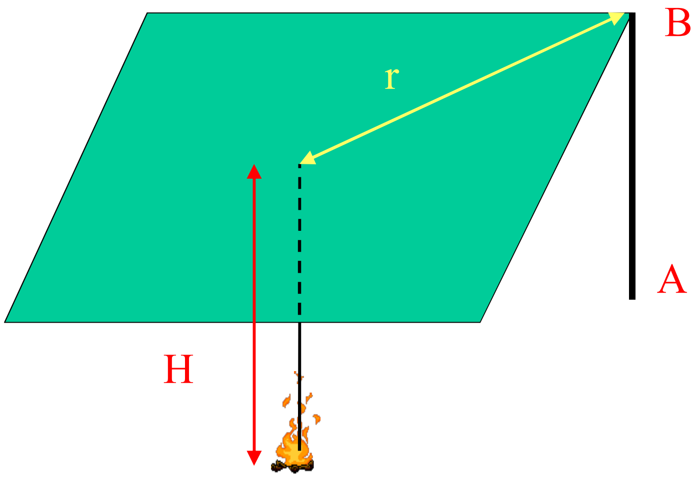
h· is the incoming flux at the level of the ceiling.



In short:

Impinging flux **at the ceiling** level is function of:
• Characteristics of the fire (Q, D)
• Vertical distance between the fire and the ceiling (H)
• Horizontal distance between the fire and the point considered (r).

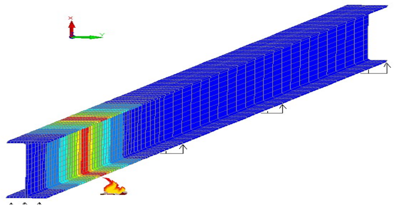




All points of the column AB, if heated by the Hasemi fire) will receive the same flux (in fact, the one calculated at point B).
⇒ HASEMI may not be the best option to heat a column.
⇒ See the course on the LOCAFI fire model.

A full 3D thermal analysis based on 3D solid elements would be much too expensive.

Here an example of 3D temperature distribution in a steel beam



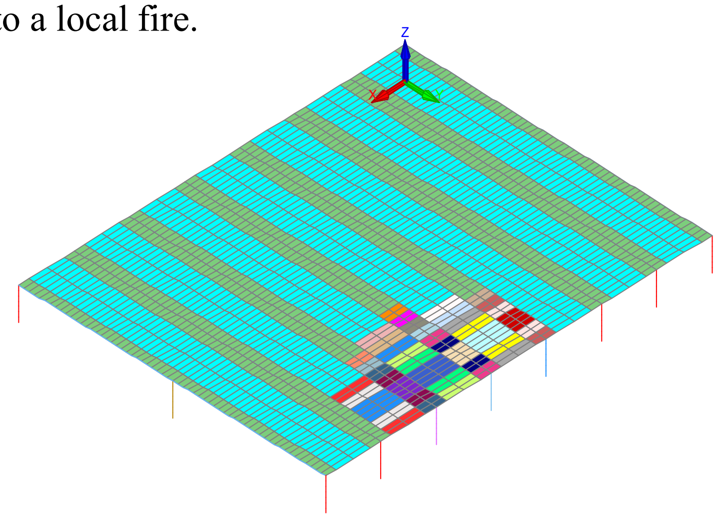
It can be observed that the longitudinal heat flux along the beams is nevertheless quite limited.

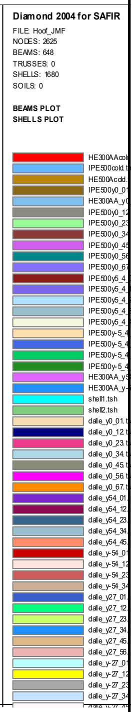
Similar conclusions can be obtained for the temperature distribution in concrete ceiling slabs.

First solution used (historically) to introduce the Hasemi fire in a SAFIR structure:

Define some zones of elements with different boundary conditions.

The old way of modelling a car park subjected to a local fire.



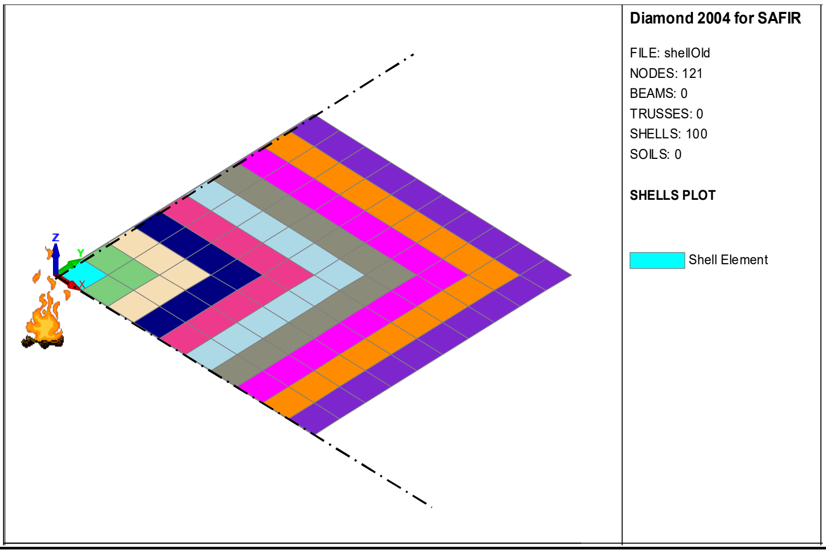


First solution used (historically) to introduce the Hasemi fire in a SAFIR structure:

Define some zones of elements with different boundary conditions.

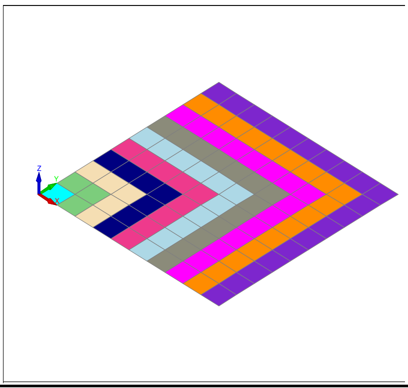
- This procedure is very time consuming for the user:
  - Definition of the bands.
  - Calculation of the average flux received in each zone.
- This procedure leads to spurious stresses in the slab (because the heating varies in a stepwise manner from zone to zone).

Example: a concrete slab (1/4 represented for symmetry reasons) represented by 10 bands, each receiving a different flux.



1) The lines of equal flux are replaced by bands of equal flux.
=> The temperature distribution does not vary in the plane of a finite element.
⇒ This leads to spurious stresses.

2) These bands of equal flux are not circles.

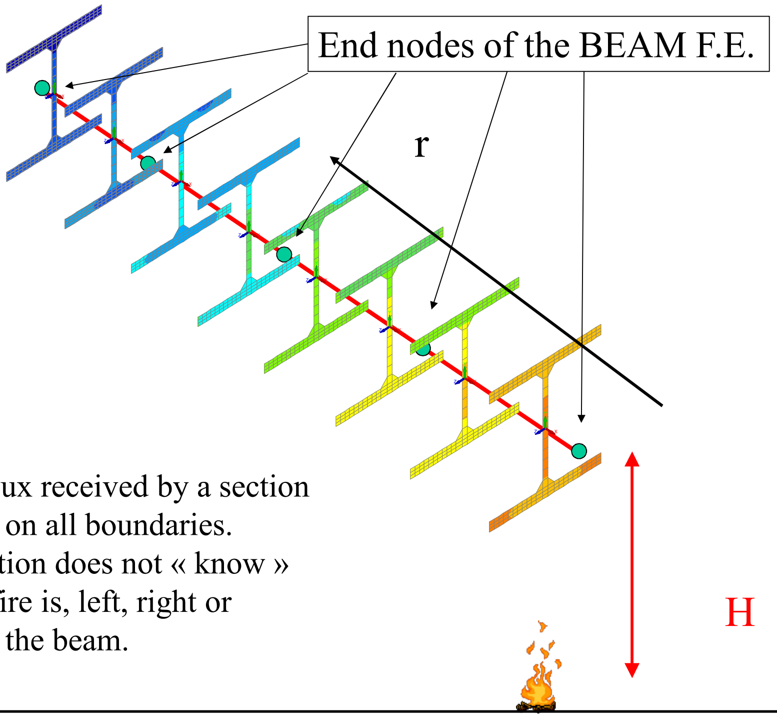


Principle of the solution used now:
in the BEAM section types that are heated by the HASEMI fire,

a 2D thermal analysis is performed

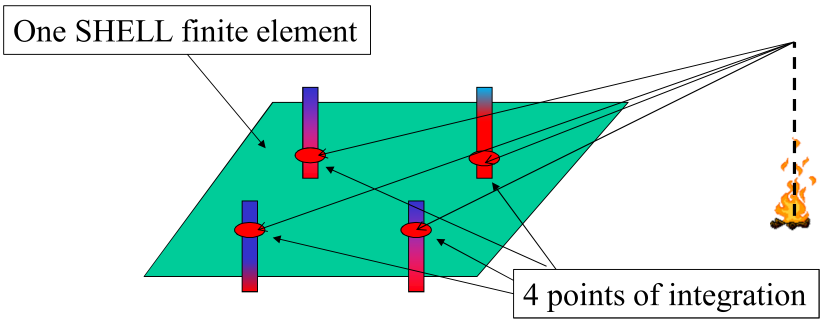
in each longitudinal integration point

of each BEAM F. E.



Note: the flux received by a section is the same on all boundaries.
=> The section does not « know » where the fire is, left, right or underneath the beam.

Principle of the solution used now :
in the SHELL section types that are heated by the HASEMI fire,
a 1D thermal analysis is performed
in each of the 4 points of integration in the plane
of each SHELL F.E.



How to do it practically?

Create the file "*hasemi.txt*" that describes the local fire(s).

It has to be present in the same folder as the input files.

The next slide shows an example of such a file.

```
HASEMI FIRE
A moving fire is here represented by 4 Hasemi fires.

     NFIRE    4

   FIRE_POS   0.5   -3.    0.0      ! Position of the fire 1 in the structure
     HEIGHT   3.                    ! distance between the source & the ceiling
   DIAMETER                         ! Diameter of the source function of time
              0.      1.
          7200.       1.
   END_DIAM
        RHR                         ! Power of the source function of time
               0      0.
             600   1.0E6
            1200      0.
            7200      0.
    END_RHR

   FIRE_POS   1.5   -3.    0.0      ! Position of the fire 2 in the structure
     HEIGHT   3.
   DIAMETER
               0.     1.
            7200.     1.
   END_DIAM
        RHR
               0      0.
             300      0.
             900   1.5E6
            1500      0.
            7200      0.
    END_RHR
```

Is not used by SAFIR

Is used by SAFIR (H in the model) for all elements

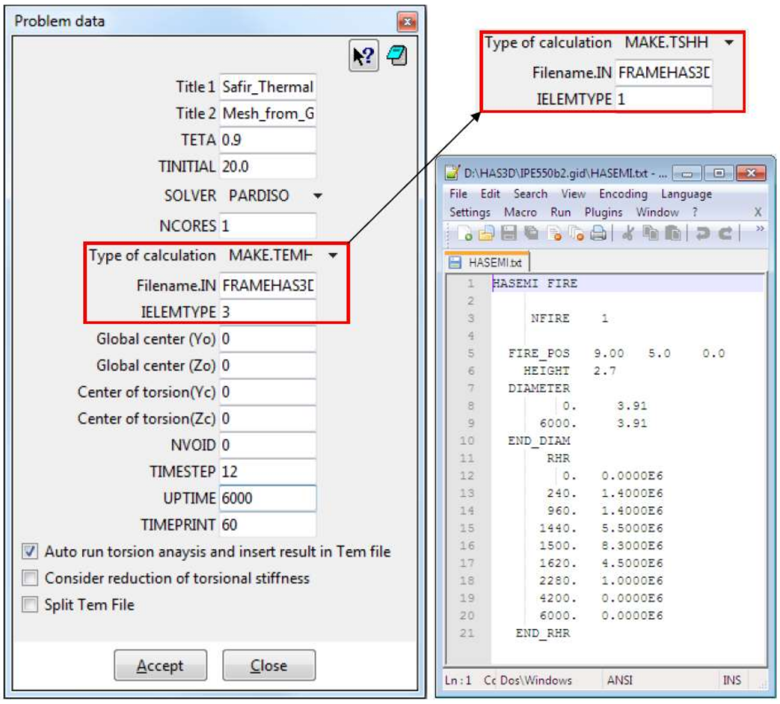
In the input files of the thermal analysis, replace:

`MAKE.TEM` by `MAKE.TEMHA`

`MAKE.TSH` by `MAKE.TSHHA`

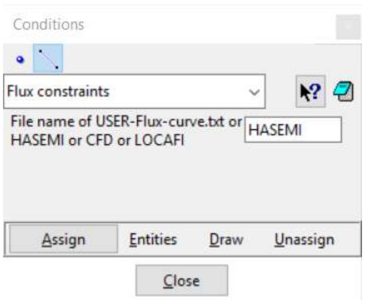
Give the name of the input file that describes the structure for the mechanical analysis (this file must be present before starting the thermal analyses in order to allow computing *r* in every point of integration).
Note: in the structural file, gravity MUST be in the direction:
minus Z for 3D structures;
minus Y for 2D structures.

Give the number of the section type in the structural file.



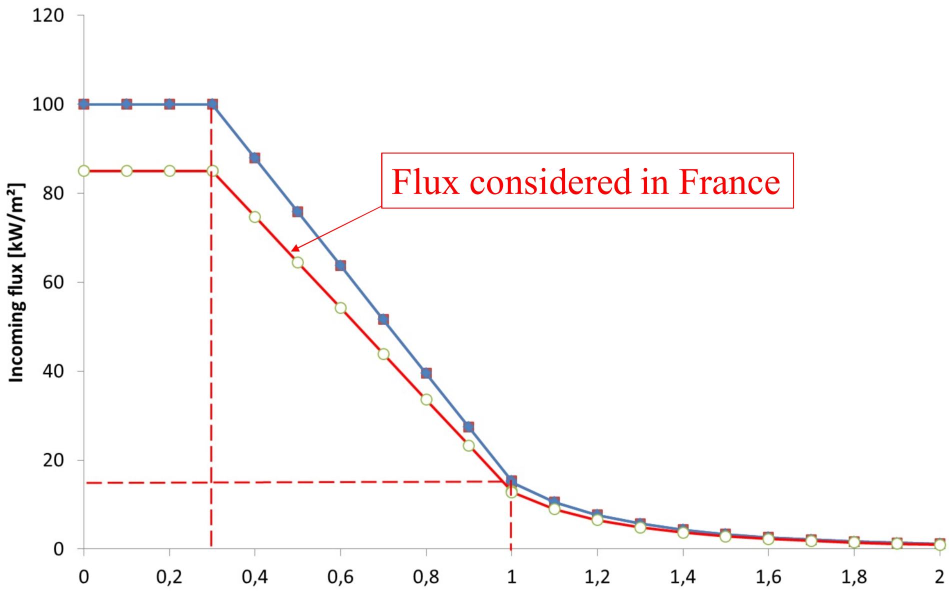
Put a HASEMI flux on the frontiers

```
FLUX   12   NO   NO   HASEMI   NO
```



Note: in FRANCE, use HASEMI_FR to consider the 0,85 factor.

```
FLUX   12   NO   NO   HASEMI_FR   NO
```



Put a HASEMI flux on the frontiers

```
FLUX   12   NO   NO   HASEMI   NO
```

Note: in FRANCE, use HASEMI_FR to consider the 0,85 factor.

```
FLUX   12   NO   NO   HASEMI_FR   NO
```

Note: SAFIR will add an « F20 » frontier condition for the flux emitted by the surface of the elements to the far field.

⇒ In the material properties, the coefficient of convection for exposed surfaces to be applied also on the unexposed surfaces.

```
STEELEC3EN    35.    35.    0.7
```

SAFIR will create the files

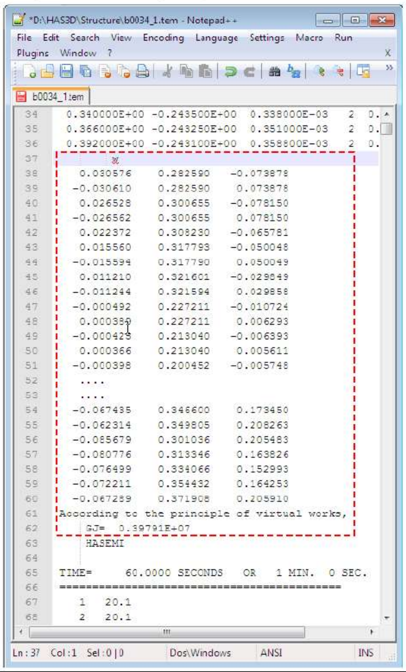
b0001_1.tem, b0001_2.tem,
b0002_1.tem, b0002_2.tem,
etc for the BEAM F.E.

and

s0001_1.tsh, s0001_2.tsh, s0001_3.tsh, s0001_4.tsh
s0002_1.tsh, s0002_2.tsh, s0002_3.tsh, s0002_4.tsh
etc for the SHELL F.E.

Note: in each section type, the information
- on torsion (for .TEM files),
- on the rebars (for .TSH files);
must be present only in the first of the "biiii_1.tem" or "siiii_1.tsh" files (the first of this section)

- Open the file *IPE550b1.tem* and copy the part dedicated to the torsional analysis to the first *b000x_1.tem* file of the corresponding beam section.

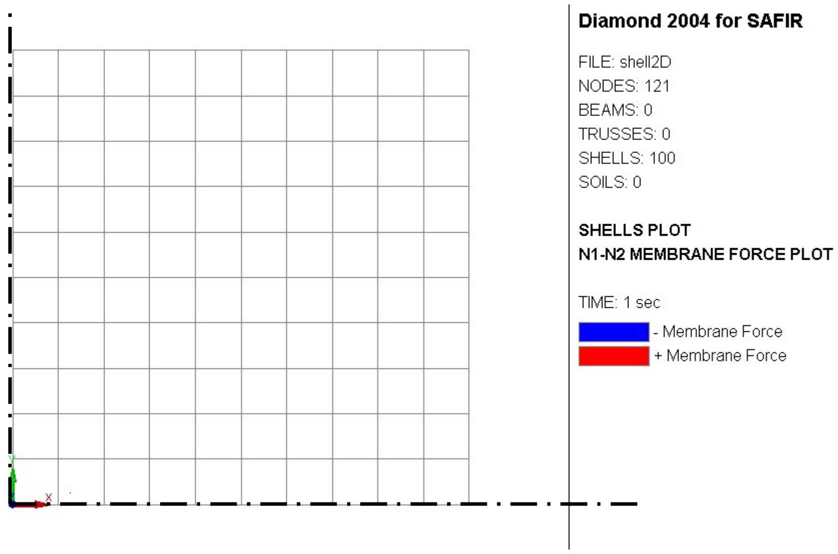



```
 0.340000E+00 -0.243500E+00  0.338000E-03   2  0.
 0.366000E+00 -0.243250E+00  0.351000E-03   2  0.
 0.392000E+00 -0.243100E+00  0.358800E-03   2  0.

   0.030576    0.282590   -0.073878
  -0.030610    0.282590    0.073878
   0.026528    0.300655   -0.078150
  -0.026562    0.300655    0.078150
   0.022372    0.308230   -0.065781
   0.015560    0.317793   -0.050048
  -0.015594    0.317790    0.050049
   0.011210    0.321601   -0.029849
  -0.011244    0.321594    0.029858
  -0.000492    0.227211   -0.010724
   0.000380    0.227211    0.006293
  -0.000425    0.213040   -0.006393
   0.000366    0.213040    0.005611
  -0.000398    0.200452   -0.005748
   ....
   ....
  -0.067435    0.346600    0.173450
  -0.062314    0.349805    0.208263
  -0.085679    0.301036    0.205483
  -0.080776    0.313346    0.163826
  -0.076499    0.334066    0.152993
  -0.072211    0.354432    0.164253
  -0.067289    0.371908    0.205910
According to the principle of virtual works,
    GJ=  0.39791E+07
    HASEMI

TIME=     60.0000 SECONDS   OR   1 MIN.  0 SEC.
===============================================
   1   20.1
   2   20.1
```

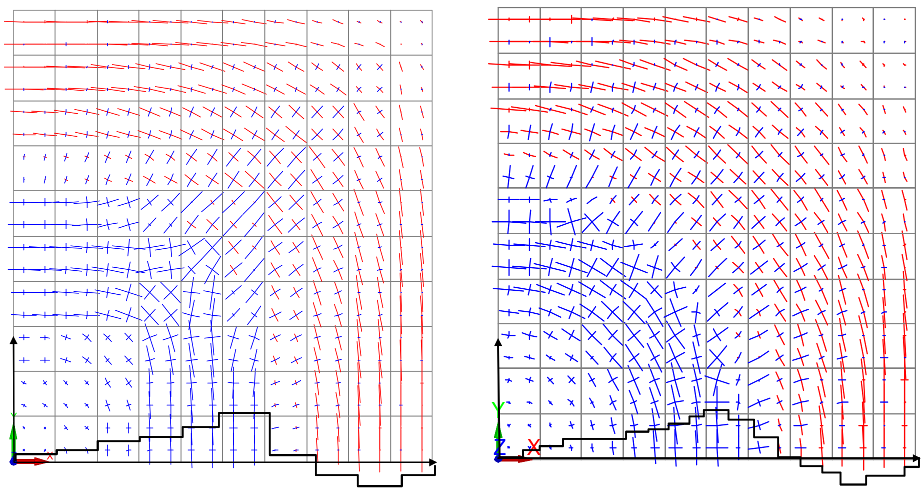
Note: in a structure, there may be different section types. It is allowed to have:

- ✓ some that are heated by Hasemi fires,
- ✓ some that are heated by $T_g = f(t)$ fires,
- ✓ some that are heated by FDS results,
- ✓ some that are heated by the LOCAFI model,
- ✓ some that are not heated.

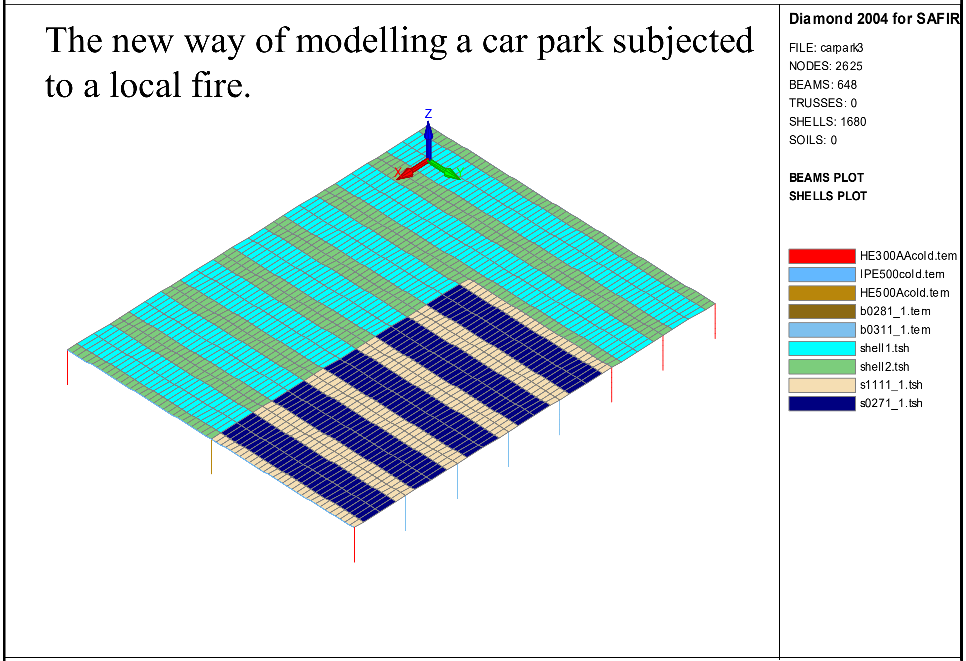
Application: ¼ of a square plate with a localised fire underneath (0 ; 0) – Membrane stresses with the old solution.



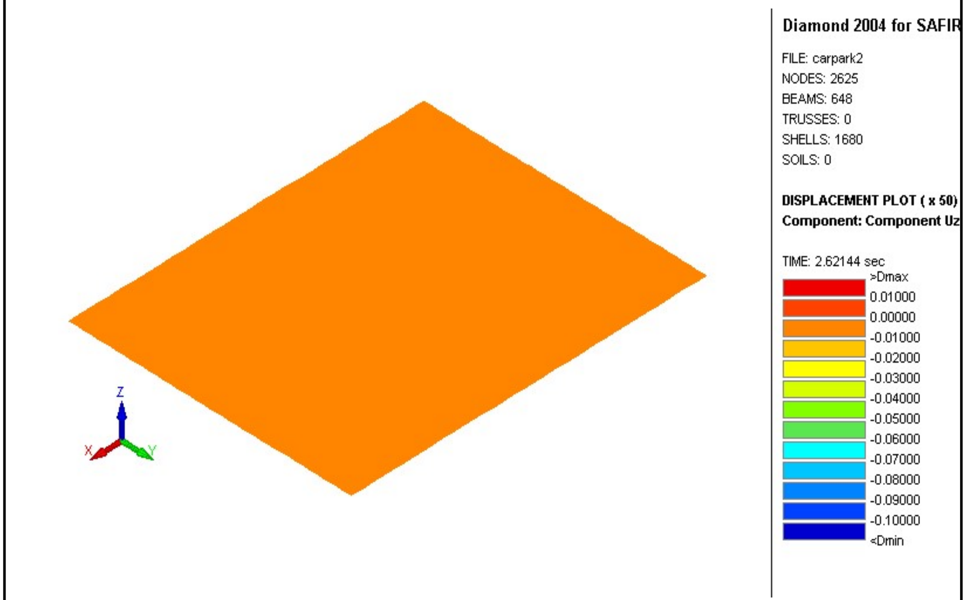
Old solution Membrane forces New solution



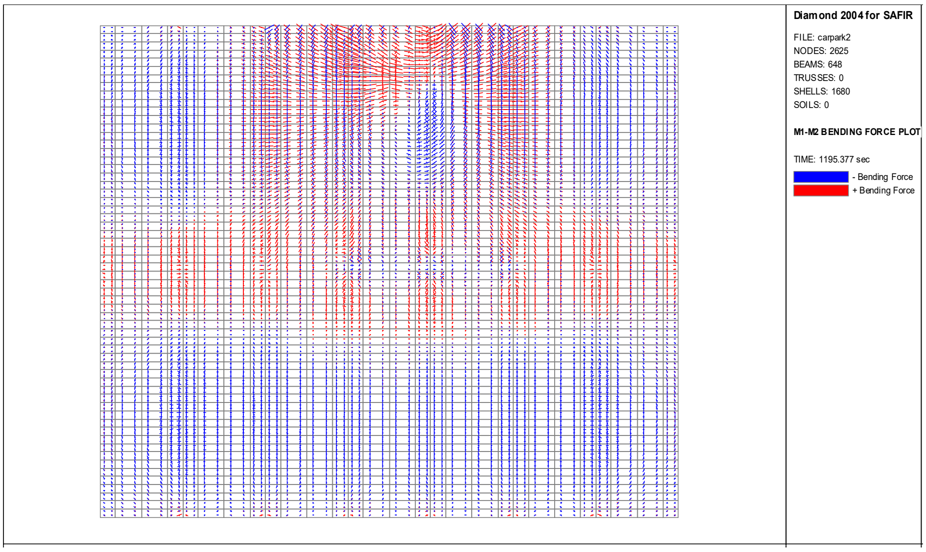
The new way of modelling a car park subjected to a local fire.



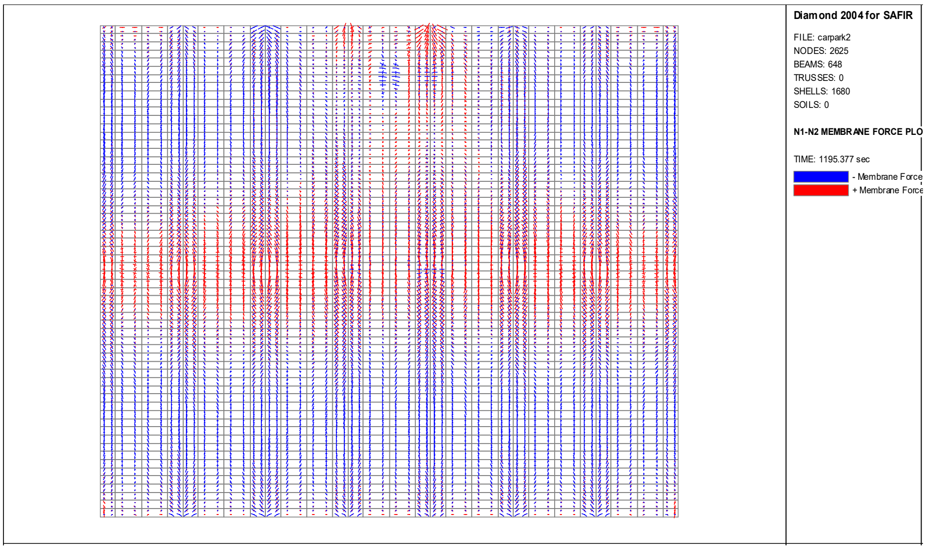
Results with the new solution: the displacement field is continuous (but this is normal for displacement based finite elements).



The field of moments is also continuous (this is not "easy")



The field of membrane forces is also continuous (not "easy")



Thank you.