SOFiSTiK

Benchmark Example No. 35

Calculation of Restraining Forces in Steel Members in case of Fire

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VERiFiCATiON
BE35 Calculation of Restraining Forces in Steel Members in case of Fire

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Front Cover

6th Street Viaduct, Los Angeles Photo: Tobias Petschke

Overview	
Element Type(s):	BF2D, SH3D
Analysis Type(s):	STAT, MNL
Procedure(s):	LSTP
Topic(s):	FIRE
Module(s):	TALPA, ASE
Input file(s):	restraining_forces.dat, quad_35.dat

1 Problem Description

This benchmark is concerned with the validation of the structural analysis in case of fire with respect to the general calculation method according to DIN EN 1992-1-2. Therefore test case 7 is employed as presented in Annex CC of the standard DIN EN 1992-1-2/NA:2010-03 [1]. In this example the restraining forces developed in an immovable steel member due to temperature exposure are investigated for the model of Fig. 1.

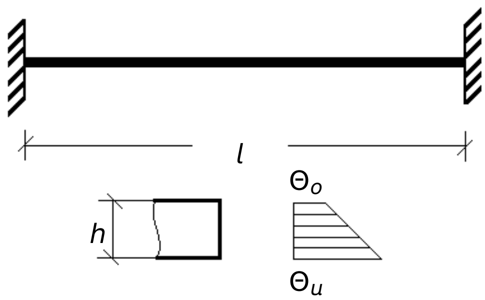

Figure 1: Problem Description

2 Reference Solution

The aim of Annex CC [1] is to check the applicability of the programs for engineering-based fire design on real structures. In this case the influence of temperature exposure on the development of restraining forces in steel is investigated. To illustrate the development of the restraining forces, consider a steel bar fixed at both ends and exposed to fire. As the bar is heated it tries to expand. However, the fixture prevents expansion in the longitudinal direction. Thus, the fixture exerts restraining forces on the bar. Since the bar is prevented from longitudinal expansion, it is possible to expand in the other directions.

3 Model and Results

The properties of the model are defined in Table 1. A beam with cross-sectional dimensions $b/h = 100/100\ mm$, $l = 1000\ mm$ and fixed at both ends, as depicted in Fig. 1, is examined here. The material of the cross-section is structural steel with a fictive yield strength of $f_{yk(20°C)} = 650\ N/mm^2$ and thermo-mechanical properties according to EN 1993-1-2. The model is exposed to different temperatures. In the first case the same temperature is assigned across the cross-section height, whereas in the second case, the temperature difference of the upper and lower fiber is $200°C$. The analysis is performed with TALPA, where the FIBER beam element is utilised. The computed and the reference results are presented in Table 2.

Table 1: Model Properties

Material Properties	Geometric Properties	Test Properties
$f_{yk(20°C)} = 650\, N/mm^2$	$l = 1000\, mm$	Case 1
$E_{a(20°C)} = 210000\, N/mm^2$	$h = 100\, mm$	Θ_o = 120°, C Θ_u = 120°C
Stress-strain curve	$b = 100\, mm$	Case 2
according to DIN EN 1993-1-2		Θ_o = 20°, C Θ_u = 220°C

Table 2: Results for Structural Steel - FIBER beam

Temperature Load Θ [° C]		Ref. [1] X	SOF. X'	$\lvert e_r \rvert$ [%]	Tol. [%]
120/120	N_{Zw} [kN]	−2585.0	−2584.8	0.006	± 1
	M_{Zw} [kNm]	0.0	0.0	0.000	± 1
	σ_{Zw} [N/mm^2]	−258.5	−258.5	0.006	± 5
20/220	N_{Zw} [kN]	−2511.0	−2503.9	0.282	± 1
	M_{Zw} [kNm]	−40.3	−40.2	0.249	± 1
	σ_{Zw} [N/mm^2]	−479.0	−479.0	0.000	± 5

Next step is the analysis of the same example with ASE where the QUAD element is now tested. The results are presented in Table 3 for both temperature loads.

Table 3: Results for Structural Steel - QUAD

Temperature Load Θ [° C]		Ref. [1] X	SOF. X'	$\lvert e_r \rvert$ [%]	Tol. [%]
120/120	N_{Zw} [kN]	−2585.0	−2595.7	0.414	± 1
	M_{Zw} [kNm]	0.0	0.0	0.000	± 1
	σ_{Zw} [N/mm^2]	−258.5	−258.98	0.186	± 5
20/220	N_{Zw} [kN]	−2511.0	−2539.7	1.14	± 1
	M_{Zw} [kNm]	−40.3	−41.23	2.31	± 1
	σ_{Zw} [N/mm^2]	−479.0	−484.65	1.180	± 5

For the quad element, the results appear to deviate from the reference solution. This is due to the fact that, as the plasticity involves at the cross-section, plastic strains appear also in the lateral direction[1].

[1] In the case of quad elements, μ is set to 0 for the better representation of the boundary conditions and the results.

This causes a biaxial stress state ($\sigma_x \neq 0$), which is not neglected by the quad formulation, as shown in Fig. 2, and has an effect on both the stresses and moments in the y direction.

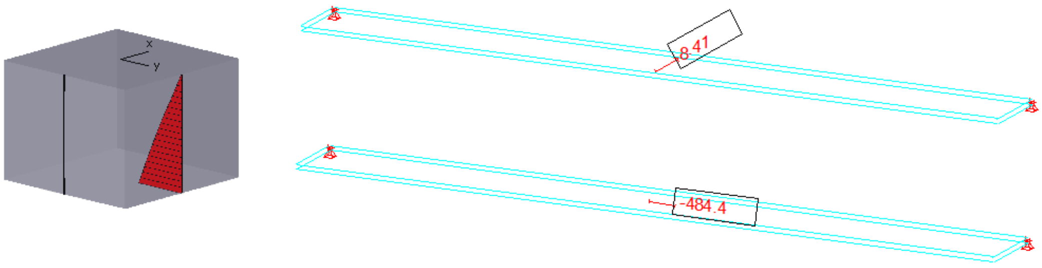

Figure 2: Nonlinear Stresses for Temperature 220 °C at Bottom Quad Layer

4 Conclusion

This example verifies the development of restraining forces in steel due to temperature exposure. It has been shown that the calculation results are in very good agreement with the reference results for both the QUAD layer element and the FIBER beam element.

5 Literature

[1] *DIN EN 1991-1-2/NA: Eurocode 1: Actions on structures, Part 1-2/NA: Actions on structures exposed to fire*. CEN. 2010.