2.5 Integration of fire and earthquake engineering to design modern steel structures

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Integration of fire and earthquake engineering to design modern steel structures

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Integration of fire and earthquake engineering to design modern steel structures

Current approach to design:

Different "accidental" actions treated independently one from the other (i.e., one action at a time)

Accordingly, justification of design is made through detailed checks for different load combinations:

- **Wind load combination**
- **Seismic load combination**
- **Fire load combination**
- **Other (impact, explosion, ...)**

Is the independency a correct assumption?

Fire must often be considered as subsequently occurring after another (primary) accidental action (e.g. a fire developing soon after an explosion or an earthquake). In such a case, the fire action structural effects must be evaluated by taking into account the effects of previous actions.

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Past earthquakes testify the high risk of a fire developing soon after an earthquake: San Francisco 1906, 1989, Tokyo 1923, Kobe 1995 are significant examples

Fire in central Kobe (courtesy of EQE)

- **Risks coming from fires following strong earthquakes are generated by several sources:**

Post-Earthquake FIRE HAZARD:
- Damage to pipelines
- Damage to electric wiring

Post-Earthquake FIRE VULNERABILITY:
- Damage to active and passive fire protection systems
- Damage to the building structure

Additional OPERATING DIFFICULTIES for firemen (obstruction of roads, multiple fires, difficulties in water supply, ...)

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Current approach to seismic design:

"Normal" structures are designed to be damaged by earthquakes.

Typical forms of damage induced by earthquakes

- Global and local buckling of braces

- Local buckling of beam-columns

- Shear yielding may induce web and flange buckling (not shown in the picture)

Excessive plastic deformation may lead to fracture

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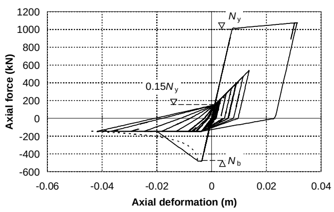
Current approach to seismic design:

"Normal" structures are designed to be damaged by earthquakes.

Buckling and fracture produce degradation of mechanical response

Example: Strength and stiffness degradation of a brace due to buckling



Hence, the question arise:

What is the fire resistance of a degraded member?

No answer available at time because of absence of experimental info

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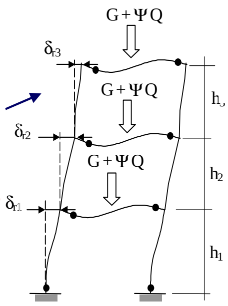
Current approach to seismic design:

"Normal" structures are designed to be damaged by earthquakes.

Going from "member level" to "structure level"

Residual deformed shape of the frame



After the earthquake, the structure geometry is different, because of some residual plastic deformations

Hence, the question arise:

What is the fire resistance of a geometrically distorted structure?

Some answer available through numerical models, discussed later on

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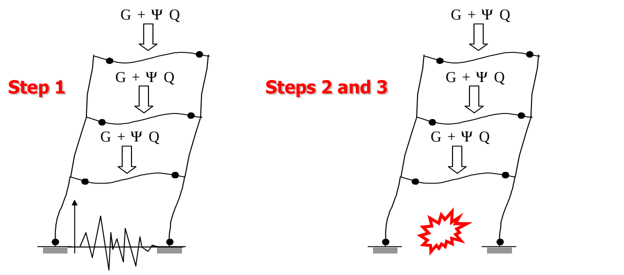
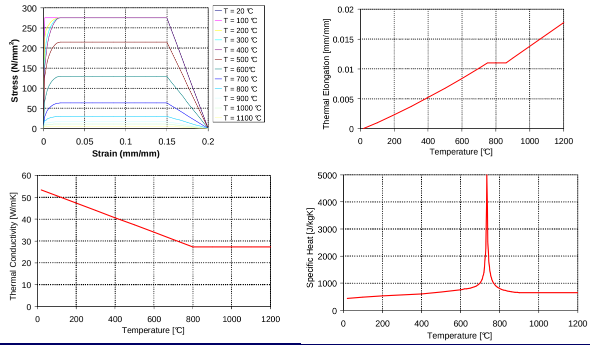
Analysis methodology

1. **Analyse the response for a selected ground acceleration time history**
2. **Assume a standard fire develops at the most unfavourable location**
3. **Analyse the fire response of a leaning frame based on the residual story displacements obtained at the end of step 1**

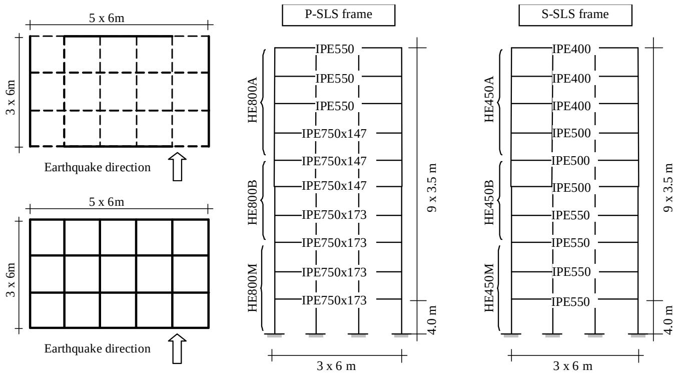


Material behaviour at high temperatures

The steel behaviour at high temperatures has been modelled according to Eurocode 3 (ENV 1993-1-2)

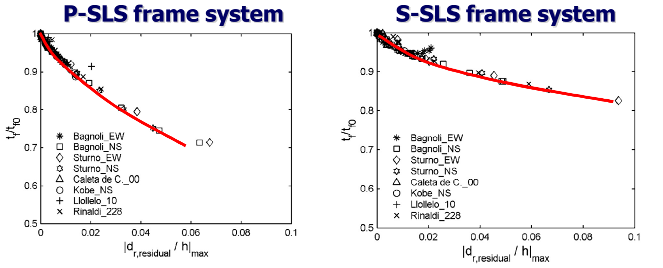


Some case studies: **'Perimeter' MR frame** **'Spatial' MR frame**



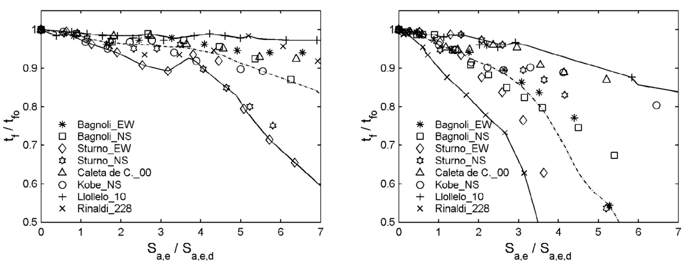
Fire resistance rating reduction vs. residual inter-story drift angle:

P-SLS frame system **S-SLS frame system**



Fire resistance rating reduction (damage level) vs. earthquake intensity:

P-SLS frame system **P-ULS frame system**



CONCLUSIONS

1. **In principle, a structure damaged by an earthquake has less fire resistance, but the importance of the reduction depends on many factors (design criteria, earthquake intensity, structural type, etc.). Research is needed to assess the significance of the reduction in typical cases and to eventually adopt countermeasures.**
2. **Some numerical investigation on the response of MR steel frames designed according to EC8 showed that residual IDRs are very well correlated with fire resistance rating reductions (but, in case of EPP hysteresis models, more research is needed).**
3. **For the investigated case studies, the fire resistance rating reductions resulted relatively small (<10%) at the design level of earthquake intensity, in case of P-MR frames satisfying the SLS or in case of S-MR frames. The reduction was often large in case of very rare earthquakes .**