Research Fund for Coal & Steel

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FISHWALL

FIre and Seismic performances of Hybrid fire WALLs in case of single-storey industrial and commercial steel buildings

SESSION: Design guide of fire walls using sandwich panels

- **Design guidelines and rules**
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- **BRIAND Métal**

Design Guide

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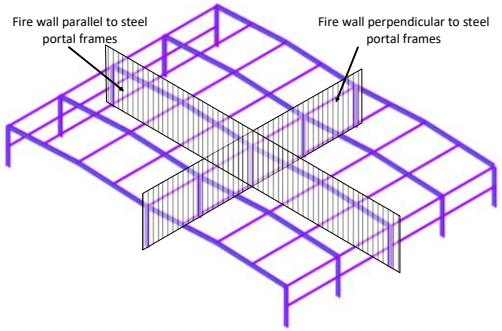
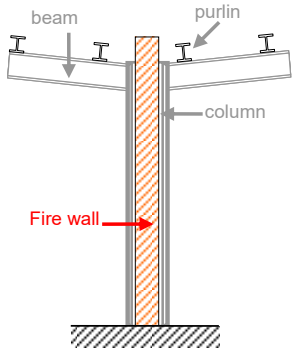
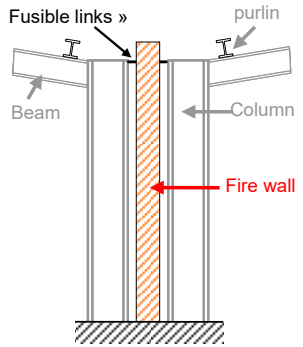
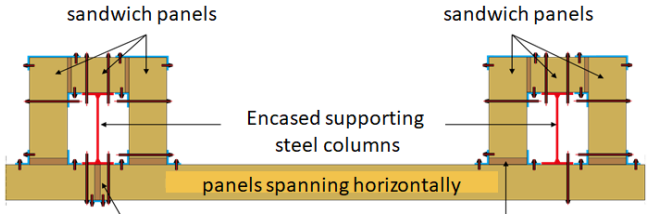
Design Guide - SCOPE

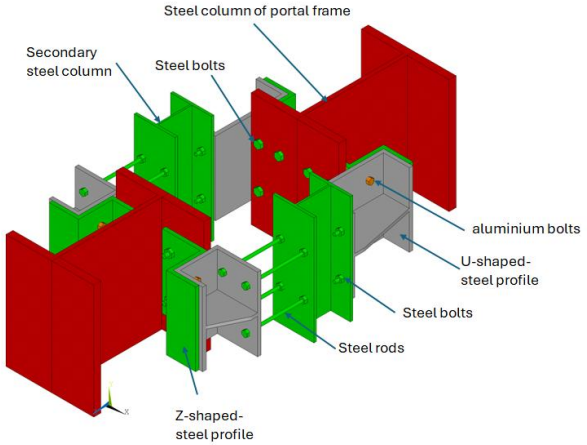
- **Steel-framed budlings**
  - Geometrical limitations
  - Divided in fire compartments
- **Fire wall**
  - no structural lightweight insulated sandwich panels
  - Parallel or perpendicular to steel portal frames
- **3 fusible link solutions**

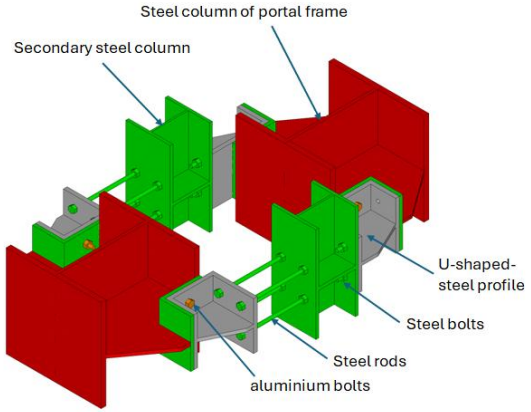


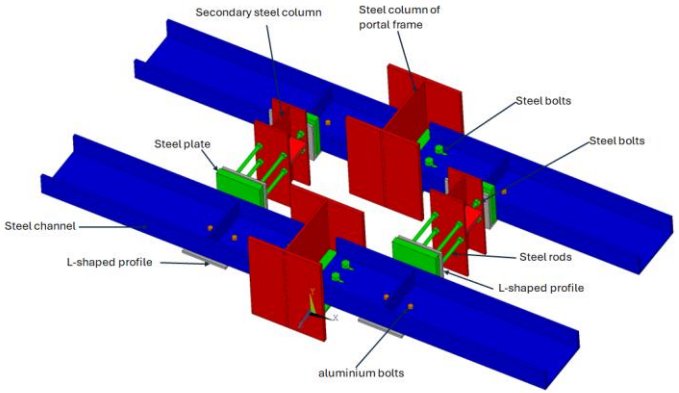












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Design Guidance – Steel structure

- **Structural design is usually performed using the Eurocode standard set. The accidental situations (e.g. fire or earthquake) that need to be considered depend on the country's regulations.**
- **Design in normal condition:**
  - Steel structures must comply with both ultimate and serviceability limit state criterion.
  - Verification of the overall stability and resistance of a steel structure is generally based on a global analysis, to determine the state of the structure when subjected to the relevant design values for actions, particularly the maximum forces that will occur in elements.
  - Once these internal forces have been identified, individual checks are carried out on the resistance of cross-sections, members and connections, in accordance with the simplified design rules set out in the relevant parts of EN 1993.
  - Design shall be based on the use of design loads and relevant combinations from EN 1990.

Design Guidance – Steel structure

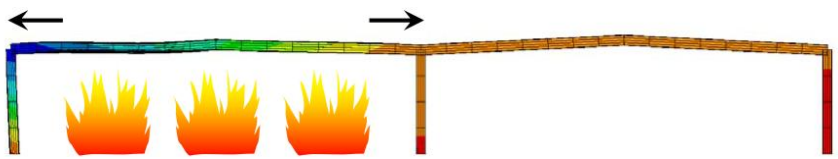
Fire design

- Structural fire resistance requirements vary significantly throughout Europe: no fire resistance rating, fire stability of 15 minutes (R15) to 60 minutes (R60).
- Design at normal temperature of the steel structures leads to a critical temperature over 650°C for steel portal frame systems, which proved to be sufficient to avoid any risk during the evacuation of occupants from the area affected by the fire
- Structures must be designed to:
  - prevent the building from collapsing outwards
  - prevent progressive failure
- A single storey building with an **unprotected** steel structure can easily meet these structural performance requirements and provide an adequate safety level

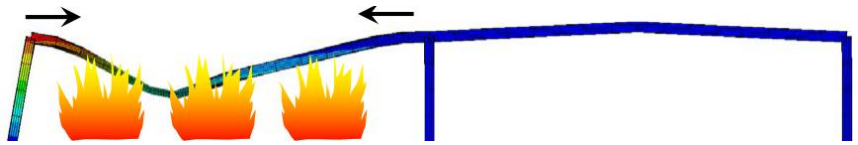
Design Guidance – Steel structure

Fire design

- Several guides or publications are available, providing design guidance for verifying the fire behaviour of single-storey steel buildings and for easily designing steel structures that meet the requirements defined in terms of structural behaviour.
- For fire wall implemented with fusible links, the steel structures that are not exposed to fire (located on the other side of the fire walls of the separating these structures to this exposed to fire) must be designed to resist the pushing forces induced by the thermal expansion of the steel structure exposed to fire.



Pushing phase



Tensile phase

Design Guidance – Steel structure

Fire design

- Single-storey buildings can be designed using the fire parts of Eurocodes, either according to the prescriptive approach or according to the performance-based approach.
  - The prescriptive approach is mostly applied to fulfil low standard fire ratings (R15), using simplified calculation models.
  - The performance-based approach, if accepted by the regulatory authorities:
    - allows to avoid to fire protect the steel structure (for high fire resistance ratings such as R60), considering the overall behaviour of the structure under real fire conditions to ensure adequate life safety for the building occupants and firemen.
    - usually requires the use of sophisticated design tools and experienced user.

Design Guidance – Steel structure

Seismic design

- Appropriate design rules from Eurocode 8 should be applied, in accordance with the region seismicity.
- Steel structures (when designed according to the state of the art in seismic design) are well known for their good performance in earthquakes:
  - The high ductility of steel gives steel members a high capacity to deform without breaking, eliminating the risk of premature failure, and allowing seismic energy to be dissipated in the plastic deformation of the members
  - The slenderness of the profiles commonly used gives steel structures lightness and great flexibility
  - Steel is an isotropic material, steel members can resist both tension and compression, which is a considerable advantage to face alternating loading specific to earthquakes

Design Guidance – Steel structure

Seismic design

Recommendations:

- **structural simplicity** -> clear and direct paths for the transmission of the seismic forces
- **uniformity, symmetry and redundancy** -> building configuration symmetrical, regularity in plan and height; close relationship between the distribution of masses and the distribution of resistance and stiffness eliminates large eccentricities between mass and stiffness.
- **bi-directional resistance and stiffness** -> horizontal seismic motion is a bi-directional phenomenon, ensuring similar resistance and stiffness characteristics in both main directions.
- **torsional resistance and stiffness** -> avoidance of torsional effects that stress the structural elements in a non-uniform way.

Design Guidance – Fire walls

Design in normal condition

Panels:

- Designed based on Annex E of EN 14509 and data provided by the sandwich panel manufacturer
- Mechanical resistance to the design loads resulting from the action of self-weight, wind, temperature and pressure gradients
- Often required that the deflection of panels should not exceed the value of span/100
- wind loads should be determined according to EN 1991-1-4 and corresponding national annexes

Supporting steel column:

- Checked using the simplified design methods in EN 1993-1-1
- Mechanical resistance to the design loads resulting from the action of self-weight (column itself, panels wall and encasement system) and wind

Design Guidance – Fire walls

Fire design

Panels:

- fire performance of walls made of sandwich panels can only be demonstrated by:
  - classification reports drawn up following EN 13501-2, based on fire resistance tests according to relevant European standards
  - technical approval issued by an accredited fire laboratory
- fire tests on sandwich panel walls are usually carried out on small specimens, but it is possible to extrapolate results for larger spans if specific criteria of applicable standards are met.
- fire-resistance rating of sandwich panel walls depends mainly on their thickness (usually between 100 and 300 mm) and the type of mineral wool used. It can vary between ½ h and 4 h.
- fire performance stated in classification and test reports is only valid for a well-defined area of application (REI or EI rating, wall components, etc.)

Design Guidance – Fire walls

- **Fire design**
  - Supporting steel column:
    - Fire walls solidly fixed to the steel structure:
      - There is no need for a specific check of the fire resistance of steel columns supporting the fire wall for the following reasons:
        - heating of the columns does not exceed 500°C if they are adequately clad with sandwich panels.
        - steel columns remain stable if their temperature rise does not exceed 500°C (EN 1993-1-2) and if they are designed in accordance with EN1993-1-1.
    - For fire walls associated with fusible links, the upper part of the columns is exposed to fire and must be checked
    - Like panels, columns must be designed at normal temperature so that the fire wall can withstand wind load if a part of the structure collapses in the event of fire.

Design Guidance – Fire walls

Seismic design

Panels:

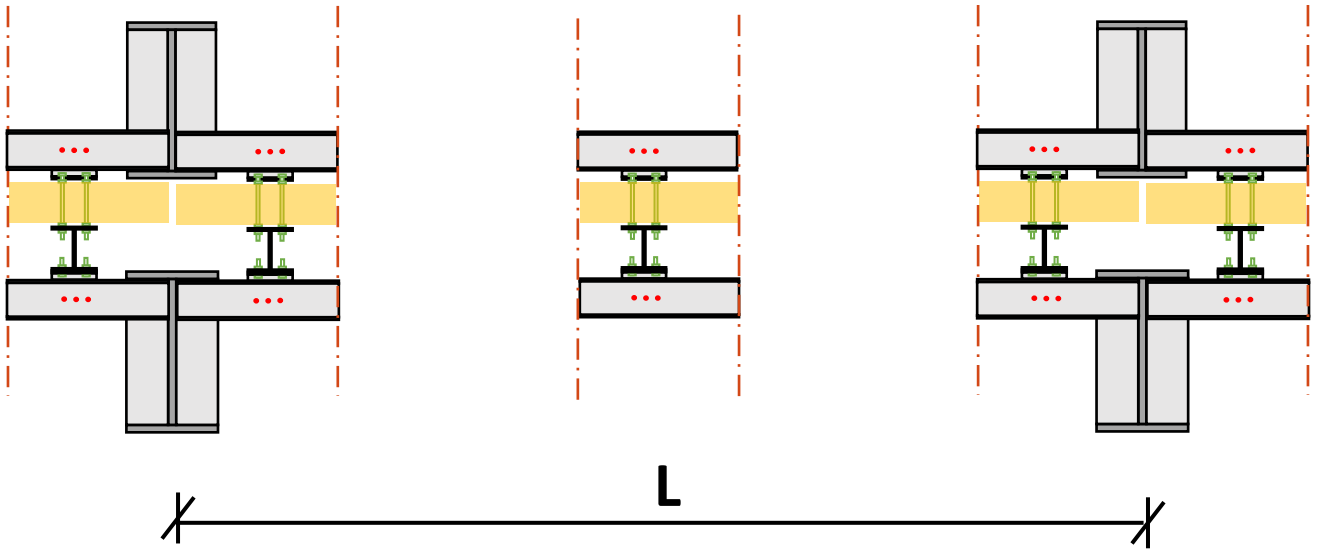
- EN 1998-1 is applicable. It must be demonstrated that:
  - the panel will not fall under the displacement applied to the supporting steel structure.
  - the panel will not fall under the acceleration applied to supporting steel structure.
- For this purpose, different design approaches can be followed:
  - A fully experimental one, by performing full-scale tests where displacements and accelerations are imposed to the tested wall solution to cover different seismic situations in a country. A test report and its interpretation are carried out by an official laboratory.
  - A hybrid approach combining testing and calculation: The maximum displacement that the panels can withstand, and the maximum admissible force that the fasteners can withstand is determined by testing. This maximum force considers the mass of the panel plus any additional mass required to simulate a span greater than that tested, multiplied by the horizontal seismic acceleration.

Design Guidance – Fire walls

Seismic design

Supporting steel column:

- Supporting columns should be designed in accordance with Eurocode 3 prescriptions.
- The resistance is governed by aluminium bolts shear failure.



Design Guidance – Fusible links

- **Fusible systems must be designed to:**
  - Withstand all combinations of loads commonly checked for conditions of normal use.
  - Resist the compressive forces due to the thermal expansion of the steel structure exposed to fire.
  - Withstand wind effects in fire situation, due to the collapse of the heated steel structure.
  - Resist the seismic actions, if relevant.
  - Ensure that in the event of a fire, the fusible links on the fire-exposed side are the first to fail in the tensile phase due to the collapse of the steel structure.

Design Guidance – Fusible links

Design in normal condition

- Fusible links can transmit tensile and compressive forces
- Fusible links covered in the guide are not designed to withstand vertical loads
- Resistance check is required for all the components:
  - Bottom flange of the U profile and the Z profile in bending
  - Steel rods in compression
  - Web of steel profiles and web stiffeners in compression
  - Upper flange of the Z profile in bending and traction
  - Steel bolts in tension or shear
  - Aluminum bolts in shear
  - …
- Sandwich panels must not be subjected to any force coming from the fusible link

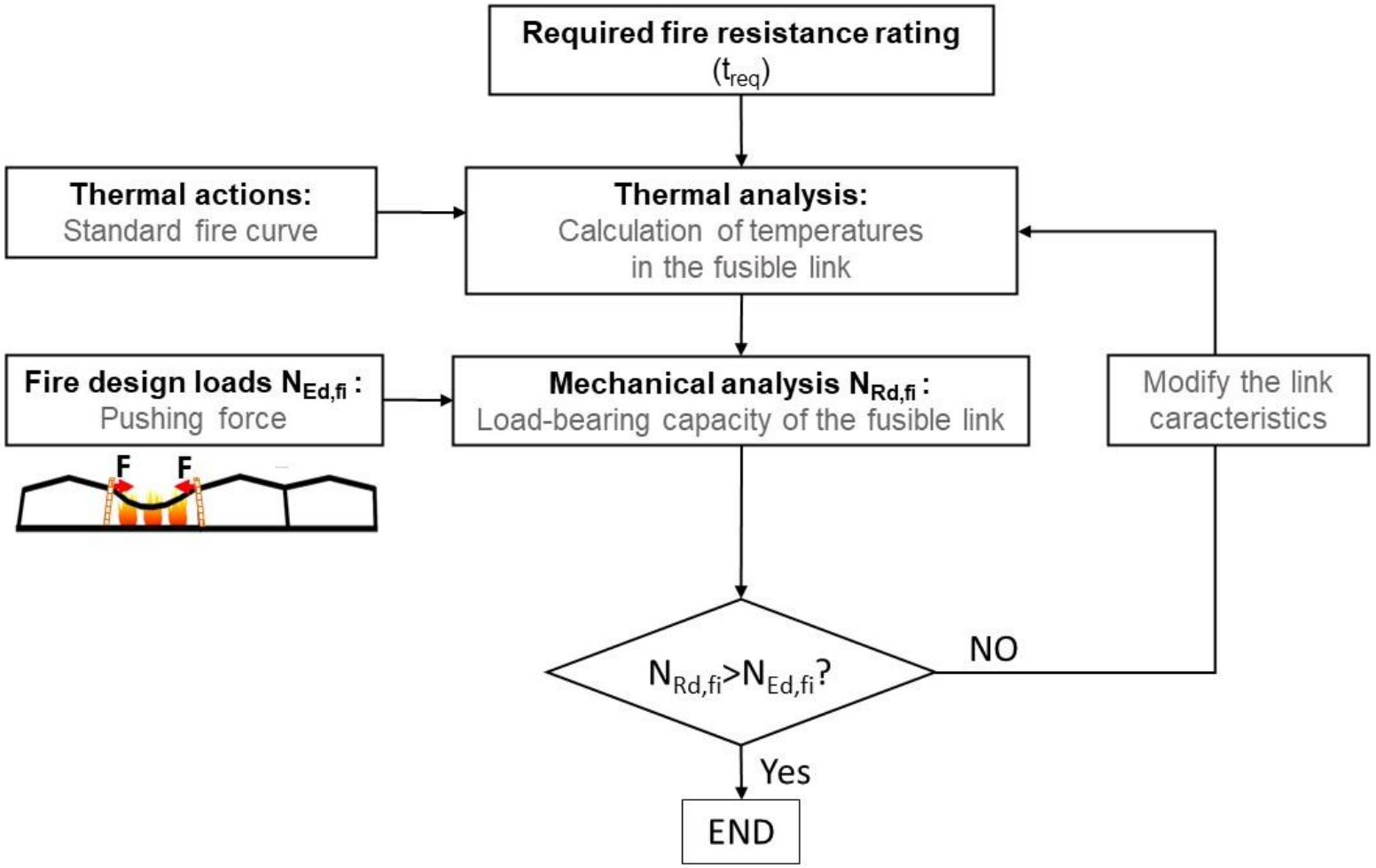
Design Guidance – Fusible links

- **Fire design**
  - Fusible links located on both sides of the wall must resist the pushing phase
    - Design strategy: achieve a R15 fire resistance rating for all the components, **except** aluminium bolts which do not contribute to the compression resistance of the links
      - Rules for estimating pushing forces
      - Rules for calculating the heating of components
      - Rules for calculating the load-bearing capacity of the fusible link
  - Fusible links located on the fire-exposed side must fail first for the tensile phase due to the collapse of the steel structure
    - Design strategy: design the fusible link **at normal temperature** to withstand the tensile forces resulting from the collapse of the structure exposed to fire (resistance mainly provided by the shear resistance of the aluminium bolts)
      - Rules for estimating tensile forces

Design Guidance – Fusible links

➢ Fire design

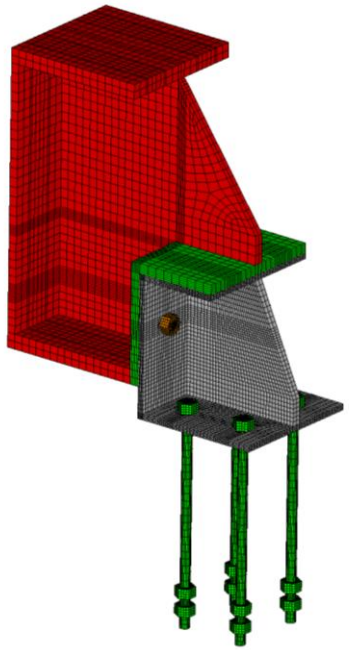
❖ Design procedure

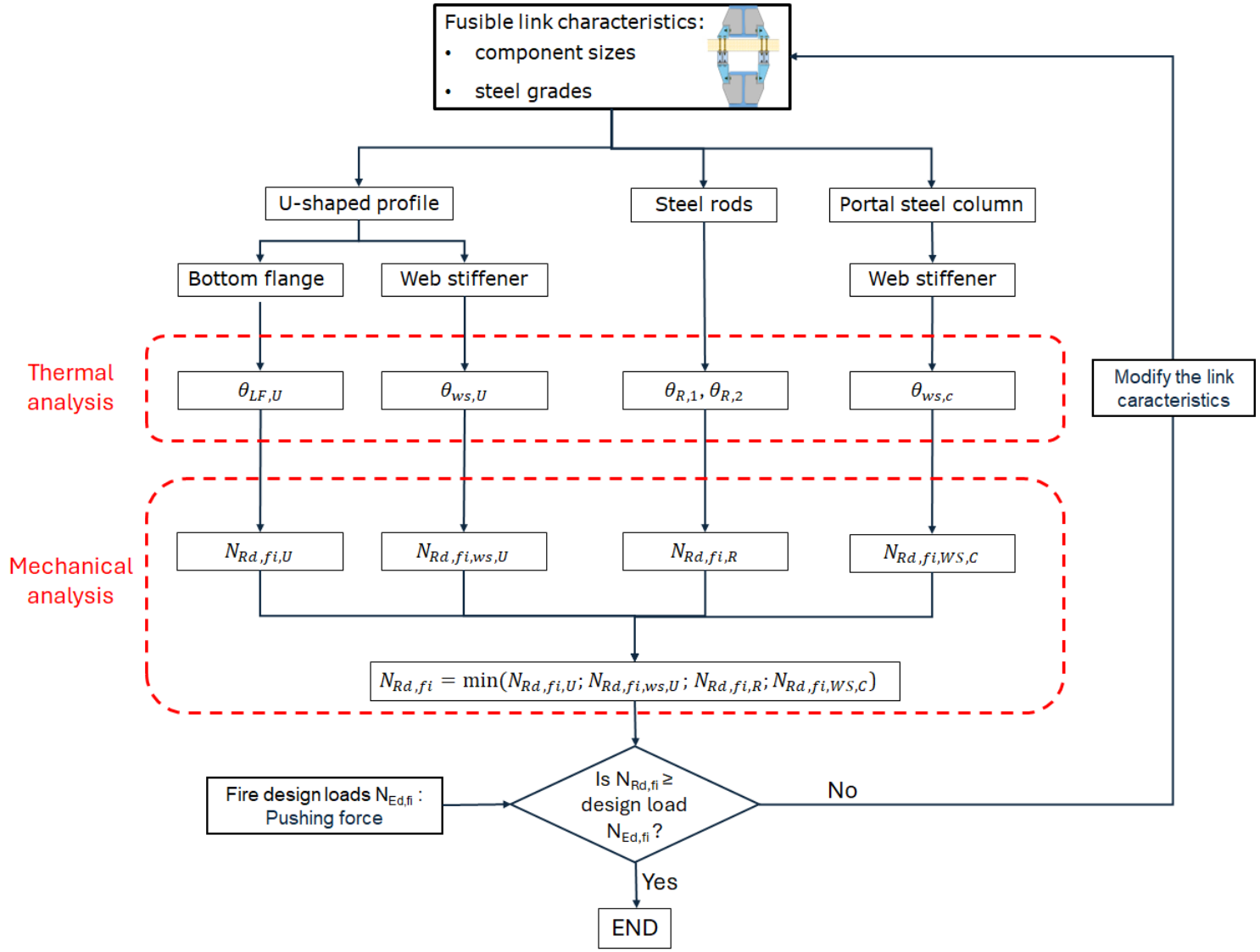


Design Guidance – Fusible links

Fire design

Example of flowchart



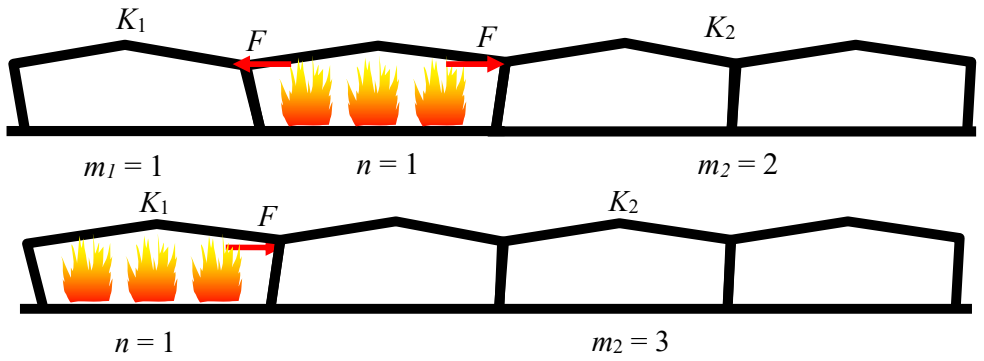


Design Guidance – Fusible links

Fire design

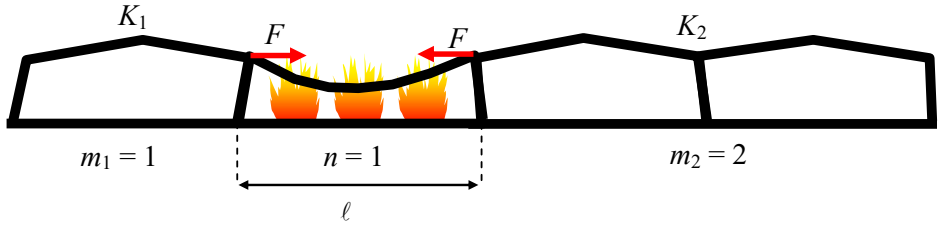
Fire design loads

- Simple rules based on previous research works
  - Pushing forces



$$F = c_{th} \frac{K_1 K_2}{K_1 + K_2} n\ell$$

  - Tensile forces



$$F = c_p n_{eff} qfi, Ed\, \ell$$

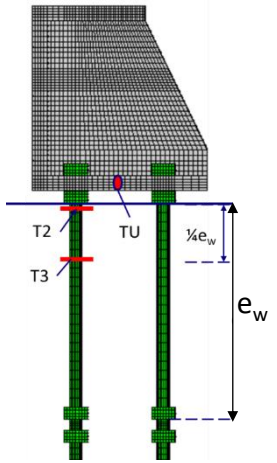
Design Guidance – Fusible links

Fire design

Calculation of heating

- Calculation of temperature rises in basic components:
  - Steel profiles, steel plates, steel rods and aluminum bolts
- The temperature of steel profiles may be assessed from:
  - The simplified method of EN 1993-1-2
  - Using appropriate local or global A/V value of the considered parts forming the link
- Temperatures in steel rods calculated from the temperature rise in steel profiles, using simple correction factors

e_w	T3/TU	T2/TU
100	0.56	0.84
175	0.47	0.84
240	0.39	0.84

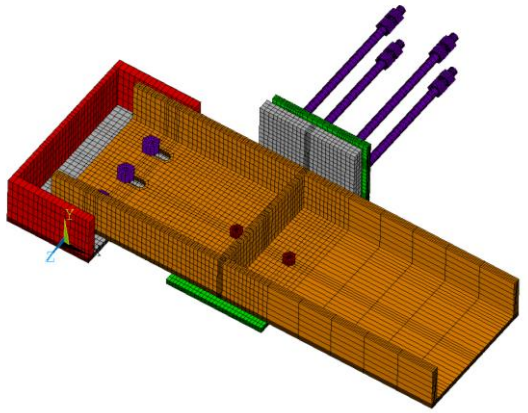


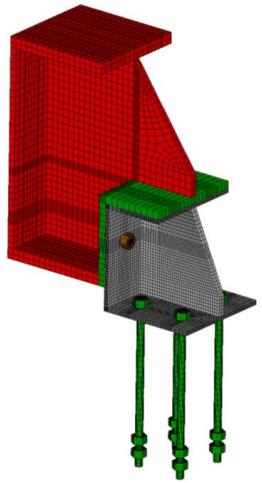
Design Guidance – Fusible links

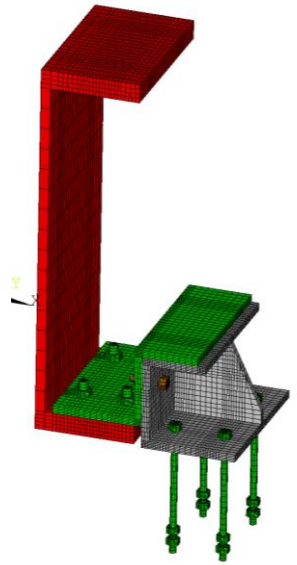
Fire design

Load bearing capacity of the fusible links

- Bearing resistance calculated according to the resistance of basic components:
  - Bottom flange of the U profile and the Z profile in bending
  - Steel rods in compression
  - Web of steel profiles and web stiffeners in compression
  - Upper flange of the Z profile in bending and traction
  - Steel bolts in tension or shear
  - …





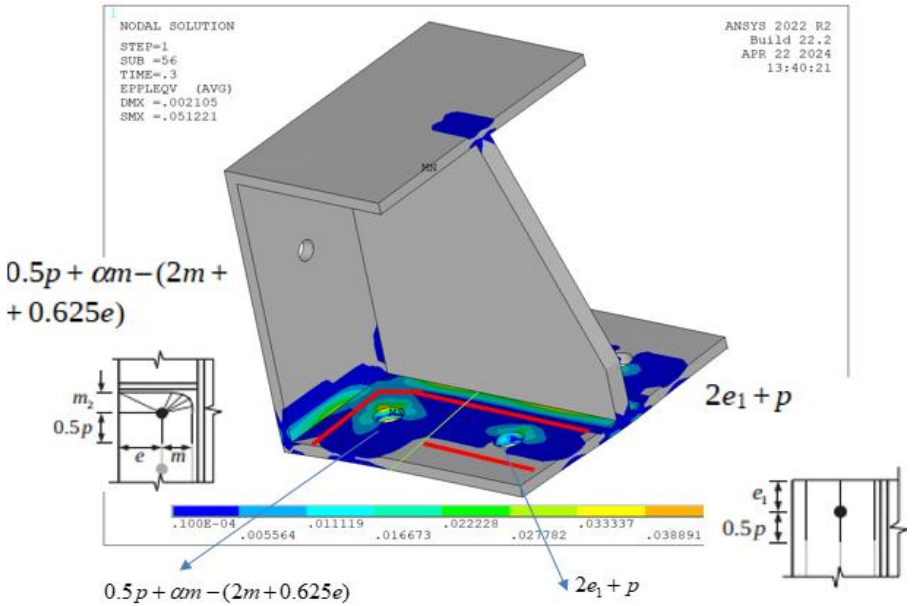


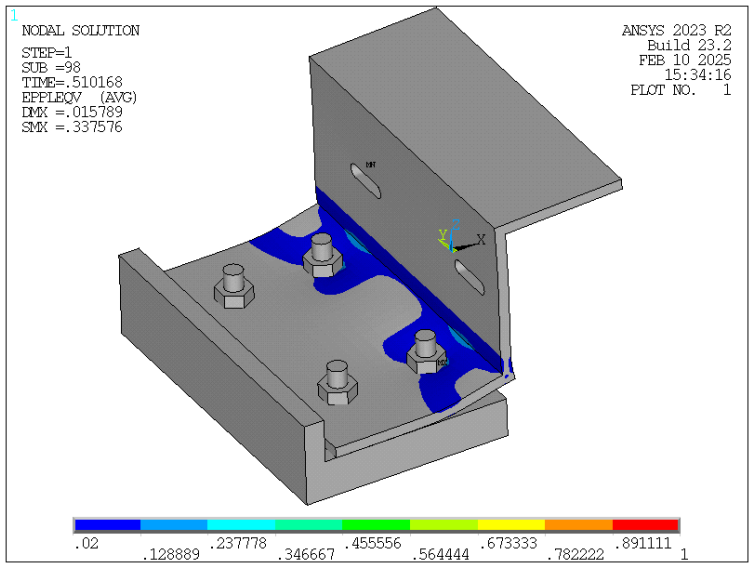
Design Guidance – Fusible links

➢ Fire design

❖ Load bearing capacity of the fusible links

- Bending resistance of the lower flange of the U and the Z profiles
  - Calculated using an equivalent T-stub model, based on yields line patterns (EN 1993-1-8) and taking account of the loss of steel strength with increasing temperature



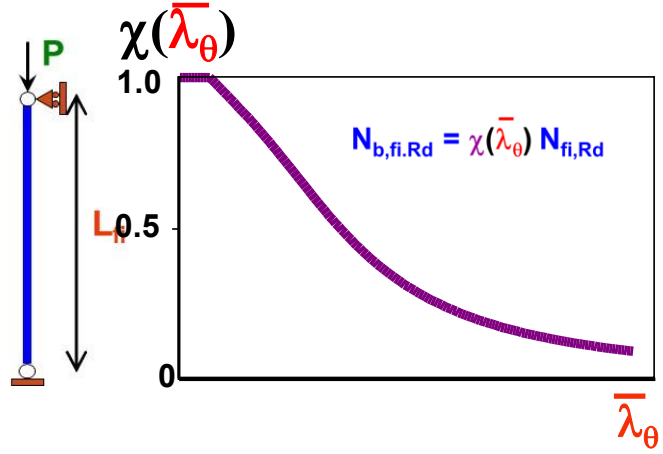


Design Guidance – Fusible links

Fire design

Load bearing capacity of the fusible links

- Resistance of steel rods in compression
  - Calculated from simplified rules for cross-section resistance and buckling resistance given in EN 1993-1-2, but using the buckling curve “C” instead of the fire buckling curve
  - Specific rules to calculate the buckling length according:
    - The fusible link solution
    - The resistance of the bottom flange of the U profile

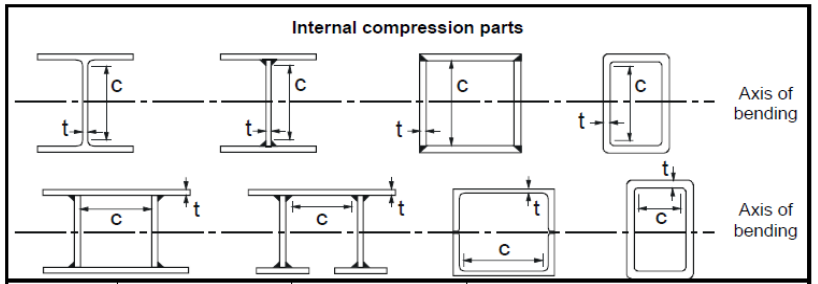


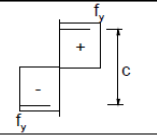
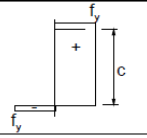
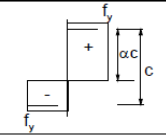
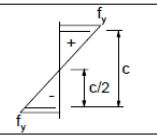
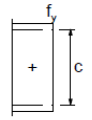
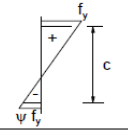
Design Guidance – Fusible links

➢ Fire design

❖ Load bearing capacity of the fusible links

- Resistance of the web of steel profiles and web stiffeners
  - Avoid class 4 cross-section ($\varepsilon_{fi} = 0{,}85\left[235 / f_y\right]^{0{,}5}$)
  - Calculated from simplified rules for cross-section resistance under compression, according to EN 1993-1-2
- Resistance of the UPN steel profile
  - Calculated from the design rules for lateral torsional buckling given in EN 1993-1-2



Class	Part subject to bending	Part subject to compression	Part subject to bending and compression
Stress distribution in parts (compression positive)			
1	$c/t \le 72\varepsilon$	$c/t \le 33\varepsilon$	when $\alpha > 0{,}5$: $c/t \le \frac{396\varepsilon}{13\alpha - 1}$ when $\alpha \le 0{,}5$: $c/t \le \frac{36\varepsilon}{\alpha}$
2	$c/t \le 83\varepsilon$	$c/t \le 38\varepsilon$	when $\alpha > 0{,}5$: $c/t \le \frac{456\varepsilon}{13\alpha - 1}$ when $\alpha \le 0{,}5$: $c/t \le \frac{41{,}5\varepsilon}{\alpha}$
Stress distribution in parts (compression positive)			
3	$c/t \le 124\varepsilon$	$c/t \le 42\varepsilon$	when $\psi > -1$: $c/t \le \frac{42\varepsilon}{0{,}67 + 0{,}33\psi}$ when $\psi \le -1^{*)}$: $c/t \le 62\varepsilon(1-\psi)\sqrt{(-\psi)}$

ε_{fi}	f_y	235	275	355	420	460
	ε	1,00	0,92	0,81	0,75	0,71

*) $\psi \le -1$ applies where either the compression stress $\sigma \le f_y$ or the tensile strain $\varepsilon_y > f_y/E$

Design Guidance – Fusible links

- **Fire design**
  - Load bearing capacity of the fusible links
    - Resistance of steel bolts
      - Calculated from simplified rules given in Annex D of EN 1993-1-2
      - Alternative rule for the bearing resistance based on EN 1993-1-1 and modified to take account of elevated temperatures

Design Guidance – Fusible links

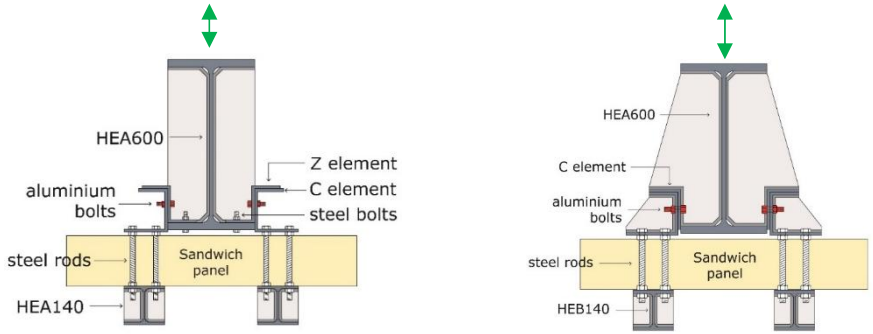
Seismic design

- The guide focuses on modelling the fusible link system within a global model representative of a single-storey building for linear dynamic analysis (which is most used in the design practice) in order to obtain design forces:
  - Supporting columns modelled as elastic beam elements;
  - Fire wall modelled as half of its mass applied to the supporting columns;
  - Fusible links details modelled as frame elements characterized by their initial stiffness estimated from the laboratory tests;
  - Supporting columns equipped with fusible links and linked between them with elastic beam elements;
  - Depending on the bracing system design, both the diagonals in tension and compression can be included in the model. Otherwise, only the tension diagonal is considered, and two different models should be developed to properly represent the seismic behaviour in the two direction of earthquake application.

Design Guidance – Fusible links

Seismic design

- Parametric analyses showed that the fusible link system experiences low forces because it is not designed to resist lateral loads, and its stiffness is low compared to the main lateral-resisting systems, such as portal frames and vertical bracing systems.
- Recommendations:
  - Details with larger size of aluminium bolts are preferable, M16 instead of M12.
  - Details with low number of aluminium bolts are preferable to avoid imperfections and misalignments observed during the test.
  - Detail 1 and Detail 2, are the best options, for low and moderate seismicity regions, respectively:



Thank you for your attention!

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