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FIRE AFTER EARTHQUAKE ANALYSIS OF STEEL FRAMES

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Introduction

- ✓ Today the design of structures is performed, according to the current design codes, individually for the seismic and the thermal actions.
- ✓ The current fire design codes are based on the assumption that at the beginning of the fire event the structure is in the elastic region of the material behaviour. This is not valid in the case of a fire outbreak after earthquake, since the structure is damaged due to the seismic loads.
- ✓ It is expected that the damage induced by earthquake can be present to both structural and non-structural members. Therefore, different fire-after-earthquake scenarios may be considered.
- ✓ In the present paper scenarios based on damage of the structural members are only considered.

Description of the problem

- The study here is focused on new buildings where the capacity design rules of Eurocode 8 have been applied.
- Fire-after-earthquake scenarios are considered leading actually to **different levels of damage** at the end of the beams.
- The fire performance of the damaged beams under these scenarios is studied.

A numerical model is used to assist the evaluation of the fire performance of steel beams. In particular, various numerical analyses are conducted in order to quantify the reduction of the fire resistance, in the time domain, due to the damages that are caused by the seismic loading. The analyses take into account :

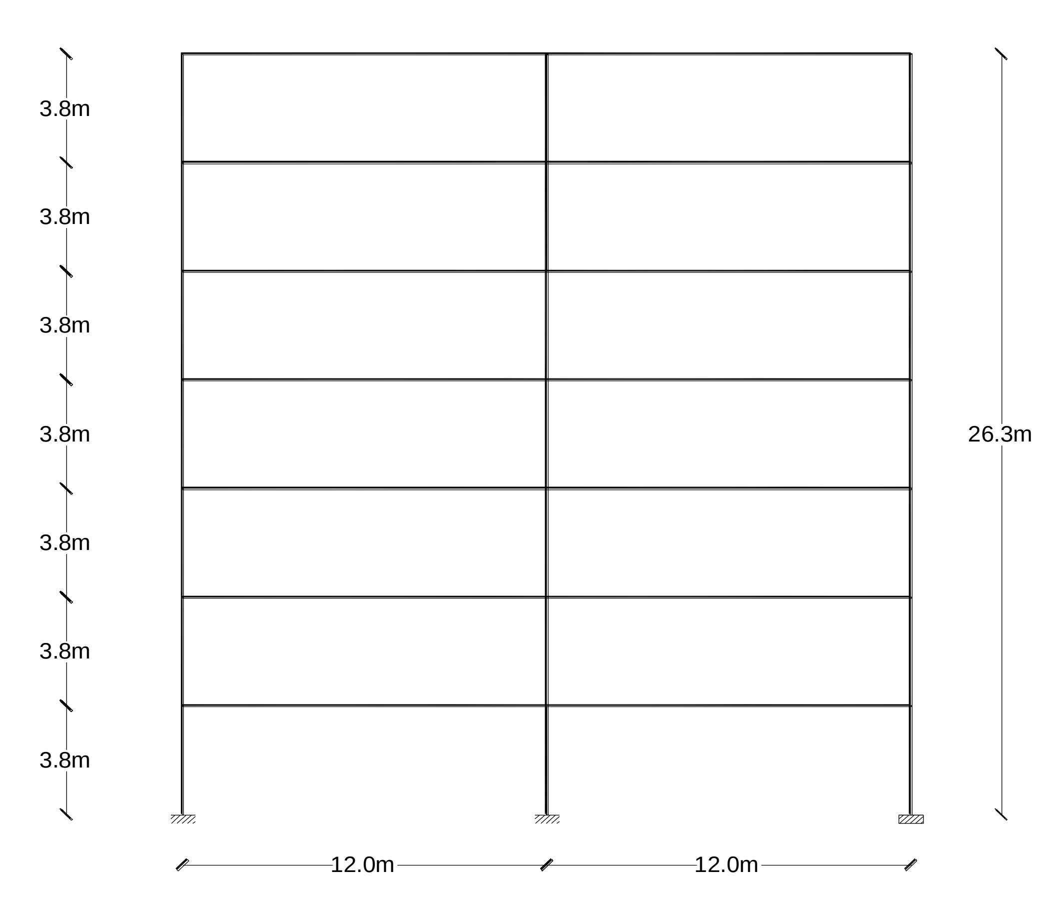
- ✓ the geometric initial imperfections of the steel beams
- ✓ the non-linear stress-strain relationship of structural steel in elevated temperatures.

Parametric analyses are conducted:

- ✓ considering various amplitudes of initial imperfections
- ✓ different levels of the loading that participates in the fire design
- ✓ different restraint conditions for the beams (**laterally restrained** and **unrestrained).**

Design of the steel frame according to current codes(1)

A seven-storey steel frame is considered.



1.Design for gravity loading

The steel frame is designed for the ultimate limit state (ULS) combination of actions for the gravity loading.

G =27kN/m

Q= 30kN/m for all the storeys

Q= 12kN/m for the last level

ULS comb. ⇒ 1.35G + 1.50Q

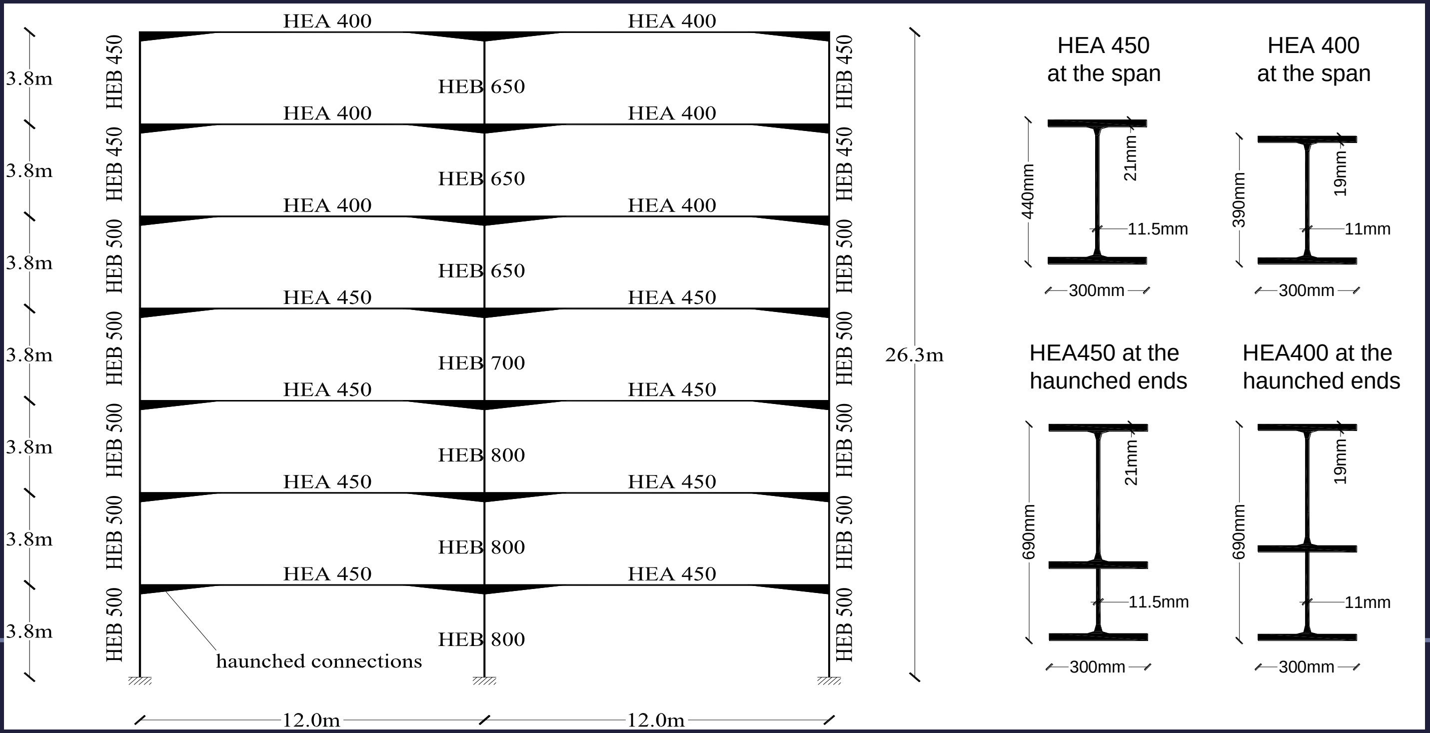
Design of the steel frame according to current codes (2)

2. Seismic design

The design for the seismic actions is performed according to EN 1998-1-1. The lateral force method of analysis is followed.

- ✓ Type 1 elastic response spectrum
- ✓ a_g=0.16g
- ✓ soil type A (S=1.00)
- ✓ behaviour factor q =6

The calculated cross sections of the beams and columns are presented in the figure



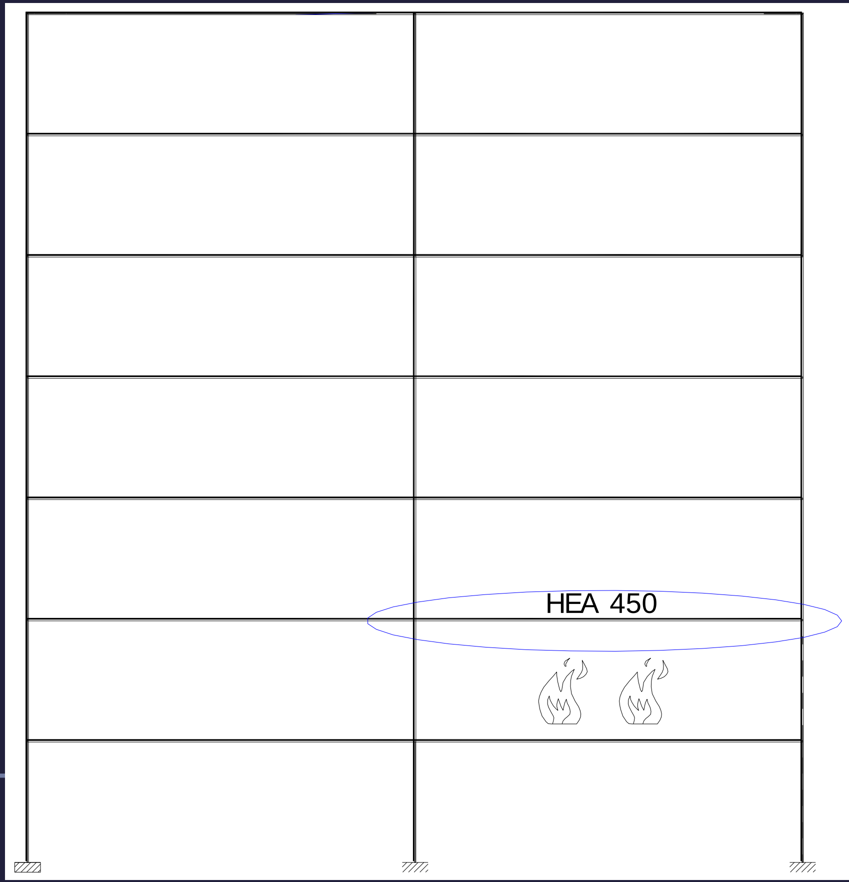
Note:
The beams are haunched for a length L_h =1.2m at both ends.

Design of the steel frame according to current codes (3)

3. Fire Design

The fire design is based on the loading combination for accidental design situations which is given in EN 1991-1-2

loading combination → $G+\psi_{2,1}Q$



- ✓ Three different cases are considered taking into account different values of the quasi-permanent combination coefficient $\psi_{2,i}$.
- ✓ The value of $\psi_{2,i}$ is considered to be equal to 0.3, 0.5 and 0.8 respectively.

In this study the fire resistance of the steel beam results from the subsequent numerical analysis.

- ✓ Two case studies are considered:
  - ➢ In the first case the beams are supposed to be laterally restrained (*Beam LR*)
  - ➢ In the second case the beams are laterally unrestrained (*Beam LU*).

  Note: Both the ends of the beams are rotationally restrained, while the longitudinal displacement is not restrained.

Fire-after-earthquake scenarios

- ✓ Two different fire-after-earthquake scenarios are considered for both case studies, considering different levels of damage caused to the steel beams by the earthquake.
- ✓ Parametric analyses are conducted considering:
  - ➢ the amplitude of the initial imperfections
  - ➢ the level of the imposed loadings

Fire-after-earthquake scenario	**Beam LR** (laterally restraint)						**Beam LU** (laterally unrestrained)		
	Loading level: % of the yield stress						Loading level: % of the yield stress		
	40		50		58		40	50	58
	Maximum amplitude of initial imperfections (mm)						Maximum amplitude of initial imperfections (mm)		
A	2	5	2	5	2	5	2	2	2
B	2	5	2	5	2	5	2	2	2

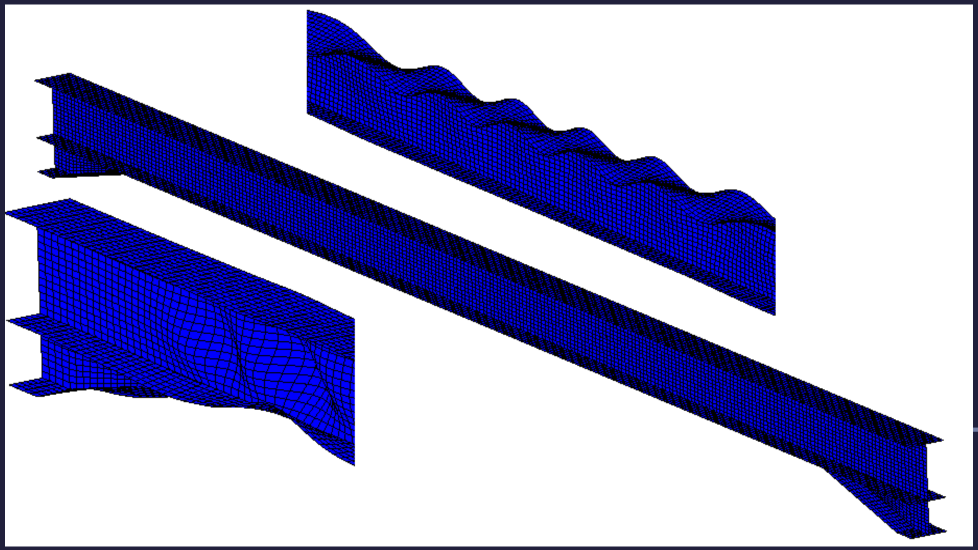
Numerical model

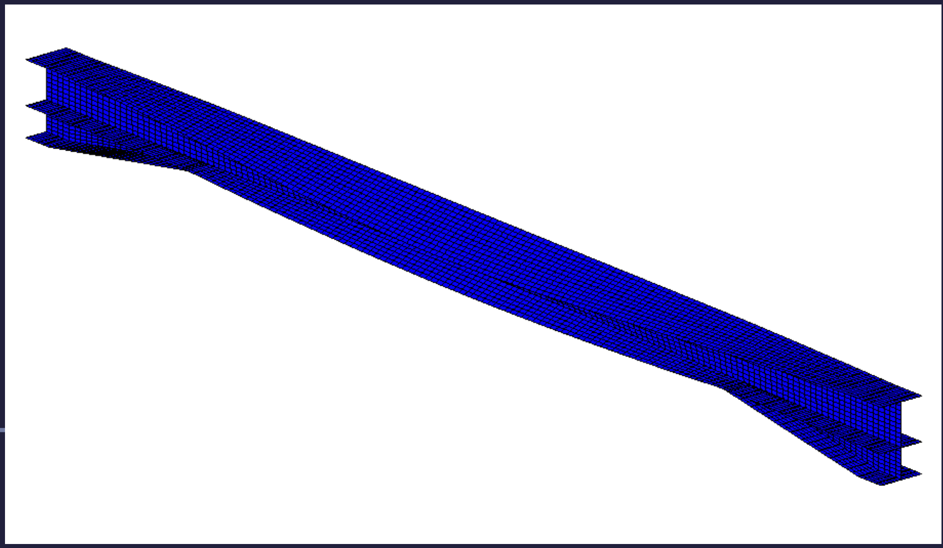
The numerical analysis is carried out using the nonlinear finite element code MSC-MARC.
Initial imperfections are incorporated in the geometry of the steel beam for a more realistic assessment of the behaviour.

For the LR-beam two eigenmodes are combined:

- ✓ eigenmode related with the local buckling at the upper flange of the beam at the mid-span
- ✓ eigenmode related with the local buckling at the lower flange of the beam at the haunched ends

For the LU-beam the eigenmode that is used is related to the lateral torsional buckling





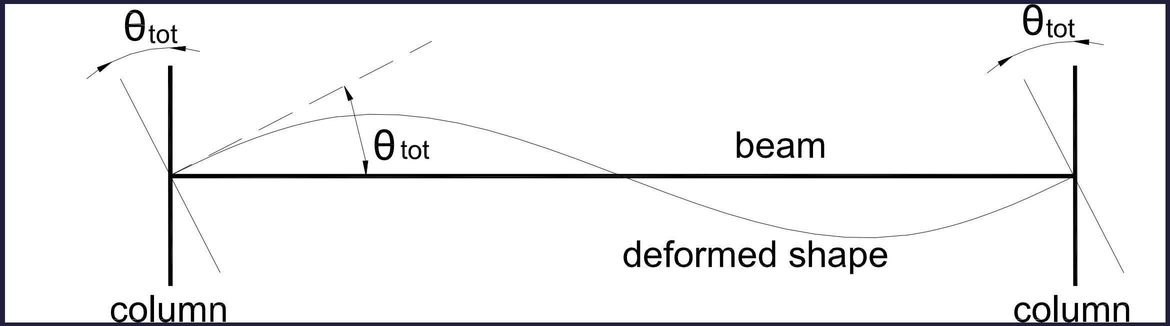
Fire Analyses

Numerical analyses are conducted in order to find the fire resistance of the steel beams for both case studies.

- ✓ The beams are exposed to the standard ISO fire curve for 60 minutes.
- ✓ The temperature profile of the cross section of the beam is assumed to be known and is defined according to the procedure that is proposed in EN 1993-1-2 for the fire exposure. Therefore, there is no thermal gradient in the cross section and the temperature is supposed to be constant along the beams.

Fire-after-earthquake analyses

The seismic actions are simulated through the storey drifts that are introduced during the earthquake excitation.



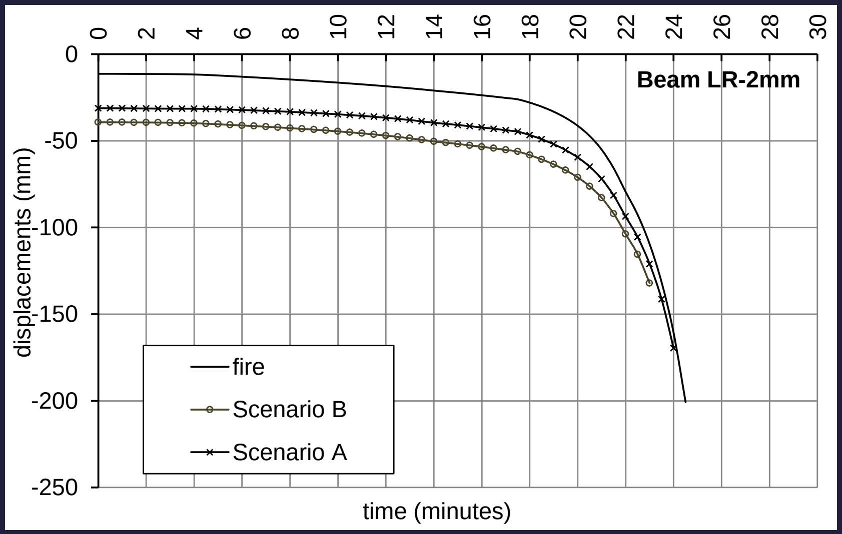
Two different fire-after-earthquake scenarios are defined:

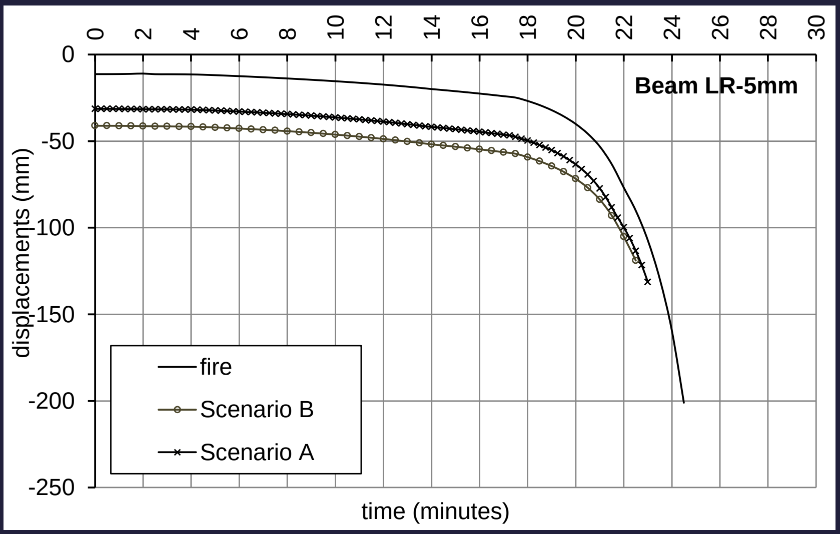
- ✓ In the first seismic scenario (A) the total rotation is θ_{tot}=20mrad
- ✓ In the second one (B) the total rotation is θ_{tot}=30mrad

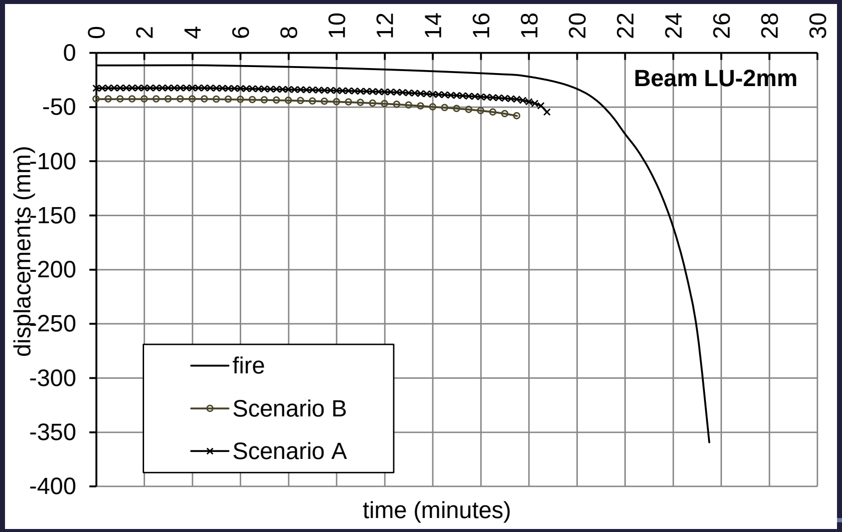
Fire-after-earthquake analysis has three different stages.

1. At the first stage the steel beams are submitted to the same rotation at both ends until the target rotation is reached.
2. The **unloading stage** follows, where the reduction of the rotation is equal to the elastic part θ_{el}.
3. At the third stage the steel beams are submitted to the standard fire ISO curve for 60 minutes.

Results of the analyses - Loading level: 40% of the yield stress

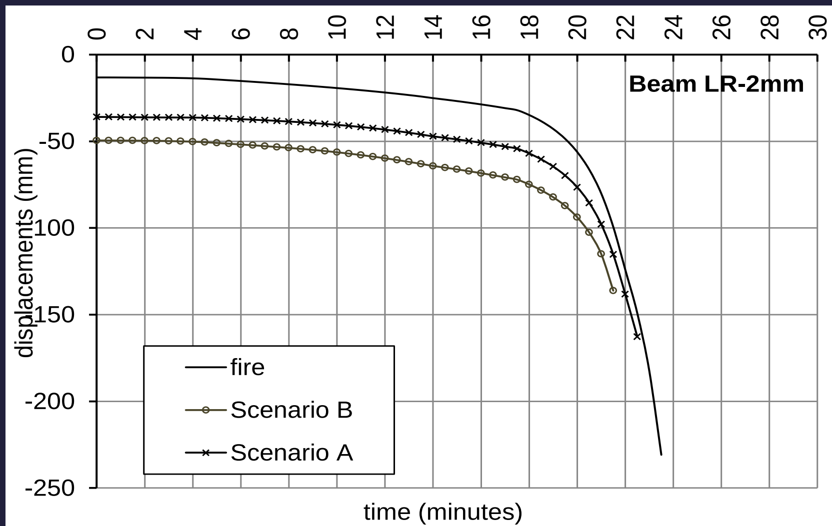


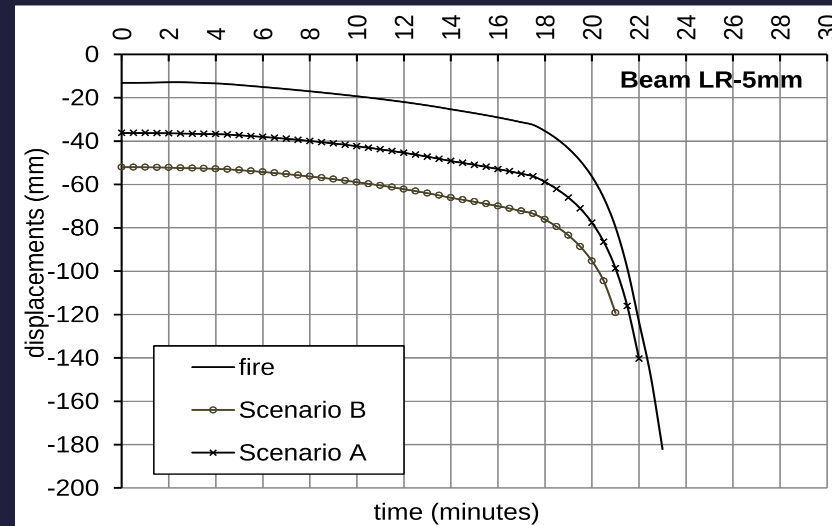


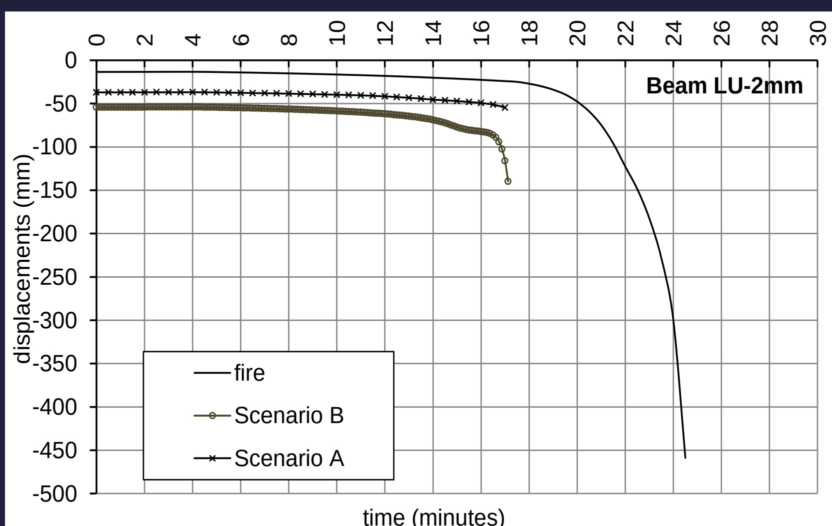


- ✓ In the case of the *lateral restrained* beam as the amplitude of the initial imperfections increases the fire resistance of the beam decreases with respect to the reference case which is the fire situation

Results of the analyses - **Loading level: 50% of the yield stress**

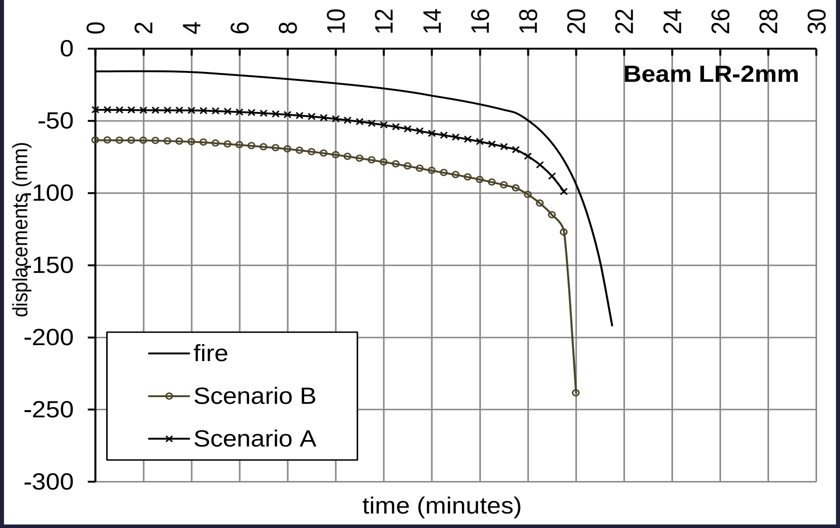


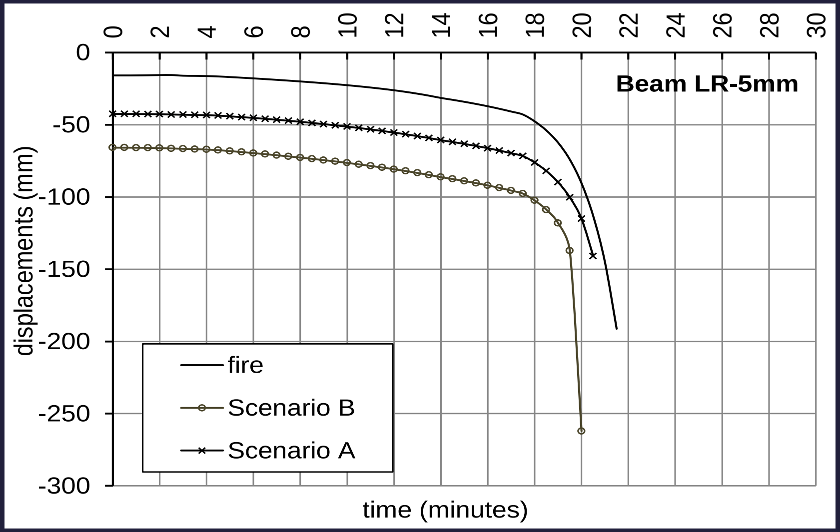


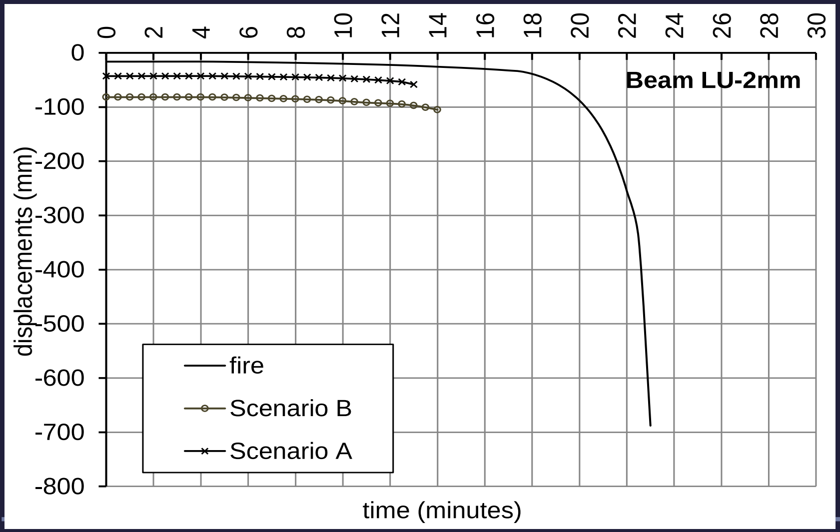


- ✓ In the case of the *lateral unrestrained* beam considerable reduction for both fire after earthquake scenarios, can be observed

Results of the analyses - **Loading level: 58% of the yield stress**







- ✓ The fire resistance of both laterally restrained and unrestrained beams is depends on the loading level
- ✓ The loading level affects the influence of the amplitude of the initial imperfections to the fire resistance of the beams with respect to the reference case which is the fire situation

Results of the analyses (1)

Parametric analyses results for the laterally restrained beam (Beam LR)

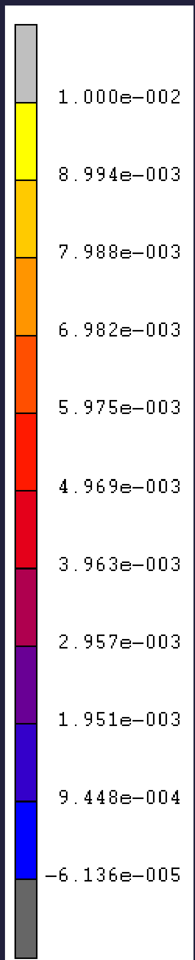
Analysis	Loading level: % of the yield stress					
	40		50		58	
	Maximum amplitude of initial imperfections					
	2mm	5mm	2mm	5mm	2mm	5mm
	Fire resistance in time domain (minutes)					
Fire	24.5	24.5	23.5	23	21.5	21.5
Scenario A	24	24	22.5	22	21	20.5
Scenario B	23	22.5	21.5	21	20	20

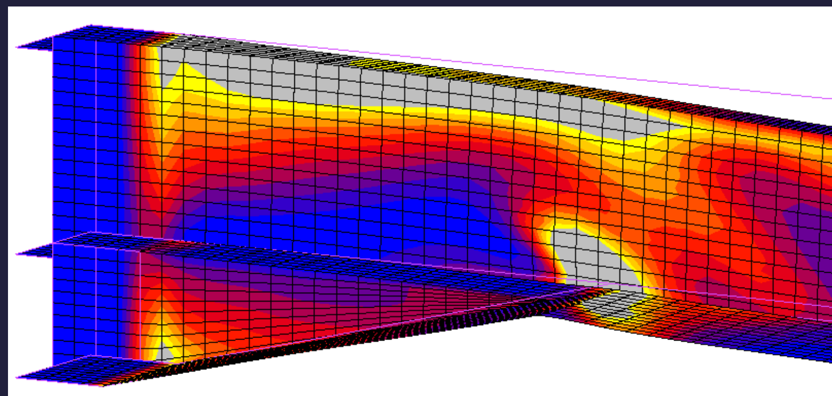
Parametric analyses results for the laterally unrestrained beam (Beam LU)

Analysis	Loading level: % of the yield stress		
	40	50	58
	Maximum amplitude of initial imperfections		
	2mm	2mm	2mm
	Fire resistance in time domain (minutes)		
Fire	25.5	24.5	23
Scenario A	18.75	17	14
Scenario B	17.5	17	13

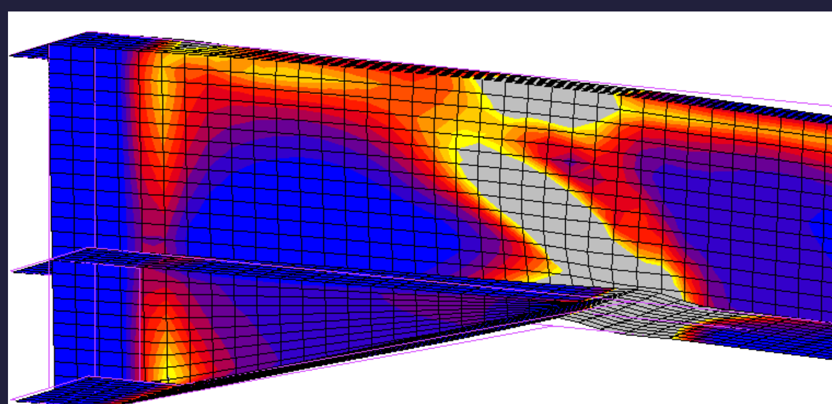
Results of the analyses - **Loading level: 40% of the yield stress**

Equivalent plastic strain field at the last increment





Analysis: Fire
Amplitude of initial imperfections: 5mm
Maximum plastic strain: 0.024
Fire resistance: 24.5minutes

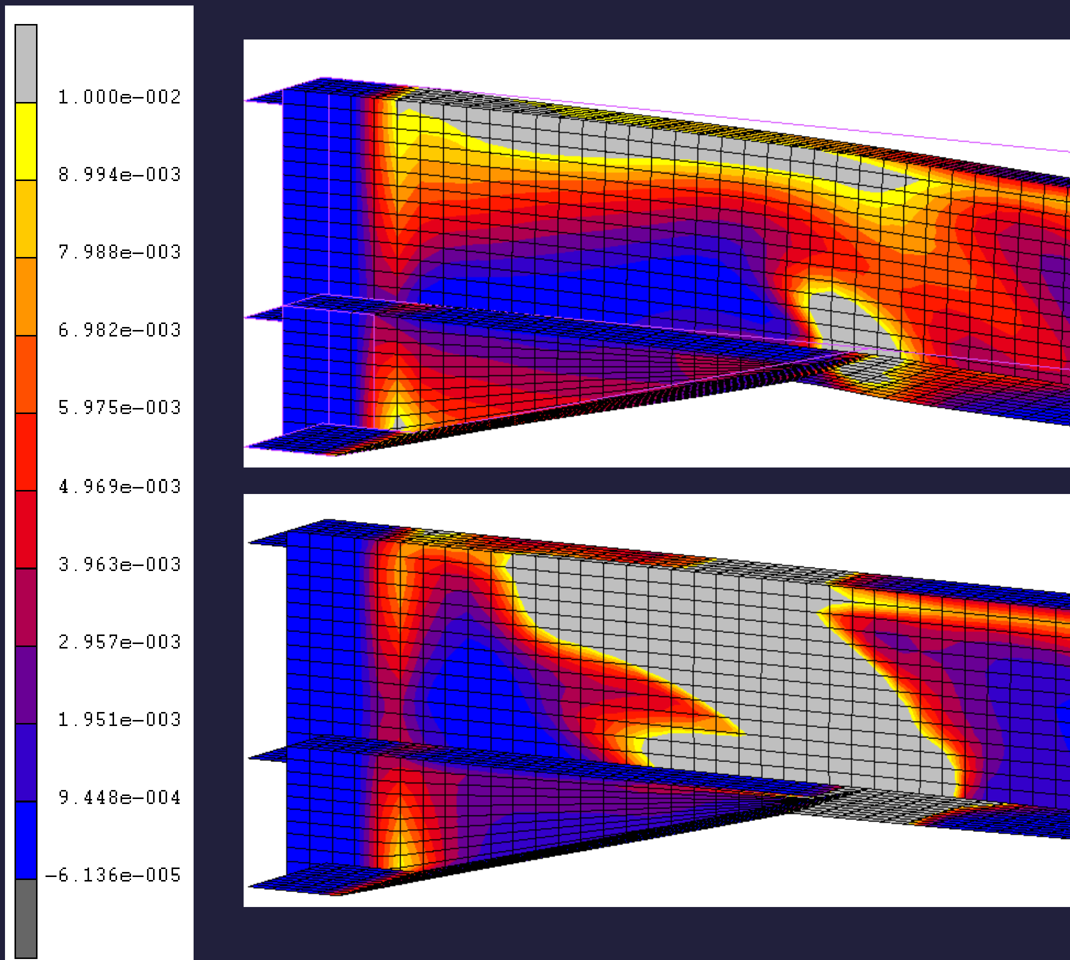


Analysis: Scenario B
Amplitude of initial imperfections: 5mm
Maximum plastic strain: 0.150
Fire resistance: 22.5minutes

Beam Laterally Restrained

Results of the analyses - Loading level: 58% of the yield stress

Equivalent plastic strain field at the last increment



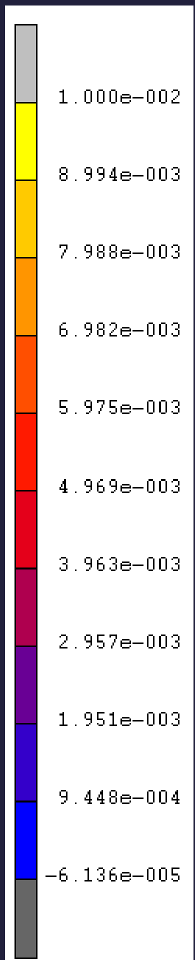
Analysis: Fire
Amplitude of initial imperfections: 5mm
Maximum plastic strain: 0.021
Fire resistance: 21.5minutes

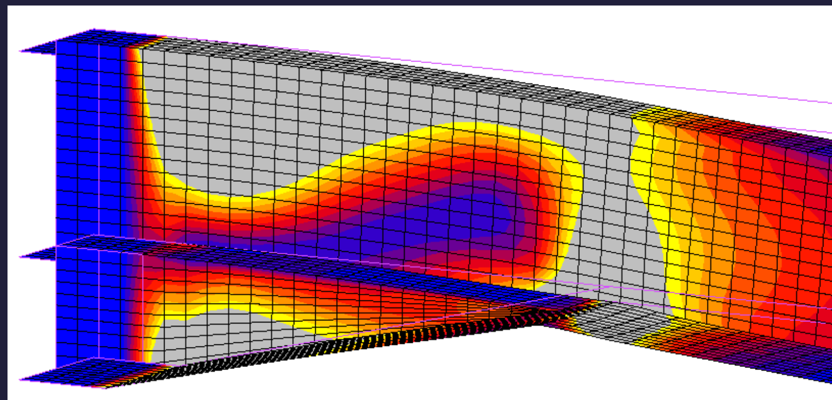
Analysis: Scenario B
Amplitude of initial imperfections: 5mm
Maximum plastic strain: 0.349
Fire resistance: 20minutes

Beam Laterally Restrained

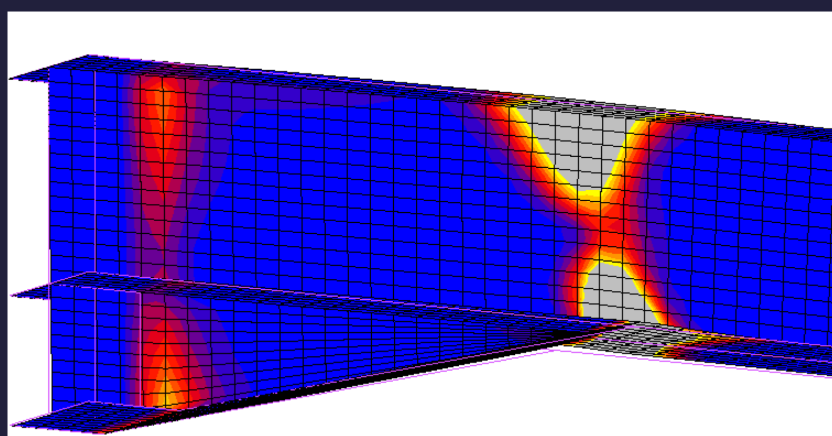
Results of the analyses - **Loading level: 40% of the yield stress**

Equivalent plastic strain field at the last increment





Analysis: Fire
Amplitude of initial imperfections: 5mm
Maximum plastic strain: 0.036
Fire resistance: 25.5minutes



Analysis: Scenario B
Amplitude of initial imperfections: 5mm
Maximum plastic strain: 0.032
Fire resistance: 18.75minutes

Beam Laterally Unrestrained

Conclusions

The results of the numerical analyses indicate:

- ✓ Considerable reduction of the fire resistance time for laterally unrestrained beams in both the examined scenarios (with respect to the reference case which is the fire situation).
- ✓ For the laterally restrained beam, the reduction of the fire resistance time in the case of fire-after-earthquake, is rather limited.
- ✓ For both fire-after-earthquake scenarios, the reduction becomes greater as the amplitude of the initial imperfections increases, but the difference is not considerable.
- ✓ Also it is noticed that the fire resistance decreases as the level of the applied loading (i.e. the coefficient $\psi_{2,i}$) increases.

Thank you for your attention

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