FIBER TOOL USER GUIDE

FIRE DESIGN OF SPEEDCORE WALLS (C-PSW/CF) AND CFT COLUMNS

Version 1.0 - Beta

Fiber Model

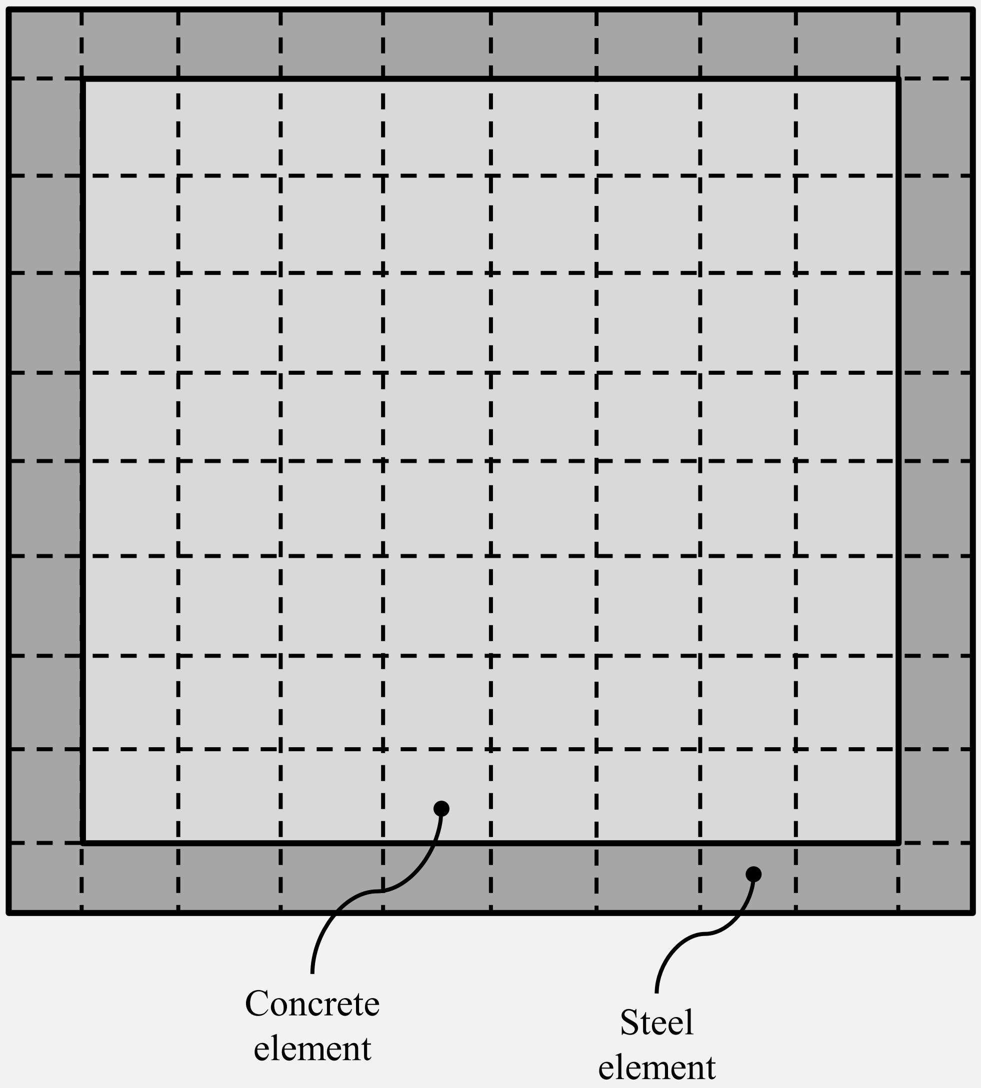
The Fiber Model serves as a simplistic tool for engineers that can be used to simulate the standard fire behavior of C-PSW/CF wall systems and CFT columns with reasonable accuracy and lesser computing time than finite element models.

This tool consist of three main major parts including:

1. 2 D heat transfer of the applied thermal loading through the composite cross-section using heat balance equations.

2. Moment – Curvature (M-ϕ) response of the C-PSW/CF wall system and CFT column's cross-section for the given axial loading and elevated temperatures computed in part 1using fiber models.

3. Overall axial and lateral displacement-time behavior of the C-PSW/CF wall systems and CFT columns under fire loading using Newwark's method for inelastic column buckling, the obtained temperatures from part 1 and the corresponding section Moment – Curvature response (part 2)



Discretized composite section into elements

A. How to use the tool:

The user can modify the input parameter such as dimensions, material properties, fire scenarios, etc. The output file's name can be defined by the user. For easier interaction of the user with the tool, the definition of each parameter was provided within the script. Two versions of the current tool were developed compatible with Matlab and Octave. The screenshots of the fiber tool script (from Matlab) have been used in the current user guide document, explaining how to input the parameters. The same script was used for the input information section for Octave version.

To run the program the user needs to open "main_function_final.m". In this file, the user can input the parameters and define the name of the output file's name. After analysis completion, the detailed results like stresses, strains, etc. within the cross-section will be stored in Matlab/Octave. The design results and general analysis result (such as axial displacement and temperatures) will be exported to excel. The development of a Graphical User Interface (GUI) for the current tool is in progress which will provide an easier interaction of the user with the tool and interactive plots of the results.

<u>To use the tool:</u>

1. Launch Matlab or Octave
2. Go to Open > main_function_final.m
3. Define the input parameters in the input information section.
4. Run the code.

B. Input information:

The “Input” section is separated from rest of the scripts by defining the beginning and the end of the section as shown below:

Beginning of the input section:

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%   INPUT INFORMATION   %%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

End of the input section:

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%  END OF INPUT INFORMATION   %%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

The Input Information involves seven main sections:

1. Analysis type
2. Geometric properties
3. Fiber discretization
4. Loading
5. Material properties
6. Heating properties
7. Name of the output files

The details of the sections including the definition of the parameters along with screenshots from the script are provided in the following pages.

1. Select analysis type: Define the type of the structural element and the analysis

C-PSW/CF =1

CFT = 2

```
%%%%%%%%%%%%%%%%%%%%%%%%%%     DESIGN CASE    %%%%%%%%%%%%%%%%%%%%%%%%%%%
%C-PSW/CF=1
%CFT=2
Design_case=1;             info(82)=Design_case;
```

Choose the analysis type
(details are presented in the table)

```
% 1-sided strip = 1
% 2-sided strip = 2
% 4-sided section = 4
heating = 2;                    info(55) = heating;
%NOTE:
%Only use 4 for CFT columns
%If heating=1 or 2, choose 15 to 19
```

Case	Analysis type	Heating scenario	Applicable section
1	1-sided strip* - Unit width segment	1 side (web)	C-PSW/CF
2	2-sided strip* - Unit width segment	2 sides (web)	C-PSW/CF
4	4-sided section - Whole section	Four sides	CFT & C-PSW/CF

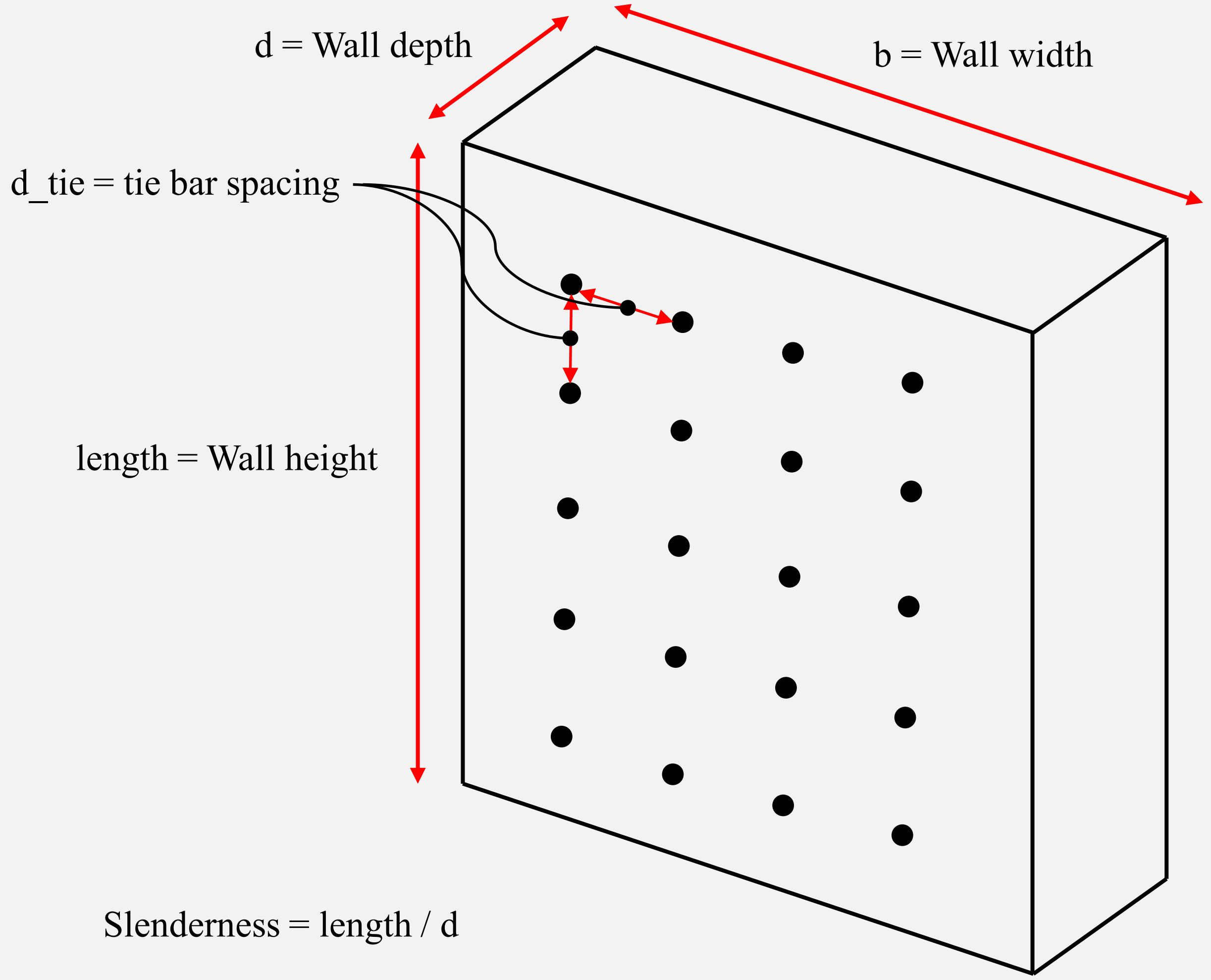
* For unit width segment method of wall only use the time-temperatures cases 15 to 19

2. Geometric properties: Input the dimensions of the section

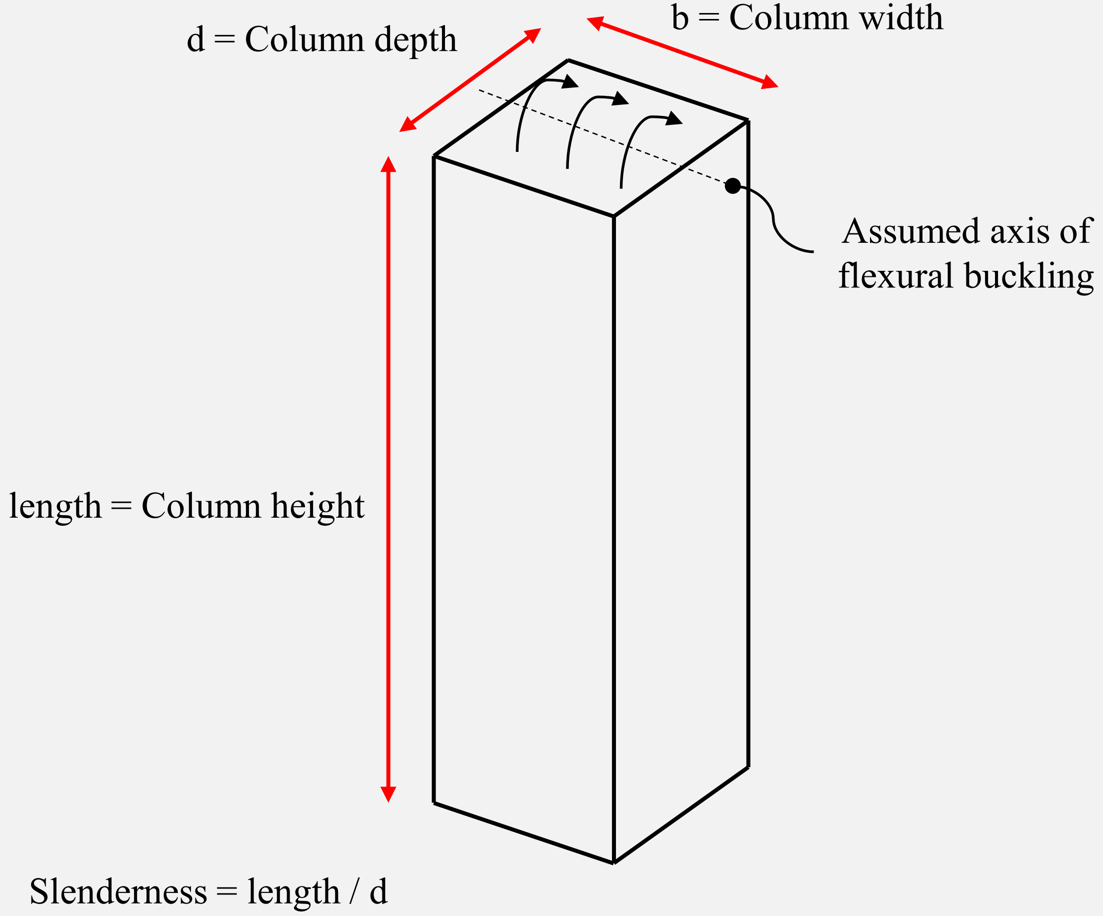
Width of the column or wall (m)	`b=150/1000;`
Tie bar spacing (m) – Only walls	`d_tie=150/1000;`
Depth (or thickness) of the wall or column (m)	`d=300/1000;`
Steel plate thickness (m)	`ts=6/1000;`
Fire protection thickness (m)	`tg=5/1000;`
The wall/column slenderness ratio (height-thickness ratio)	`Slenderness = 20;`
Initial imperfection = Length/imperfection	`imperfection = 1000;`
The code calculates the height of the member based on the slenderness ratio- The user does not need to specify the height directly	`Length = d*Slenderness;`

```
%%%%%%%%%%%%%%%%%%%%%%    GEOMETRIC PROPERTIES    %%%%%%%%%%%%%%%%%%%%%%%%%
b=150/1000;                 info(1)=b;              % Enter Width of column/wall (m)

d_tie=150/1000;             info(29)=d_tie;         % Enter Tie bar spacing  (m)

d=300/1000;                 info(28)=d;             % Enter Depth of wall/column (m)

ts=6/1000;                  info(2)=ts;             % Enter Thickness of steel faceplates (m)

tg=5/1000;                  info(3)=tg;             % Enter Thickness of FP layer  (m)

Slenderness = 20;           info(76)=Slenderness;   % Enter Height / Depth or Thickness

imperfection = 1000;        info(22)=imperfection;  % Enter Initial column imperfection

Length = d*Slenderness;     info(18)=Length;
```

2. Geometric properties



C-PSW/CF wall



CFT column

3. Fiber discretization: Define the number of elements in concrete along x and y axis

Number of concrete elements in X axis (Use even numbers)

Number of concrete elements in Y axis (Use even numbers)

Number of elements in the height of the member

Maximum analysis time (sec)
The analysis will stop if the analysis time exceeds t_max

```
%%%%%%%%%%%%%%%%%%%%%%%%   FIBER DISCRETIZATION    %%%%%%%%%%%%%%%%%%%%%%%%%%
Ncx=10;                     info(4)=Ncx;          % Enter Number of concrete element along x axis

Ncy=20;                     info(27)=Ncy;         % Enter Number of concrete element along y axis

N_ele = 14;                 info(19)=N_ele;       % Enter number of element in the beam-column

t_max=700*60;               info(8)=t_max;        % Max time duration of simulation (sec)
```

4. Loading: Input the axial load

Axial load (kN)
If there is no load, enter a small non-zero value

Ambient temperature (°C)

Eccentricity of the axial load.
If there is no eccentricity,enter a small non-zero value

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%   LOADING    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Pn = 300;                      info(75)=Pn;            % Enter the applied axial load (kN)

ini_temp = 20;                 info(17)=ini_temp;      % Enter initial temperature (Ambient)

ecc = 0.001;                   info(20)=ecc;           % Enter eccentricity of load
```

5. Material properties: (i) Define the properties of the material (at ambient temperature)

- Density of steel (kg/m^3)
- Density of concrete (kg/m^3)
- Density of FP material (kg/m^3)
- Thermal conductivity of FP (W/m °C)
- Specific heat of FP (J/kg °C)
- Steel yield stress (Mpa)
- Compressive strength of concrete (Mpa)

```
%%%%%%%%%%%%%%%%%%%%%%%%   MATERIAL PROPERTIES   %%%%%%%%%%%%%%%%%%%%%%%%
Ds=7850;                     info(9)=Ds;         % Enter Density of steel (kg/m^3)

Dc_20=2400;                  info(10)=Dc_20;     % Enter Density of concrete (kg/m^3)

Dg=900;                      info(11)=Dg;        % Enter Density of FP (kg/m^3)

kg=0.120;                    info(12)=kg;        % Enter Thermal conductivity of FP (W/m - C)

Cg=1047;                     info(13)=Cg;        % Enter Specific heat conductivity of FP (J/kg - C)

Fya_s=345;                   info(14)=Fya_s;     % Enter yield stress of steel (MPa)

Fya_c=40;                    info(15)=Fya_c;     % Enter compressive strength of concrete (MPa)
```

(ii) the limiting width to thickness ratios (AISC360-16, Table I1.1a)

- λ_p (Compact/Noncompact)
- λ_r (Noncompact/Slender)

```
lambda_p = 2.26*sqrt(200000/Fya_s); info(91)=lambda_p;        % Compact slenderness limit

lambda_r = 3*sqrt(200000/Fya_s);    info(92)=lambda_r;        % Non-compact slenderness limit
```

(iii) Select the material stress-strain model

List of the available material models

Choose the desired material model

Define the limiting strain for concrete (Default value – if applicable)

Define the limiting strain for steel (Default value – if applicable)

```
%%%%%%%%%%%%%%%%%%%%%     Material property choice    %%%%%%%%%%%%%%%%%%%%%%%
% Lie steel at ambient and Lie concrete === 1
% Lie steel at elevated and Lie concrete === 2
% Poh steel at ambient and Lie concrete ===3
% Poh steel at elevated and Lie concrete === 4
% Fire resistant steel property and Lie concrete ==5
% Elastic-perfectly-plastic Steel and Concrete ==6  ONLY FOR AMBIENT
% Effective Stress-strain curves for steel == 7
% Eurocode Stress-strain Curves for Steel and Concrete == 8
mat_case = 8;                   info(50)=mat_case;

% Limiting strain for concrete material
limit_strain_c=0.03;            info(51)=limit_strain_c;

% Limiting strain for steel material
limit_strain_s=0.06;            info(53)=limit_strain_s;
```

6. Heating properties: (i) select the fire time-temperature case

List of available time-temperature curves

```
%%%%%%%%%%%%%%%%%%%%%%     FIRE TIME-TEMPERATURE    %%%%%%%%%%%%%%%%%%%%%%%%%
% ASTM Time-temperature = 1
% ASTM Time-temperature w/o FRP = 10
% Han's column 9 steel temperature = 2
% Han's column 10 steel temperature = 3
% Han's column 11 steel temperature = 4
% sakumoto's bare steel column surface steel temperature = 5
% Sakumoto's steel surface temperature = 6
% Lie's column steel surface temperature = 7
% Eurocode compartment model FIRE temperature = 9
% Gas Temperature curve without fire protection = 12
% FEM generated surface temperature = 15
% Eurocode compartment gas temperature (includes FP)  = 16
% User input gas temperature (w/o FP)  = 17
% User input gas temperature (w/ FP)  = 18
% User input steel surface temperature = 19
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
T_surf_case = 19;             info(52)=T_surf_case;

input_temp = "00-User_Input_Temp.xlsx";
```

Choose the desired time-temperature curve

Define the user input time-temperature file (cases =17-19)

An example of user input time-temperature spreadsheet:

First column = Time (minute)
Second column = Temperature (Celsius)

Time(min)	Temp(°C)
0.00	20.00
2.00	52.42
4.00	107.24
6.00	149.74
…	…

(ii) Define the Eurocode compartment fire time temperature curve

Total opening area (m^2)	`A_v=1.0658;`
Height of the opening (m)	`H_v=1.1361;`
Total compartment area (m^2)	`A_t=301.0058;`
Floor area (m^2)	`A_f=83.6127;`
Fire load density (MJ/ m^2 floor area)	`e_f=800;`
Fuel controlled fire scenario duration of burning (min) – See next page	`t_lim=25;`
Compartment surface material density (kg/m^3) *	`Dec=711;`
Compartment surface material thermal conductivity (W/m °C) *	`kec=0.258;`
Compartment surface material specific heat (J/kg °C) *	`Cec=1089;`

```
%%%%%%%%%%%%%%%%   EUROCODE COMPARTMENT FIRE PARAMETERS   %%%%%%%%%%%%%%%%%
A_v=1.0658;              info(63)=A_v;          % Total openning area (m^2)

H_v=1.1361;              info(64)=H_v;          % Height of opening (m)

A_t=301.0058;            info(65)=A_t;          % Total compartment area (m^2)

A_f=83.6127;             info(66)=A_f;          % Floor area (m^2)

e_f=800;                 info(67)=e_f;          % Fire load energy density (floor area - m^2)

t_lim=25;                info(68)=t_lim/60;     % Fuel controlled duration of burning (min)

%Fire compartment material thermal properties
Dec=711;                 info(69)=Dec;          % Density  (kg/m^3)

kec=0.258;               info(70)=kec;          % Thermal conductivity (W/m - C)

Cec=1089;                info(71)=Cec;          % Specific heat (J/kg - C)
```

*The tool calculates the thermal inertia as $b = \sqrt{D_{ec} \times k_{ec} \times C_{ec}}$

(ii) Define the Eurocode compartment fire time temperature curve

Occupancy	**Fire growth rate**	**t_{lim} (min)**
Dwelling	Medium	20
Hospital (room)	Medium	20
Hotel (room)	Medium	20
Library	Fast	15
Office	Medium	20
Classroom of a school	Medium	20
Shopping	Fast	15
Theatre (cinema)	Fast	15
Transport (public space)	Slow	25

Adopted from Eurocode 1 Part 1.2 (CEN, 2002)

CEN (2002b) *Eurocode 1: Actions on structures - Part 1-2: General actions - Actions on structures exposed to fire. EN 1991-1-2*. European Committee for Standardization, Brussels

(iii) Define convection and radiation information

- Convection coefficient (W/m^2 °C)
- Stefan-Boltzmann constant (W/m^2 °C^4)
- Emissivity for the fire protection
- Emissivity for steel material
- Emissivity for air

```
%Convection and radiation information
h=25;                    info(23)=h;             % Convection coeficient (W/m2 C)
sigma=5.67E-8;           info(24)=sigma;         % Stefan-Boltzman constant (W/m2-C4)
eg=0.9;                  info(25)=eg;            % emissivity of gypsum
es=0.95;                 info(30)=es;            % emissivity of steel
ef=0.75;                 info(26)=ef;            % emissivity of fire smoke
```

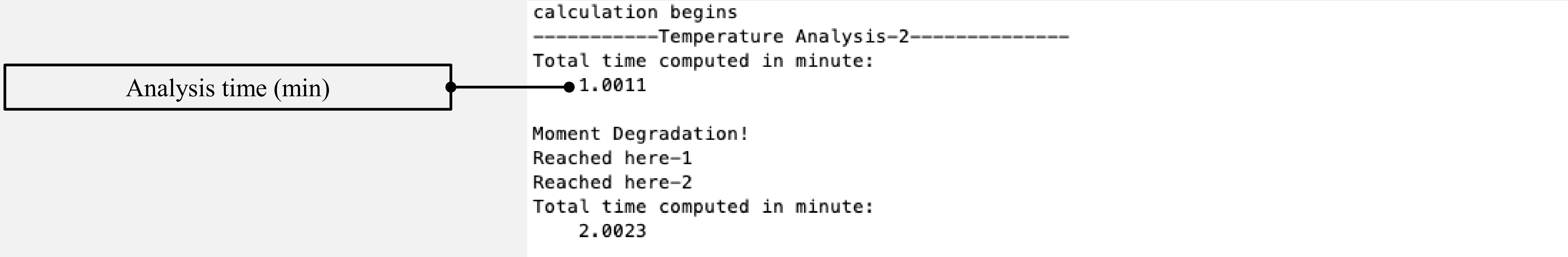
7. <u>Name of the output files</u>: The results of the analysis will be written in three excel files. The name of the files can be defined in the user input section.

- Define name of the design file
- Define name of the result file
- Define name of the temperature (temp) file

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%   Define name of the output files   %%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
design_file = '01-Design.xlsx';              %Design
result_file = '02-Results.xlsx';             %Analysis result
temp_file = 'result_temp_node.xlsx';         %Temperatures
```

C. Running the program:

After inputting the parameters, the program is ready to run. The analysis time can be tracked from the command window. In the figure below, a screenshot of the command window during running the code is shown.



D. Analysis results: (Design results)

Design results file includes $P_{no}(T)$, $EI_{eff}(T)$, $P_e(T)$, $P_n(T)$ of the cross-section, calculated based on the temperature of the elements at the maximum surface temperature and the estimated fire resistance rating (for walls). Also, the temperature of the elements through the thickness will be provided in the file. An example of the design output file are shown below:

Analysis time (min)	27.2067				
Max. Surface Temperature (C)	497.6866				
OOP displacement (mm)	0.19527				
Pno_T (kN)	1883.4378				
EI_eff_T(kN.m2)	8351.1633				
Pe_T(kN)	2289.5188				
Pn_T(kN)	643.063				
Fire resistance rating (R)-hr (only wall)	1.3353				
Cross section temperature profile					
Steel ele	Concrete ele	Concrete ele	Concrete ele	Concrete ele	....
495.0905	368.9227	188.7766	108.7658	71.1952	....

The utilized equations for design outputs are presented in the next page.

D. Analysis results: (Design results)

The utilized equations to calculate $P_{no}(T)$, $EI_{eff}(T)$, $P_e(T)$, $P_n(T)$ and the fire resistance rating of C-PSW/CF are presented below:

$$P_{no}(T) = A_s f_y(T) + \sum_{i=concrete\_ele} A_{ci} f'_{ci}$$

Nominal axial compressive strength of zero length

$$C_3 = 0.45 + 3(A_s / A_g) \leq 0.9$$

Coefficient for calculation of effective rigidity of filled composite compression member

$$EI_{eff}(T) = E_s I_s + \sum_{i=concrete\_ele} C_3 E_c I_c$$

Effective stiffness of composite section

$$P_e(T) = \frac{\pi^2 EI_{eff}(T)}{(L_c)^2}$$

Elastic critical buckling load

$$P_n(T) = 0.32^{\left(\frac{P_{no}(T)}{P_e(T)}\right)^{0.3}} P_{no}(T)$$

Nominal axial strength for C-PSW/CF

$$P_n(T) = 0.45^{\left(\frac{P_{no}(T)}{P_e(T)}\right)^{0.3}} P_{no}(T)$$

Nominal axial strength for CFT

$$R = \left[-18.5\left(\frac{P_u}{P_n}\right)^{\left(0.24 - \frac{L/t_{sc}}{230}\right)} + 15\right]\left(\frac{1.9\, t_{sc}}{200} - 1.0\right) < 8hr$$

Fire resistance rating of C-PSW/CF

Note: The following limitations should be satisfied to use the fire resistance rating equation:

a) $\frac{L}{t_{sc}} \leq 20$ b) $t_{sc} \leq 600mm$ c) $\frac{P_u}{P_n} \leq 0.20$

D. Analysis results: (Analysis result)

Analysis result file includes the time, surface temperature, axial displacement and out-of-plane displacement of the member during the heating. An example of the result file is shown below:

Time (min)	Surface temperature (C)	Axial displacement (mm)	Out-of-plane displacement (mm)
1.0074	37.4274	0.12769	0.12055
2.0107	55.0484	0.50432	0.12025
3.0239	72.8437	0.89432	0.12031
4.0293	90.5015	1.3422	0.12046
5.0417	108.2829	2.3698	0.12118
6.0426	125.8625	3.4193	0.12271
7.048	143.5201	4.5226	0.12449
8.0571	161.2429	5.755	0.12646
9.0691	179.0182	6.9944	0.12862
10.0836	196.8346	8.2405	0.13098
11.0903	214.5232	9.4778	0.1335
12.0971	232.2126	10.7151	0.13608
13.1039	249.9021	11.9528	0.13875
14.1107	267.5918	13.1931	0.14155
15.1176	285.2819	14.4361	0.14453
16.1244	302.9724	15.681	0.1477
17.1313	320.6636	16.9273	0.15106

D. Analysis results: (Temperatures result)

The temperature of the elements will be recorded in **Temperatures result** file. The elements' temperature for each time step will be saved in separate sheets. An example of the temperatures result file is shown below:

Concrete element temperature

Steel element temperature

535.839	534.6409	533.6435	533.3949	533.3394	533.328	533.3281	533.34	533.3972	533.6472	534.6427	535.8389
534.6426	457.1199	362.7391	340.4573	335.8396	334.9081	334.9082	335.8403	340.4598	362.7431	457.1219	534.6426
533.6457	362.7413	160.1523	116.5378	104.7118	101.7229	101.7229	104.7118	116.538	160.1526	362.7415	533.6457
533.3954	340.4578	116.5379	70.53137	54.5034	49.83101	49.83101	54.50342	70.53141	116.5379	340.4579	533.3954
533.3395	335.8397	104.7118	54.50341	36.38196	30.97676	30.97676	36.38197	54.50341	104.7118	335.8397	533.3395
533.328	334.9081	101.7229	49.83101	30.97676	25.32776	25.32776	30.97676	49.83101	101.7229	334.9081	533.328
533.328	334.9081	101.7229	49.83101	30.97676	25.32776	25.32776	30.97676	49.83101	101.7229	334.9081	533.328
533.3395	335.8397	104.7118	54.50341	36.38196	30.97676	30.97676	36.38196	54.50341	104.7118	335.8397	533.3395
533.3954	340.4579	116.5379	70.53139	54.50341	49.83101	49.83101	54.50341	70.53139	116.5379	340.4579	533.3954
533.6457	362.7415	160.1525	116.5379	104.7118	101.7229	101.7229	104.7118	116.5379	160.1525	362.7415	533.6457
534.6426	457.1217	362.7415	340.4579	335.8397	334.9081	334.9081	335.8397	340.4579	362.7415	457.1217	534.6426
535.8389	534.6426	533.6457	533.3954	533.3395	533.328	533.328	533.3395	533.3954	533.6457	534.6426	535.8389

Notations

A_s	Area of steel in the composite cross section
A_c	Area of concrete in the composite cross section
t_{sc}	Wall thickness
L	Wall/column height
f_y	Yield strength of steel
$f_c^{'}$	Compressive strength of concrete
E_s	Modulus of elasticity of steel
E_c	Modulus of elasticity of concrete
I_s	Moment inertia of steel
I_c	Moment inertia of concrete
P_u	Axial loading
$P_{no}(T)$	Nominal axial compressive strength of zero length at elevated temperatures
C_3	Coefficient for calculation of effective rigidity of filled composite compression member
$EI_{eff}(T)$	Effective stiffness of composite section at elevated temperature
$P_e(T)$	Elastic critical buckling load at elevated temperature
P_n	Nominal axial strength at ambient temperature $P_n = 0.658^{\frac{P_{no}}{P_e}} P_{no}$
$P_n(T)$	Nominal axial strength at elevated temperature
R	Fire resistance rating of C-PSW/CF