1. Introduction

The present thesis deals with the pre-qualified friction joint, products of the FREEDAM and FREEDAM+ projects, funded by the *Research Fund for Coal & Steel* (RFCS), a research program managed by the European Commission. The **purpose** of this thesis is the evaluation of the behaviour of these joints, installed in a multi-storey demonstration building, which will be built within a new project, DREAMERS, also funded by RFCS. Regarding the **methodology**, these joints were studied through finite element parametric analyses, with the aim of investigating and optimizing their performance under seismic and column loss conditions.

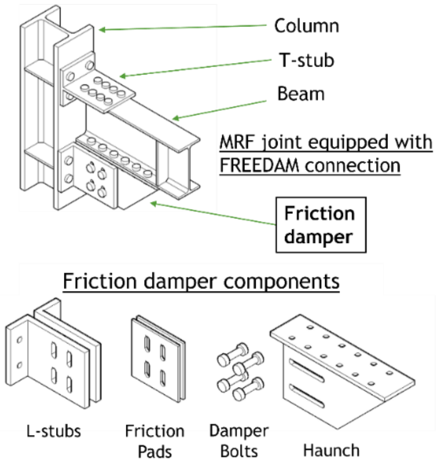


Fig 1: FREEDAM connection and its components

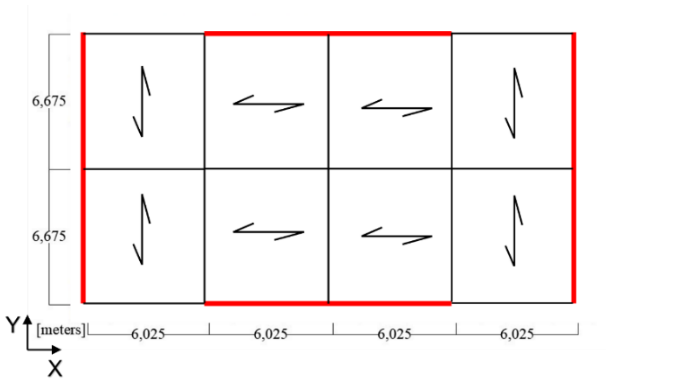


Fig 2: Plan view of the DREAMERS building; MRFs are highlighted in red

The joints equipped with FREEDAM connections are able to withstand destructive earthquakes without the connected structural elements, beam and column, being damaged. These joints fall into the category of *Sliding Hinge Joints* (SHJ), with *Symmetric Friction Connection* (SFC). The energy dissipation occurs through sliding friction between the friction pads, the L-stubs and the haunch. The friction in question is of the dynamic type, and the components of the Device are provided with slotted holes, to allow a certain relative displacement between the components.

All joints of the moment resistant frames (MRF) of the DREAMERS demonstration building will be equipped with such FREEDAM connections.

2. Numerical analysis

2.1. Modelling assumptions

There are 5 different FREEDAM Devices, which can be equipped on a given range of beam/column profiles. These devices differ from each other in the geometric dimensions of the components and the number of bolts used. In the FREEDAM manual there is a table with the pre-qualification limits of the friction joints, which supplies the device to be used according to the profile of the connected beam and the corresponding bending capacity level (i.e. the ratio between the connection resistance and the plastic resistance of the beam).

In the DREAMERS building these two Devices will be used: D1 and D2A.

Beam Size	m (Bending Capacity Level)			
	0.3	0.4	0.5	0.6
IPE 270			D1	D1
IPE 300		D1	D1	D1
IPE 360	D1	D1	D2	D2
IPE 400	D1	D2	D2	D2
IPE 450	D1	D2	D2	D3
IPE 500	D2	D2	D3	D3
IPE 550	D2	D3	D3	D4
IPE 600	D2	D3	D4	D4
IPE 750 x 147	D3	D4	D5	D5
IPE 750 x 161	D3	D4	D5	D5
IPE 750 x 173*	D3	D4	D5	D5
IPE 750 x 185	D4	D5	D5	D5

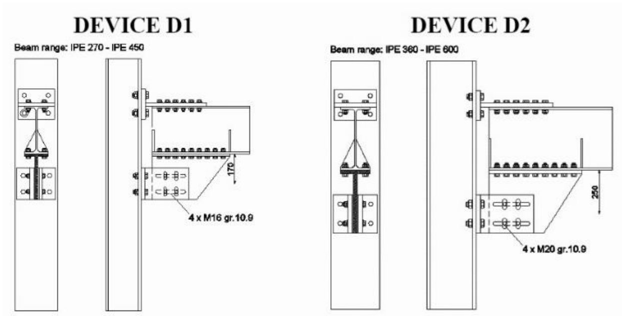


Fig 3: Prequalification table for the FREEDAM devices (left); FREEDAM devices to be used in the DREAMERS building (right)

The DREAMERS building has plan dimensions of 15 m x 25 m, 4 bays along X and 4 along Y, 3 floors for a total height of about 12 metres. In the elevation views, the MRF spans are indicated in red.

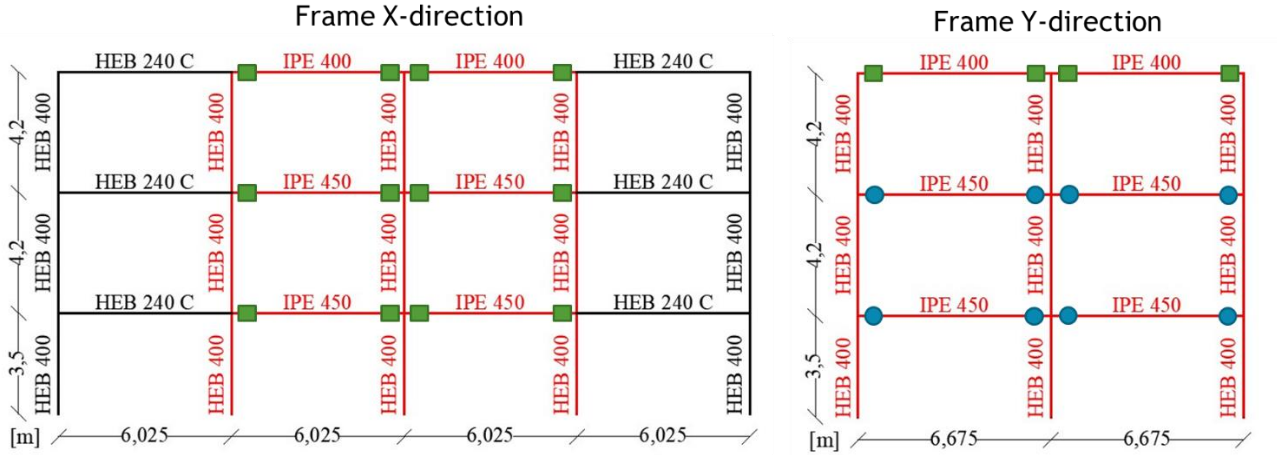


Fig 4: 2D view of the MRFs in both principal direction -X and -Y of the building

Name	Device	Column	Beam	$F_{p,C}^{d}$ [kN]	$f = F_{p,C}^{d} / F_{p,C}^{EC3}$ [-]	h_s [mm]
X-III-TJ	D1-0.3	HEB400	IPE400	57,59	0,52	570
X-III-XJ	D1-0.3	HEB400	IPE400	57,59	0,52	570
X-II-TJ	D1-0.3	HEB400	IPE450	68,96	0,63	620
X-II-XJ	D1-0.3	HEB400	IPE450	68,96	0,63	620
Y-III-TJ	D1-0.3	HEB400	IPE400	57,59	0,52	570
Y-III-XJ	D1-0.3	HEB400	IPE400	57,59	0,52	570
Y-II-TJ	D2A-0.4	HEB400	IPE450	81,43	0,47	700
Y-II-XJ	D2A-0.4	HEB400	IPE450	81,43	0,47	700

Fig 5: Overview of the analysed joints

The FE modeling was done at the sub-structure level, modeling the joint assemblies belonging to the seismic-resistant frames, with reference to the boundary conditions given by the different load scenarios investigated: seismic or robustness. The studied joints are in two configurations: external joint (T-joint) and internal joint (X-joint). Quasi-static analyses were performed. The material has been modeled with engineered curves (true stress-true strain curves, obtained from tensile tests). Geometric and material non-linearities have been taken into account.

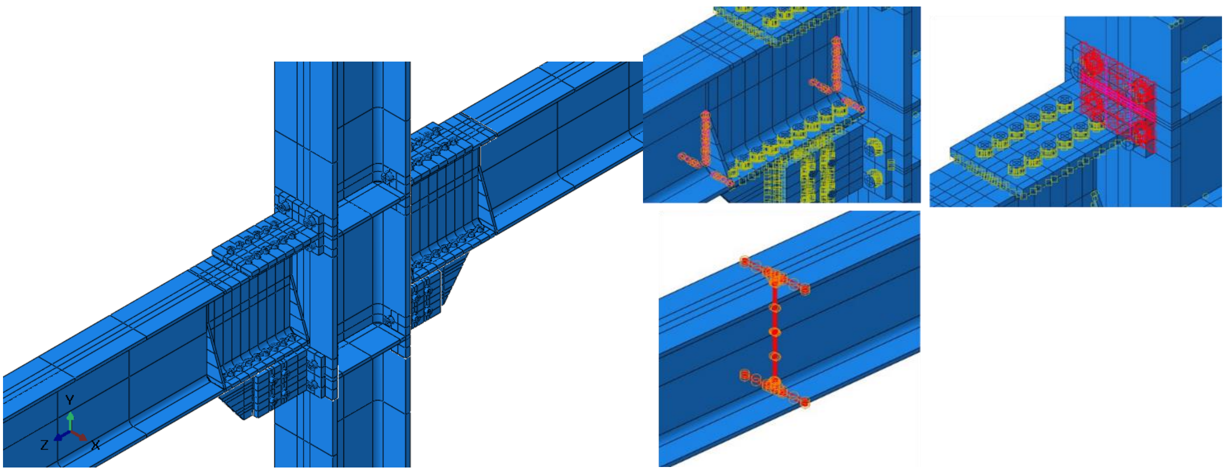


Fig 6: X-joint as modelled in the FE software (left), interactions, rigid body constraints, tie costraints (right, clockwise)

Several analyses were carried out, which required specific boundary conditions:

- Seismic Scenario: Monotonic Loading with negative moment, Monotonic Loading with positive moment, Cyclic Loading
- Robustness Scenario: Loss of Column with negative moment, Loss of Column with positive moment

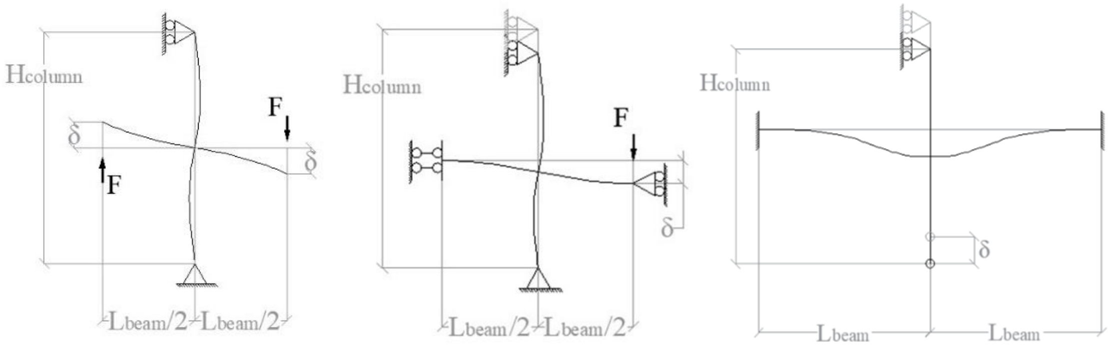
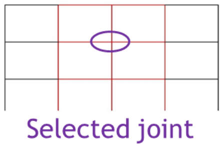


Fig 7: Boundary conditions of each Scenario: Seismic Scenario (left), Column Loss with hogging bending moment (middle), Column Loss with sagging bending moment (right)

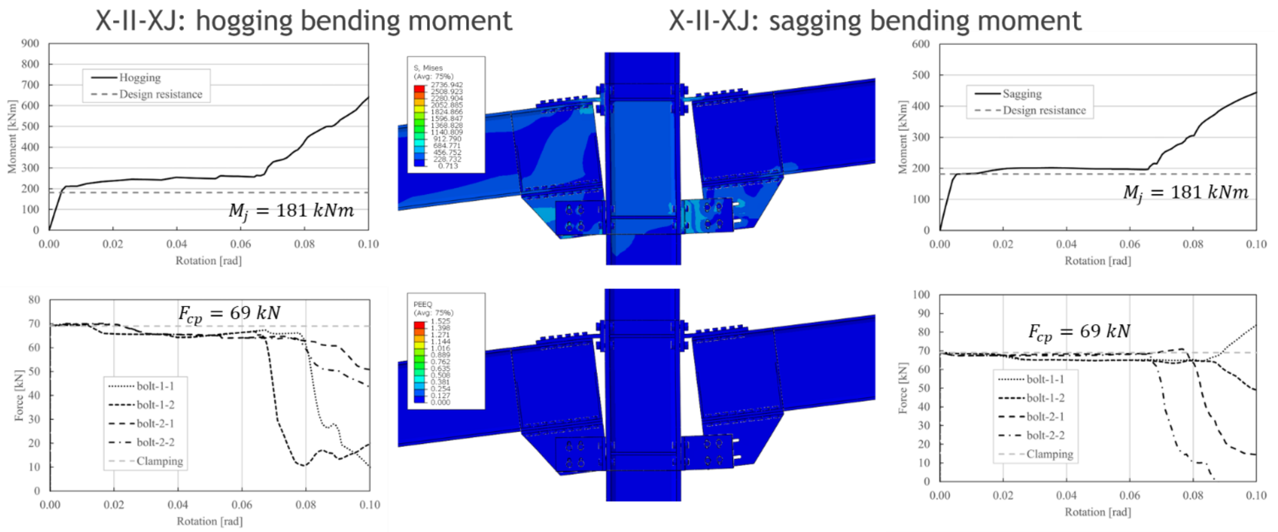
2.2. Results



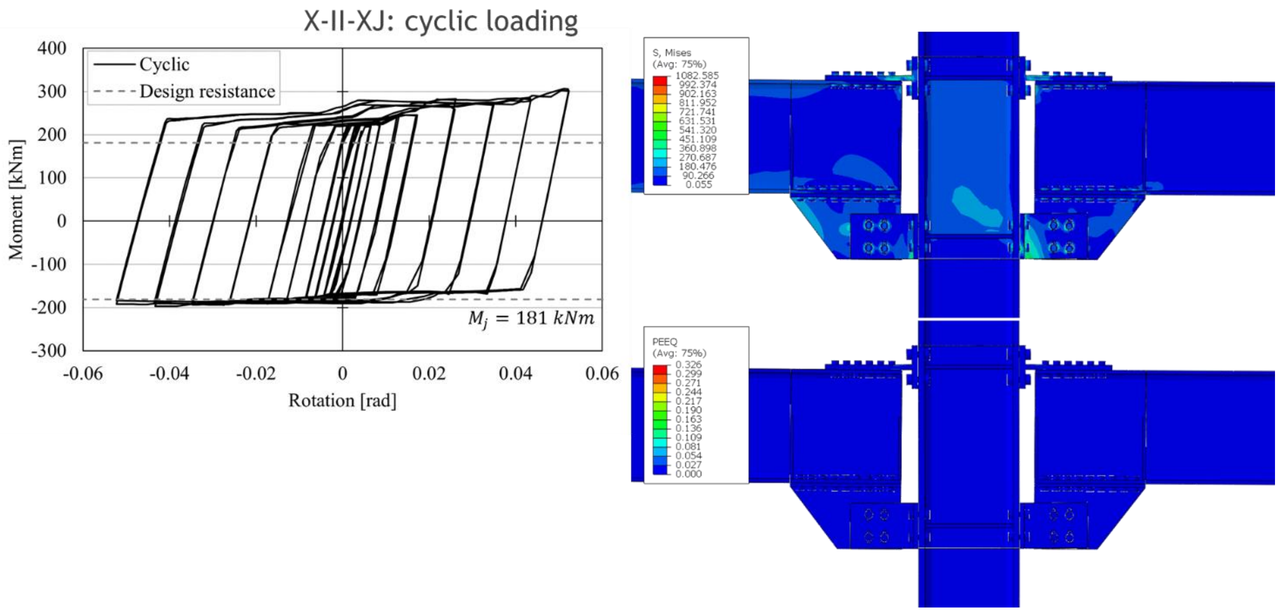
With reference to the joint X-II-XJ, X-joint at the second floor, belonging to the seismic-resistant frame in the X direction.

2.2.1. Phase 1: joint as-it-is

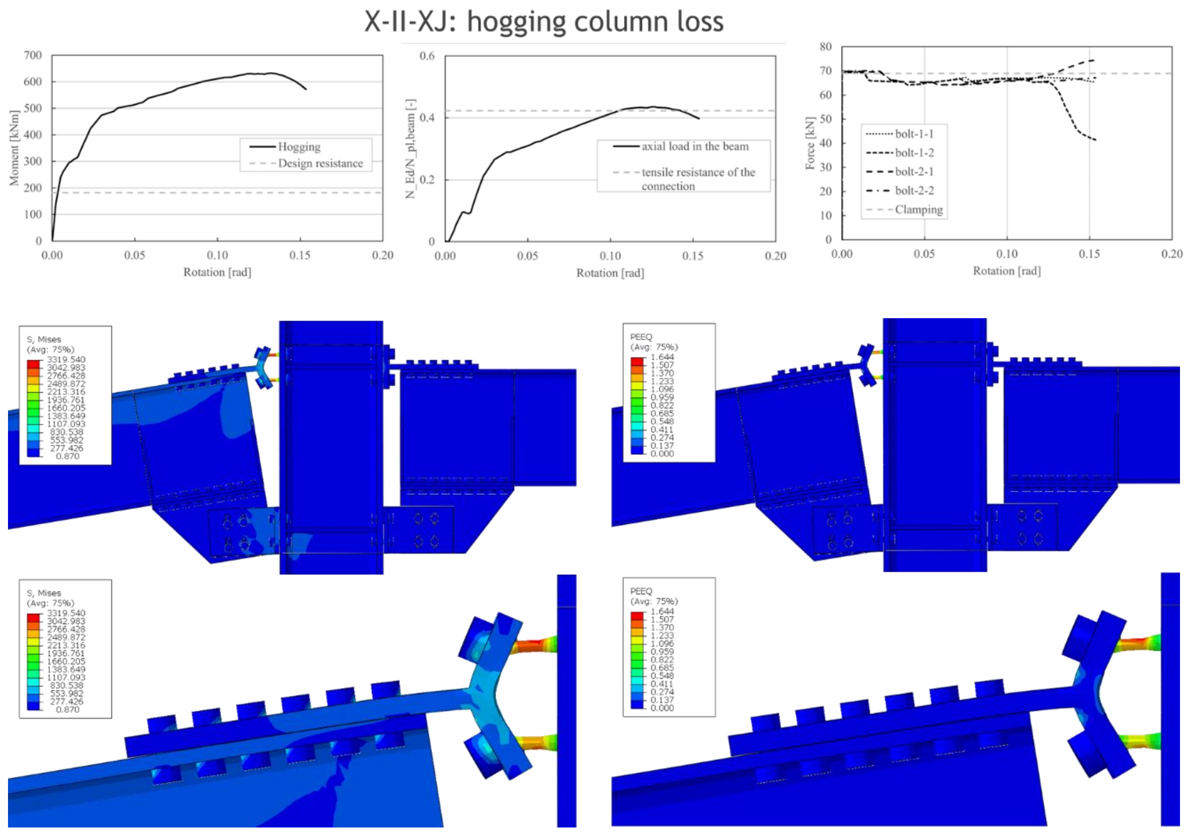
Monotonic Loading: stable response of the joint up to 0.06 rad, close to the resistance of the connection. After this threshold, an increase in stiffness is observed on the moment-rotation diagram: the shank of the bolts of the Device has come into contact with the slotted holes of the haunch. Up to this threshold of 0.06 rad, the bolts of the Device maintain their tightening.



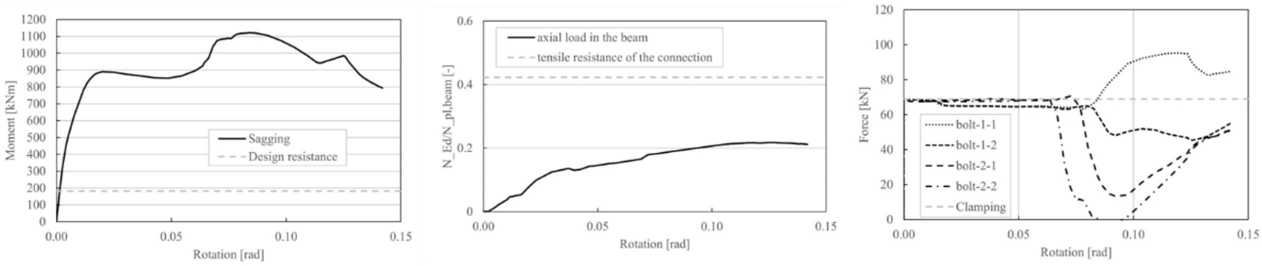
The **cyclic response** of the joint is characterized by regular and equal-shaped hysteretic cycles. The maximum rotation reached is 0.05 radians.

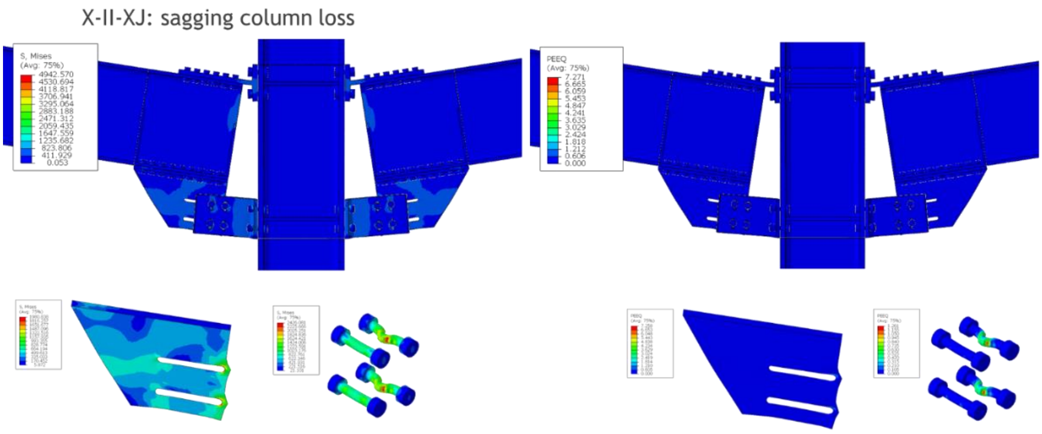


In case of **negative Moment induced by Column Loss** the catenary action on the joint can be observed (diagram in the middle). It is immediate to notice that the upper T-stub undergoes a mode-2 crisis, with partial plasticization of the flange and breakage of the shank of the four connecting bolts (2 bolts per row). Therefore, it was necessary to redesign the T-stub, to guarantee a more ductile failure type and a higher rotational capacity.

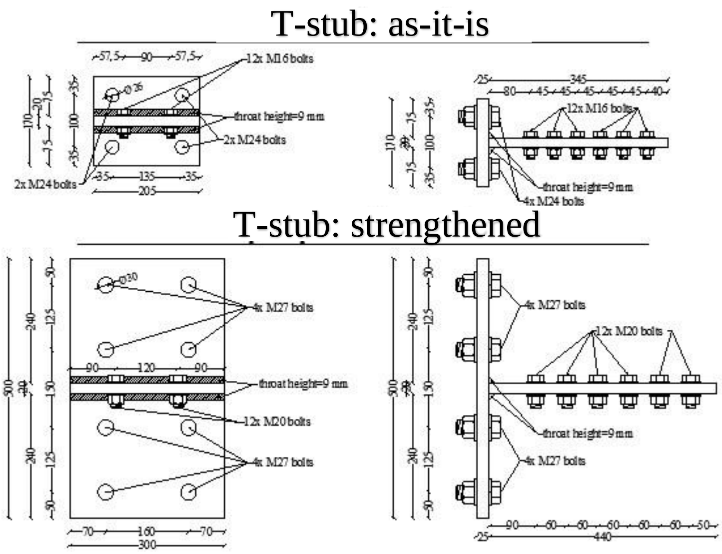


In case of **Positive Moment induced by Column Loss** the situation is analogous, the failure is localized in the shank of the damper bolts, when they come into contact with the stiffening plate.





2.2.2. Phase 2: strengthened joint



The detail of the T-stub is reported, as per the FREEDAM manual (above) and in an improved version (below). From the simulations it was possible to estimate the design value of the tensile force acting on the T-stub in 0.4 times the plastic resistance of the connected beam:

$$N_{Ed} = 0.4 N_{pl,Rd,beam}$$

Therefore, in order to improve the performance of the joint under Column Loss, the following modifications have been made to the upper T-stub: enlargement of the flange and web of the T-stub, increase of the number and diameter of the bolts (now we have four rows of bolts).

Proposed modifications:

- T-stub flange
  - Base: 300 mm instead than 205 mm
  - Height: 500 mm instead than 170 mm
- T-stub web
  - Base: 300 mm instead than 205 mm
  - Length: 440 mm instead than 345 mm
- Flange bolts
  - 8x M27 bolts instead than 4x M24 bolts
- Web bolts
  - M20 bolts instead than M16 bolts (same quantity equal to 12)

It has to be noted that the thickness of flange and web weren't modified.

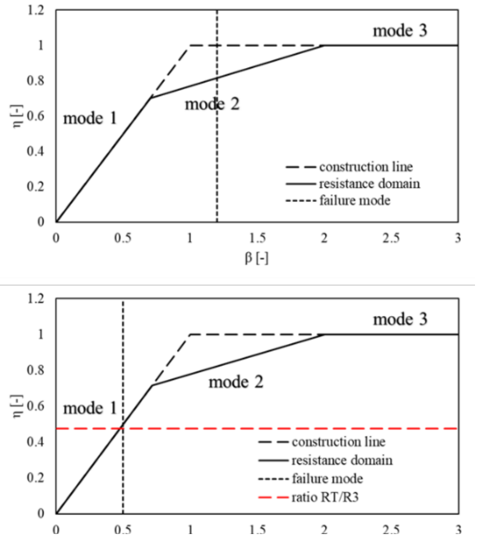
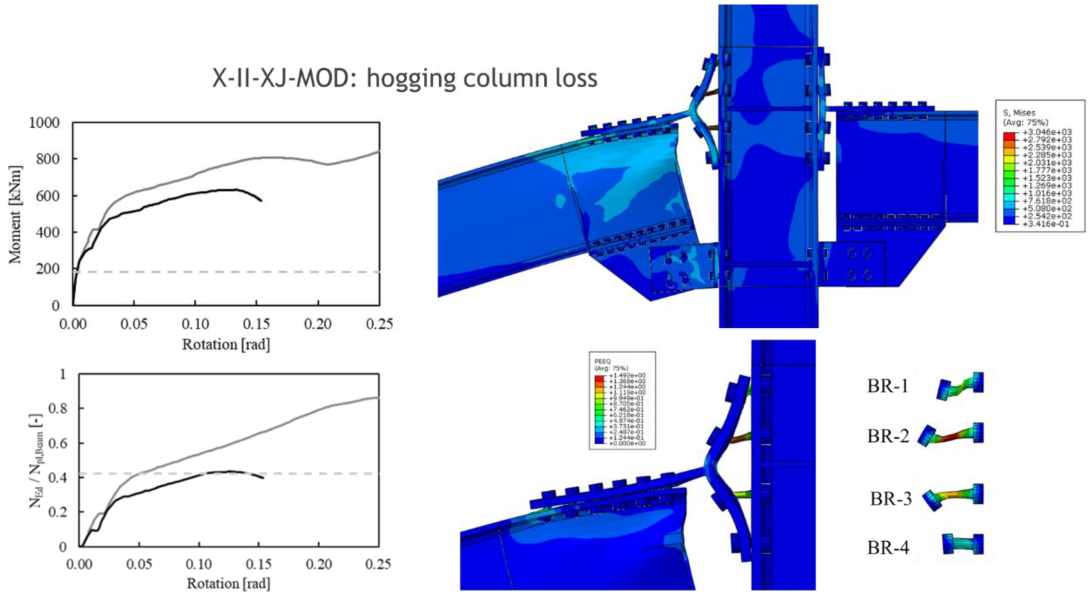
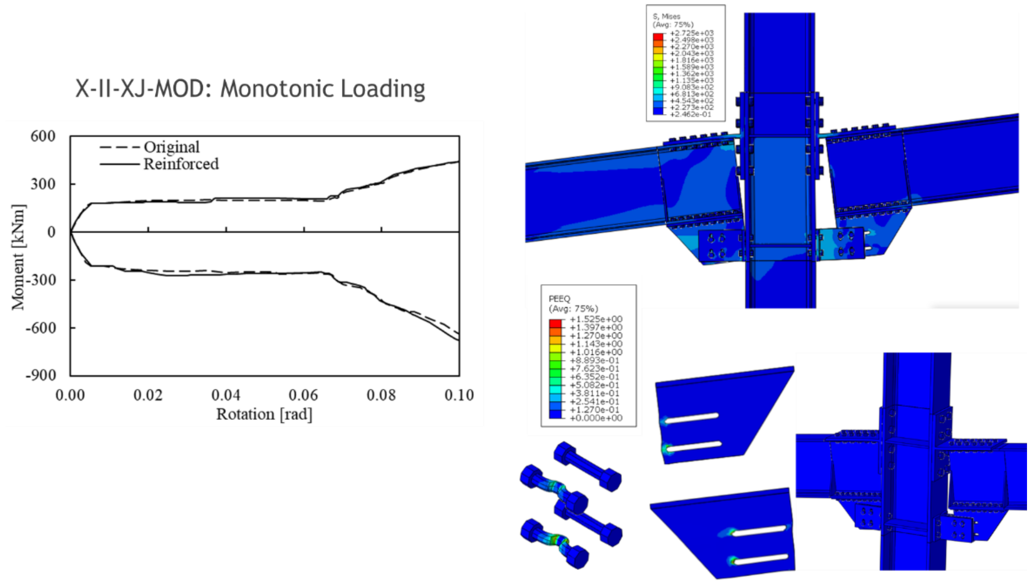


Fig 8: Resistance domains of the T-stub: before (up) and after the proposed modification (down)

In case of **Negative Momentum induced by Column Loss**, a great improvement is noticed thanks to the use of the modified T-stub; in fact, observing the moment-rotation diagram, the modified joint (in gray in the diagram) reaches considerably higher rotations, in the order of 0.25 radians, and presents a ductile failure: in fact, bolts of the T-stub close to the web fail, while those placed away from the web still possess residual resistance.



The reinforced joint has the same seismic behaviour as the original joint; therefore, all considerations made about FREEDAM joints previously are still valid.



3. Conclusions

- FREEDAM connections show an excellent seismic response and will be used in the DREAMERS building.
- However, such joints do not perform adequately under column loss, resulting in brittle failure of the upper T-stub.
- The modified joint manages to achieve a rotation of 0.25 radians, satisfying the demands in terms of rotational capacity under the Loss of Column scenario.
- Further studies are needed to investigate the column loss behavior of the three-dimensional joint, evaluating the influences of transverse beams and slabs.

4. References

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