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Steel cladding systems for stabilization of steel buildings in fire

KULDEEP VIRDI
City, University of London

OUTLINE

Context – STABFI project funded by RFCS

Brief summary of work

ECCS Recommendations for ambient temperature design using EN 1993-1-1 Buckling Rules

- Columns stabilsed with sandwich panels

Modifications for the fire design using EN 1993-1-2

Example

Conclusion

RFCS Project - STABFI

Steel cladding systems for stabilization of steel buildings in fire

PROJECT SCOPE

STABFI – PROJECT SCOPE

At the time of the proposal, design recommendations existed for member and frame stabilization using sandwich panel and trapezoidal sheet cladding in ambient temperatures.

The aim of the STABFI project was to develop parallel design rules for the same applications, but for fire.

STABFI – PROJECT OBJECTIVES

To derive validated design rules to include

- Natural fires in single storey industrial or commercial buildings
- Temperatures of connectors and steel members near cladding structures
- Translational and rotational stiffness and resistance of typical joints between cladding and steel frames;
- Strength of stabilised members using ENV1993-1-2.

WORK PACKAGES

WP1 – TEMPERATURE CALCULATIONS

The approach is based on using Natural Fires.

FDS can be used to determine the temperatures in structural members, but requires time for modelling.

CFAST is easier to model but consistently underestimates the maximum localised temperatures compared with FDS.

EXPERIMENTS – WP2

PANEL AND JOINT TESTS IN FIRE

Testing in normal temperature and elevated temperature of sandwich panels.

Bending, rotational and torsional stiffness values were determined.

EXPERIMENTS – WP3

FULL-SCALE FURNACE TESTS

In these tests the aim was to determine temperature fields in steel sections, trapezoidal sheets, sandwich panels and joints.

Measurements included load bearing capacity of the transversely loaded beam sections laterally restrained by trapezoidal sheets and sandwich panels.

EXPERIMENTS – WP4

TESTS IN NORMAL CONDITIONS SIMULATING FIRE

In these tests, heating was done using electrical elements, hence ‘conditions simulating fire’.

Resistance of the main member was measured when cladding was at an elevated temperature. Tests were both with I- and tubular sections.

NUMERICAL WORK – WP5

FEM SIMULATION OF TEST RESULTS

Extensive numerical work was carried out to model the experiments.

This enabled some parametric studies to be carried out to augment the experimental data.

NUMERICAL WORK – WP6

STABILIZATION OF DISTINCT STRUCTURAL MEMBERS

This was done using a building being designed by one of the industrial partners in the project.

Existing design rules available in literature for ambient temperature, principally ECCS recommendations, were used.

FE analysis of the entire building was done, under design loads.

NUMERICAL WORK – WP6

STABILIZATION OF DISTINCT STRUCTURAL MEMBERS

Stability was examined of the wall panels at ambient temperatures with

- **Traditional bracing**
- **Sandwich panels**
- **Trapezoidal sheeting**

Stability was also examined of the roof panels with

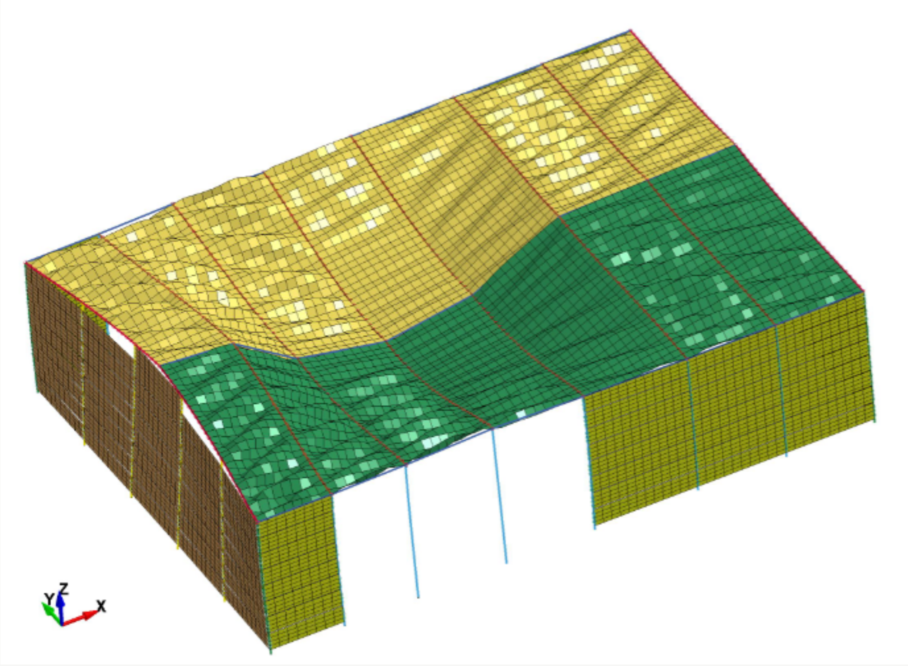
- **Sandwich panels**
- **Trapezoidal sheeting**

NUMERICAL WORK – WP6

STABILIZATION OF ENTIRE BUILDING IN FIRE

FE analysis of the entire building

- **FDS for temperature distribution**
- **ABAQUS for structural response**



RESULTS PERTINENT TO AXIAL CAPACITY CALCULATIONS

EXPERIMENTS – PERTINENT RESULTS

Main Member: Temperature of the main member is assumed to be the same as the fire temperature if not protected.

Fastener: The temperature of a fastener loaded in shear may be expected to be the same as the temperature of the supported main member

EXPERIMENTS – PERTINENT RESULTS

The temperature of steel sheet unexposed to fire may be calculated using the effective thermal conductivity λ_{eff}.

Expressions and tables are proposed, for example, for sandwich panels with PIR:

Panel thickness mm	Gas temperature in the fire compartment	λ_{eff} W/m°C
0.10	to 850 °C	0.018
	from 851 °C to 950 °C	$0.41 - 0.001\ \theta_{m,unex}$
0.16	to 950 °C	$1.20 - 0.001\ \theta_{m,unex}$
0.23	from 20 °C to 950 °C	0.018

EXPERIMENTS – PERTINENT RESULTS

Similar results/expressions also proposed for sandwich panels with Mineral Wool and for trapezoidal sheeting.

MEMBERS STABILISED WITH SANDWICH PANELS:

AXIAL CAPACITY UNDER

AMBIENT CONDITIONS

DESIGN PROCEDURE FOR AMBIENT CONDITIONS

Existing design rules for the stabilisation of buildings using sandwich panels for the non-fire state adopted from ECCS Recommendations are now described in outline form.

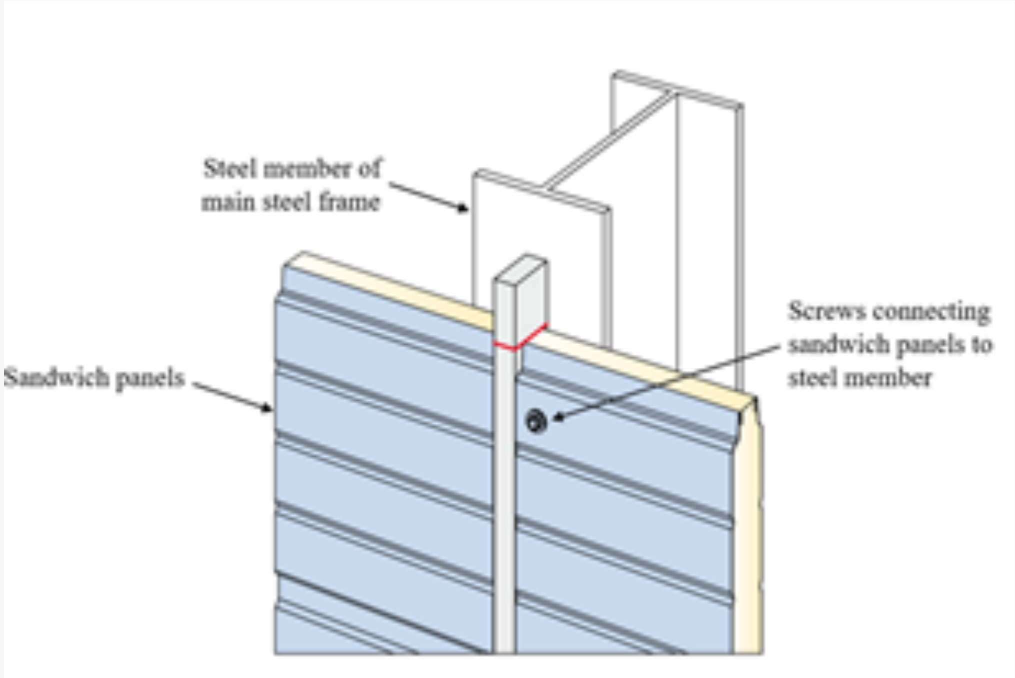
The same rules were later modified to include the effect of temperature on structural components.

ECCS RECOMMENDATIONS

STRUCTURAL MODEL

Sandwich panels are connected to the main member, a column in this case, using screws.

Fire is assumed to be on the inside.



ECCS RECOMMENDATIONS

STEPS IN THE CALCULATION OF AXIAL STRENGTH

1. Evaluate Shear Stiffness of the fastener. The input data include connector and sandwich panel geometrical and material properties.

2. Evaluate the increase in critical buckling load, ΔN_{cr}, of the column due to the restraining effects of sandwich panels. The input data are the Shear Stiffness calculated in Step 1 and the connector spacing.

ECCS RECOMMENDATIONS

STEPS IN THE CALCULATION OF AXIAL STRENGTH

3. **Evaluate the critical buckling load of the unstrained steel member, N_{cr}, using the effective length, L_{cr}, based on end conditions.**

4. **Calculate the critical buckling load, $N_{cr,res}$, of sandwich panel-restrained steel member in the plane of panels.**

$$N_{cr,res} = N_{cr} + \Delta N_{cr},$$

ECCS RECOMMENDATIONS

STEPS IN THE CALCULATION OF AXIAL STRENGTH

5. Calculate the modified effective length, $L_{cr,res}$, of sandwich panel-restrained steel member in the plane of panels.

   This length would be less than the original column effective length resulting in enhanced strength.

   The column strength can now be calculated using Eurocode 3 (EN1993-1-1).

MEMBERS STABILISED WITH SANDWICH PANELS:

AXIAL CAPACITY UNDER

ELEVATED TEMPERATURES

EFFECT OF TEMPERATURE

STEPS IN THE CALCULATION OF AXIAL STRENGTH

1. Calculate the temperatures in the main member, sandwich panel and the connector.

   For some specific cases, there are proposals, mentioned earlier.

2. Evaluate Shear Stiffness of the fastener. The input data include connector and sandwich panel geometrical and material properties reduced for temperatures.

EFFECT OF TEMPERATURE

STEPS IN THE CALCULATION OF AXIAL STRENGTH

3. Evaluate the critical buckling load of the unstrained steel member, N_{cr} , using the effective length, L_{cr} , based on end conditions and reduced material properties due to temperature.

4. Evaluate the increase in critical buckling load, ΔN_{cr}, of the column due to restraining effects of sandwich panels. The input data are the Shear Stiffness calculated in Step 2 and the connector spacing.

EFFECT OF TEMPERATURE

STEPS IN THE CALCULATION OF AXIAL STRENGTH

5. Calculate the critical buckling load, $N_{cr,res}$, of sandwich panel-restrained steel member in the plane of panels.

$$N_{cr,res} = N_{cr} + \Delta N_{cr},$$

EFFECT OF TEMPERATURE

STEPS IN THE CALCULATION OF AXIAL STRENGTH

6. Calculate the modified effective length, $L_{cr,res}$, of sandwich panel-restrained steel member in the plane of panels.

The column strength can now be calculated using Eurocode 3 Fire Part 2 (EN1993-1-2).

SOME EXPRESSIONS:

STIFFNESS AT ELEVATED TEMPERATURES

CONNECTOTR STIFFNESS

EXPRESSION ADAPTED FROM ECCS RECOMMENATIONS

The expression is a function of panel and connector geometrical and material properties.

Some of the terms above have further expressions to fully define the connector stiffness

CONNECTOTR STIFFNESS

REDUCTION FACTORS TO USE

By applying different reduction factors for material properties to the experimentally observed stiffness, the following recommendations are made.

1. Elastic Modulus of the fastener steel is subject to a reduction factor $k_{(E,\theta)}$ for temperature θ.

CONNECTOTR STIFFNESS

REDUCTION FACTORS TO USE

2. Elastic Modulus of the fastener steel is subject to a reduction factor $k_{(E,\theta)}$ for temperature θ.

3. A similar reduction is applied to the Elastic Modulus of the steel of the main member

CONNECTOTR STIFFNESS

REDUCTION FACTOR TO USE

4. For calculating the stiffness of the connector, its material strength is subject to a reduction factor for proportional limit $k_{(p,\theta)}$ for temperature θ.

The justification is that this factor was the only one to fit well with the experimentally observed values of the stiffness.

STRENGTH OF THE CONNECTOR

AT ELEVATED TEMPERATURES

CONNECTOTR STRENGTH

REDUCTION FACTOR TO USE

For calculating the strength of the connector, however, strength of the panel steel is subject to a reduction factor for ultimate strength $k_{(u,\theta)}$ for temperature θ.

SUMMARY

DESIGN RULES, GUIDES AND SOFTWARE – WP7

Existing design rules, for the stabilisation of buildings using sandwich panels for the non-fire state, have been adapted for the fire limit state.

Software (STABFIsoft) has been developed, implementing the new design rules.

A design guide, covering the new design rules as well as the use of new software has been written.

STABFIsoft

The computer program (STABFIsoft) has the following features:

- User-friendly interface
- Built-in steel sections: HEA, RHS, etc.
- For given temperatures, calculates connector stiffness, enhanced critical load, reduced effective length
- Design to EN1993-1-2

STABFIsoft

STABFIsoft

The software has a complete implementation of design of a column stabilised by sandwich panels at room temperature.

Includes major axis bending of column to establish lower of the strength due to bending in two separate planes. Major axis plane strength can be lower due to higher effective length.

STABFIsoft - STEPS

1. Specify mechanical properties of steel for the main member (column or beam)

2. Specify cross-section properties of main member (Standard sections can be recalled or the section can be user-defined

3. Specify properties of metal sheet of sandwich panels (products from project partner companies are included. Non-standard sections can also be specified)

STABFIsoft - STEPS

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STABFIsoft - STEPS

4. Specify properties of fasteners

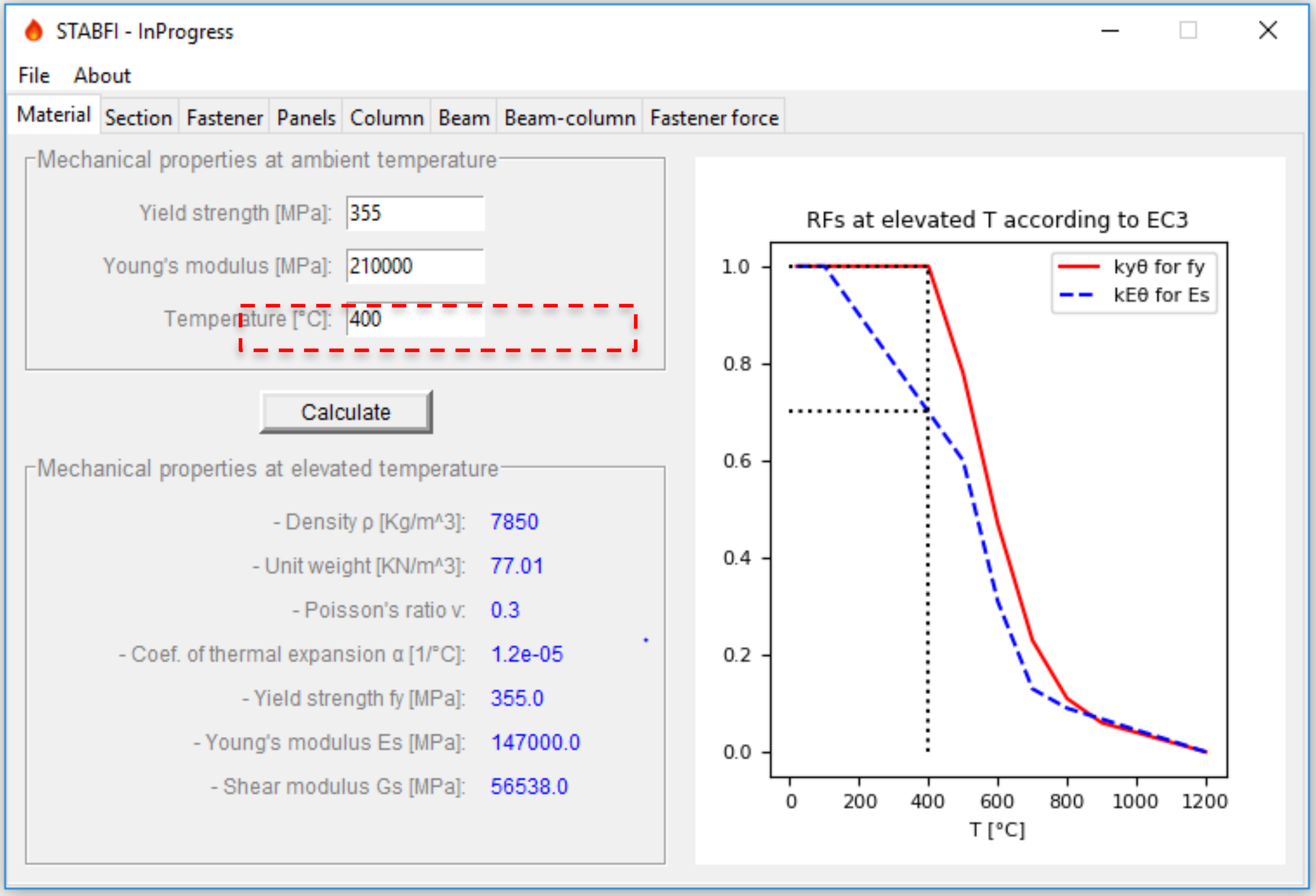
5. Specify boundary conditions

6. Analyse the assemblage for strength

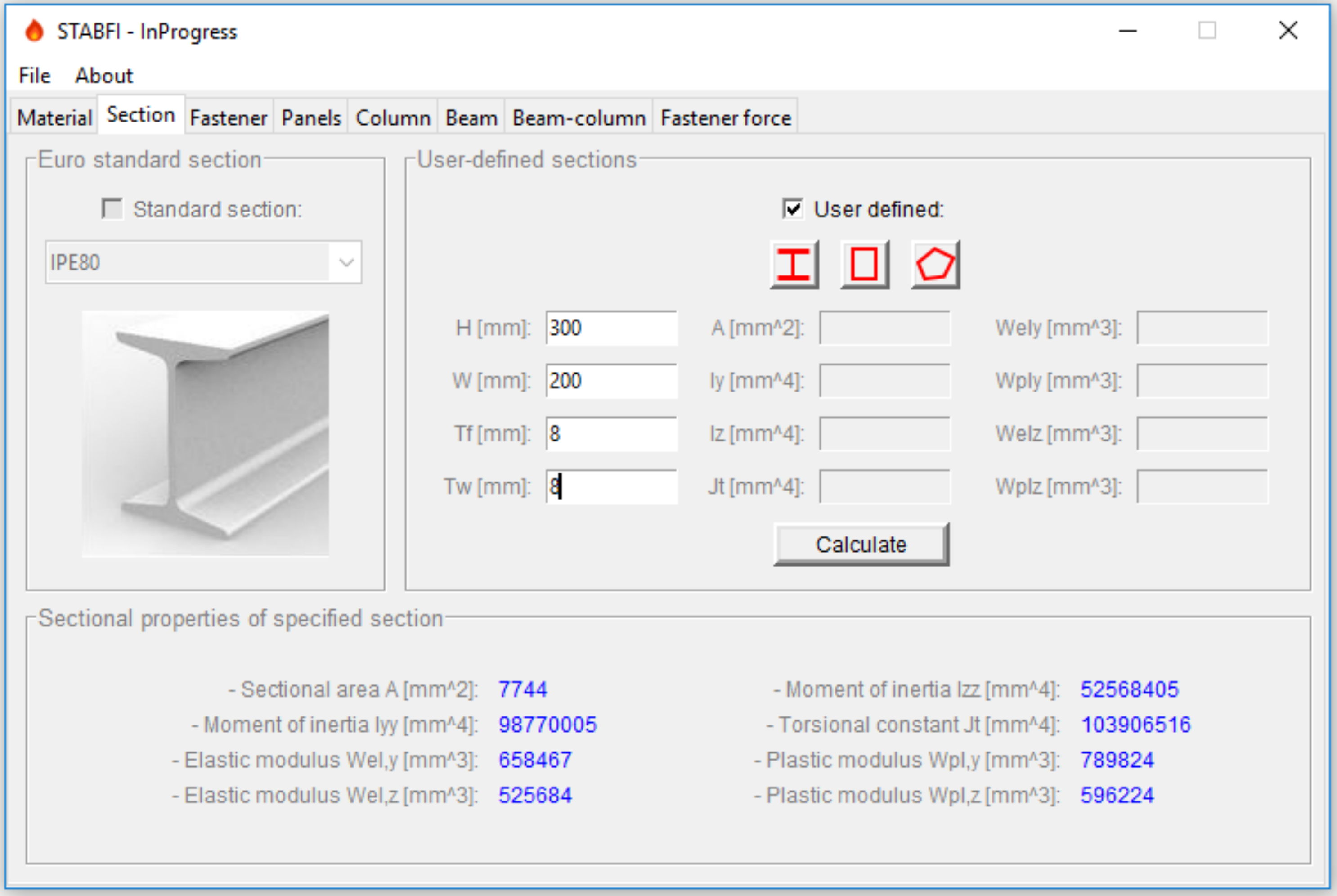
EXAMPLES OF FORMS IN SOFTWARE

THE NEED FOR FIRE REGULATION

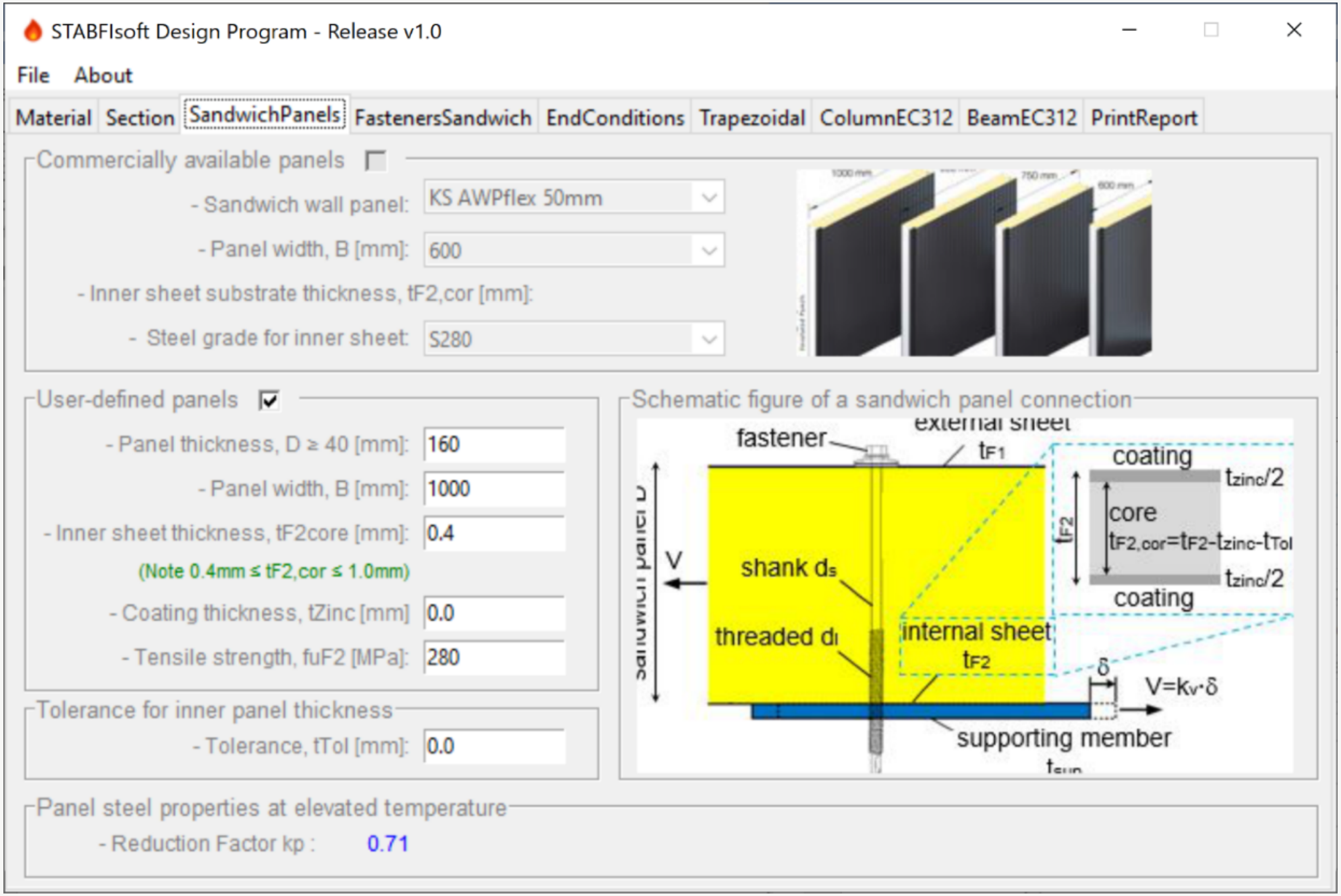
MATERIALS FORM



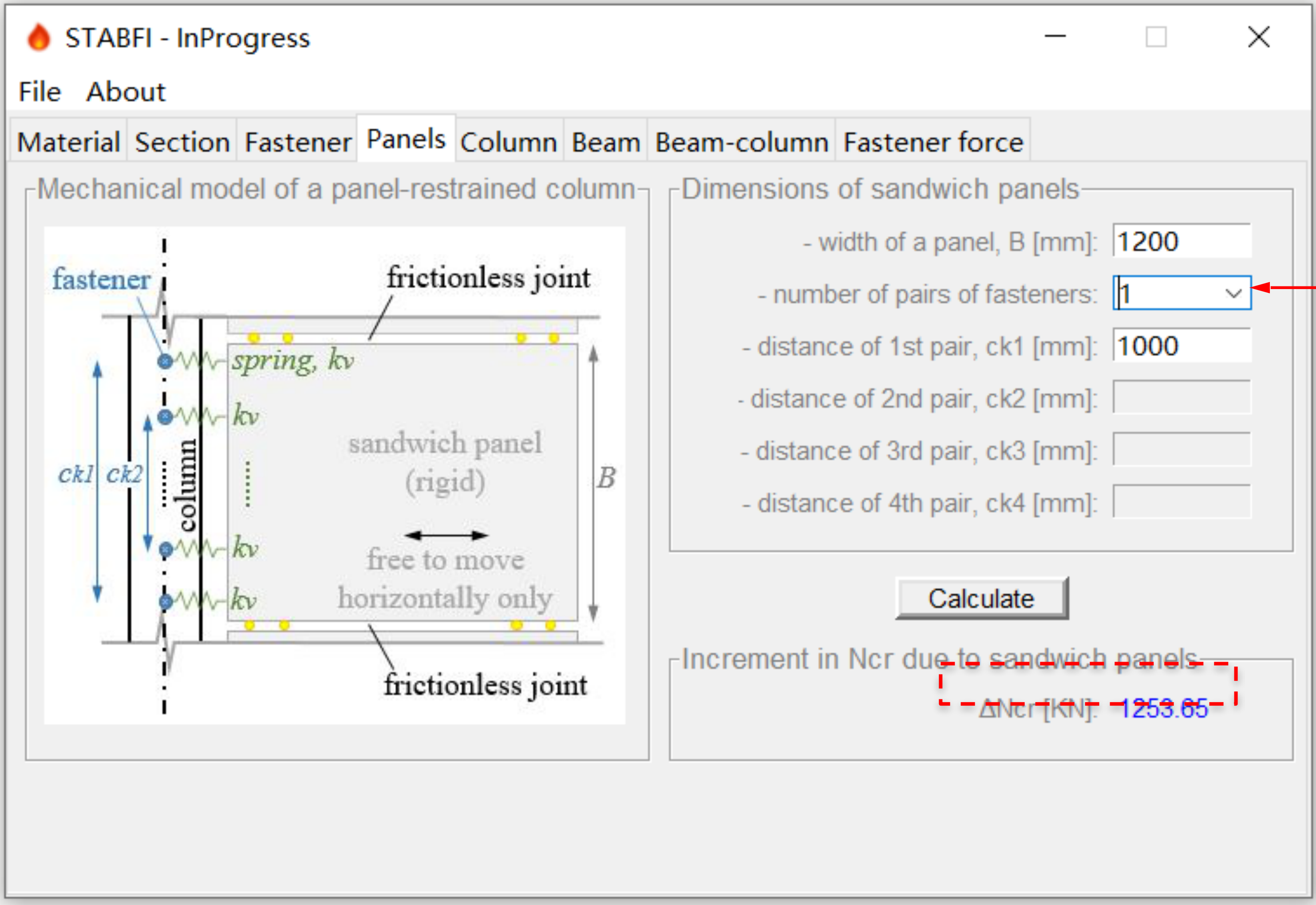
SECTIONS – STANDARD AND USER DEFINED



SANDWICH PANELS

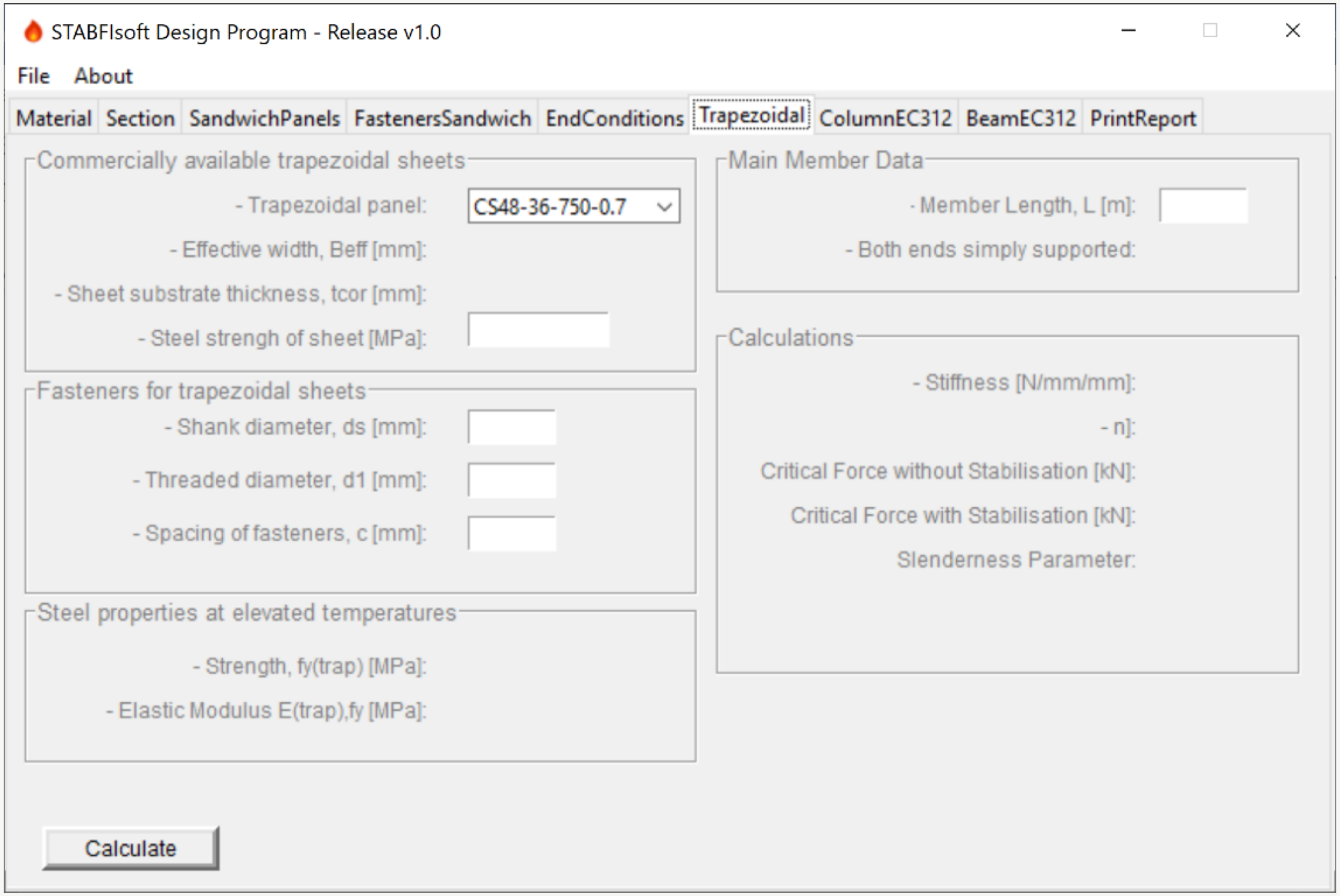


FASTENERS

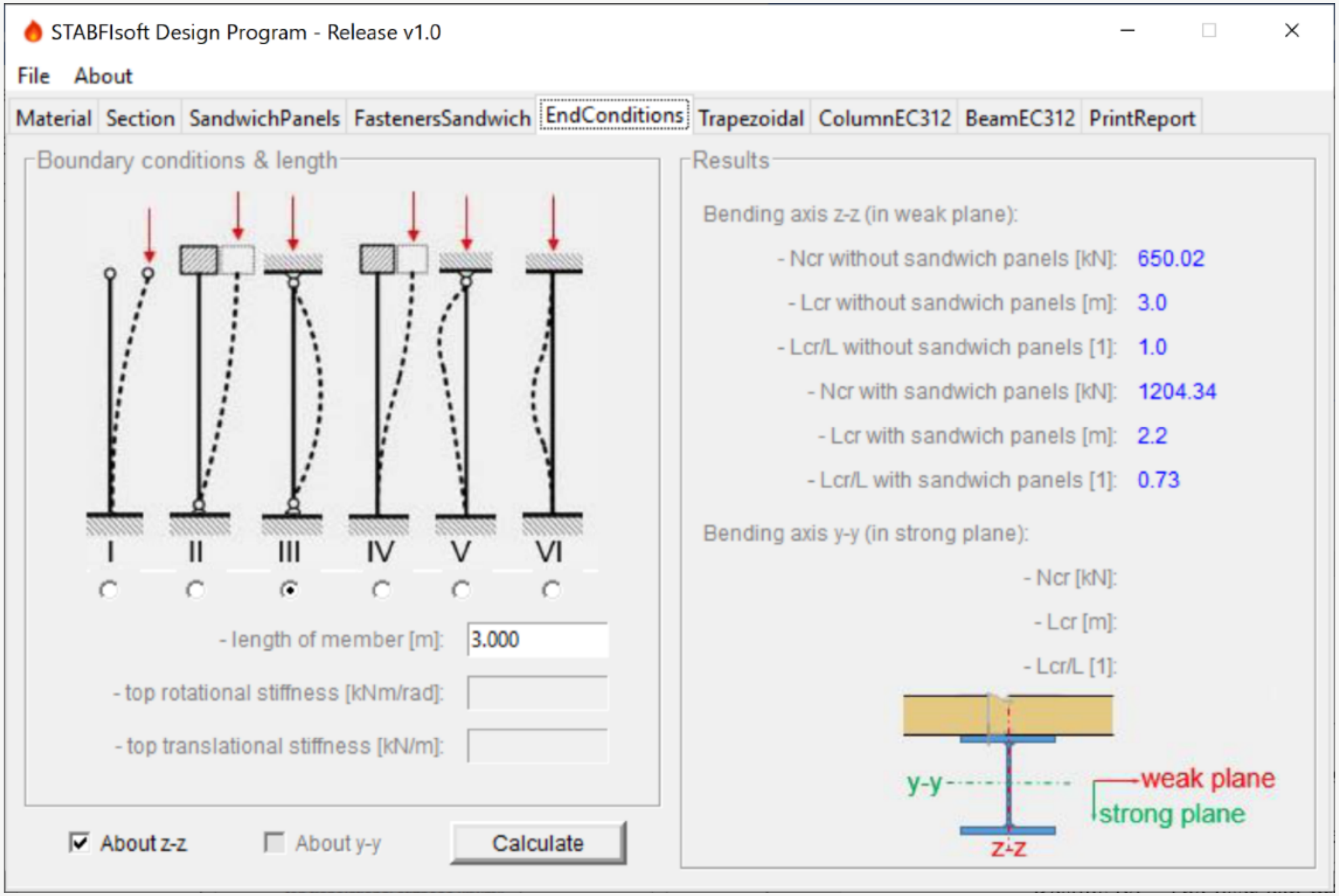


up to 4 pairs of fasteners per panel

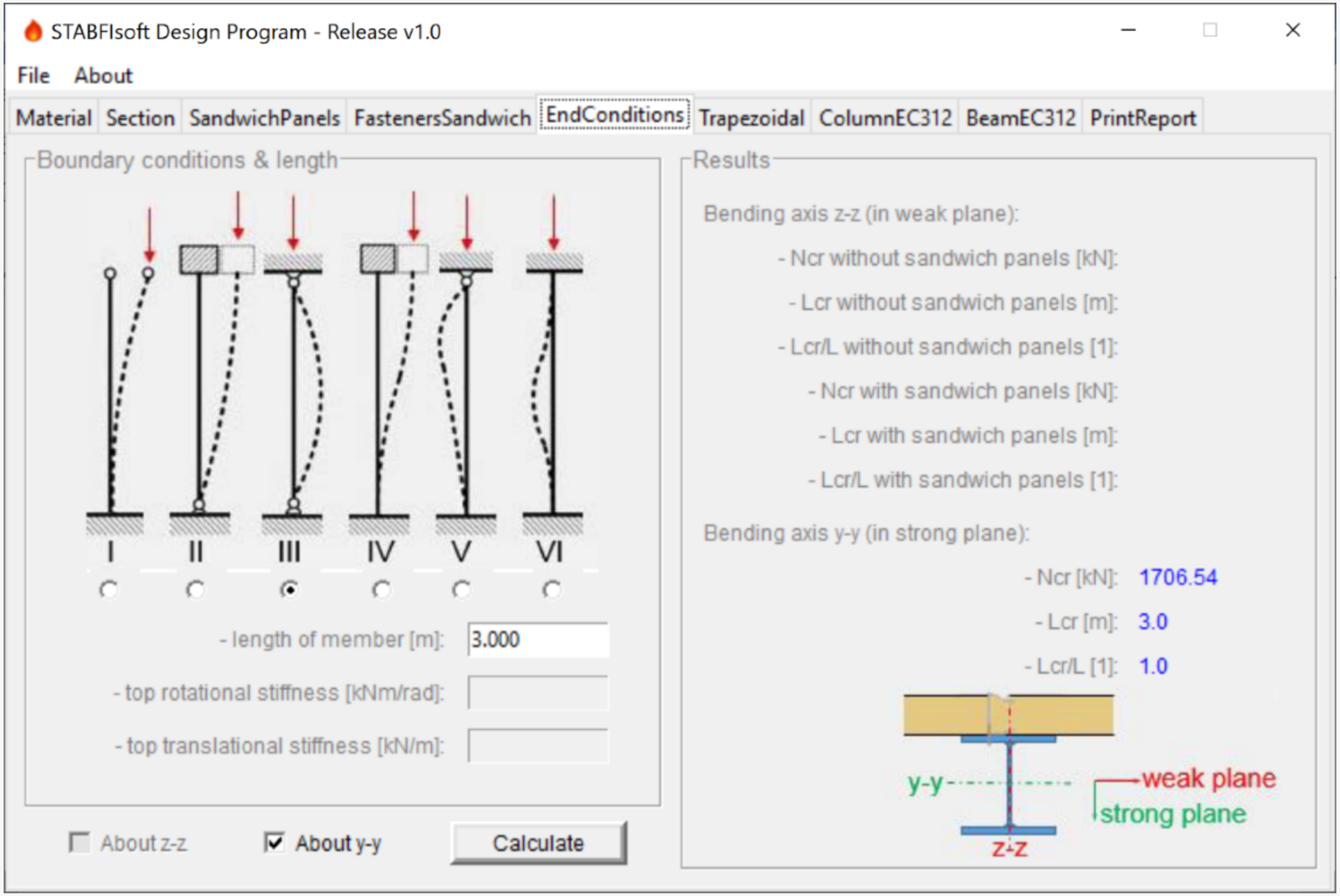
TRAPEZOIDAL SHEETS



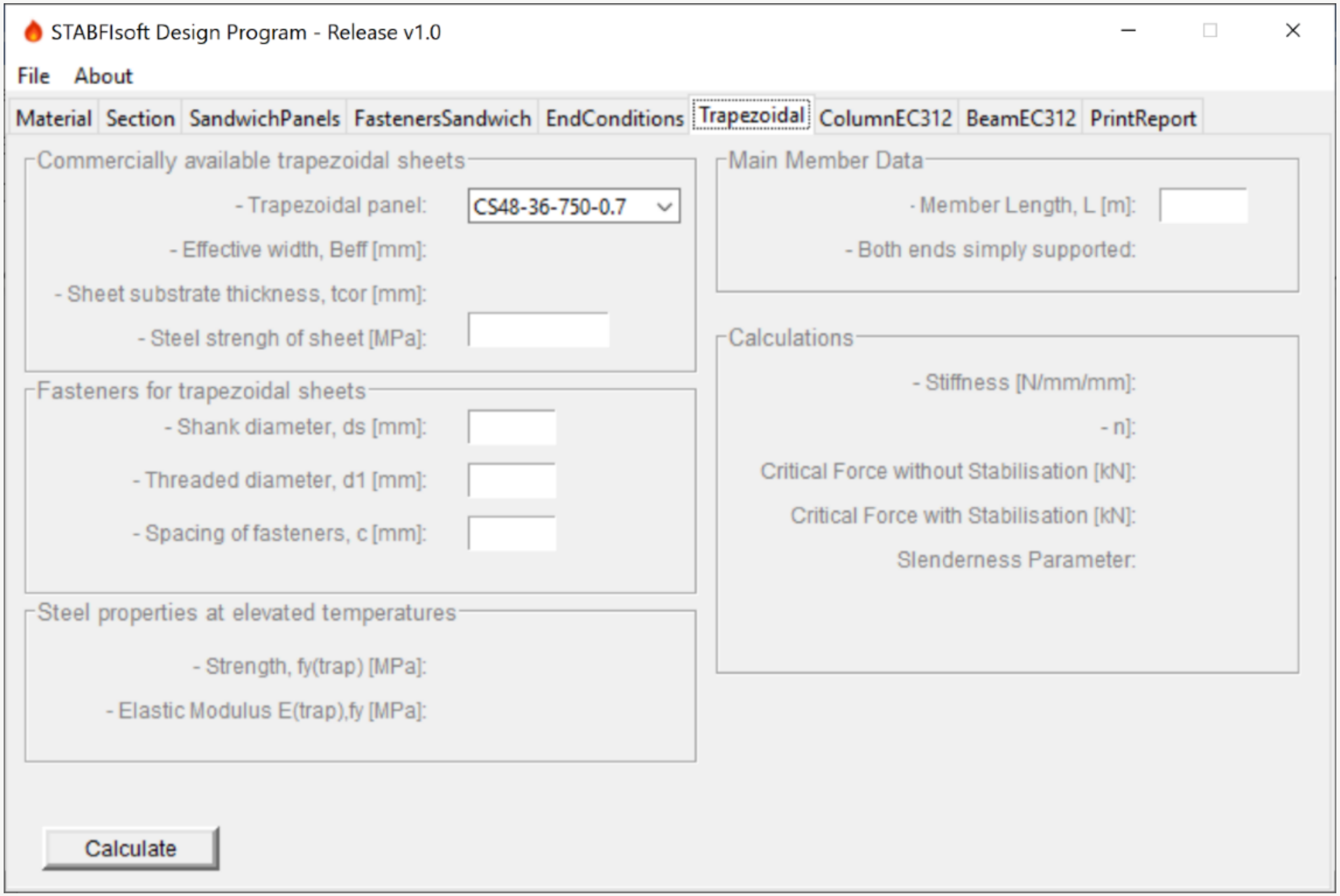
BOUNDARY CONDITIONS – IN PLANE



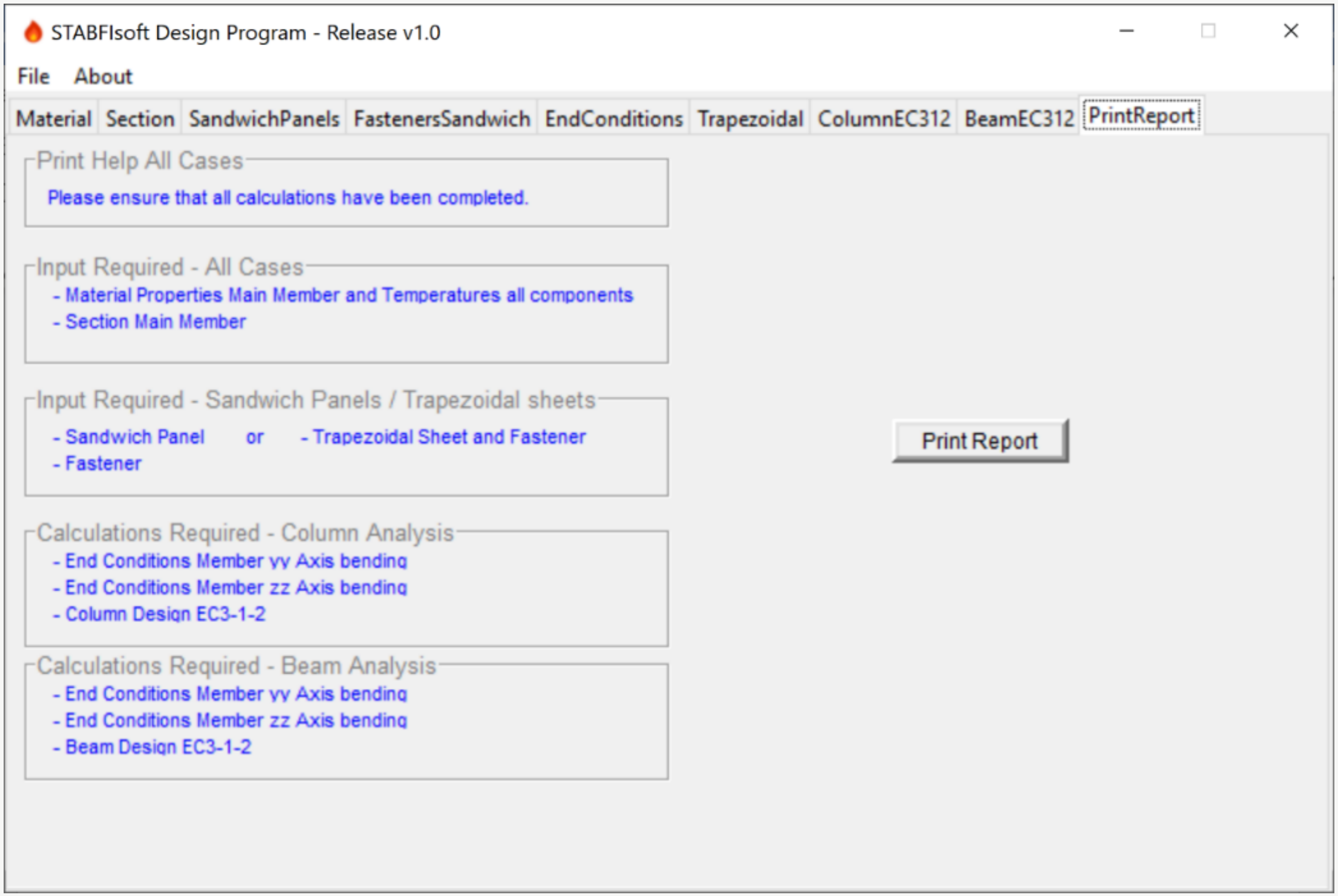
BOUNDARY CONDITIONS – OUT OF PLANE



RESULTS


STABFIsoft Design Program - Release v1.0
File About
Material Section SandwichPanels FastenersSandwich EndConditions Trapezoidal ColumnEC312 BeamEC312 PrintReport
Commercially available trapezoidal sheets
- Trapezoidal panel:
CS48-36-750-0.7
- Effective width, Beff [mm]:
- Sheet substrate thickness, tcor [mm]:
- Steel strengh of sheet [MPa]:
Fasteners for trapezoidal sheets
- Shank diameter, ds [mm]:
- Threaded diameter, d1 [mm]:
- Spacing of fasteners, c [mm]:
Steel properties at elevated temperatures
- Strength, fy(trap) [MPa]:
- Elastic Modulus E(trap),fy [MPa]:
Main Member Data
- Member Length, L [m]:
- Both ends simply supported:
Calculations
- Stiffness [N/mm/mm]:
- n]:
Critical Force without Stabilisation [kN]:
Critical Force with Stabilisation [kN]:
Slenderness Parameter:
Calculate

CHECK LIST


STABFIsoft Design Program - Release v1.0
File
About
Material
Section
SandwichPanels
FastenersSandwich
EndConditions
Trapezoidal
ColumnEC312
BeamEC312
PrintReport
Print Help All Cases
Please ensure that all calculations have been completed.
Input Required - All Cases
- Material Properties Main Member and Temperatures all components
- Section Main Member
Input Required - Sandwich Panels / Trapezoidal sheets
- Sandwich Panel
or
- Trapezoidal Sheet and Fastener
- Fastener
Calculations Required - Column Analysis
- End Conditions Member yy Axis bending
- End Conditions Member zz Axis bending
- Column Design EC3-1-2
Calculations Required - Beam Analysis
- End Conditions Member yy Axis bending
- End Conditions Member zz Axis bending
- Beam Design EC3-1-2
Print Report

PRINTED OUTPUT

The program produces a printed output which can be used as a design report.

Example of Output from StabFiSoft

StabFi Software

Printed on = 25-06-2020

Buckling about zz axis

Slenderness factor for fire lamda,bar,fi = 0.958

Reduction factor for buckling, fire Khi,fi = 0.531

Axial Buckling Resistance Nb,fiRdzz (kN) = 599

Buckling about yy axis

Slenderness factor for fire lamda,bar,fi = 0.811

Reduction factor for buckling, fire Khi,fi = 0.61

Axial Buckling Resistance Nb,fiRdyy (kN) = 688

Lower buckling axial capacity : In-Plane bending

The column strength is governed by : Instability

END OF PRINTOUT

EXAMPLE

EXAMPLE

One of the columns tested in WP4

Brief data:

- HEA120 pinned at both ends.
- PIR sandwich panel, 160mm thick, 1000mm wide.
- Connector 4.7mm threaded diameter
- Two pairs (4) of connectors at 300mm spacing

EXAMPLE - CALCULATIONS

Shear stiffness = 1277 N/mm

Critical axial force without stabilisation, N_{cr} = 650 kN

Increment in critical axial force, ΔN_{cr} = 508 kN

Augmented critical axial force = 1158 kN

Modified effective length = 2250 kN

Strength from EN1993-1-2 = 581 kN

Strength from experiment = 516 kN

(Possible reason for deviation – material properties)

CONCLUSION

CONCLUSION

The project has delivered a design procedure for axial capacity of members stabilised with sandwich panels (as described in the presentation) and trapezoidal sheeting.

As part of the procedure, simplified approach has been formulated for calculating the temperatures in the unexposed side of the panel for a limited combination of materials, notably, PIR and Mineral Wool.

CONCLUSION

The procedure involves calculation of connector stiffness for a given temperature, leading to calculation of a reduced effective length of the main member, thereby resulting in enhanced strength. Appropriate reduction factors for material properties have been identified.

The axial strength of the member so stabilised is then calculated using EN1993-1-2.

ACKNOWLEDGMENT

ACKNOWLEDGEMENT

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Häme University of Applied Sciences, Hämmenlinna
Ruukki Construction Oy
Kingspan Research and Developments
SFS intec Oy

THANK YOU

City, University of London
Northampton Square
London
EC1V 0HB
United Kingdom

T: +44 (0)20 7040 5060
E: department@city.ac.uk
www.city.ac.uk/department