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SECTION DE GÉNIE CIVIL

Seismic retrofit of existing steel concentrically braced frame with friction damper

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Introduction

Objectives

- Investigate the seismic behaviour of a Concentrically Braced Frames CBF structural system located in a moderate seismic zone by means of time-history non-linear analysis.
- Assess the pertinence and potential of a friction damped retrofit solution.

Motivation

- As they are economical, efficient to meet both strength and deformation restrictions, CBFs are commonly used as lateral-load resisting systems in steel buildings.
- More of 75 % of the Swiss dwelling building stock is not designed to resist seismic actions and therefore are very vulnerable in case of an earthquake. Even if the seismic hazard is low, the risk is high because of this great vulnerability and the associated cost in case of damages:

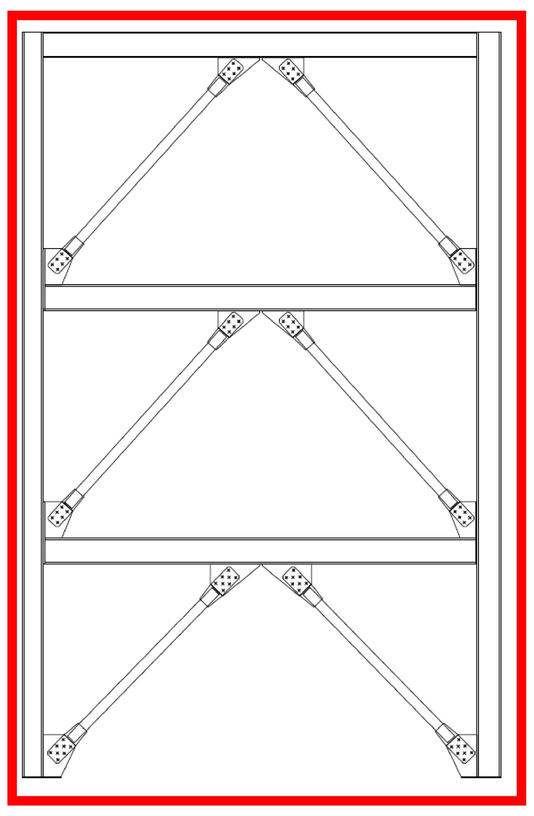
$$Seismic\ risk = Hazard * vulnerability * value$$

- Consequently, innovative approaches must fill the need for efficient and economic retrofitting. Novel approach using friction damper can be one solution.

Current state

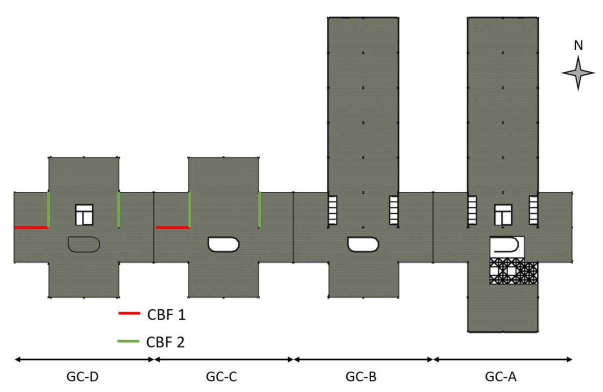
Studied structure: EPFL Civil Engineering (GC) building

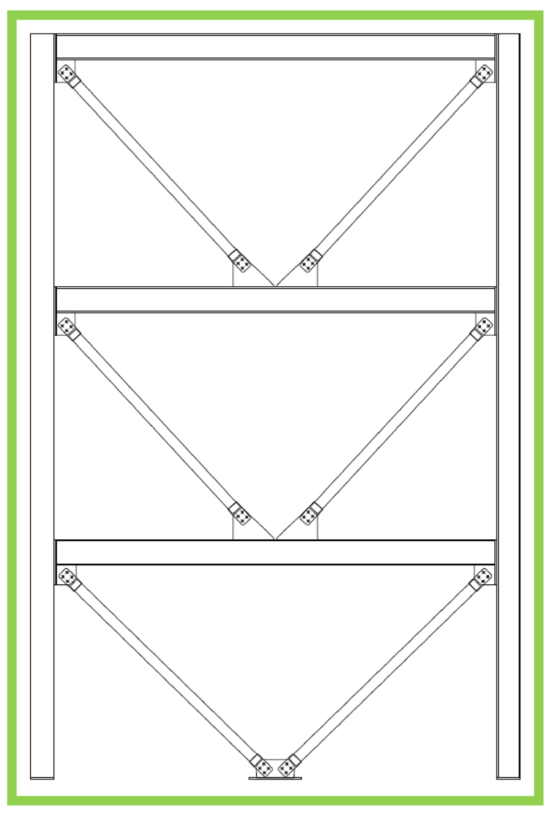
- Constructed between 1976 and 1982, before 1989 and introduction of the first seismic code in Switzerland
- The structure is a regular steel frame separated in four sub-building. Each one is separately stabilised.
- Past studies have shown several deficiencies, among other, in the brace connection systems. The bolts that connect the brace to the gusset plate are critical. But the main problem comes from the used single-sided splice connections. They imply an eccentricity that triggers a concentration of out-of-plane deformations. This response avoid the brace to behave correctly and lead to an early failure of the connection plates.



Two CBFS are selected according to their vulnerability as part of the GC building, their representativeness as steel structures and the reduction of parasitic effect to focus on the applicability assessment of the dampers.

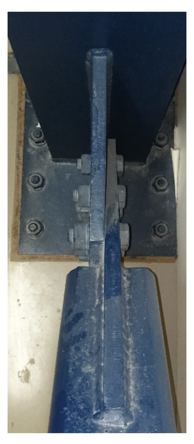
← CBF1 *CBF2 →*



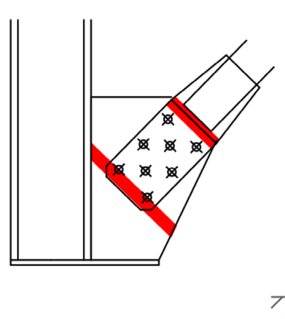


OPenSees models

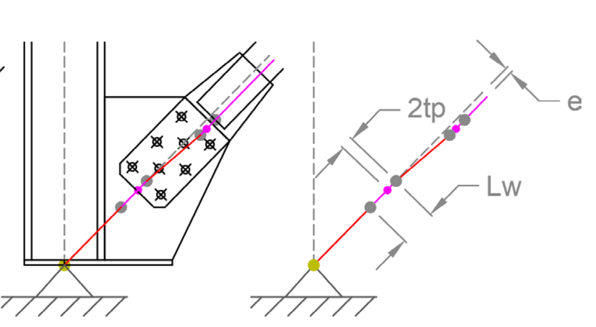
Typical connection



Expected failure mode

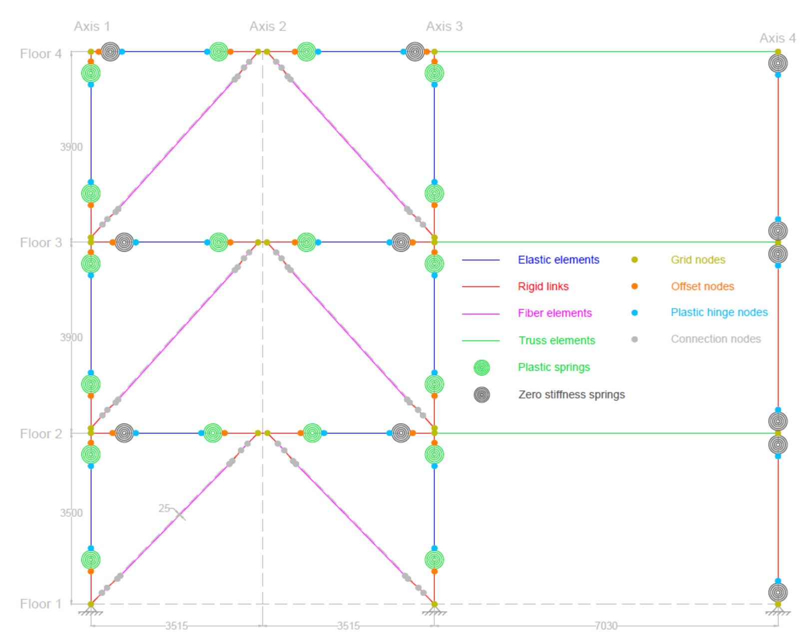


Numerical model

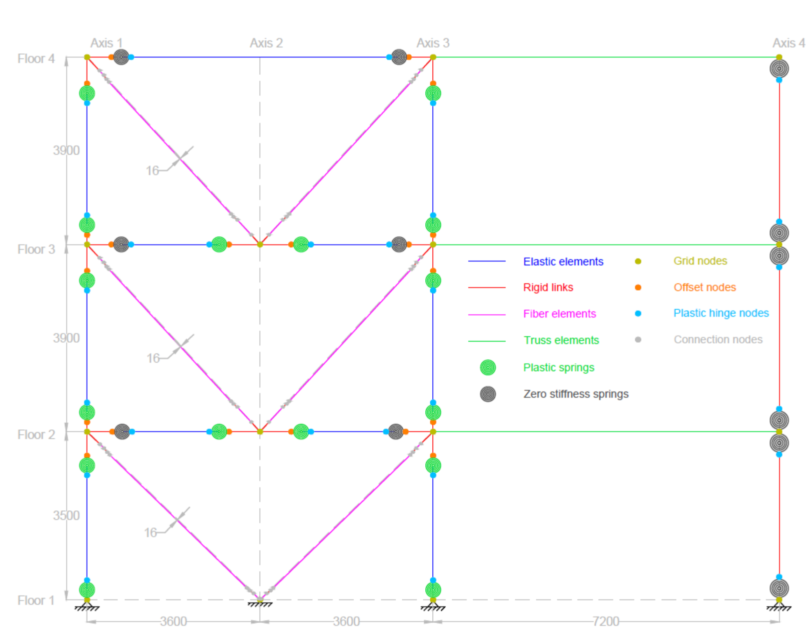


Fibre element	
Width	Whitmore width
Thickness	Plate thickness
Length	Buckling length
Steel material	Tri-linear relationship

CBF1



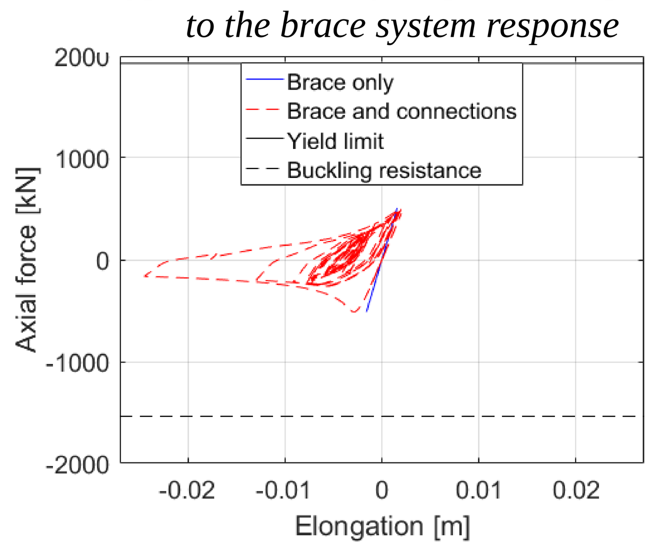
CBF2



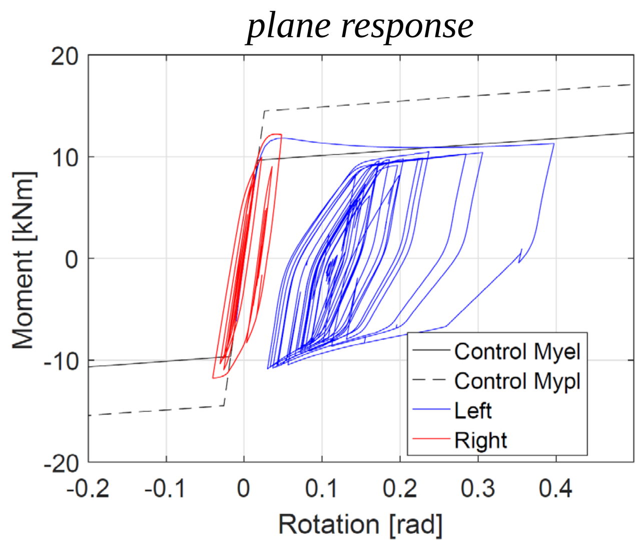
Results

- In both cases, the global collapse is avoided but the connection plates are damaged.
- The deformations are concentrated in the connections and therefore, the brace remains elastic. Moreover, the beams appear to be undersized and cannot support the unbalanced force of the braces.

Typical brace only response compared to the brace system response



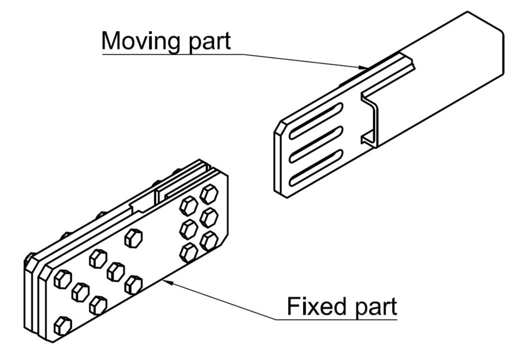
Typical connection plate out-of-plane response

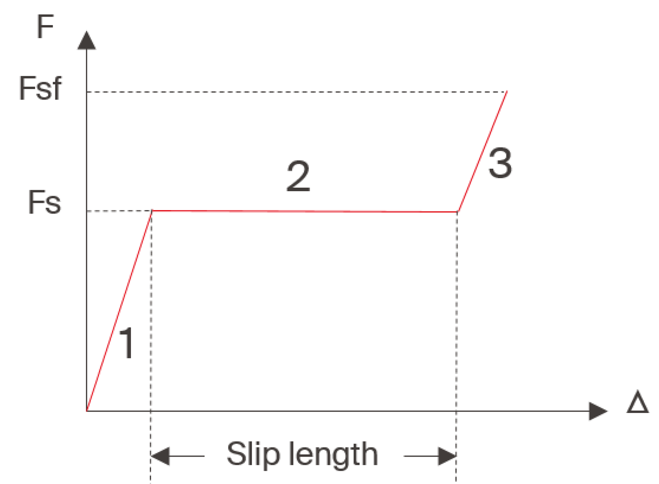


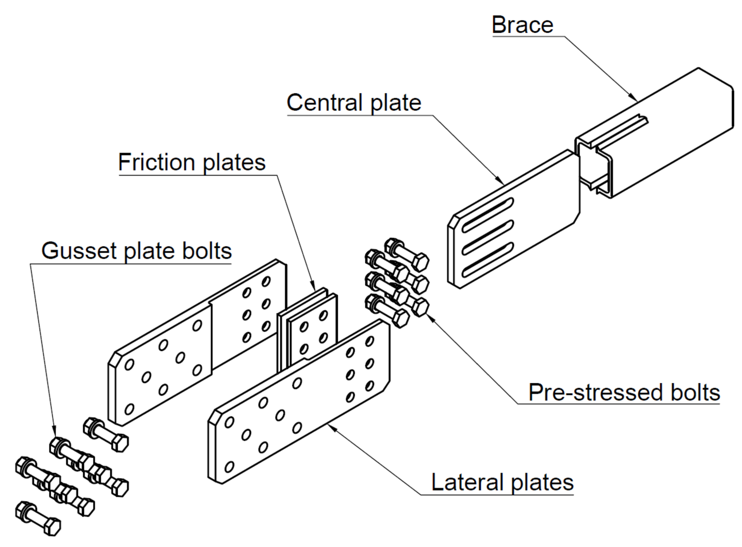
Seismic retrofit

Friction dampers

- Made of a series of steel and friction plates that can slide to dissipate the energy. These plates are clamped with pre-stressed bolts that allow to control the activation load (slip load). The damper is installed in-line with the brace and adapted to the existing elements.
- Function
  1. Until reaching the slip load: no displacement within the device, the system reacts elastically.
  2. The slip load is reached: the device start sliding and the axial load in the brace cannot increase.
  3. If the displacement capacity is reached: the bolts impact the end of the slotted holes and potentially fail in shear.







Goals

- Provide a structure that can:
  - Behave like a braced frame in service load condition
  - Increase its flexibility during major earthquakes and hence change its oscillation period to reduce the solicitations
  - Dissipate most of the energy though friction
- Avoid any damages of the members or at least delaying them.
- Provide a retrofit solution simple to implement and keep as much as possible existing elements.

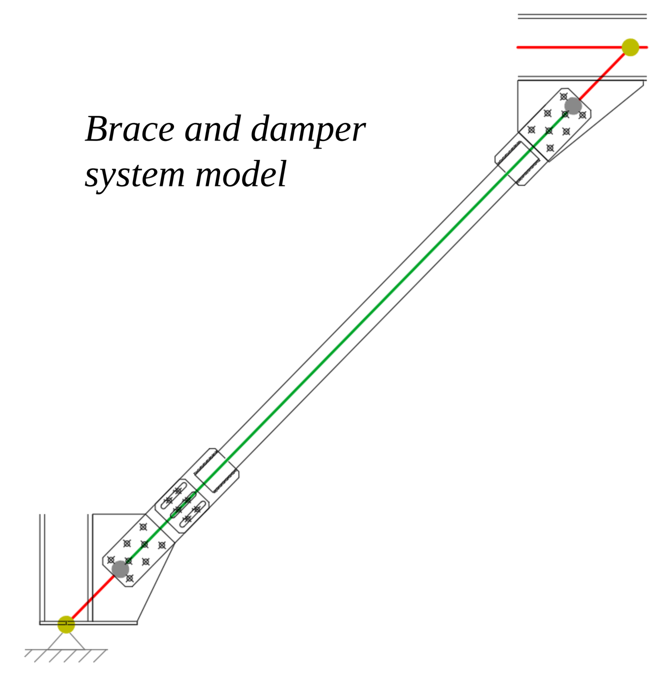
Design approach

1. Define the maximal and minimal allowable force in the brace.
2. Optimise the slip loads within these boundaries to:
   - Reduce the maximal experienced acceleration e
   - Reduce the maximal peak inter-storey drift
   - Reduce the maximal residual inter-storey drift
3. Design the devices according to the selected slip loads and associated slip lengths.

OPenSees models

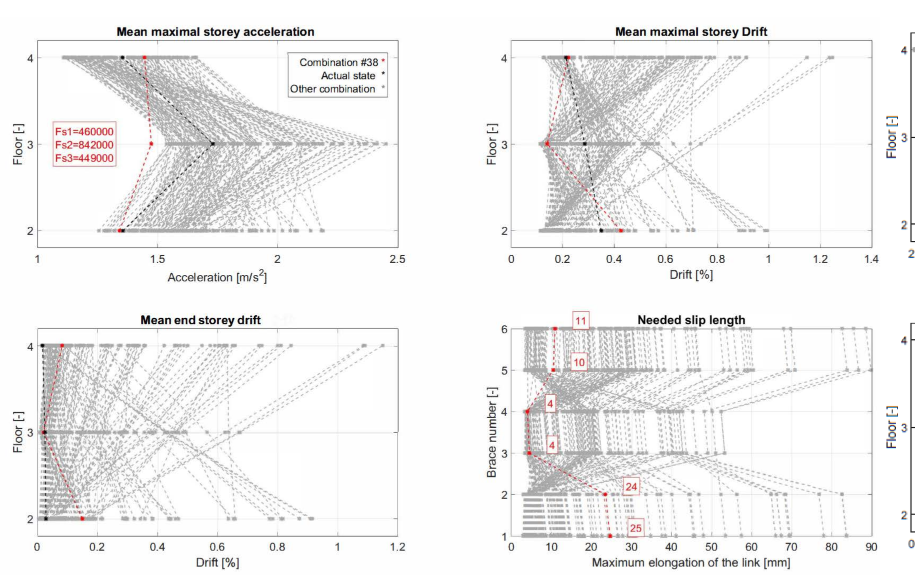
- The combined response of the brace and the damper is simulated with a truss element:
  - Directly attached to the rigid links
  - Provided with the total length and the cross-sectional area of the brace
  - Provide with a Menegotto-Pinto steel model whose yield strength is adapted to represent the slip force
- During the elastic phase, the link must simulate the stiffness provided by the brace but at the slip load the axial force reaches its limit and remains stable.
- The remaining elements are similar to the current state modelling.

Brace and damper system model

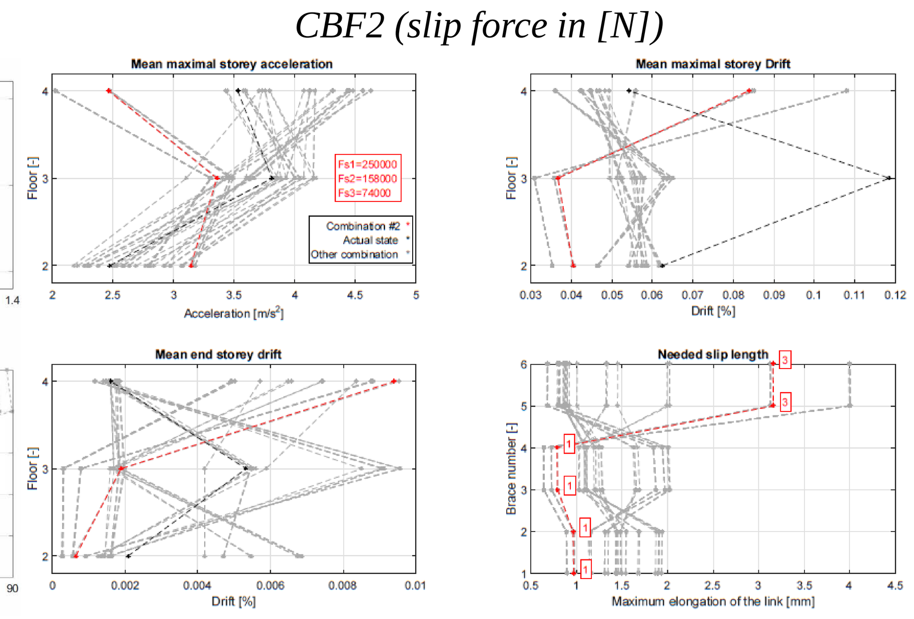


Selected slip forces and global response

CBF1 (slip force in [N])



CBF2 (slip force in [N])



Conclusion

- The new links can protect the structure and improve the global behaviour. The unwanted behaviour is changed for an effective friction dissipation, this should avoid the need of post-earthquake intervention.
- The intervention process is simplified compared to a classical retrofit. As the new link can be assembled in the shop and quickly bolted to replace the existing elements.
- The dampers are able to accommodate mush stronger seismic events. The only thing to do is to change the slot length, the slip load can remain the same.