USFOS

Reality Engineering

USFOS AS
Gosen 82
5253 Sandsli
Norway

Phone: +47 905 05 717

www.USFOS.com

Enterprise No.: NO 986 827 374 MVA

REPORT

TITLE	FOR YOUR ATTENTION	COMMENTS ARE INVITED	FOR YOUR INFORMATION	AS AGREED
USFOS analysis of I-Girder Fire Test.				
DISTRIBUTION USFOS users	X			

FILE CODE	CLASSIFICATION
USR-2013-001	Confidential
REFERENCE NO.	

PROJECT NO.	DATE	PERSON RESPONSIBLE / AUTHOR	NUMBER OF PAGES
	2013-01-01	Tore Holmas and Jorgen Amdahl	23

Summary:

This report re-calculates a lab test from 2005 using FAHTS and USFOS.

Using typical values for emissivity, convection and absorption coefficients and using the measured gas temperature in the furnace as the heat source, FAHTS reproduces the measured steel temperatures.

Based on the temperatures produced by FAHTS, and the measured yield strength, USFOS predicts the bending-torsion collapse of the system for both loading conditions.

If typical fire-design parameters were used, (thermal properties, material strength and FE model), the FAHTS-USFOS analysis gives *conservative* results, (earlier failure and lower push-down load than observed in the lab).

00	2013-01-01	Issued for information	JAm
Revison	Date	Comment	Check

CONTENTS

1 Introduction

A paper from 2005 /1/ presents the results from testing of unprotected I-section beams exposed to fire. This document describes the test set-up and the computer model used by FAHTS and USFOS to re-produce the lab test results.

The use of FAHTS and USFOS in fire design is discussed.

2 Test Setup

2.1 Mechanical System

The simply supported beam with length 4.200m is exposed to 4 concentrated loads, located as shown in Figure 2-1. Two different load cases were tested:

- S1 : P_1 = 10.5 kN, (equivalent to 10.0 kN/m)
- S2 : P_2 = 17.5 kN, (equivalent to 16.7 kN/m)

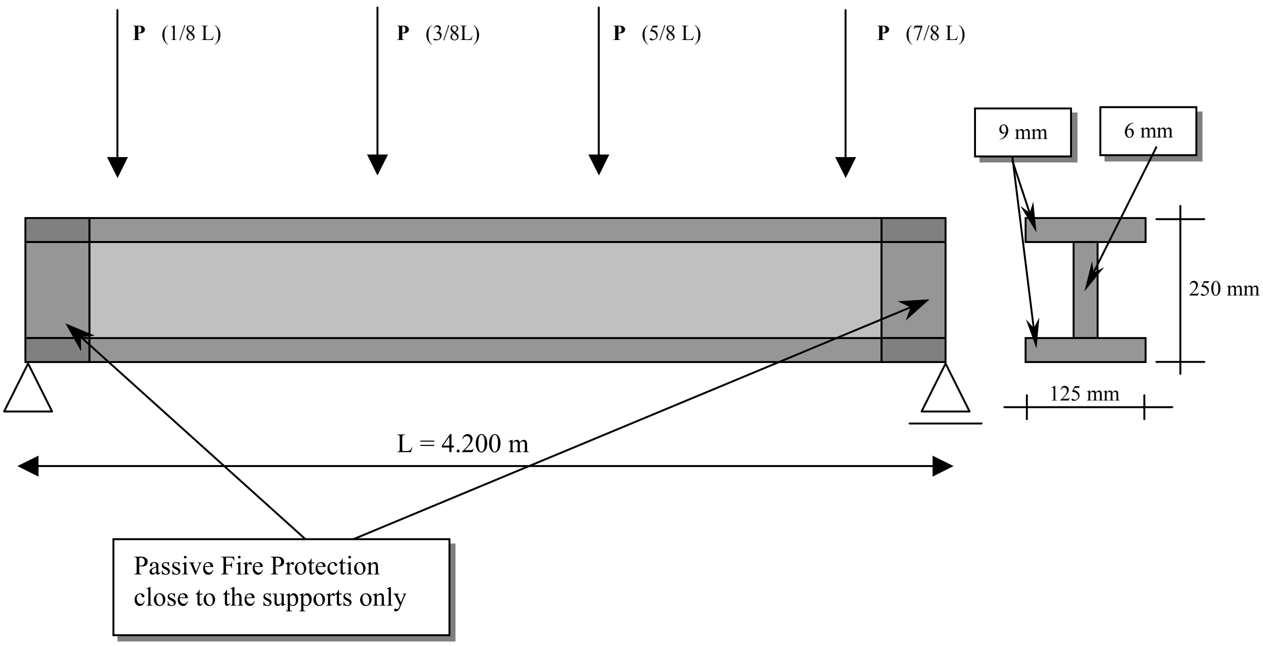

Figure 2-1 Schematic description of the Model Set Up.

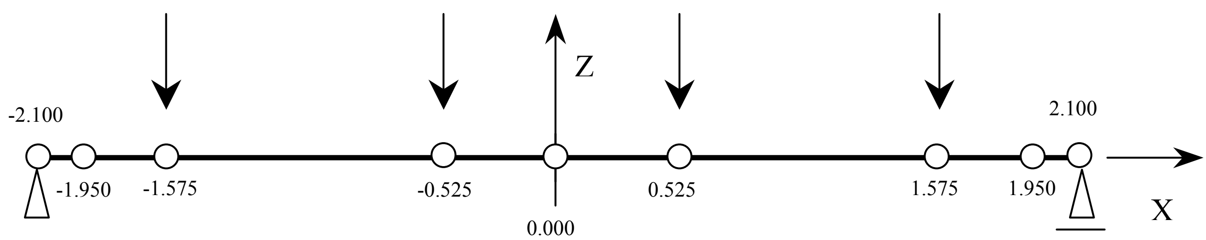

Figure 2-2 Finite Element model with 9 nodes and 8 beams. Description of X-Coordinates.

2.2 Fire Exposure

Figure 2-3 describes the heat exposure on the I-profile, where the lower flange and the web are exposed to heat from 2 sides. The upper flange is exposed to fire from the under side only. The over side of the upper flange has some thermal insulation, which gives limited cooling of the upper flange.

The 2-side exposure results in a more rapid temperature increase (the resultant heat input to the 6 and 9mm steel plates are 2 times the heat flux.

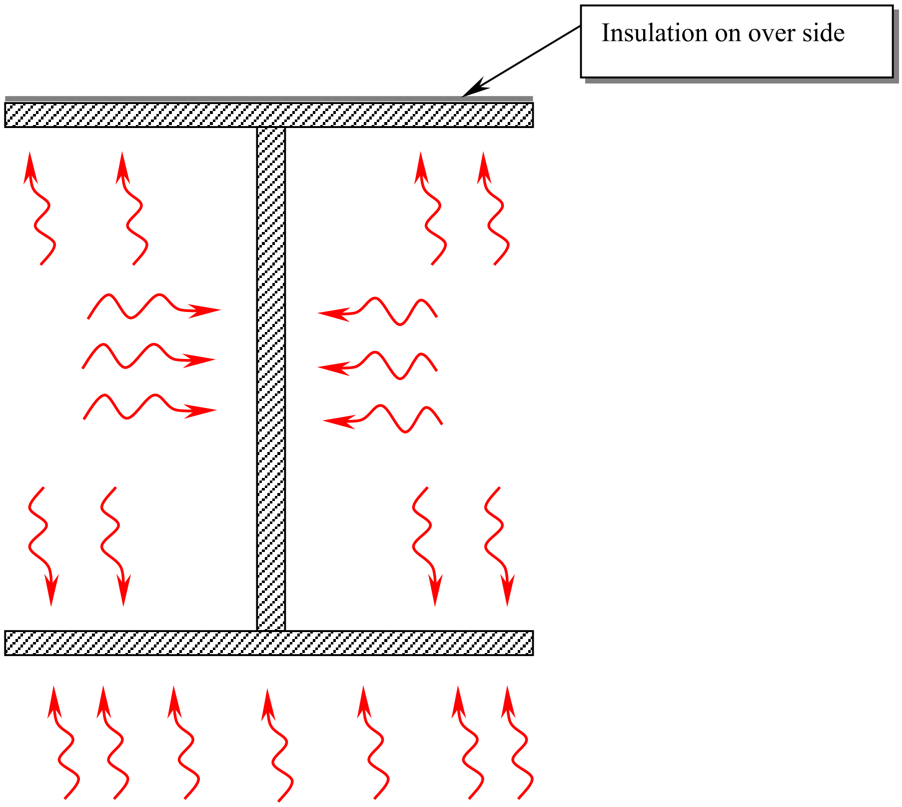

Figure 2-3 Heat Exposure on the I-Section. Lower flange and Web have 2-side exposure.

3 Fire temperature and heat flux

The measured temperature in the furnace, near the I-profile is shown in Figure 3-1, the red curve. The standard ISO curve often used for fire testing (f ex for "A"-rating of products) is described by the green curve.

After approx. 16 minutes, the temperature drops, but is "back on track" after 5-6 minutes. Since several tests are performed, it is unlikely that all tests experienced exactly the same temperature. (At least two different load conditions were tested).

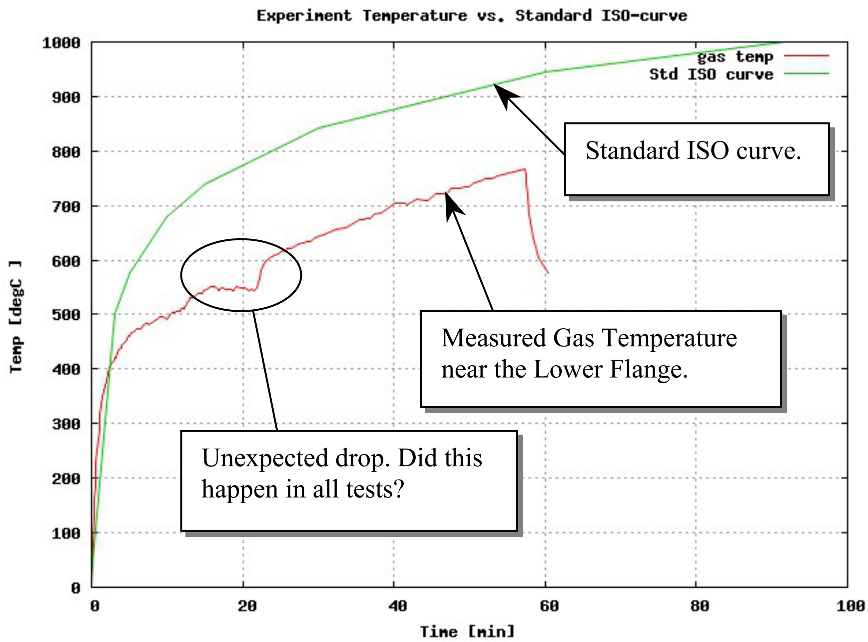

Figure 3-1 Measured Temperature in furnace. Standard ISO curve indicated for info

The heat transfer from the hot gas to the steel surface could be express as a radiation part and a convective part, where:

Q_{RAD} $= \varepsilon_{GAS} \bullet \sigma \, (T_{GAS}{}^{4} - T_{STEEL}{}^{4})$, $\sigma = 5.67E\text{-}8$. (St-Boltzmann's constant) and ε_{GAS} is the gas emissivity.

Q_{CONV} $= C \bullet \Delta T$, where $\Delta T = (T_{GAS} - T_{STEEL})$, and C is the convection number.

The exact values for the emissivity are unknown, but some typical values are used:

ε_{GAS} = 0.7 – 0.8 [-]
C = 10 [W/m^{2}K] (could be found from the formula: C =4U + 5.6, where U is the airspeed)

4 Measured Temperatures

Figure 4-1 presents the measured temperatures /1/, and the following should be noted:

- The web temperature is lower than the lower flange temperature. This indicates a lower heat flux since the web has less thickness (and thus less thermal inertia) than the flanges (6 vs. 9mm).
- The upper flange temperature rises slower due to one-side exposure, (the web and lower flanges are exposed from two sides), It has approx 150°C lower temperature than the lower flange, but at the end of the test the difference is reduced to 50°C.

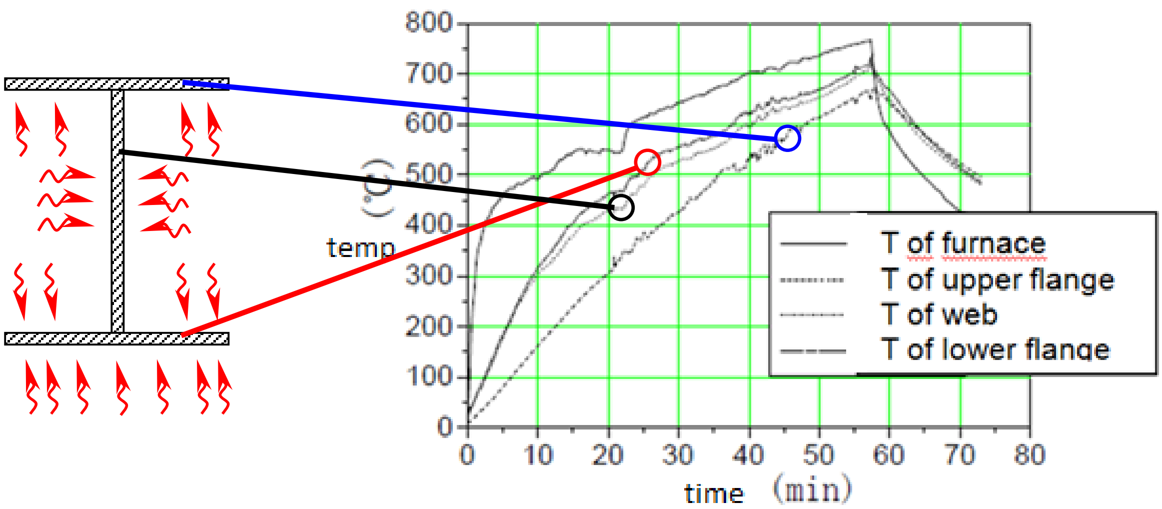

Figure 4-1 Measured temperatures of Gas, Flanges and Web

5 Material Properties

The *thermal* properties used in the FAHTS (thermal) analysis are:

Emissivity Coefficient	:	0.7	(typical "best estimate" value)
Thermal Conductivity	:	50 W/mK	(constant alternative)
Heat Capacity	:	500 J/kgK	(constant alternative)
Density of steel	:	7 850 kg/m^3	

The *mechanical* parameters used in the USFOS analyses for the Q235-B grade are:

Yield stress	:	330 MPa	(Measured data, see Appendix-1)
E-mod	:	210 000 MPa	
Thermal Expansion	:	1.4E-5	
Density of steel	:	7 850 kg/m^3	

The mechanical properties are strongly dependent on the temperature and are assumed to follow the Eurocode 3 curves, and in Figure 5-1 the degradation of the *effective* yield stress and E-mod are shown. The thermal expansion coefficient is kept constant for all temperatures, (less influenced by temperature).

The upper curve (square markers) represents the degradation of the "effective" yield stress, (ε=2%), and for temperature below 400°C, the ultimate stress is assumed unaffected, (in reality the effective strength is higher due to strain hardening).

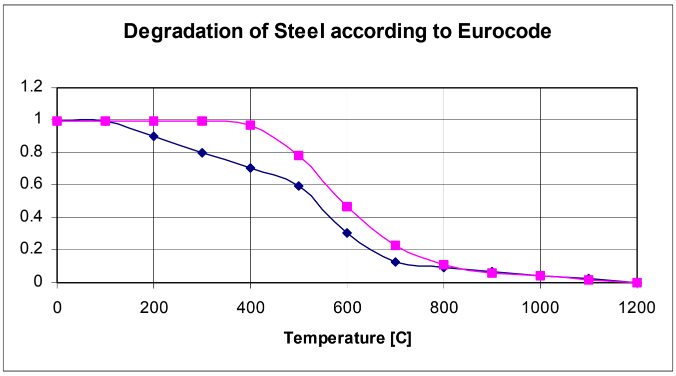

Figure 5-1 Temperature degradation for Yield and E-mod. (Eurocode-3)

Figure 5-2 describes the temperature dependent thermal properties. However, constant parameters give approximate same results as the detailed, (see Figure 6-2).

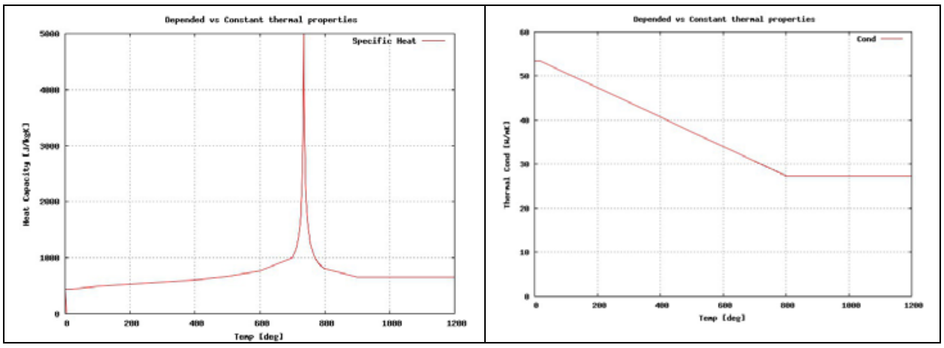

Figure 5-2 Temperature dependency of heat capacity (left) and conductivity (right).

6 Temperature simulation using FAHTS

The beam model containing 8 elements is converted to a shell model by FAHTS. (see Figure 6-1). Each beam element is transferred to 8 elements in the longitudinal direction and 6 elements along the web and flanges, (using the MESHIPRO command).

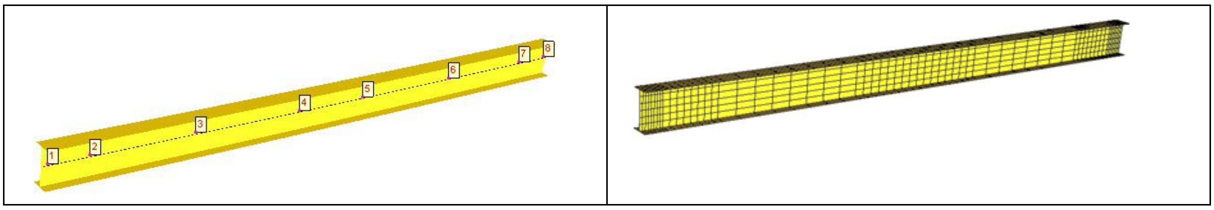

Figure 6-1 The beam model (left) is translated to the shell model (right) used in FAHTS

The exact heat flux is unknown, and therefore the simulation is performed with ε_{GAS} set to 0.7 and 0.8. The convection number is set to 10 for both analyses, and an approximated value for ε_{GAS} is set to 0.75.

Figure 6-2 presents the temperature history for the lower flange. The plot to the left shows the gas temperature (blue line) and the FAHTS temperatures for ε_{GAS} set to 0.7 and 0.8. The discrete points are the measured temperatures.

The plot to the right shows the impact from using constant vs. temperature dependent thermal properties. The comparison is done for ε_{GAS} set to 0.75.

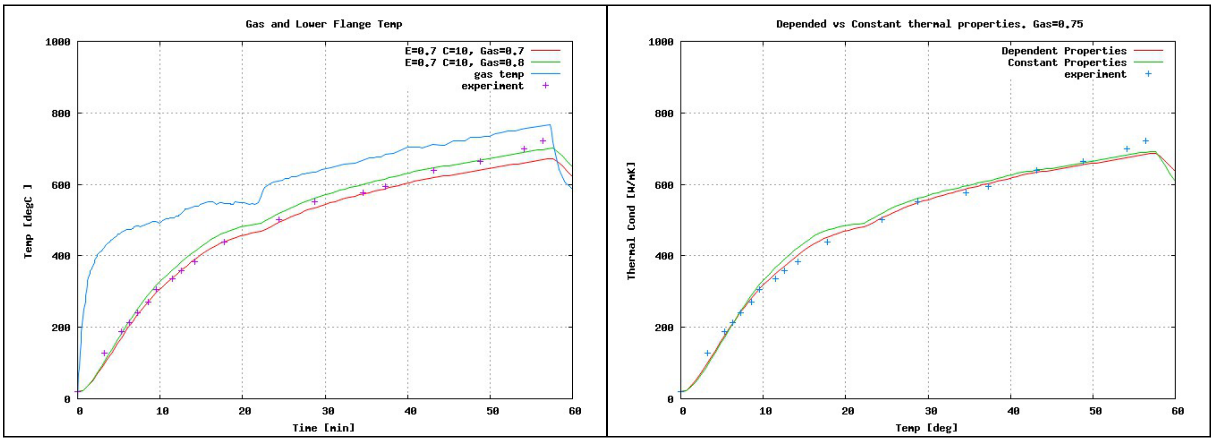

Figure 6-2 Temperature history for Lower Flange. Fahts and Experiment (discrete points)

Following conclusions could be found:

- The temperature in the flange is little affected by the temperature dependency. Constant values give approximate the same results.
- The gas emissivity could be set to 0.75 for this experiment.
- FAHTS predicts the temperature development with good accuracy.

The heat flux on the upper flange and the thermal boundary conditions on the upper flange over side is not know in details, but in the simulations, the given gas temperature is used. The over side surface is given some insulation (U-value is set to 50 W/m^{2}K) to simulate the cover on top of the beam. The ends (150mm) are fully protects. Figure 6-3 presents the temperature field after approx 50 minute and Figure 6-4 presents the temperature histories of the lower- and upper flanges. It should be noted that the upper-flange is heated more rapidly in the simulations, likely because the gas temperature is lower close to the upper flange. The gas temperature will be reduced due to cooling from the unprotected steel surface, and this cooling is more effective in the beginning of the test when the steel has low temperature.

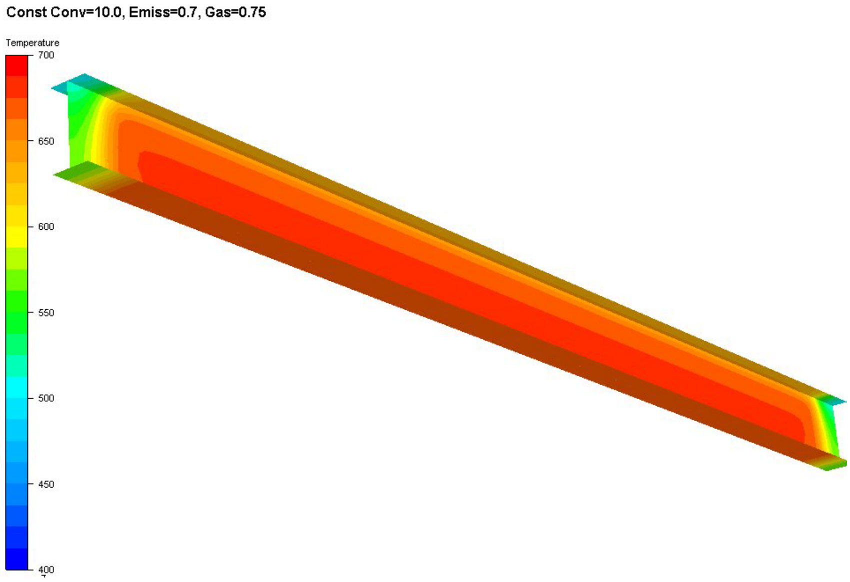

Figure 6-3 Temperature Field from FAHTS.

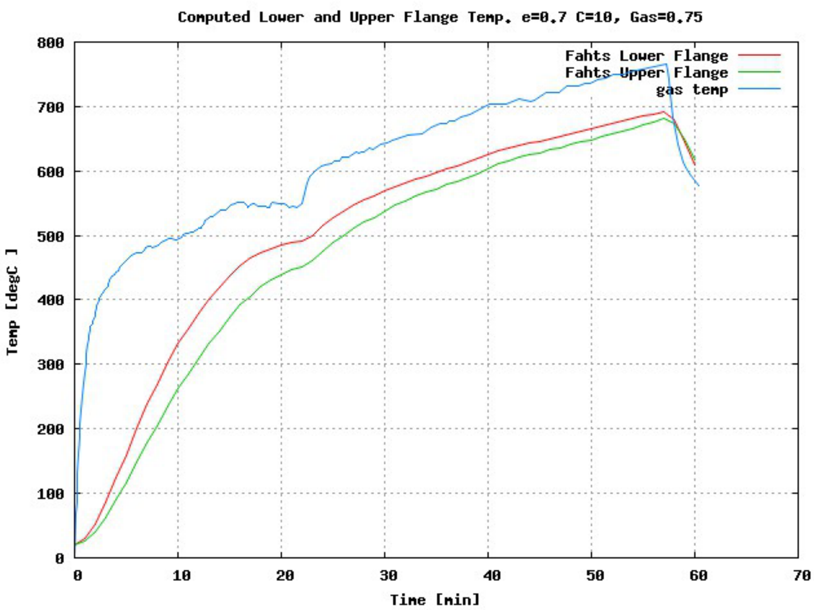

Figure 6-4 Temperature history for lower and upper flanges. Gas temp is indicated.

7 Mechanical response using USFOS

7.1 Ultimate Capacity

Two load cases are checked, S1 and S2 (10.0 and 16.6 kN/m respectively). The elastic section modulus is computed as: We = Iy/0.125 = 3.893E-5 / 0.125 =3.11E-4. The self-weight of the beam is 0.28 kN/m, and this gives following mid-span bending moment and stresses:

S1: q = 10.00+0.28=10.28kN/m. Mid-span Bending = 10.28 x 4.2^2 /8 = **22.7** kNm =>σ = 73 MPa
S2: q = 16.66+0.28=16.95kN/m. Mid-span Bending = 16.95 x 4.2^2 /8 = **37.4** kNm =>σ =120 MPa

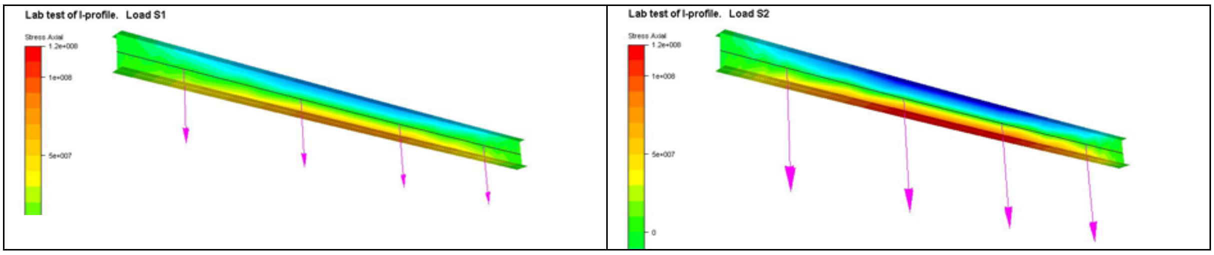

Figure 7-1 Stress distribution for loads S-1 and S-2. (Red color represents 120 MPa)

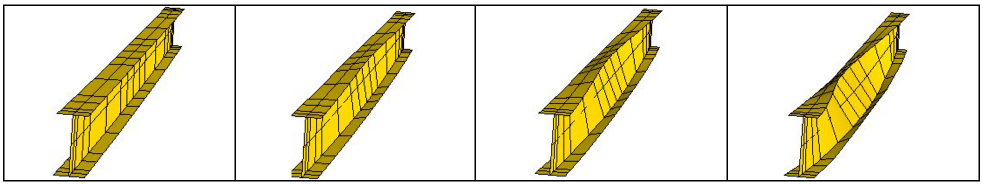

Figure 7-2 Four stages of the bending-torsion buckling predicted by USFOS.

Figure 7-3 presents the deformed shape when the beam collapses. The image to the left presents the side view, while the image to the right shows the top view where the upper flange moves horizontally. Figure 7-4 presents the photos from the test.

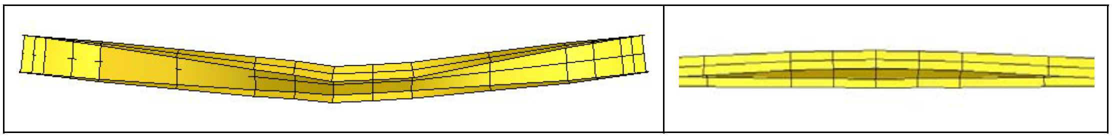

Figure 7-3 Deformed shape. Side view (left) and from above (right). USFOS.

图 4 S-1 破坏形式

Figure 7-4 Deformed shape. Side view (left) and from above (right). Test.

Figure 7-5 presents the USFOS global history for the two load cases using Yield Stress = 330 MPa. The red curve represents load case S-1 lower and the blue load case S2. The approximated failure time from the tests are indicated, (based on reported flange temperature).

The predictions by USFOS with LTB activated are very close to the reported failure times.

The main failure mode of the test specimens were bending-torsion buckling, see also Figure 7-2 to Figure 7-4.

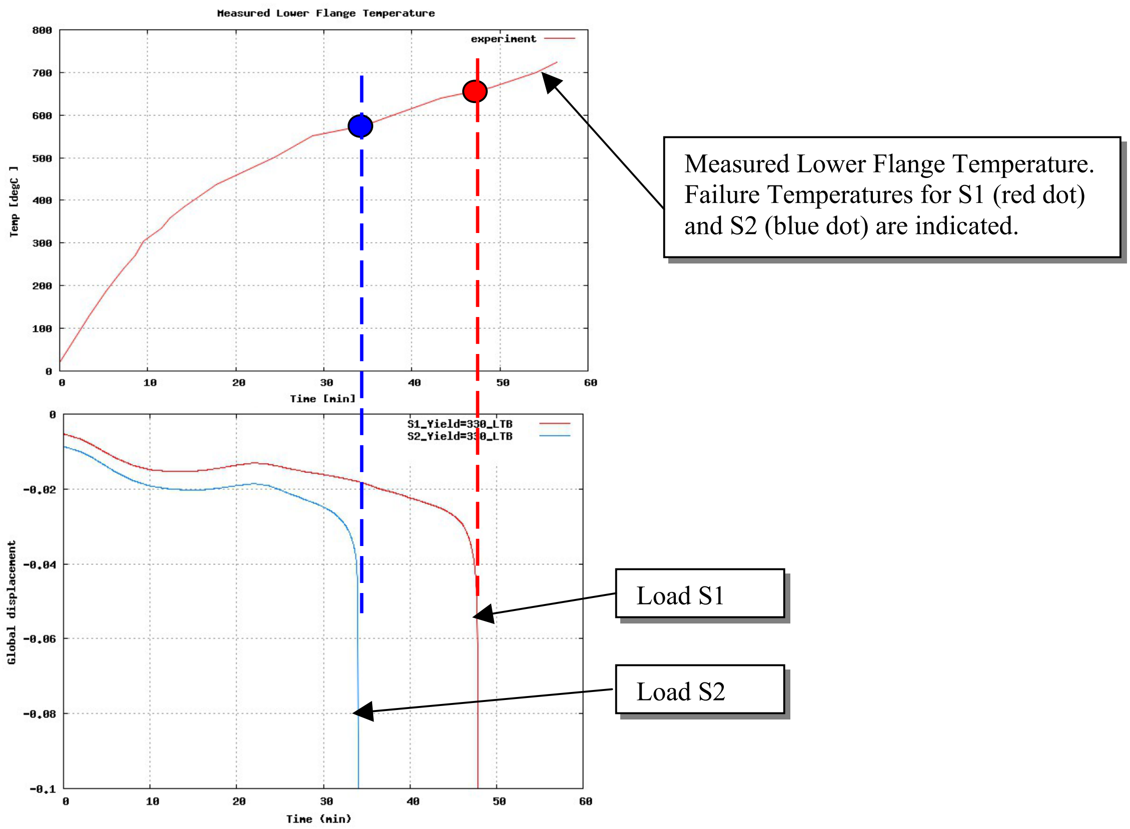

Figure 7-5 Usfos Global history for Loads S-1 and S2. Yield=330MPa.

7.2 Deformations

Figure 7-6 presents the measured axial deformation. The original plot (to the right) presents the elongation vs. flange temperature, and in the plot to the left, the information is transformed to deformation history. After approx 30 minutes, the elongation is 30mm, and at the end of the test, the elongation is approx. 37mm.

Figure 7-7 presents the deformation history computed by USFOS based on the temperatures computed by FAHTS. The computed history is slightly different in the first phase, but is almost identical from 30 minutes.

The computed elongation at the end of the test is 37mm, (i.e. the same as measured).

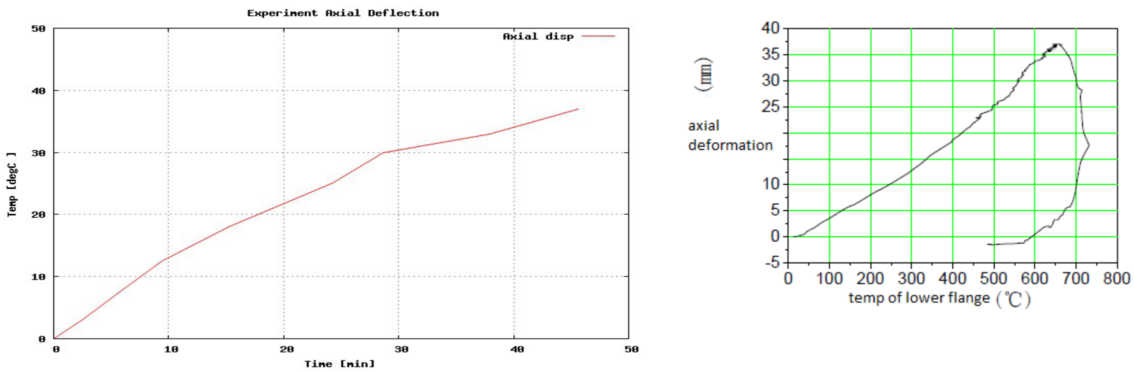

Figure 7-6 Measured Axial deformation (elongation). Vs. time (left) and vs. temp (right)

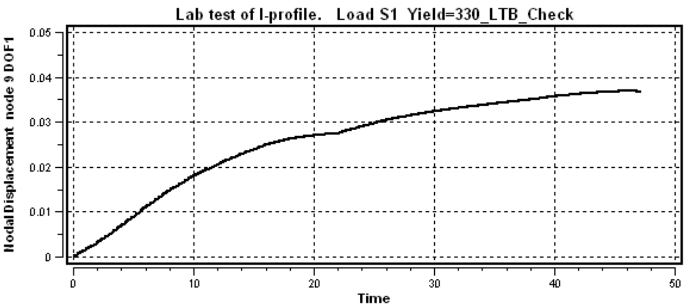

Figure 7-7 Computed Axial deformation (elongation) vs. time. USFOS

Figure 7-8 presents the original measurements of the vertical deformations. The fire time corresponding to the flange temperature is indicated. Figure 7-9 presents the USFOS history plot of the midpoint deflection, and the approximate measured deformations at the midpoint are indicated with the red triangles.

USFOS predicts the measured deformations with sufficient accuracy.

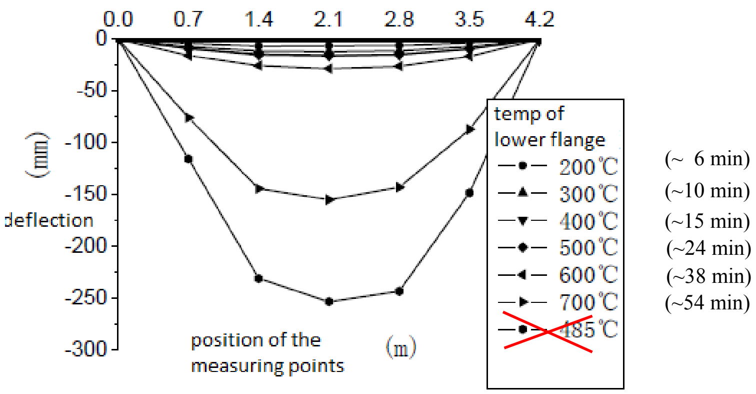

Figure 7-8 Measured Vertical deformation. Note that the "485°C" plot is after collapse.

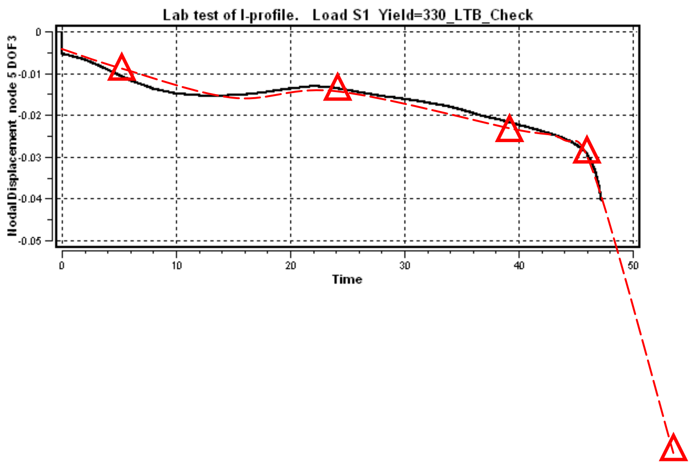

Figure 7-9 Vertical deformation history. USFOS. Approx. measured disp. are indicated.

8 Fire Design Analysis

8.1 Lab test model

When a lab-test is re-calculated, the "best-estimate" values are used. In connection with design, more conservative data are used. In this case the design values are:

ε_{STEEL} = 0.8 [-]
ε_{GAS} = 1.0 [-]
C = 10 [W/m^{2}K]
Yield = 235 MPa *) (the specified, "nominal", values, not measured, see Appendix-1)

**) The measured strength of 330 MPa is higher than what is expected for the 235-steel. A better estimate on "nominal" (average) strength could be 275 MPa.*

It is also normal to *not* account for sideways instability (LTB) because the main steel normally has secondary steel attached to the upper part of the section, (the upper flanges are "flush").

8.1.1 Incremental Temperature Method

This procedure means that the mechanical loads are applied first, and then the temperatures (from FAHTS) are incremented until the system becomes unstable. Figure 8-1 presents the response for the two load cases, and the specified yield strength (235 MPa) is used.

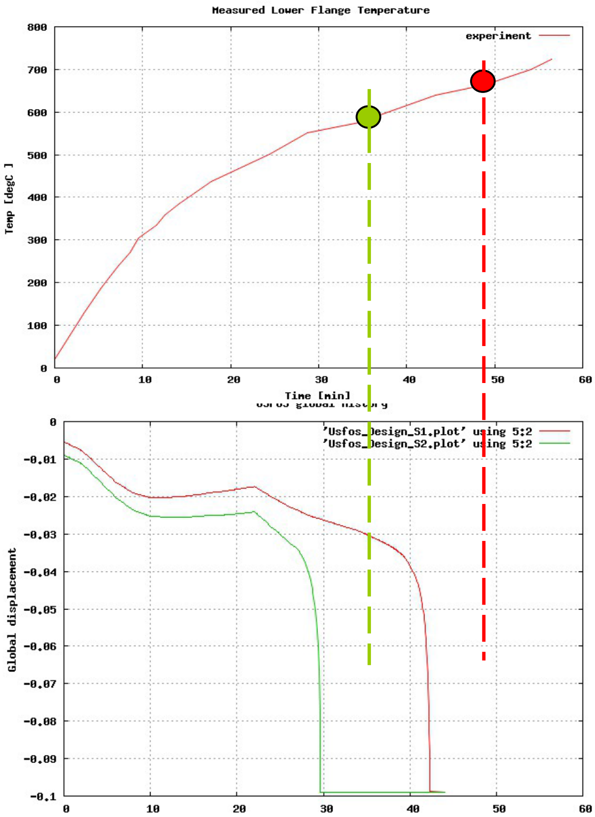

Figure 8-1 Usfos Global history for Loads S-1 and S2. Design values. Yield=235MPa

For comparison, the examples are also checked for Yield =275 MPa, see Figure 8-2.

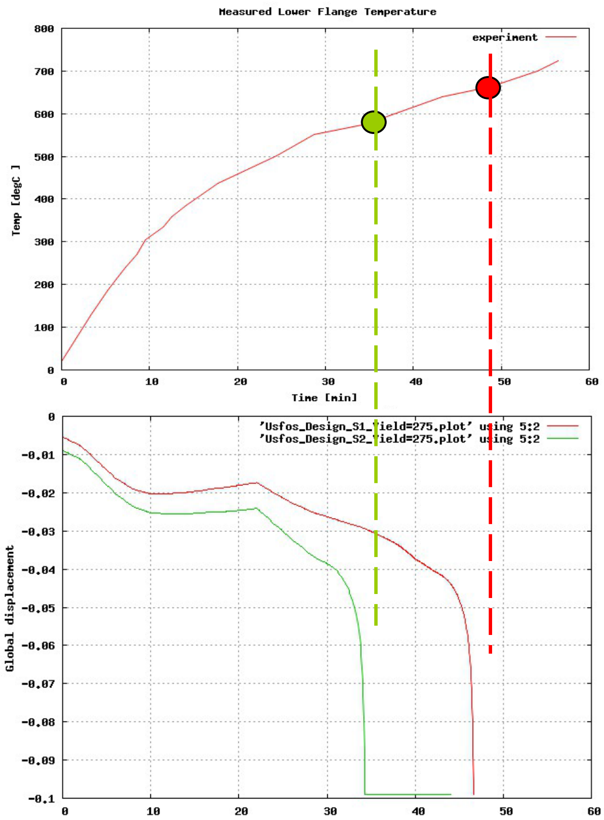

Figure 8-2 Usfos Global history for Loads S-1 and S2. Design values. Yield=275MPa

The plots show that the typical design values give a conservative prediction for both load cases and also for the more realistic “design yield stress”: 275 MPa.

8.1.2 PushDown

For complex structures, the “PushDown” check gives valuable information about the ultimate capacity for a certain time. While the “temperature incremental” procedure keeps the mechanical load constant and changes the temperature, this check is opposite: Keeping the temperature constant and increases the mechanical load.

A typical design check is using “all-time-high” temperature of each element and checks the performance. Figure 8-3 shows the performance for the two loads, here using yield strength = 235 MPa:

- Load S1 : Carries ~68% of the load at time for max temperature
- Load S2 : Carries ~41%

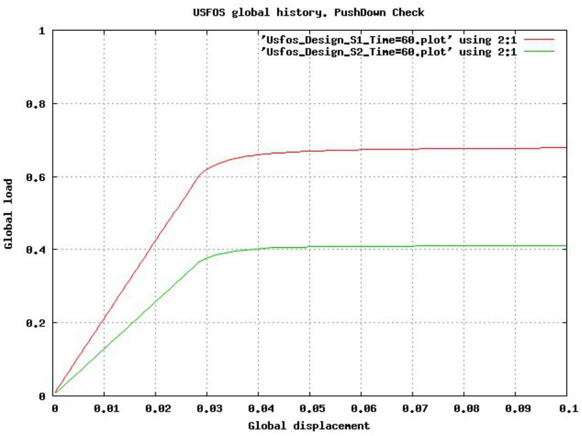

Figure 8-3 PushDown check based on "all-time-high" temperature

The next is to check the two cases at the time for collapse found in the previous section (temperature incrementing method). Load S1 fails after 42 min and S2 after 30 min. Figure 8-4 shows that the peak load level is 1.0 for both cases. I.e. the pushdown check and the incremental procedure give same conclusion.

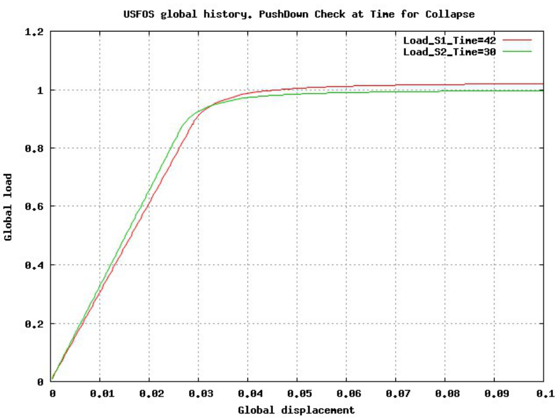

Figure 8-4 PushDown check at time for beginning collapse.

8.1.3 One Single Beam Element per Physical Member

Often, the real structures are modelled with one beam element per physical member. The previous "PushDown" check is analysed once more, but this time using only *one* element, (see Figure 8-5). The load is modelled using distributed load (BeamLoad). Figure 8-6 shows the deformed element together with the actual temperature field used by USFOS.

Figure 8-7 presents the "Global History" for both load cases, (S1 and S2) for yield=235 MPa. The plot shows that one element is able to predict the correct member capacity, (68% and 41% of the actual load).

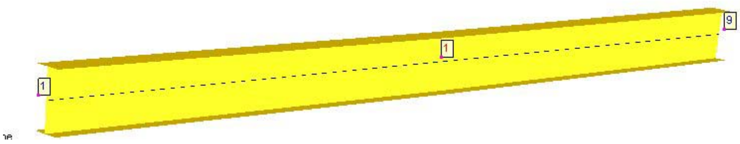

Figure 8-5 PushDown check using only one beam element

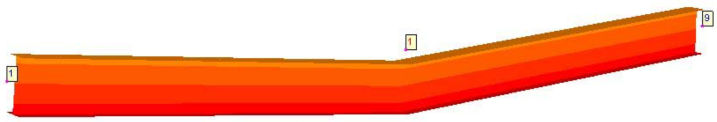

Figure 8-6 Deformed shape (plastic hinge at mid span) for actual load and temperature

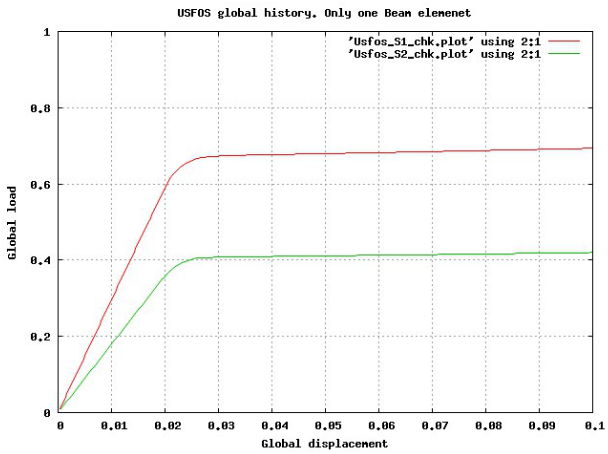

Figure 8-7 Global History. Only one Beam Element

8.2 Better fire design

Both simulations and the tests show that the actual simple supported beam with no warping resistance could be extremely unstable and collapses rapidly.

Below, the same I-beam is used with different boundary conditions:

- Boundary-0: Simply supported, free warping (lab example)
- Boundary-1: Simply supported, warping prevented
- Boundary-2: Axially fixed, rotationally free, warping prevented
- Boundary-3: Axially fixed, rotationally fixed, warping prevented

The comparison is using the "push-down" analysis of the S2 load case together with the highest recorded temperature (temperature after approx 55 minutes). Yield strength is set to 330 MPa in this comparison. The results, (load level vs. midpoint deflection), are shown in Figure 8-8.

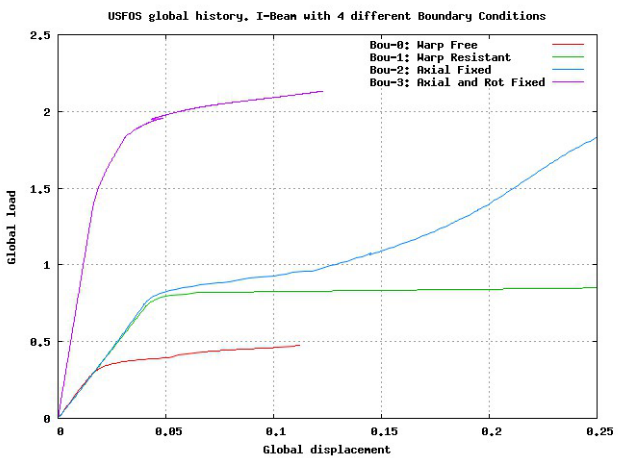

Figure 8-8 Global History for 4 different boundary conditions

Summarized:

Case	Load Level	Comments
0	0.45	
1	0.77	
2	1.8	Limited by Strain fracture and strength of connections
3	>2.0	-------- " ------------

The examples emphasize the importance of the boundary conditions of the structural components.

- The two cases with axial fixation would have survived the entire fire with the highest load (S-2) with good margins.
- The two cases without axial fixation failed before load level 1.0 was reached.
- Case-0 without warping prevention failed for approx 40% of the actual S2 load.

9 Discussions

The analyses show that the capacity of an I-girder depends on the side-ways boundary conditions. If the load is introduced at the top of the section as shown in Figure 9-1, to the right, the system becomes very unstable.

The system in the middle, (concrete slab support), has similarities to the unstable lab set-up. Loads from the concrete slabs are transferred to the top of the I-sections through neoprene bearing pads. Such pads have relatively low sideways stiffness, and the system could fail due to lateral torsional buckling, (LTB).

The typical offshore topside solution (left), however, has the secondary steel welded to the web/flange, and this provides good sideways support. In addition, the continuous deck-frames will also give axial resistance, and this means that the member will carry more of the loads through axial, tension (membrane action) for increasing deformations. This will also reduce the possibility for getting sideways instabilities (LTB).

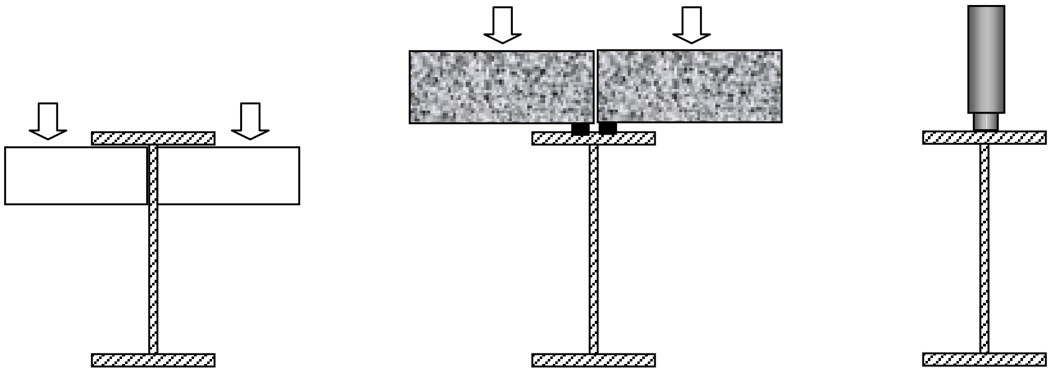

Figure 9-1 Use of I-girders: Typical Offshore Topside, building and test set-up (right)

The lab test specimen failed mainly due to sideways instabilities, (jacks acting on top of the section, image to the right). This set-up represents a lower bound case of the "concrete slab resting on I-girder".

In the previous section, it is demonstrated the ultimate strength for different boundary conditions. The cases with "best" boundary conditions have 4 times higher ultimate capacity than the "worst" case.

This is essential information in connection with fire design of steel structures. The unstable and unsafe systems with possibility for sideways buckling (warping) should not been used because of low capacity and sudden collapse.

The preferred solutions are the cases where torsion buckling is avoided and where axial forces could be introduced, (i.e. a certain axial fixation, see also / 2 /). Such systems will "sag" gradually and find new equilibrium positions as the steel becomes softer and weaker (due to increasing temperature).

10 Conclusions

A lab test from 2005 /1/ is re-calculated using FAHTS and USFOS.

Using typical values for emissivity, convection and absorption coefficients and using the measured gas temperature in the furnace as the heat source, FAHTS reproduces the measured steel temperatures.

Based on the temperatures produced by FAHTS, and the measured yield strength, USFOS predicts the bending-torsion collapse of the system for both loading conditions.

If typical fire-design parameters were used, (thermal properties, material strength and FE model), the FAHTS-USFOS analysis gives *conservative* results, (earlier failure and lower push-down load than observed in the lab).

The actual lab set-up is a very unstable system, with possibility for a rapid bending-torsion collapse. Such systems should be avoided in real structures. A beam-system where torsion buckling is prevented and the beam-ends are axially fixed will perform far better, (up to 4 times higher ultimate capacity). Such systems, (continuously welded beam-frames), are common for major parts of offshore topside modules.

11 References

/ 1 / *Experimental investigation of behavior of simple supported steel beams under fire*
Cong Shuping, Liang Shuting, Dong Yuli
JOURNAL OF SOUTHEAST UNIVERSITY, 2005

/ 2 / *Behaviour of beam-column connections subjected to extreme loads during fire*
Holmas, Amdahl, Skallerud and Langhelle.
Structures Exposed to Extreme Loading, Toronto, 2003

12 Appendix-1. Material info

The actual material is Q235-B with guaranteed yield strength of 235 MPa.

According to the paper, the measured yield strength of the actual test specimen was 330MPa.

Your current location : Home >> News

Q235B steel Imechanical property and Chemical composition about Q235

Double-click automatically scroll   Information Publisher:领航钢管0086-0635-2999999 Information release time:2010-4-23Hits:4522Times 【Font:Big Medium Small】

Material	mechanical property					Chemical composition				
	yield strength		tensile strength		elongation	C	Si	Mn	S	P
	MPa	kg/mm²	MPa	kg/mm²	min		Not more than		Not more than	Not more than
Q215A Q215B	215	22	335-410	34-42	31	0.09-0.15	0.03	0.25-0.55	0.050 0.045	0.045
Q235A **Q235B** Q235C Q235D	235	24	375-460	38-47	26	0.14-0.22 0.12-0.20 ≤0.18 ≤0.17	0.30	0.30-0.65 0.30-0.70 0.35-0.80 0.35-0.80	0.50 0.45 0.40 0.035	0.045 0.045 0.040 0.035
[illegible]	[illegible]	[illegible]	510-	[illegible]	[illegible]	0.12-	0.20-	[illegible]	[illegible]	[illegible]

Figure 12-1 Material data for Q235-B