Department of
Building Environment and Energy Engineering
建築環境及能源工程學系

The Hong Kong Polytechnic University
香港理工大學

SiF2022: OpenSEES Workshop

Session 5: Application of localized fire model for performance-based structural fire design

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The 12th International Conference on Structures in Fire
SiF 2022, Hong Kong

About Me

Zhuojun NAN

- BSc in Civil Engineering, MSc (UoE) in Structural and Fire Safety Engineering
- Graduate Fire Engineer in Arup (Shanghai)
- A PhD candidate at the Hong Kong Polytechnic University
- Research lies in the influence of localised failures on the global response of structures in realistic fires
- Interested in the application of travelling fires and AI for structural fire safety
- Email me at zhuojun.nan@connect.polyu.hk

SureFire
Smart Urban Resilience and Firefighting

Outline

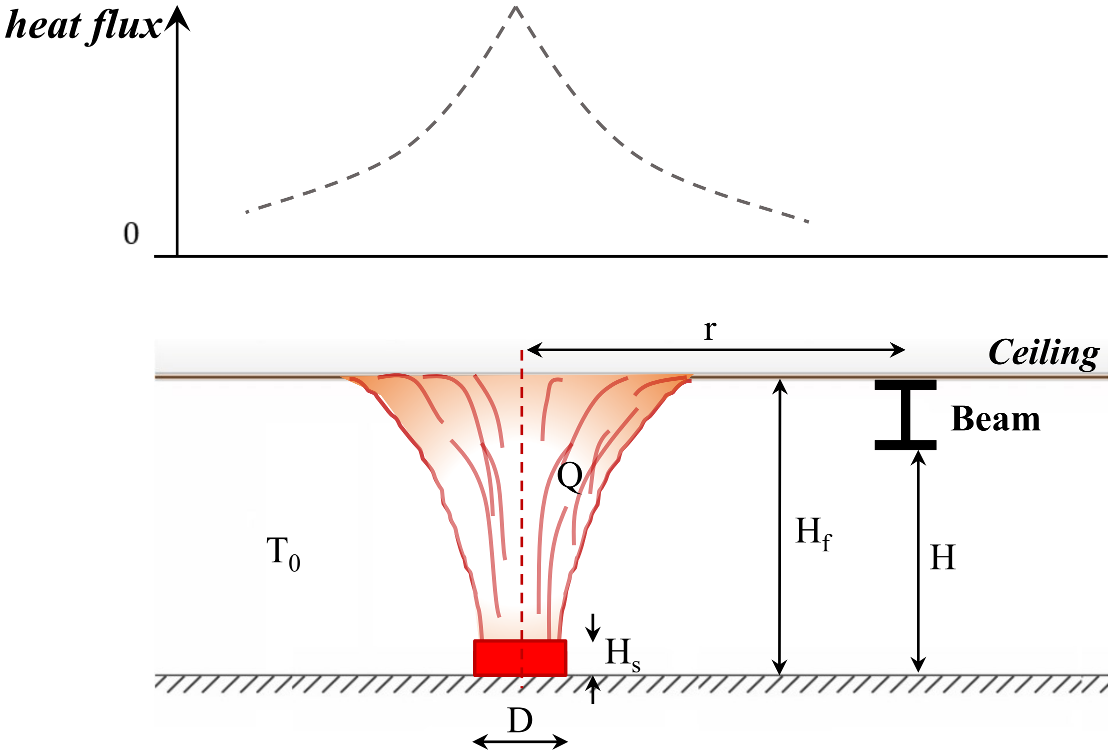
1. What is the Hasemi's localized fire?
2. How to apply localized fire model in performance-based structural fire design?
3. How to set-up localized fire model in OpenSEES?
4. Can we use GiD to simulate the thermal and structural responses under localised fire scenarios?

Hasemi's localized fire

- Proposed by Yuji Hasemi in 1996 [1]
- BS EN 1991-1-2:2002 (Annex C) [2]
- Parameters used in Hasemi's localized fire model to calculate heat flux from fire source to the beam.

***Hasemi's localized fire* external heat flux $\dot{h}$ (W/m^2)**

$$\dot{h} = 100000 \qquad if\ \ y \leq 0.30$$
$$\dot{h} = 136300 - 12100y \quad if\ \ 0.30 < y \leq 1.0$$
$$\dot{h} = 15000y^{-3.7} \qquad if\ \ y \geq 1.0$$



Application of Hasemi’s localized fire in PBD

Hasemi’s localized fire model has been widely applied as the necessary fire scenario in performance-based structural fire design for practical projects.

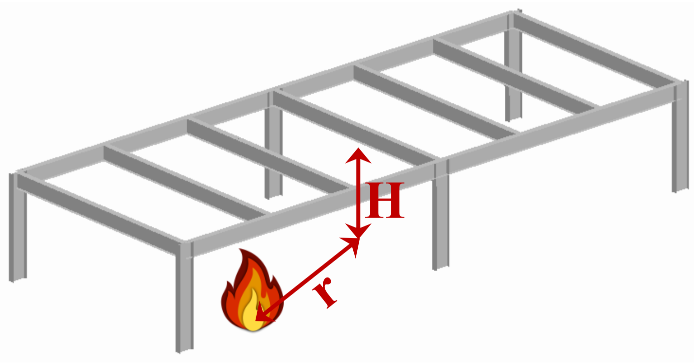
Especially, for large space steel structures, such as…

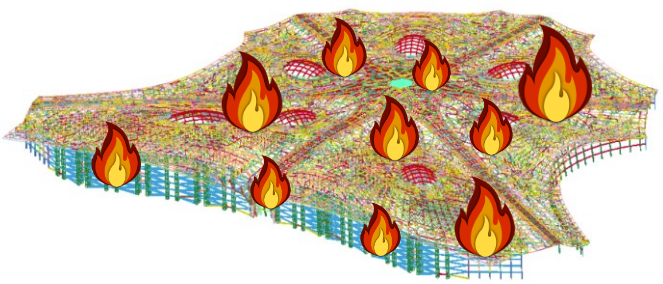
- Beijing Daxing International Airport - 2019
- Hangzhou Xiaoshan International Airport T4 - 2022
- Hohhot Shengle International Airport - 2024
- Wintastar Ice World (Shanghai) - 2023

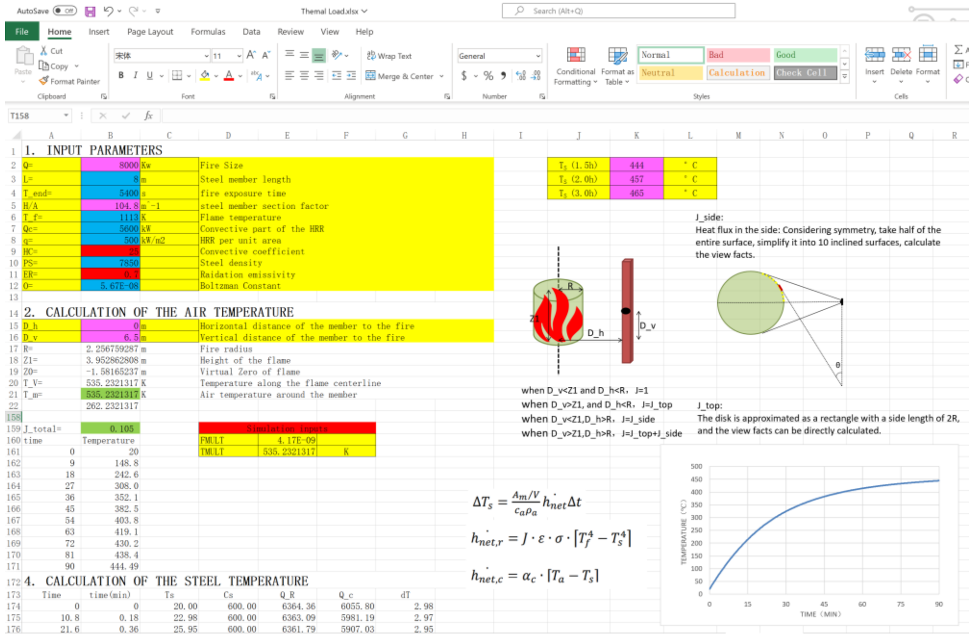
Application of Hasemi's localized fire in PBD

Current method - Excel

- Design fire scenarios
- Determine distances (horizontally & vertically) between structural members and fire
- Calculating thermal load on structures (i.e., heat transfer analysis)
- FEM - structural response analysis







Set up localized fire model in OpenSEES

Real-scale localized fire experiments - Takashi Wakamatsu and Yuji Hasemi (1997)

Example http://openseesforfire.github.io/Subpages/Examples/HT2_beam.html

OPENSEES FOR FIRE

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Heat Transfer

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Command manual

Examples

Developers

Documents

Q&A

Heat transfer of I-section steel beam subjected to localised fire

Developed by Zhuojun Nan

Introduction

Figure HT2-2 shows a 6m steel beam subjected to a localised fire which is set just under the centre of the beam. This example is established according to the real-scale localised fire tests reported by Wakamatsu and Hasemi.

Please refer to this paper: Thermal analysis infrastructure in OpenSees for fire and its smart application interface towards natural fire modelling, Fire Technology, 2020

OpenSees Model	Type used for this example
HT Entity	Isection3D, I-section (400mm*200mm*13mm*15mm)
Material	CarbonSteelEC3
Fire Type	Localised fire (1127kW)

Download: This Example Package

Model Geometry

The construction size of the real-scale localised fire tests is 6.0m × 6.0m × 3.4m (Ceiling Height). The observed steel beam under the centre of the ceiling is a 150mm(H) × 75mm(W) × 5(Web) × 6mm(Flange) H-shape section. A rectangular gas burner 1.0m × 1.0m was setting in the centre of the floor with 1.0m vertical height. This burner used propane as the fuel. The heat release rates are in equivalent to different fire sizes controlled by the volume of flowing gas and assumed complete combustion. *The real-scale localised fire tests without protection soffit.

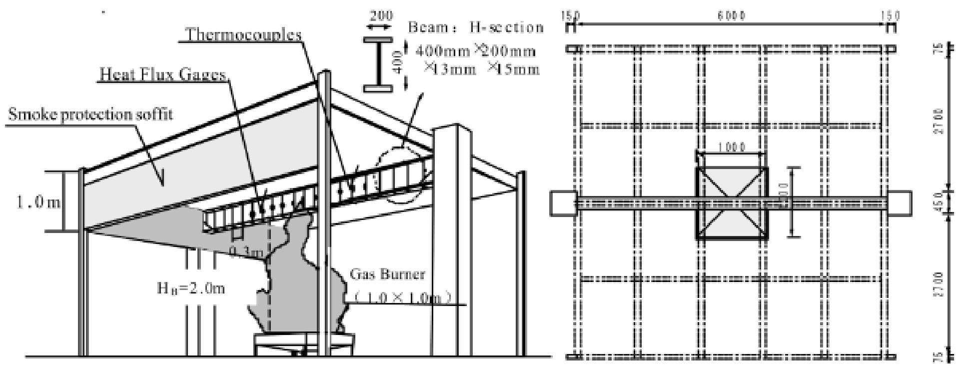


Figure HT-1: Schematic of steel beam subjected to localised fire(Wakamatsu and Hasemi, 1997)

Set up localized fire model in OpenSEES

Example Tcl

```
#FireModel - the Eurocode 1 Localised Fire Model
#$fireTYype $fireTag $firePars
FireModel Localised 1 -origin 0.0 -2.0 $Centrez -firePars 1.0 1127.0E3 2.4 2 ;
```

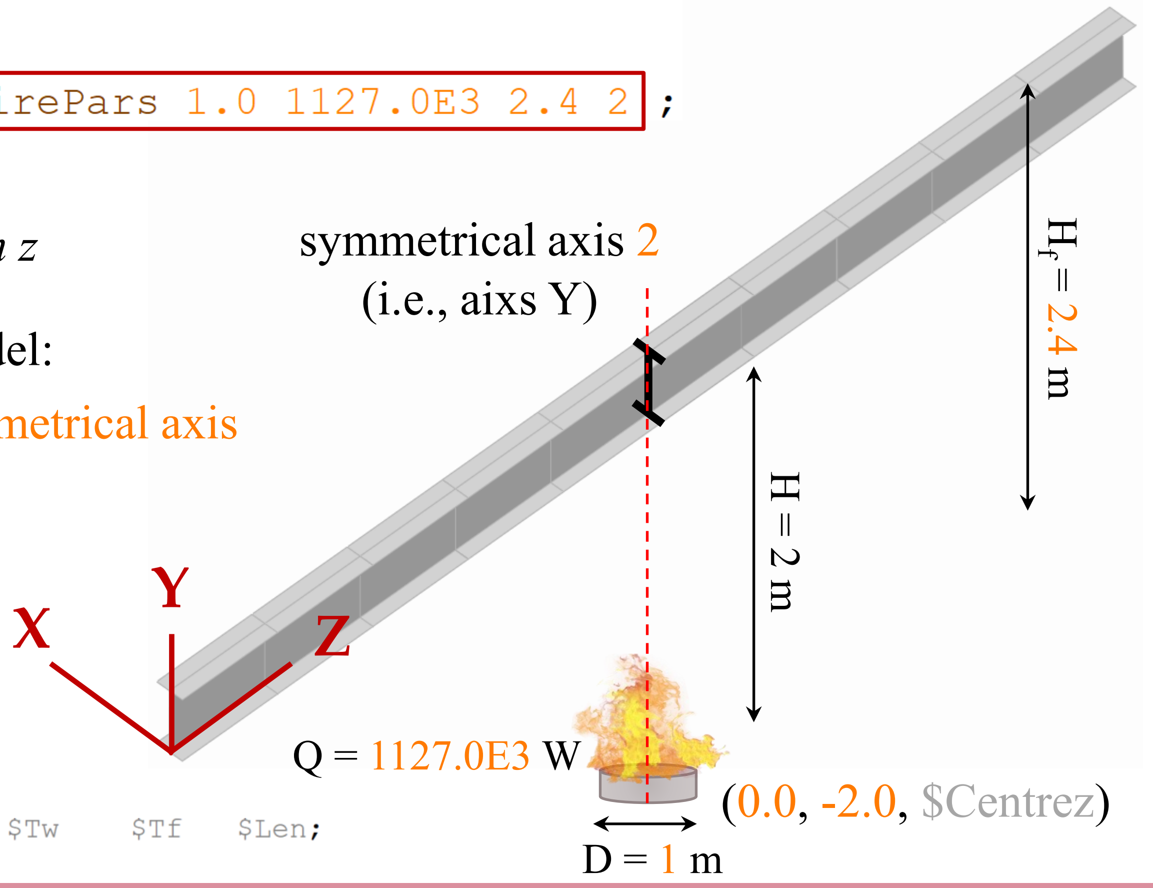
-origin is to set location of fire source:

locx (m), locy (m), locz (m) *where locz stands for location z*

-firePars is to set parameters used in Hasemi's localized fire model:

equivalent Diameter of fire (m), Q (W), Ceiling height (m), symmetrical axis

```
#Dimension of beam
set BF 0.20;  #Width of flange (m)
set HB 0.40;  #Height of beam (m)
set Tw 0.013; #Thickness of web (m)
set Tf 0.015; #Thickness of flange (m)
set Len 6.0;  #Length of beam (m)
set Centrex 0.0
set Centrey [expr $HB/2.0]
set Centrez [expr $Len/2.0]
HTEntity  Isection3D  1   $Centrex   $Centrey  $Centrez   $BF   $HB  $Tw   $Tf   $Len;
```



Set up localized fire model in OpenSEES

```
#FireModel - the Eurocode 1 Localised Fire Model
#$fireTYype $fireTag $firePars
FireModel Localised 1 -origin 0.0 -2.0 $Centrez -firePars 1.0 1127.0E3 2.4 2 ;
```

Considering effect of smoke via use **SetFirePars**

```
#Set(overwrite fire parameters)
SetFirePars firemodel 1 0.0 -2.0 $Centrez 1127.0E3 1.0 327 10E3;
```

fireTag: 1

locx (m): 0.0

locy (m): -2.0

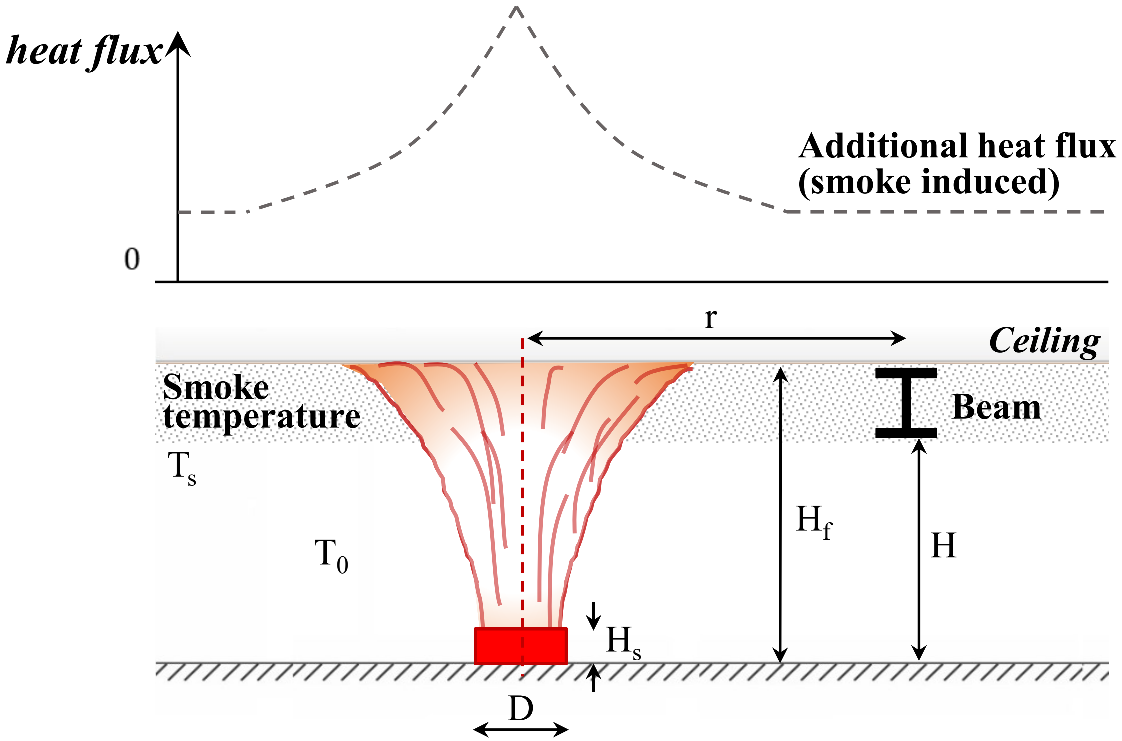
locz (m): $Centrez

Q (W): 1127.0E3

Equivalen diameter of fire (m): 1.0

Smoke temperature (°C): 327

Additional heat flux (smoke induced, w/m^2): 10E3



Set up localized fire model in OpenSEES

NaturalFire.cpp
NaturalFire.h

OPENSEES FOR FIRE

Development of Natural Fire Model

Loading time-variant input fire parameters via external firepsars.dat

```
#FireModel
#input parameters in firepsars.dat
FireModel NaturalFire 6 -firePars -file firepars.dat 2;
```

firepars.csv firepars.dat

Time (s)	locx (m)	locy (m)	locz (m)	Q (W)	Equivalen diameter of fire (m)	Ceiling height (m)	Smoke temperature (℃)	Additional heat flux (smoke induced, w/m^2)
0	3.6	0	0.292517	0	0	4.689637815	20	0
10	3.6	0	0.292517	4690	0.077275439	4.689637815	20	0
20	3.6	0	0.292517	18760	0.154550878	4.689637815	20	0
30	3.6	0	0.292517	42210	0.231826317	4.689637815	20	0
40	3.6	0	0.292517	75040	0.309101756	4.689637815	20	0
50	3.6	0	0.292517	117250	0.386377195	4.689637815	20	0
					⋮			
780	3.6	0	0.292517	28533960	6.027484238	4.689637815	20	0
790	3.6	0	0.292517	29270290	6.104759677	4.689637815	20	0
800	3.6	0	0.292517	30000000	6.180387232	4.689637815	20	0
810	3.6	0	0.292517	30000000	6.180387232	4.689637815	20	0
820	3.6	0	0.292517	30000000	6.180387232	4.689637815	20	0
					⋮			
1780	3.6	0	0.292517	30000000	6.180387232	4.689637815	20	0
1790	3.6	0	0.292517	30000000	6.180387232	4.689637815	20	0
1800	3.6	0	0.292517	30000000	6.180387232	4.689637815	20	0

Flexibility & Maneuverability!

- # Time (s) ← *Time-variant*
- # locx (m)
- # locy (m)
- # locz (m)

  } *Different fire locations (spatially) even can applied for travelling fire*
- # Q (W) ← *Growth & Cooling phases*
- # Equivalen diameter of fire (m)
- # Ceiling height (m) ← *Impinged or not*
- # Smoke temperature (°C) ← *Smoke effect*
- # Additional heat flux (smoke induced, w/m^2)

Case in Gid for demonstration

Aluminium reticulated roof structure

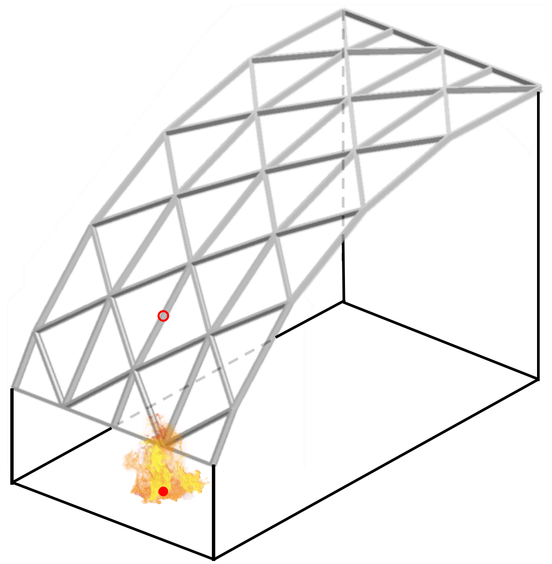
GiD OpenSees

Natural fire model (OpenSees)

design fire scenarios →

← *thermocouple* →

FEM structural model



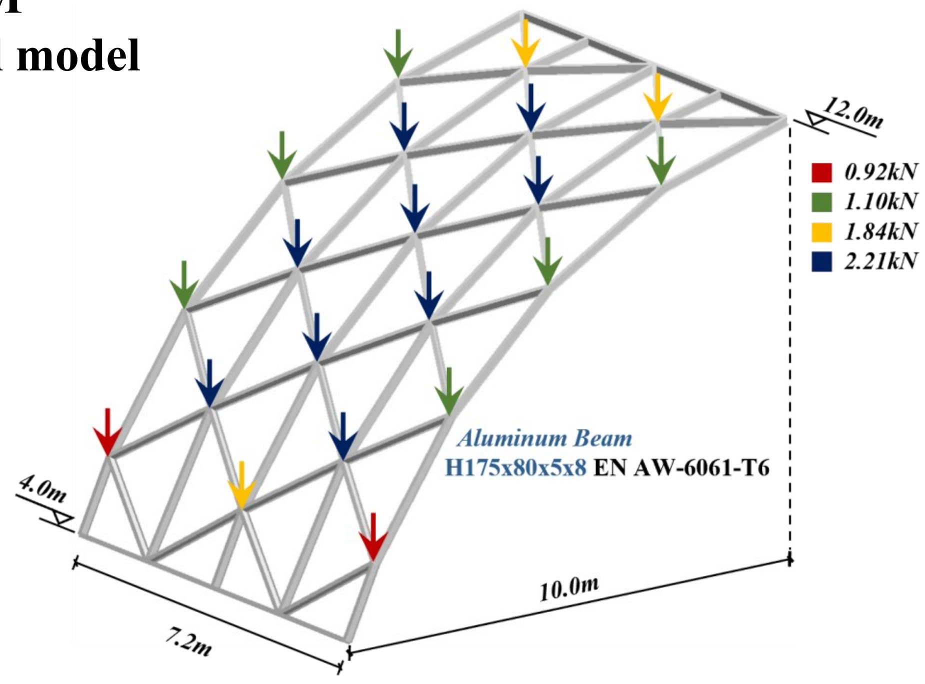
Fire location: lower center

Fire size: 30 MW

HRRPUA: 1000 kW/m^2

Fire growth rate "fast": 0.0469 kW/s^2

Fire duration: 30 min



Case in Gid for demonstration

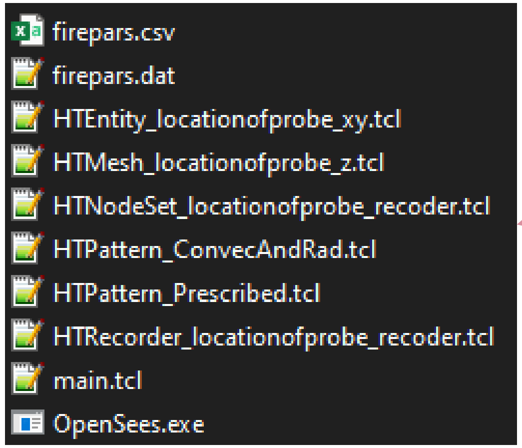
Assign thermocouples

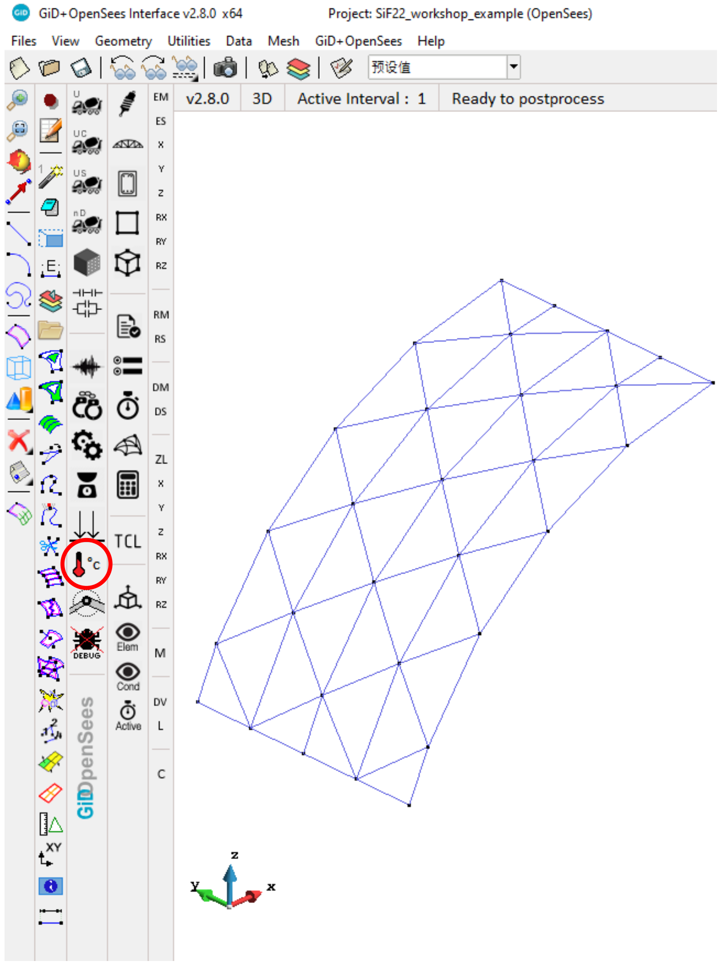
Natural fire model (OpenSees) — *design fire scenarios* → **FEM structural model**

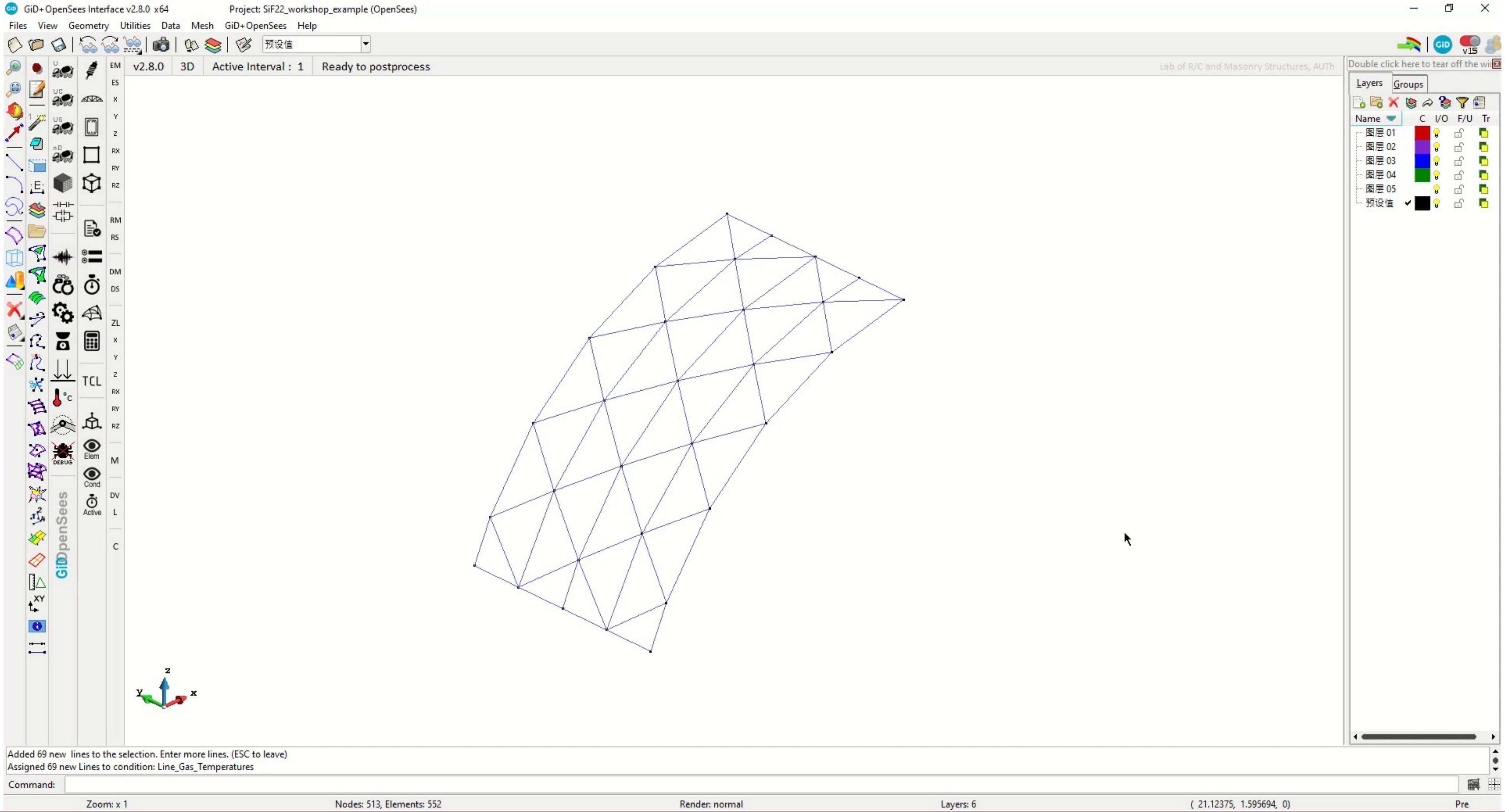
← *thermocouple* →

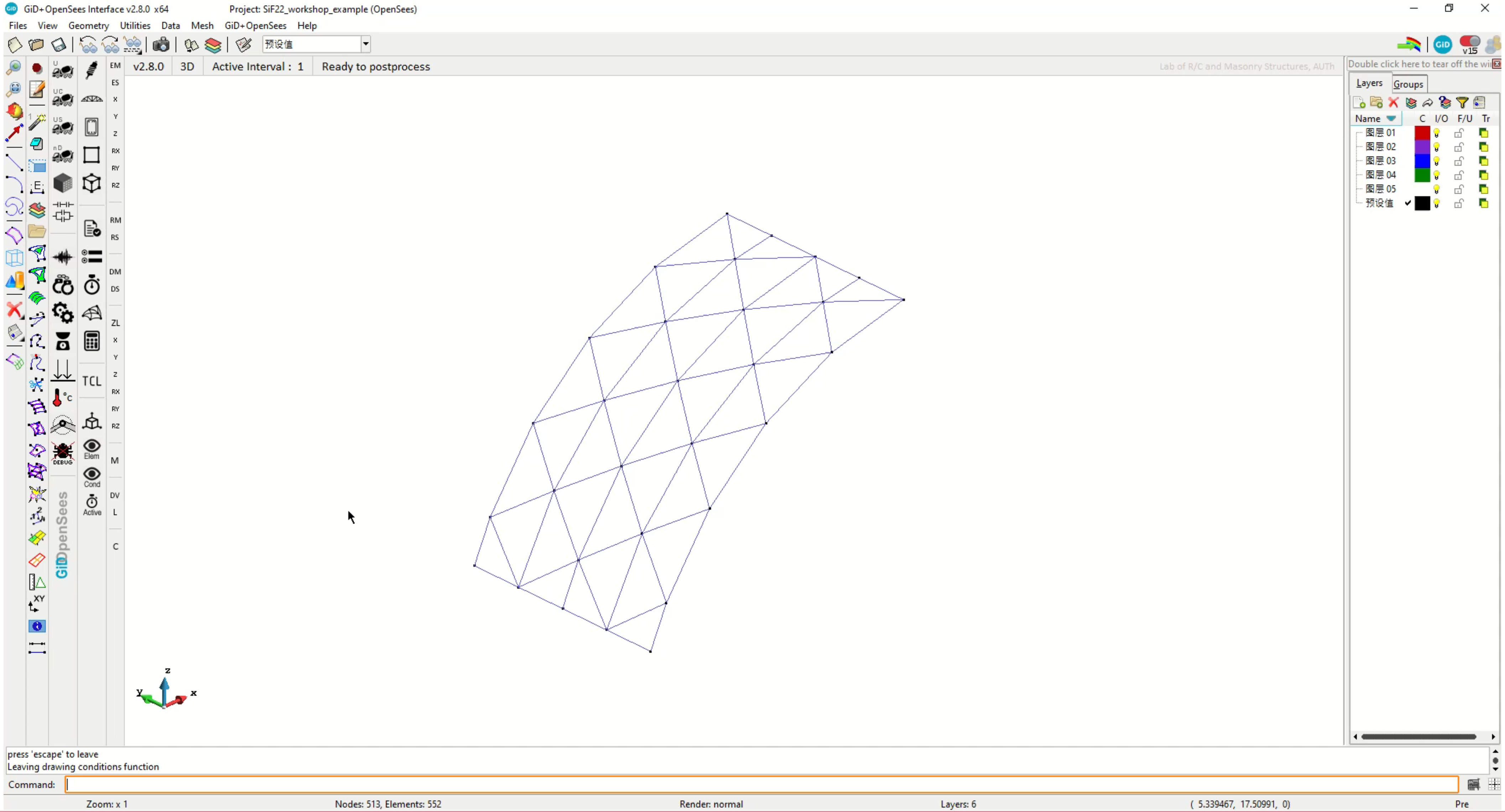
Set-up probes as thermocouples — *Gas temperature as thermal load* → Assign thermocouples

Determining location of thermocouples



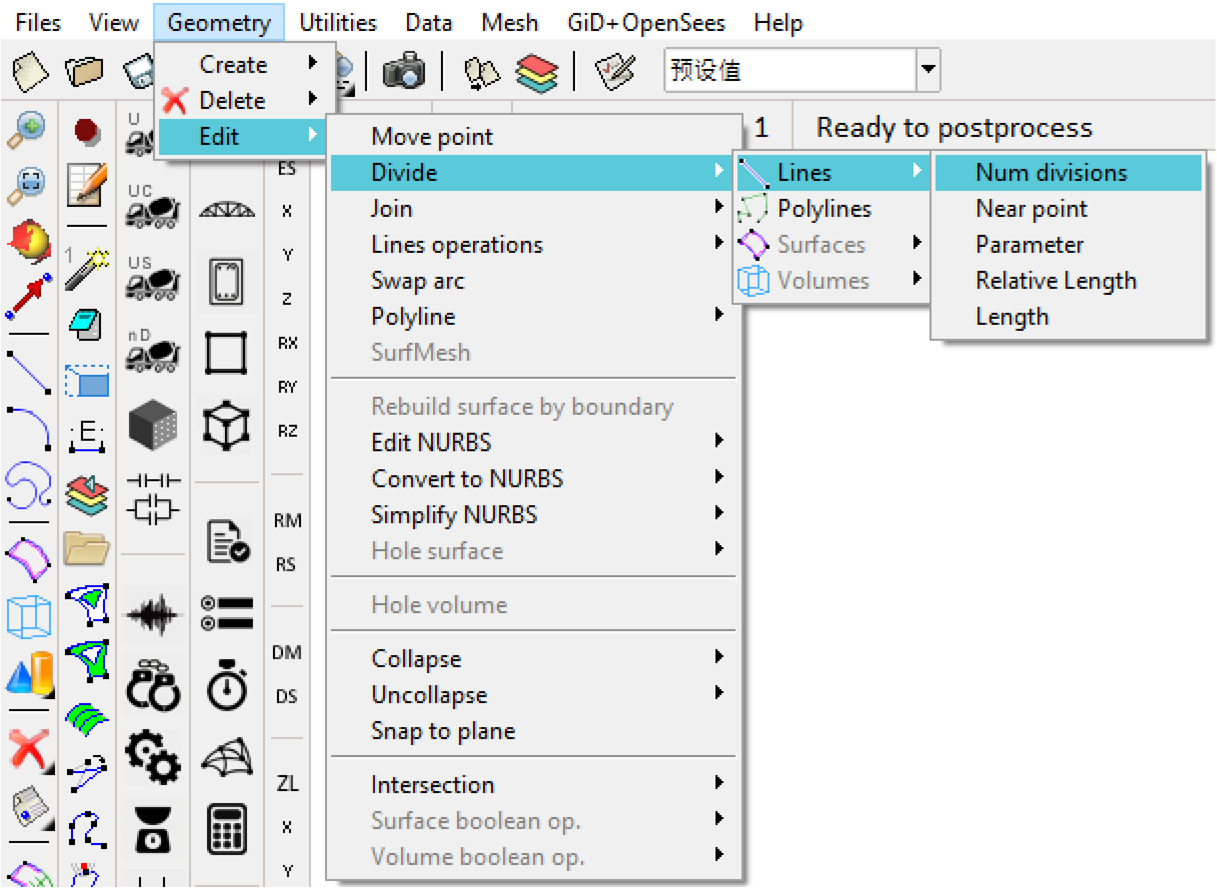


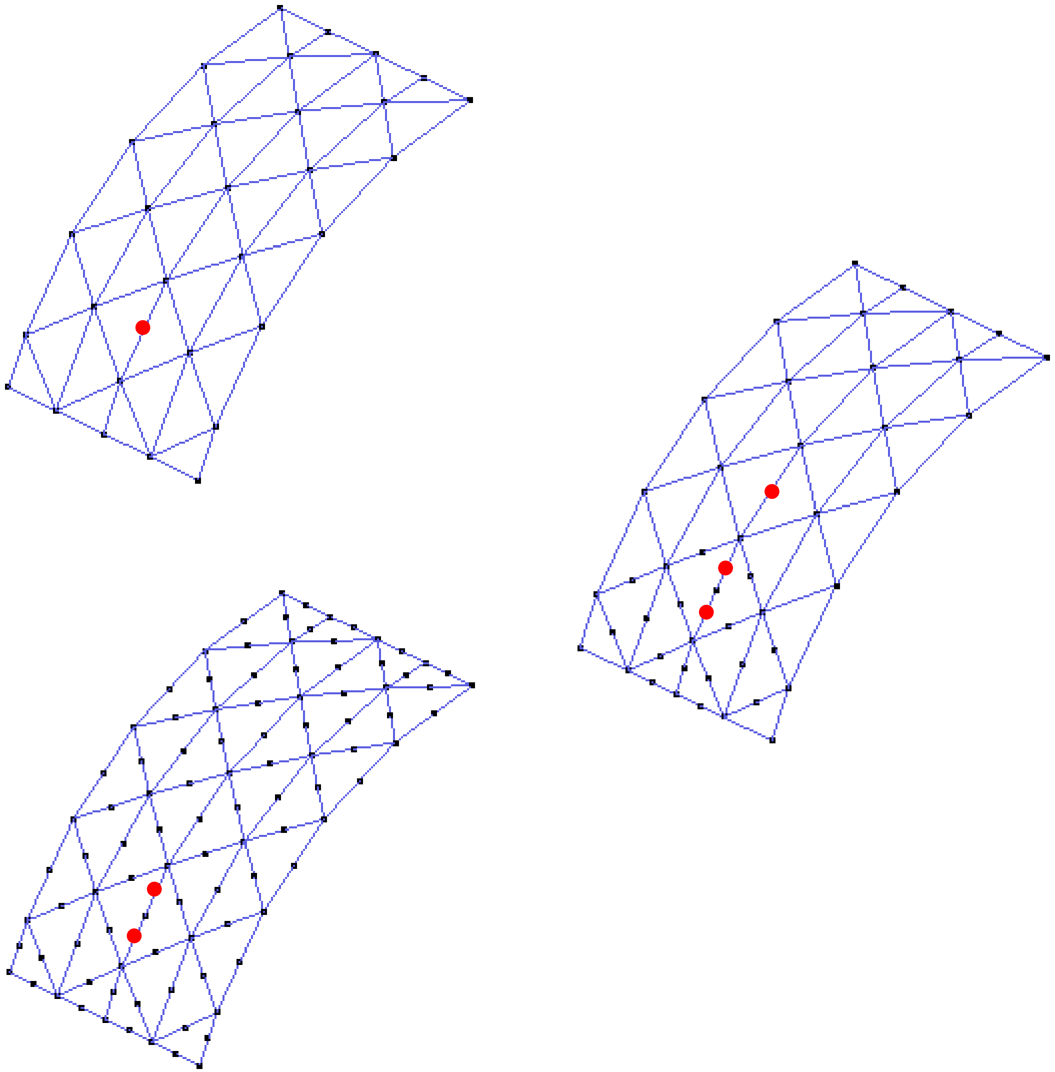

GiD+OpenSees Interface v2.8.0 x64
Project: SiF22_workshop_example (OpenSees)
Files View Geometry Utilities Data Mesh GiD+OpenSees Help
v2.8.0 3D Active Interval : 1 Ready to postprocess
Layers Groups
Name C I/O F/U Tr
图层 01
图层 02
图层 03
图层 04
图层 05
预设值
Added 69 new lines to the selection. Enter more lines. (ESC to leave)
Assigned 69 new Lines to condition: Line_Gas_Temperatures
Command:
Zoom: x 1
Nodes: 513, Elements: 552
Render: normal
Layers: 6
(21.12375, 1.595694, 0)
Pre


GiD+OpenSees Interface v2.8.0 x64
Project: SiF22_workshop_example (OpenSees)
Files View Geometry Utilities Data Mesh GiD+OpenSees Help
v2.8.0 3D Active Interval : 1 Ready to postprocess
Layers Groups
图层 01
图层 02
图层 03
图层 04
图层 05
预设值
press 'escape' to leave
Leaving drawing conditions function
Command:
Zoom: x 1
Nodes: 513, Elements: 552
Render: normal
Layers: 6
(5.339467, 17.50991, 0)
Pre

Case in Gid for demonstration

Set-up of thermocouples depends on the geometry of structure

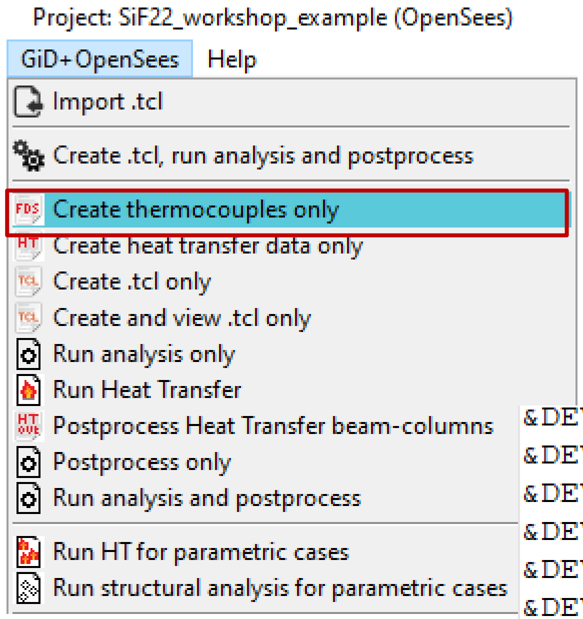


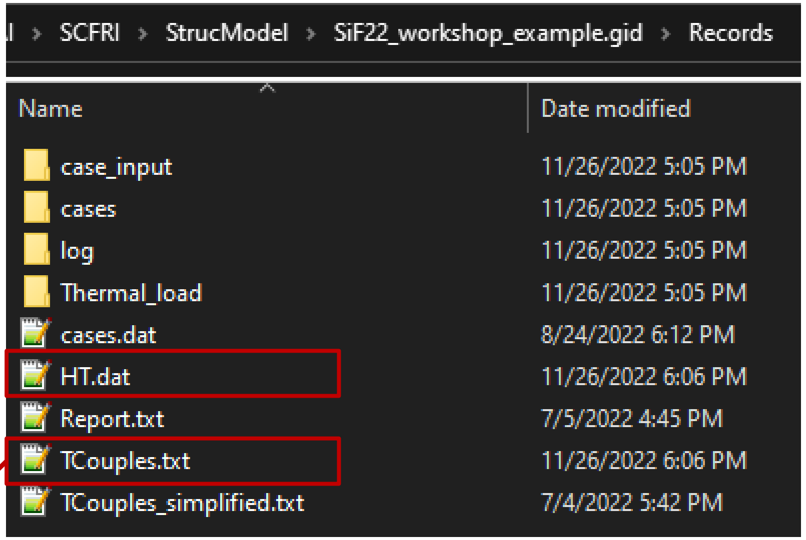


Case in Gid for demonstration

TCouples.txt - location information of thermocouples

HT.dat - parameters for heat transfer analysis






```
&DEVC ID = '1', QUANTITY='TEMPERATURE', XYZ=0.2925172745680061,0.9,4.689637815135496/
&DEVC ID = '2', QUANTITY='TEMPERATURE', XYZ=0.960423007397631,0.9,6.027542689709241/
&DEVC ID = '3', QUANTITY='TEMPERATURE', XYZ=1.7883321201875098,0.9,7.272795267089568/
&DEVC ID = '4', QUANTITY='TEMPERATURE', XYZ=2.763587474912843,0.9000000000000001,8.406358022491794/
&DEVC ID = '5', QUANTITY='TEMPERATURE', XYZ=3.871279274160793,0.9000000000000001,9.410900937686844/
&DEVC ID = '6', QUANTITY='TEMPERATURE', XYZ=5.094472989248232,0.8999999999999999,10.271066431832777/
&DEVC ID = '7', QUANTITY='TEMPERATURE', XYZ=6.414468348725407,0.8999999999999999,10.973704229265767/
&DEVC ID = '8', QUANTITY='TEMPERATURE', XYZ=7.8110851107736465,0.8999999999999998,11.5080723228947/
&DEVC ID = '9', QUANTITY='TEMPERATURE', XYZ=9.262971564690638,0.8999999999999998,11.866001217145609/
&DEVC ID = '10', QUANTITY='TEMPERATURE', XYZ=0.2925172745680061,2.6999999999999997,4.689637815135496/
```

Setting probe in Tcl as thermocouples to record gas temperature

```
#This Tcl file is written for demostrating tcl commands for Heat Transfer module in OpenSees

#Dimension of probe
set blockw 0.0001; # probe block width
set blockt 0.0001; # probe block thickness


#Mesh sizes
set elex [expr $blockw/10]
set eley [expr $blockt/10]


wipe;

HeatTransfer 2D;          #HeatTransfer activates the HTModule. 2D ,or 2d, or 3D or 3d indicate the model dimension.

HTMaterial CarbonSteelEC3 1;       #Defining HeatTransfer Material with Material tag 1.
#HTMaterial ConcreteEC2 2 0.0;
```

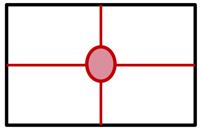
locx locy

```
#HT Entity
HTEntity Block 1 0.0 [expr $blockt/2] $blockw $blockt;
HTEntity Block 2 0.0 [expr $blockt/2] $blockw $blockt;
HTEntity Block 3 0.0 [expr $blockt/2] $blockw $blockt;
HTEntity Block 4 0.0 [expr $blockt/2] $blockw $blockt;
HTEntity Block 5 0.0 [expr $blockt/2] $blockw $blockt;
HTEntity Block 6 0.0 [expr $blockt/2] $blockw $blockt;
HTEntity Block 7 0.0 [expr $blockt/2] $blockw $blockt;
HTEntity Block 8 0.0 [expr $blockt/2] $blockw $blockt;
#HTEntity Block $tag $centreX $centreY $slabB $slabH;


#HTMesh $MeshTag $EntityTag  $MaterialTag -SecondMat 2
#SectionLoc is to set the 2D section location for the 3rd coordinate. Here it is z-axis location
HTMesh 1 1 1 -phaseChange 0 -SectionLoc 2.1 -MeshCtrls $elex $eley
HTMesh 2 2 1 -phaseChange 0 -SectionLoc 4.5 -MeshCtrls $elex $eley
HTMesh 3 3 1 -phaseChange 0 -SectionLoc 6.9 -MeshCtrls $elex $eley
HTMesh 4 4 1 -phaseChange 0 -SectionLoc 9.3 -MeshCtrls $elex $eley
HTMesh 5 5 1 -phaseChange 0 -SectionLoc 11.7 -MeshCtrls $elex $eley
HTMesh 6 6 1 -phaseChange 0 -SectionLoc 14.1 -MeshCtrls $elex $eley
HTMesh 7 7 1 -phaseChange 0 -SectionLoc 16.5 -MeshCtrls $elex $eley
HTMesh 8 8 1 -phaseChange 0 -SectionLoc 18.9 -MeshCtrls $elex $eley
```

locz

```
HTMeshAll;
puts "mesh done";
```

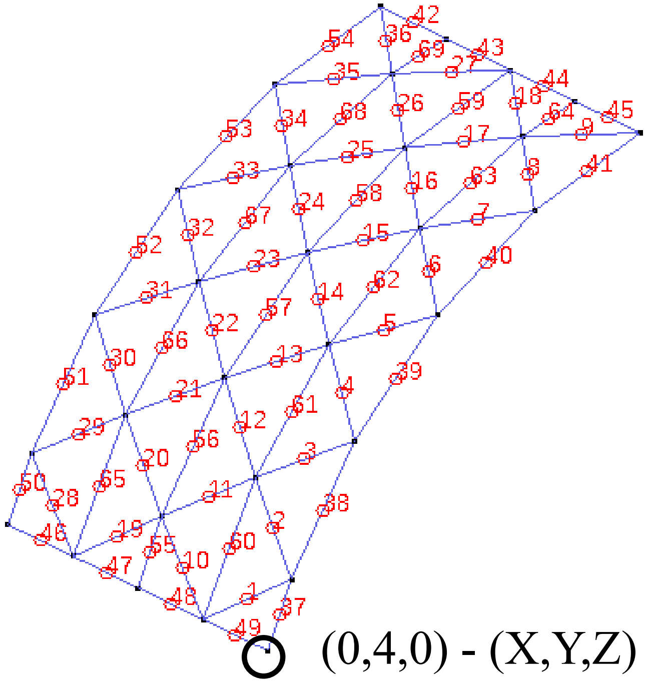


Center of the block probe

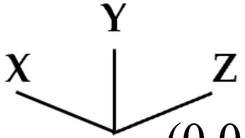
Example:

Setting (locx, locy) in HTEntity

Setting locz in -SectionLoc



(0,4,0) - (X,Y,Z)

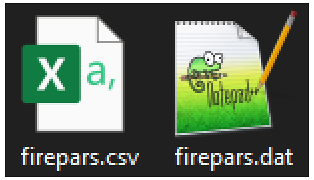


(0,0,0)

Coordinate system in OpenSEES for establishing fire scenarios

Case in Gid for demonstration

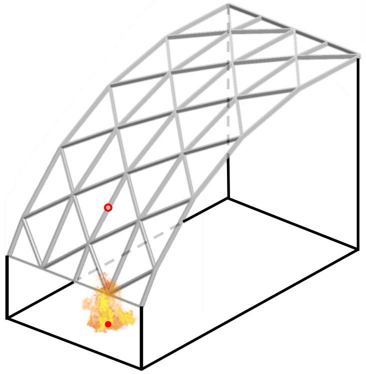
Setting probe in Tcl as thermocouples to record gas temperature



	Time (s)	locx (m)	locy (m)	locz (m)	Q (W)	Equivalen diameter of fire (m)	Ceiling height (m)	Smoke temperature (℃)	Additional heat flux (smoke induced, w/m^2)
2	0	3.6	0	0.292517	0	0	4.689637815	20	0
3	10	3.6	0	0.292517	4690	0.077275439	4.689637815	20	0
4	20	3.6	0	0.292517	18760	0.154550878	4.689637815	20	0
5	30	3.6	0	0.292517	42210	0.231826317	4.689637815	20	0
6	40	3.6	0	0.292517	75040	0.309101756	4.689637815	20	0
7	50	3.6	0	0.292517	117250	0.386377195	4.689637815	20	0

Natural fire model (OpenSees)

design fire scenarios



Fire location: lower center

Fire size: 30 MW

HRRPUA: 1000 kW/m^2

Fire growth rate "fast": 0.0469 kW/s^2

Fire duration: 30 min

Set-up probes as thermocouples

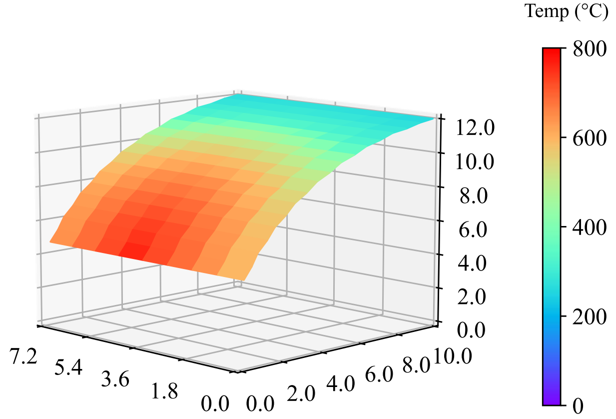
Assign thermocouples

- firepars.csv
- firepars.dat
- HTEntity_locationofprobe_xy.tcl
- HTMesh_locationofprobe_z.tcl
- HTNodeSet_locationofprobe_recoder.tcl
- HTPattern_ConvecAndRad.tcl
- HTPattern_Prescribed.tcl
- HTRecorder_locationofprobe_recoder.tcl
- main.tcl
- OpenSees.exe

Determining location of thermocouples

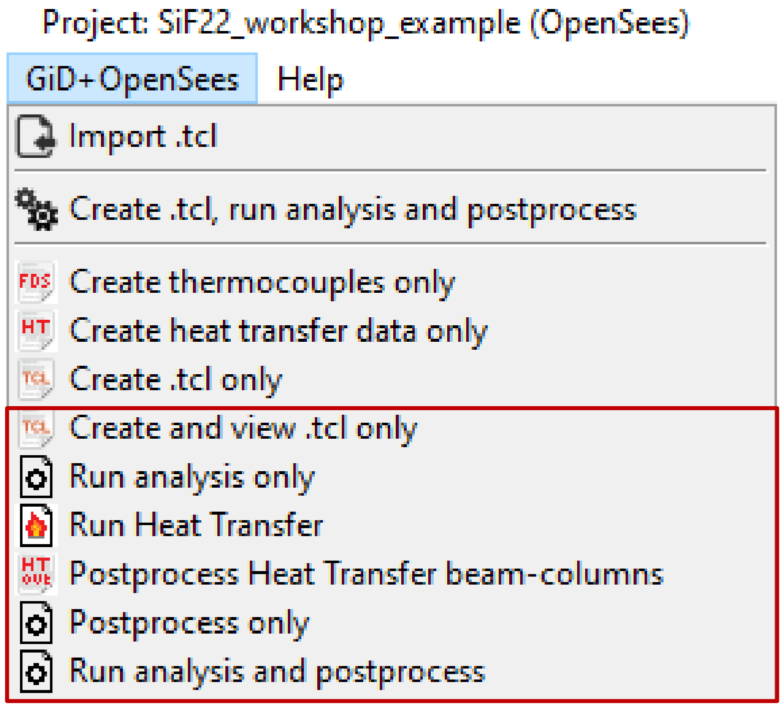
Gas temperature as thermal load

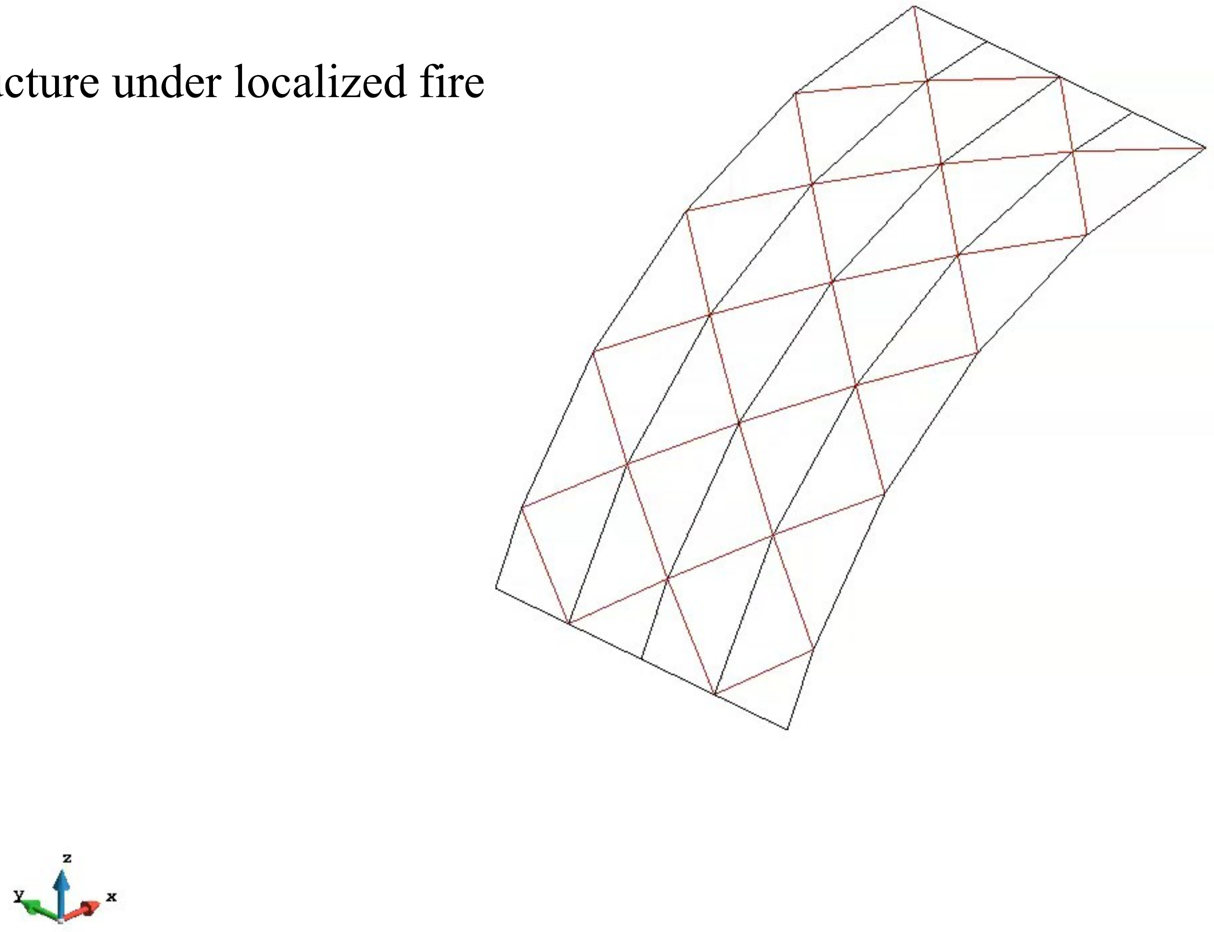
- templLoc1.out
- templLoc2.out
- templLoc3.out
- templLoc4.out
- templLoc5.out
- templLoc6.out
- templLoc7.out
- templLoc8.out
- templLoc9.out
- templLoc10.out



Thermal & Structural analysis in GiD

Heat transfer analysis and structural analysis of structure under localized fire





Deformation (x1): Nodes//Displacements of Interval 2 - Static, step 0.

Application of Localized Fire Model for Performance-based Structural Fire Design

Relevant publications & links

Development of Gid

- Orabi MA, Khan AA, Jiang L, Yarlagadda T, Torero J, Usmani A. Integrated nonlinear structural simulation of composite buildings in fire. Eng Struct 2022;252:113593.
- https://github.com/Anwar8/gidopensees

Considering smoke effect in localized fire model

- Khan AA, Nan Z, Jiang L, Gupta V, Chen S, Khan MA, et al. Model characterisation of localised burning impact from localised fire tests to travelling fire scenarios. J Build Eng 2022;54:104601.

Application of natural fire model

- Nan Z, Khan AA, Jiang L, Chen S, Usmani A. Application of travelling behaviour models for thermal responses in large compartment fires. Fire Saf J 2022;134:103702.

Aluminium reticulated roof structure (Day1 Parallel Session B1-2 11:30-11:45)

- Nan Z, Orabi MA, Zhang X, Khan AA, Huang X. Rapid Forecasting of the Structural Failure of a Full-Scale Aluminium Alloy Reticulated Shell Structure in Fire. 12th Int. Conf. Struct. Fire, Hong Kong, China: 2022.

SureFire
Smart Urban Resilience and Firefighting

www.polyu.edu.hk/beee/web/PolyUFire/index.html