

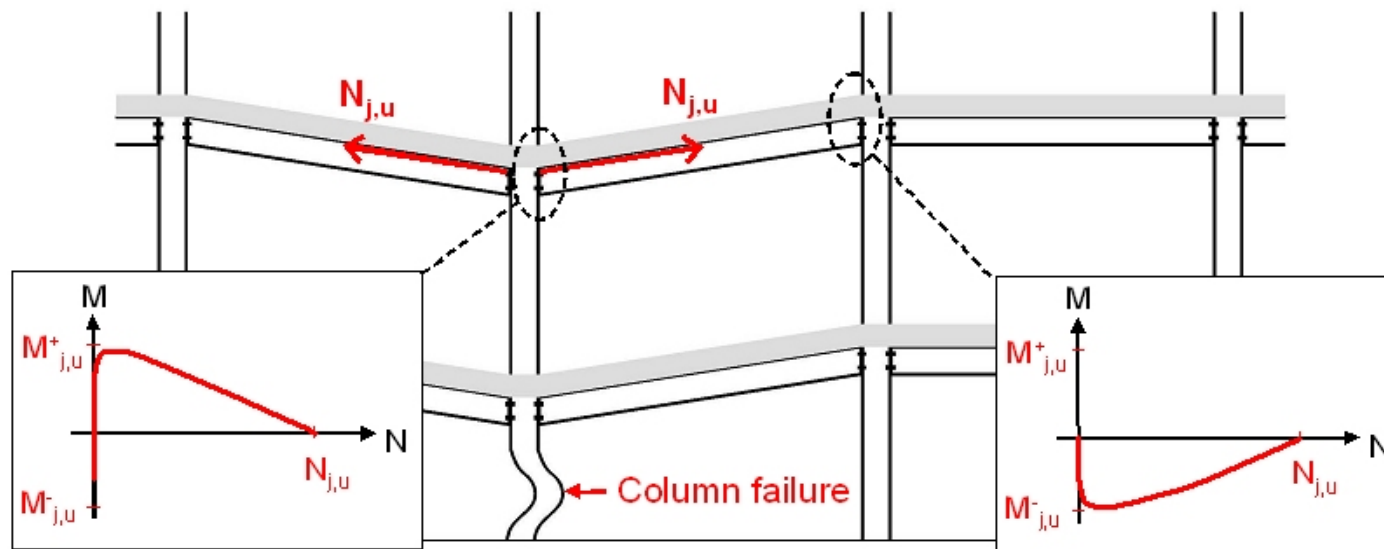
COST ACTION TU0601

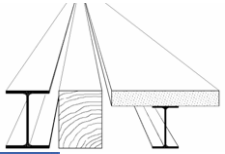
Robustness of Structures

Workshop Zürich 04./05. February 2008

Redundant and Robust Structures by Joint Ductility

Prof. Dr.-Ing. Ulrike Kuhlmann, Lars Rölle

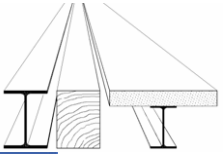




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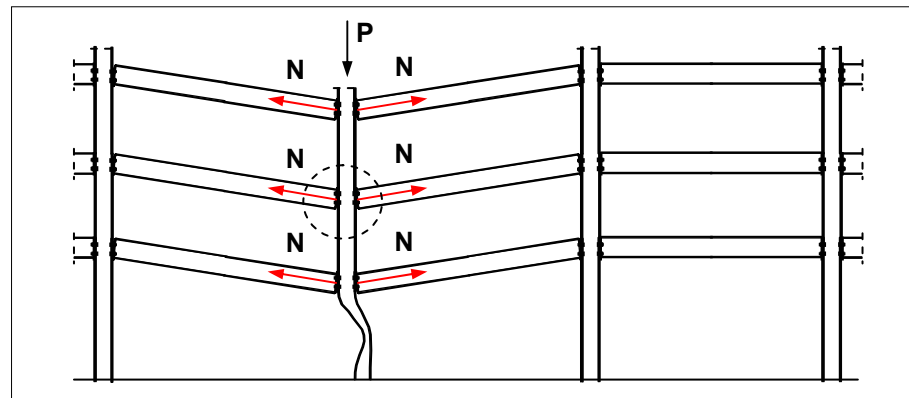
- 1 - Objectives of the RFCS-project „ROBUSTNESS“
- 2 - Different strategies to achieve robustness
- 3 - Simulation of the event „loss of a column“
- 4 - Composite joint tests under biaxial loading
- 5 - Ductile joints for redundant frame structures

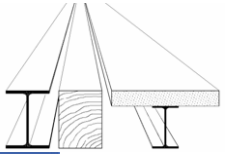




Objectives of the RFCS-project ROBUSTNESS

- Prevent *progressive collapse* caused by local damage
- Create *redundant frame structures* allowing for moment and force redistribution
 - ⇒ by developing new *ductile joints solutions*



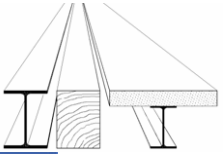


RFCS - research project Robust structures by joint ductility

Partners:

- Universität of **Stuttgart** – Institute of Structural Design (Coordinator), Germany
- Université de **Liège** - Département de mécanique des matériaux et structures, Belgium
- **PROFILARBED**-Research
- Product Department, Luxembourg
- **PSP** – Technologien GmbH, Germany
- Università degli Studi di **Trento**
- Dipartimento di Ingegneria Meccanica e Strutturale
Laboratorio Prove Materiali e Strutture, Italy

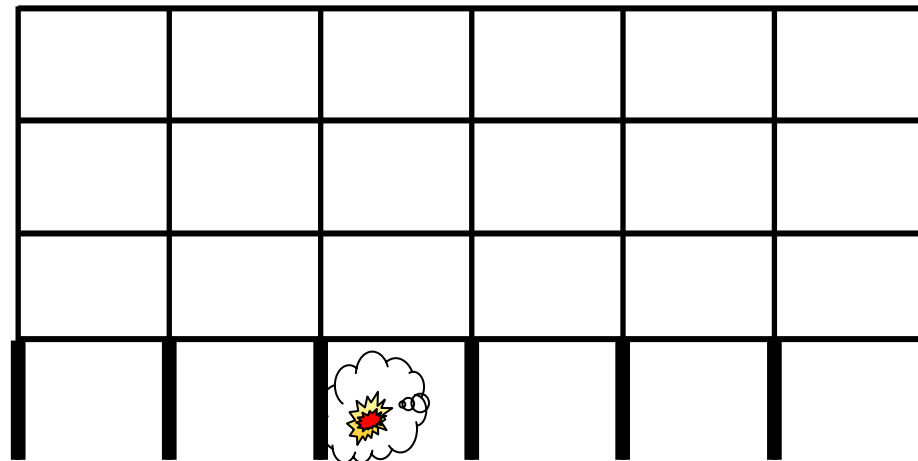




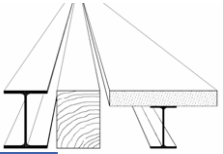
Different strategies to achieve robustness

- *Direct Design Methods:*

Specific local resistance



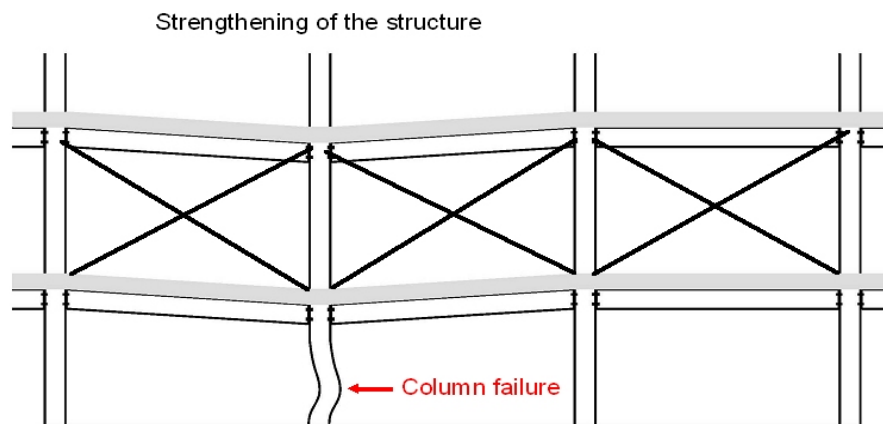
providing specific local resistance to key-elements



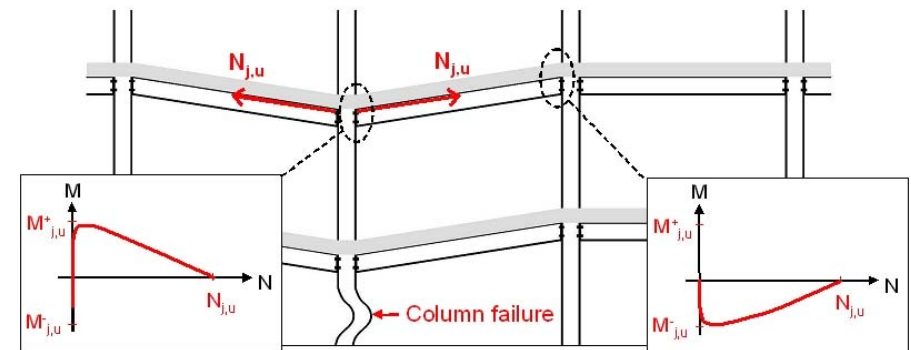
Different strategies to achieve robustness

- *Direct Design Methods:*

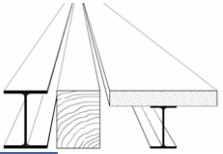
Alternate load path method



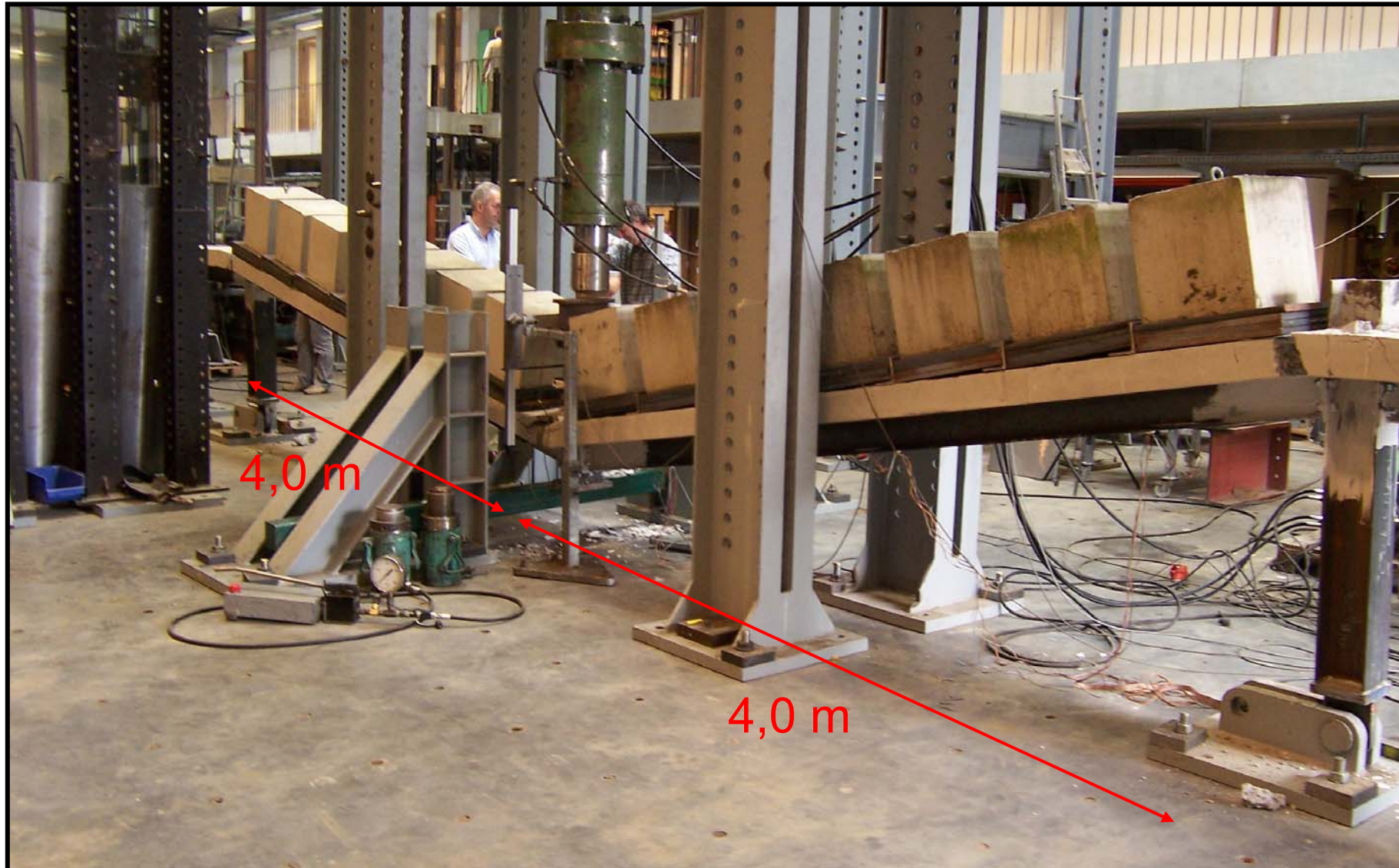
strengthening of one/more floors



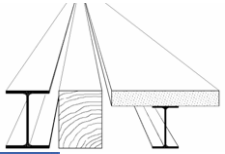
redistribution of loading by joints with
sufficient ductile behaviour



Simulation of the event “Loss of a column”

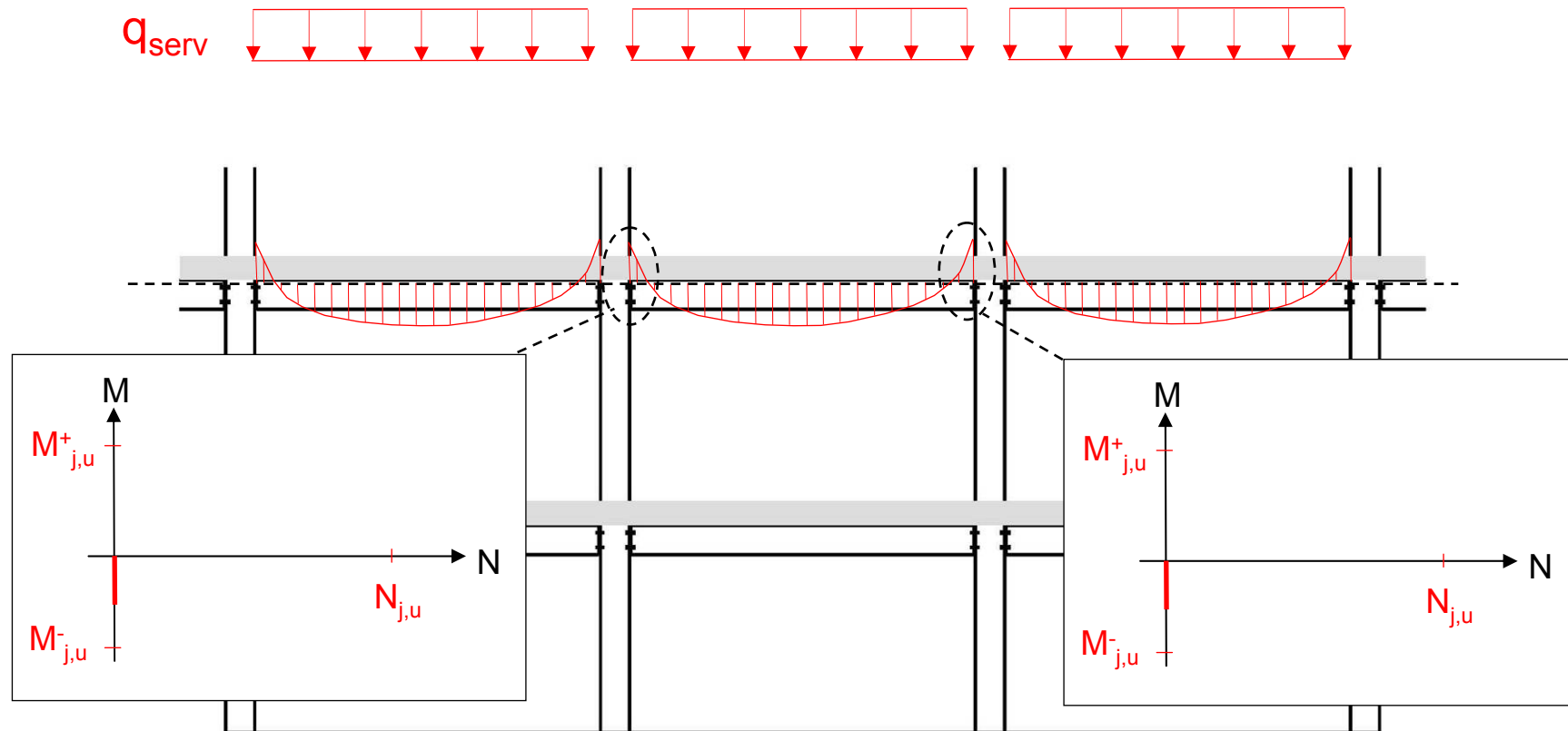


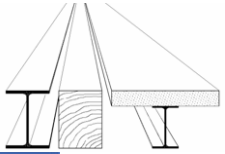
[Substructure tests in Liège within RFCS-project „Robustness“]



Simulation of the event “Loss of a column”

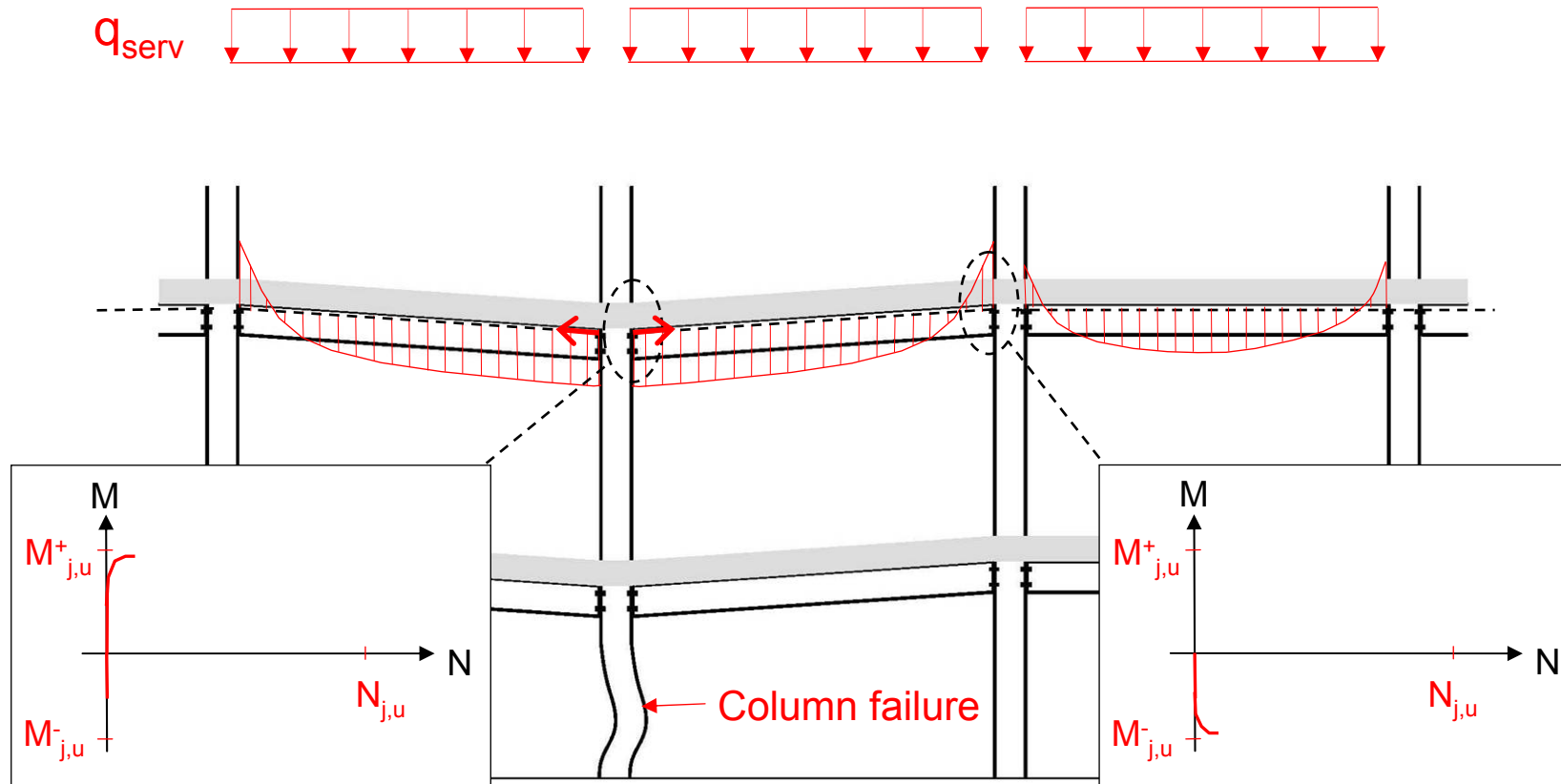
Load path example: Stage I - service condition -

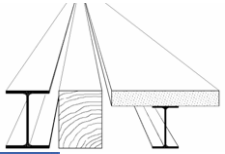




Simulation of the event “Loss of a column“

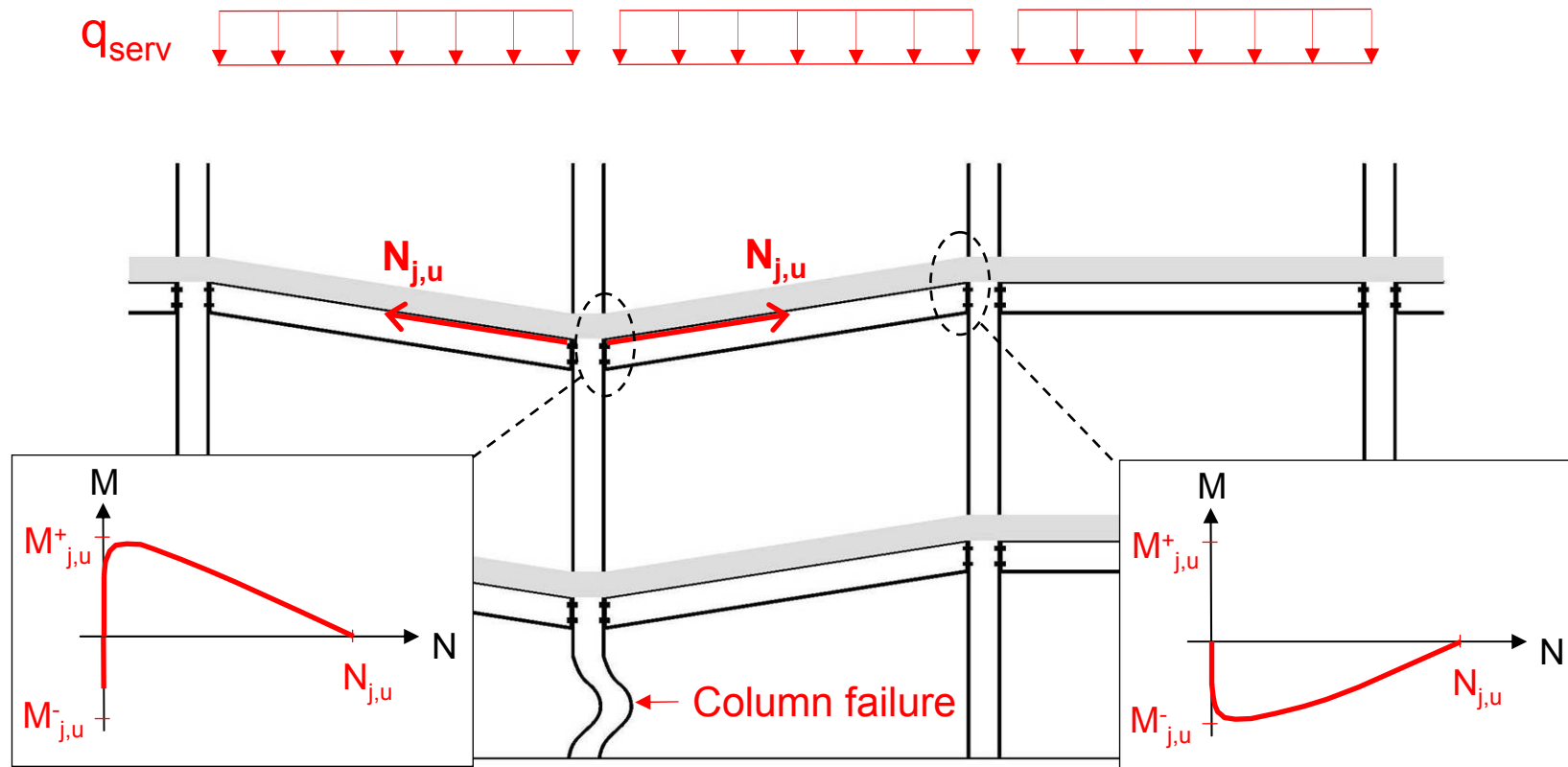
Load path example: Stage II - column failure -

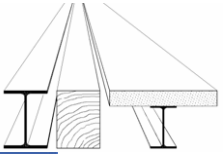




Simulation of the event “Loss of a column”

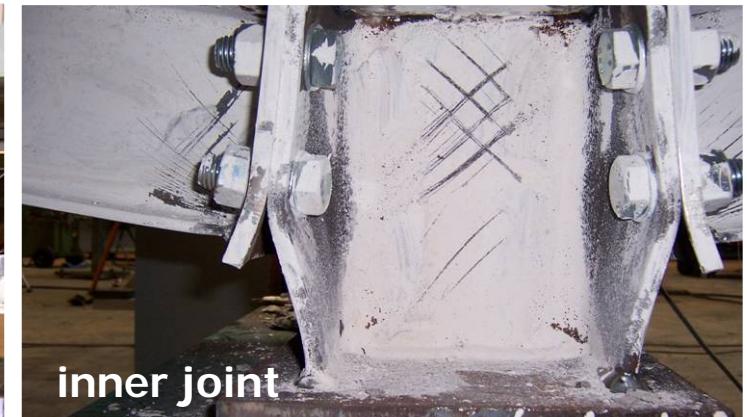
Load path example: Stage III - membrane effect -



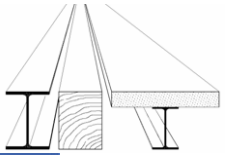


Simulation of the event “Loss of a column”

Ductile joints with membrane forces allow for redistribution

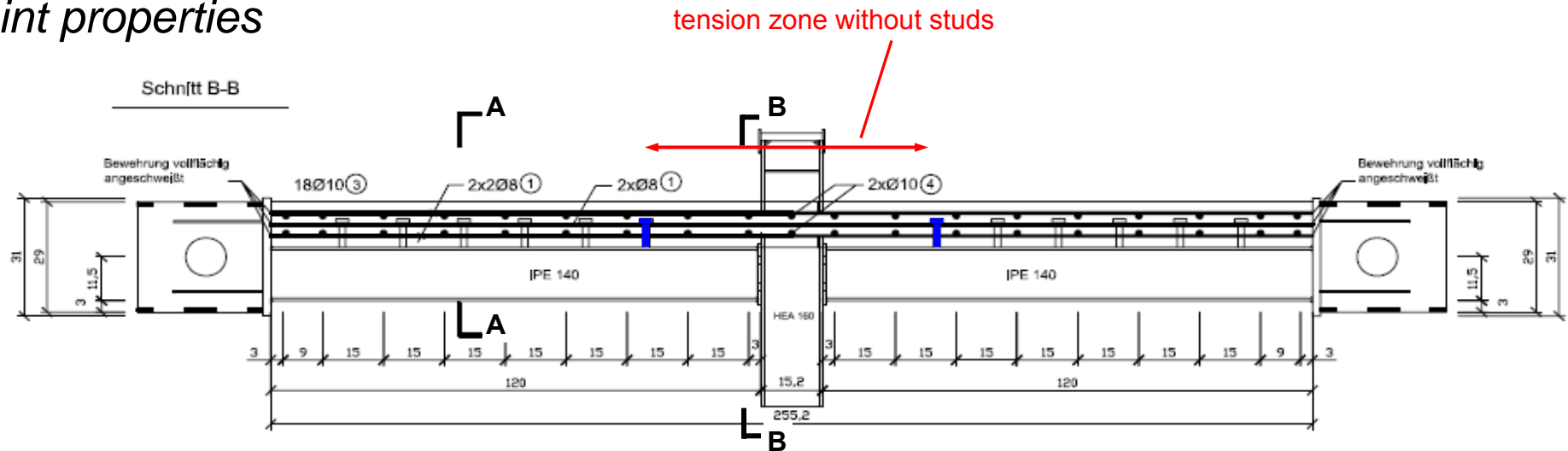


[Substructure tests in Liège within RFCS-project „Robustness“]

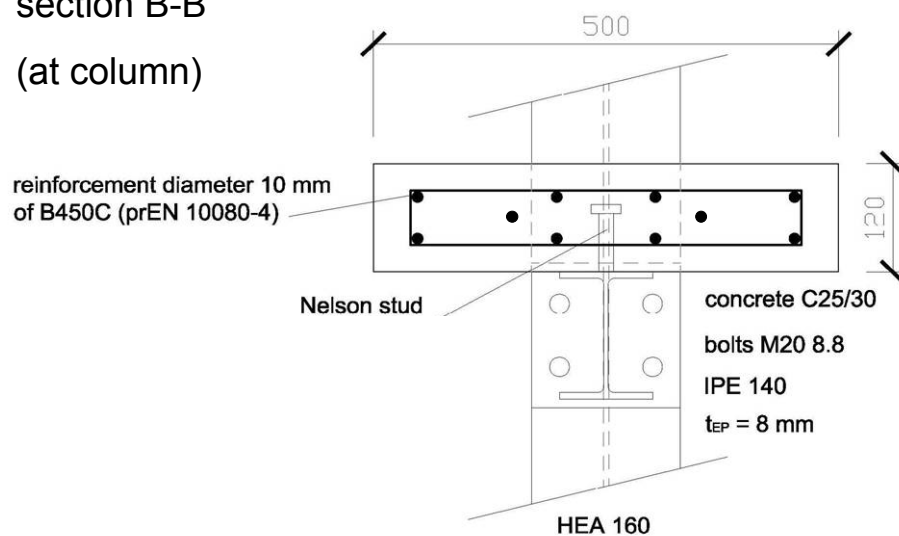


Composite joint tests under biaxial loading

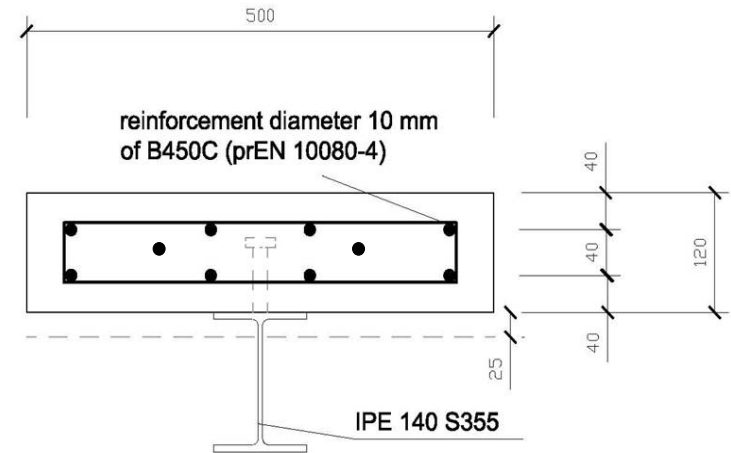
Joint properties

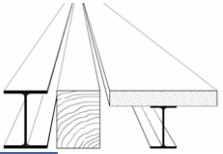


section B-B
(at column)



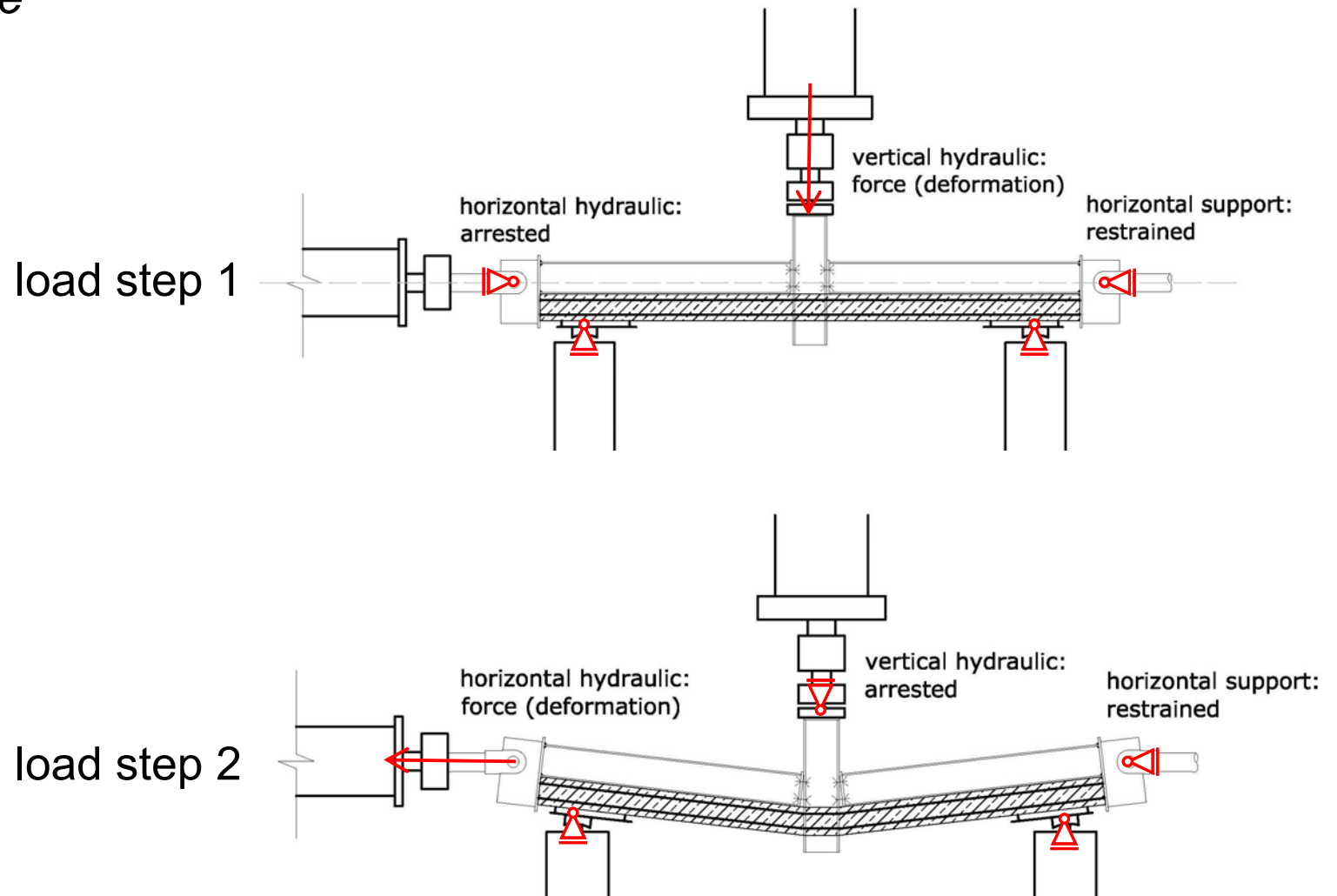
section A-A
(in span)

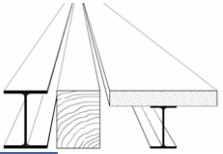




Composite joint tests under biaxial loading

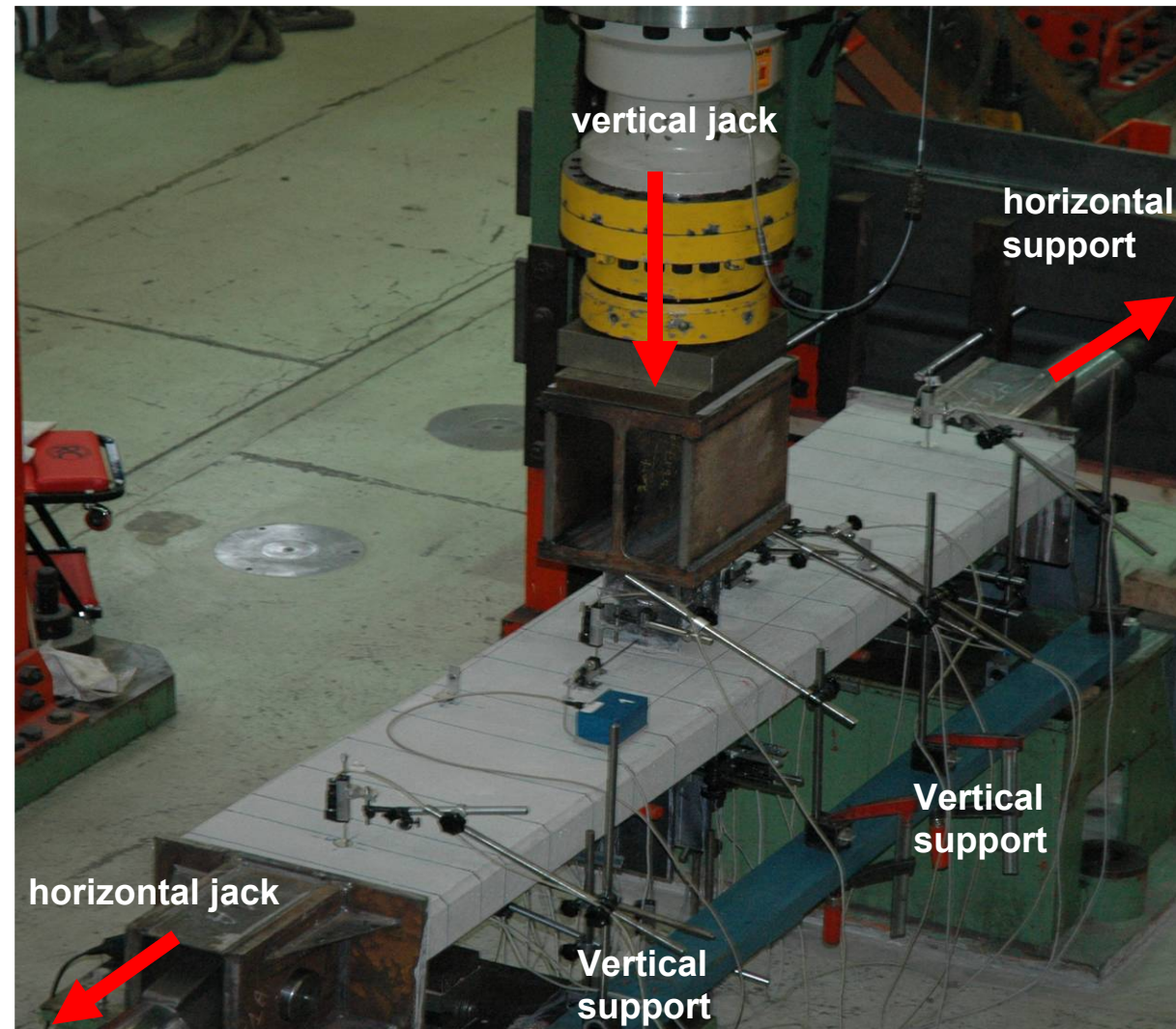
Test procedure

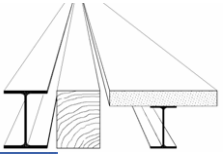




Composite joint tests under biaxial loading

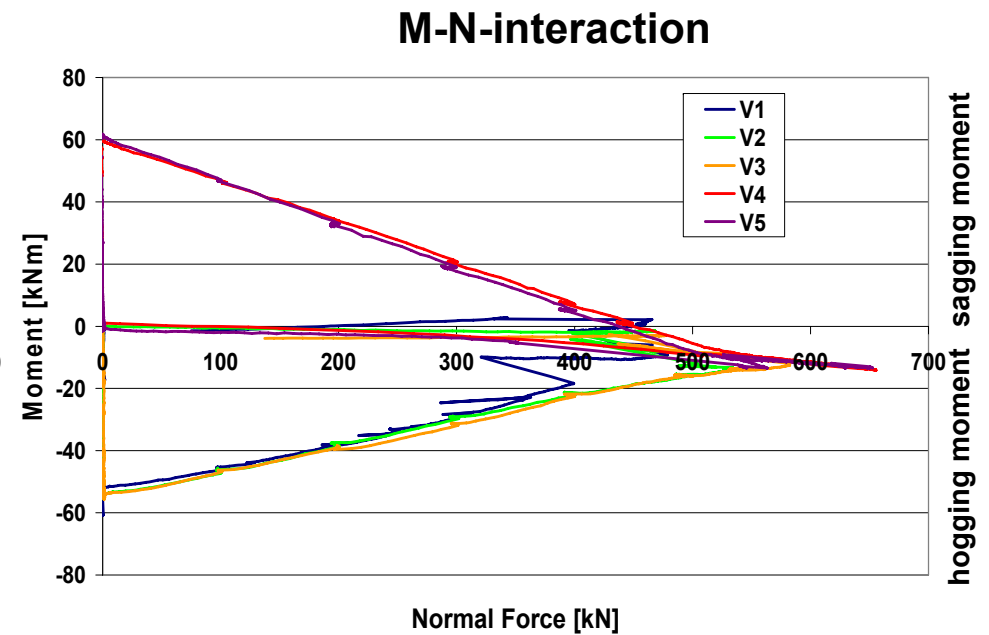
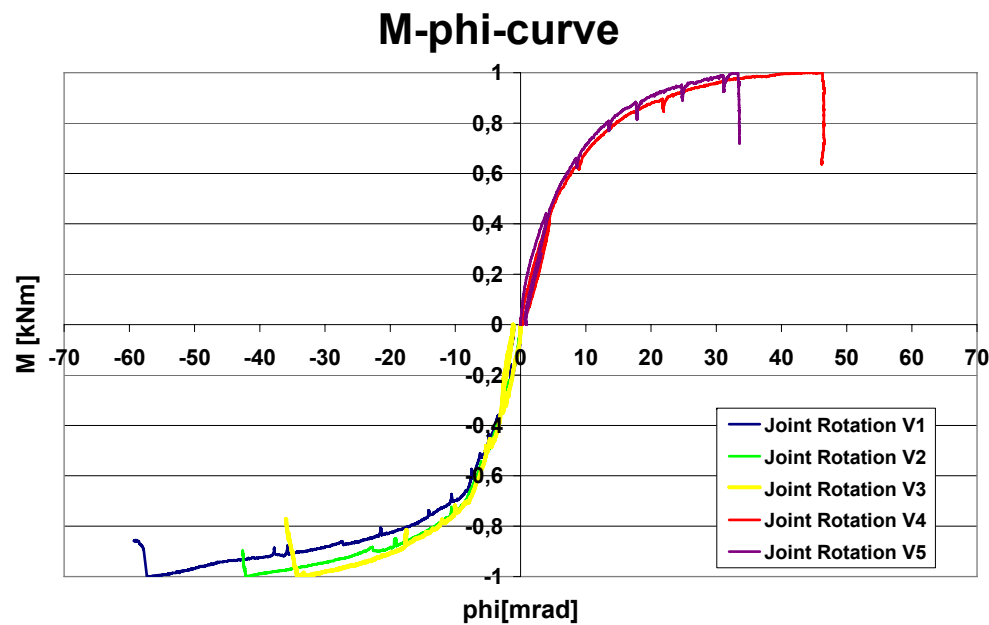
Test setup



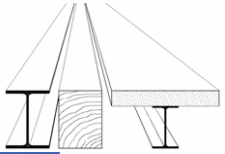


Composite joints under biaxial loading

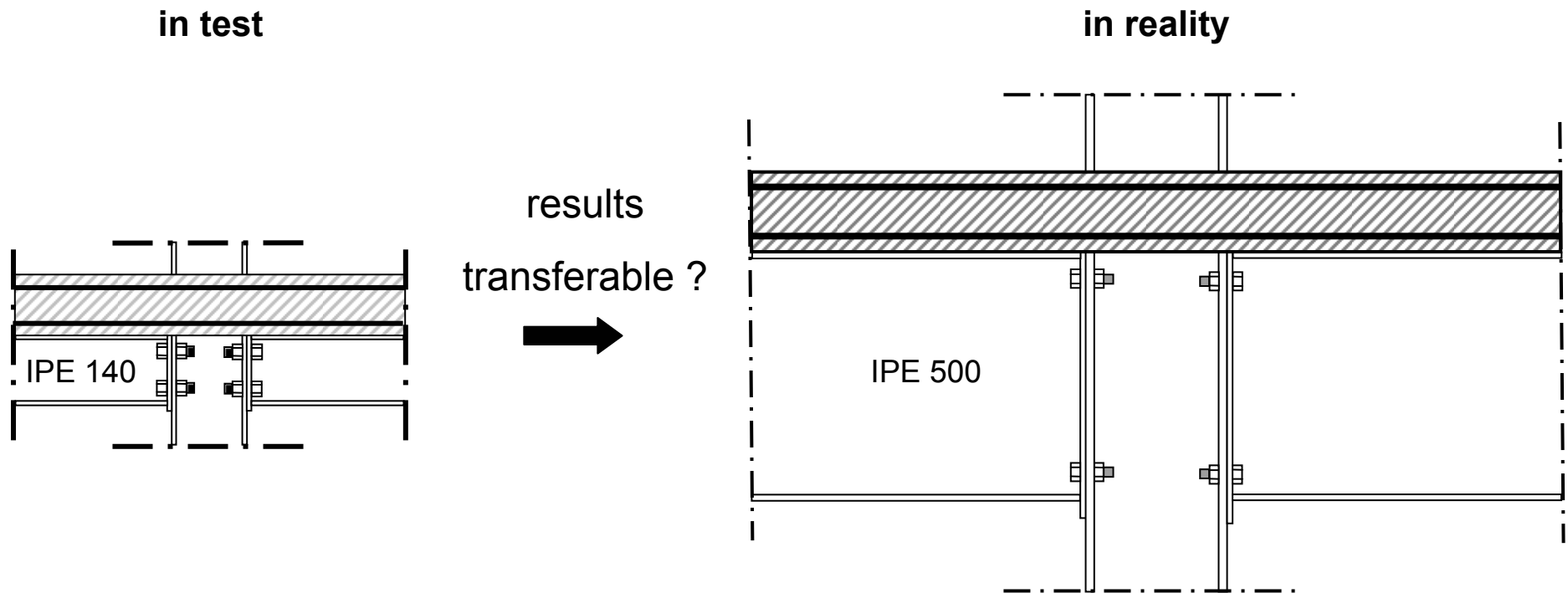
Test results



→ Joints have been able to follow the whole M-N-curve from pure bending state to pure tension state due to **sufficient ductility**

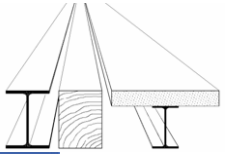


Transferability of the results to larger profiles

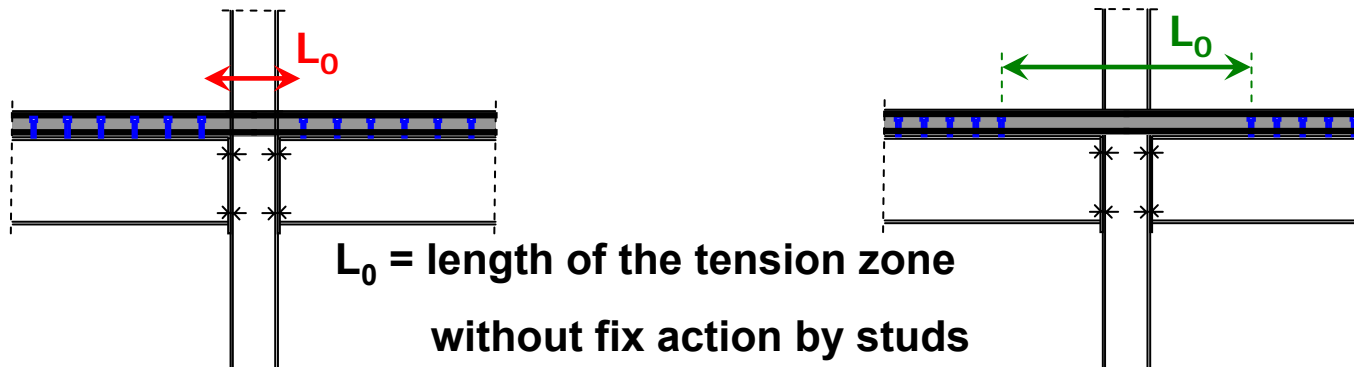
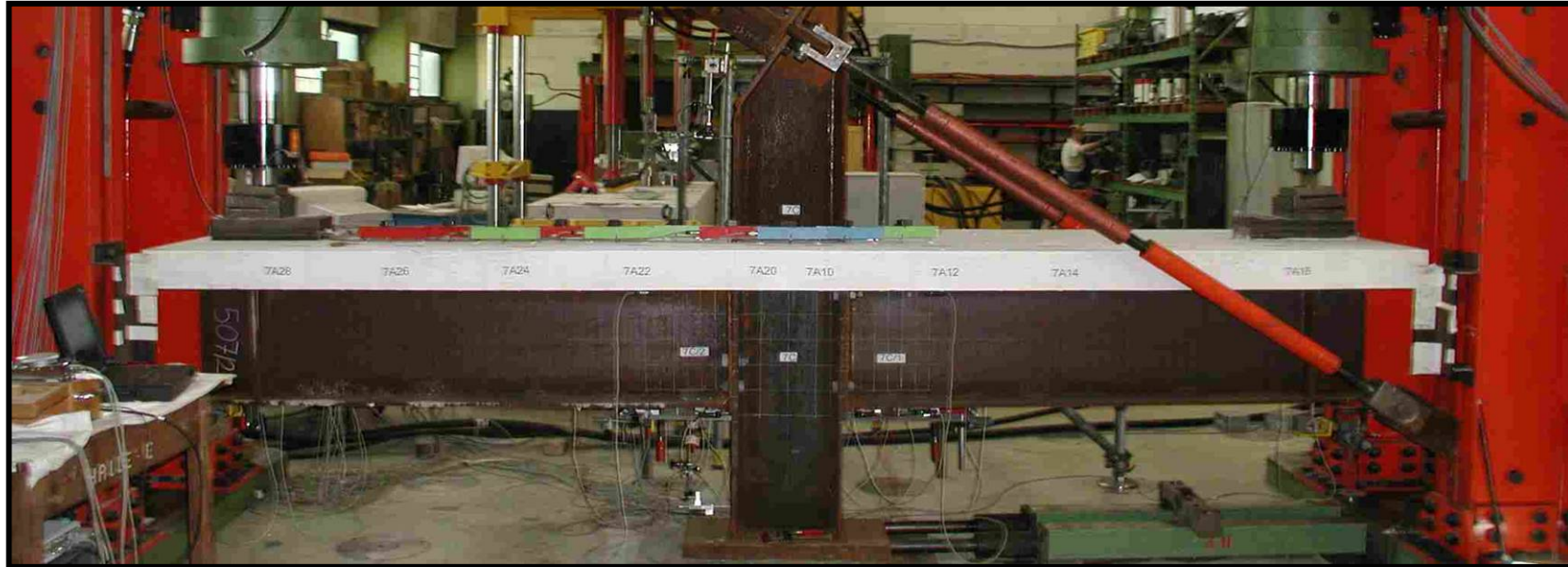


→ Influence of size?

→ What have to be taken into account for larger profiles?

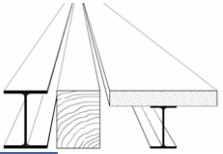


Former tests on composite joints by Martin Schäfer (2003)



Aim of these tests on composite joints:

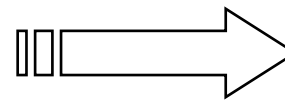
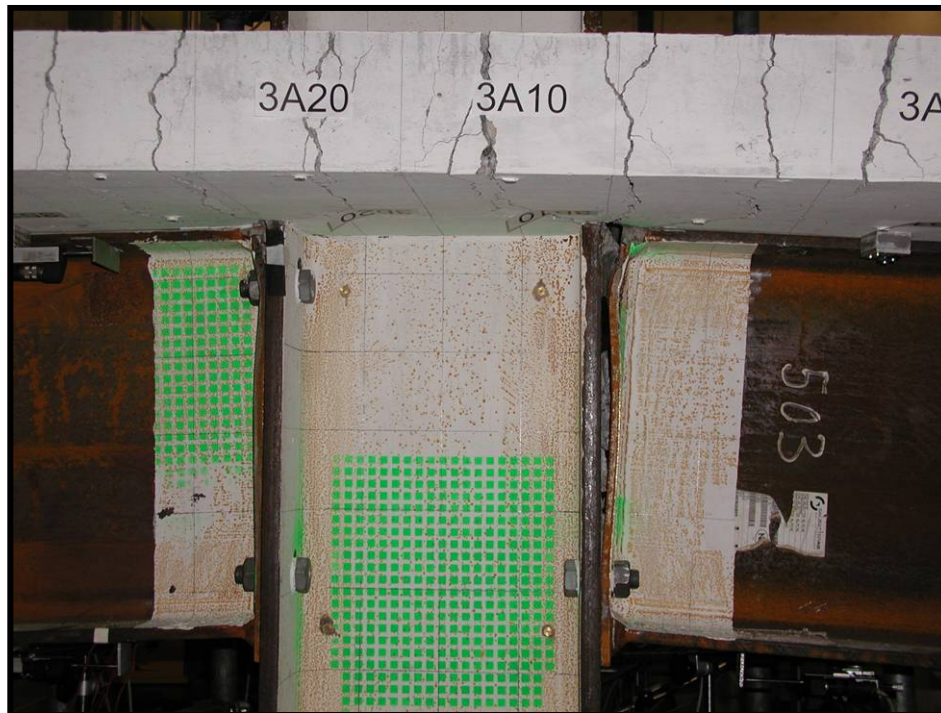
→ development of a “tension bar“ in the concrete slab to improve rotation capacity

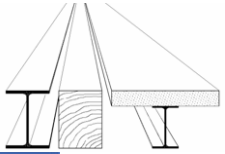


Former tests on composite joints by Martin Schäfer (2003)

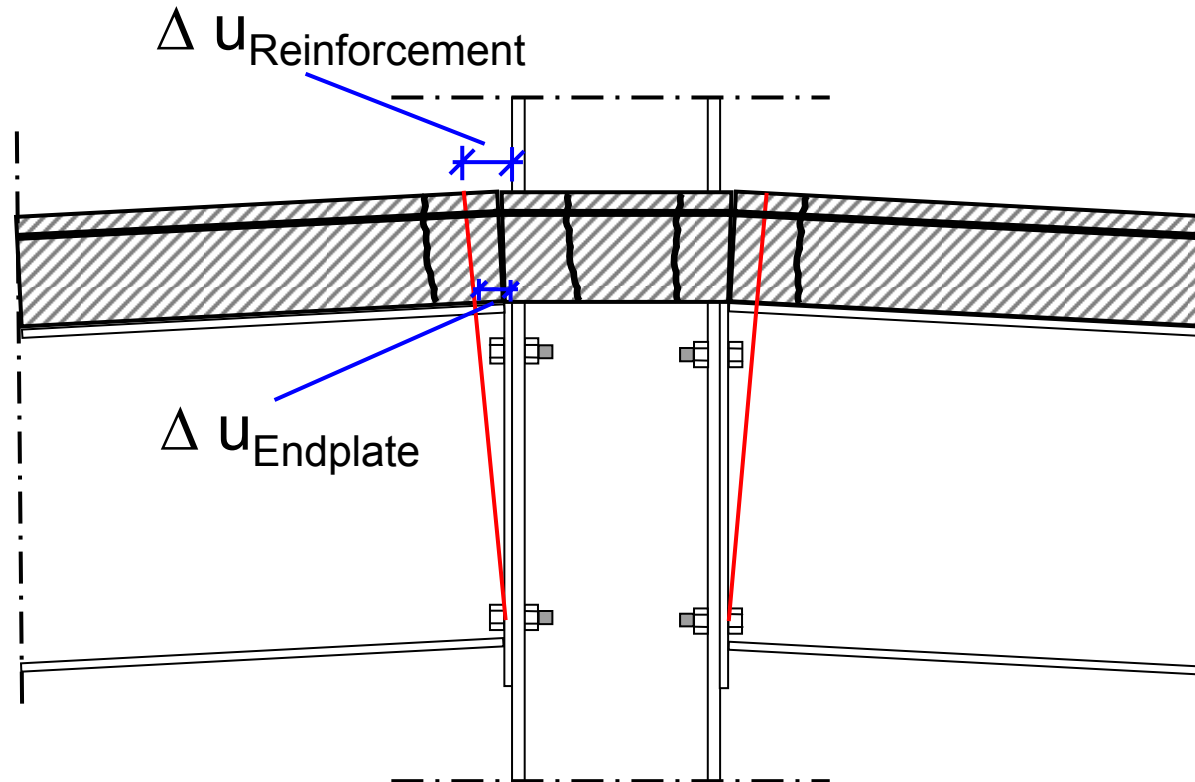
One of the tests showed that although the ductility criterion acc. EC3 part 1-8 was not violated a premature brittle bolt failure occurred:

- *the “tension bar“ (in the concrete slab) could not be activated totally*
- *limited ductility of the joint*





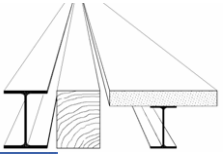
Ductile joints for redundant frame structures



Tension components of the „pure steel joint“ have to have a certain ductility:

- to ensure a complete activation of the component RFT
- to ensure highly ductile joint behaviour

→ **Special focus on the arrangement & adjustment of the single components**

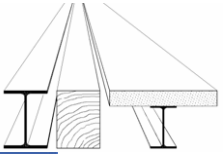


Additional tests on pure steel joints within RFCS-project “Robustness“



Aim of the steel joint tests - *investigation on:*

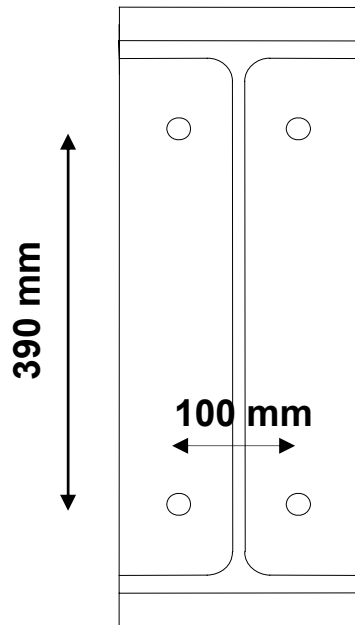
- **membrane effects in the endplate** → **underestimation of EP bearing capacity**
- **influence of the bolt arrangement** → **bearing capacity + ductility**



Steel joint tests

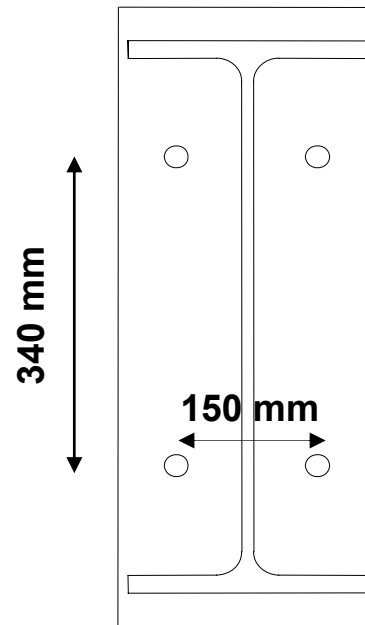
Parameter variation S1-S6

S1 – S4



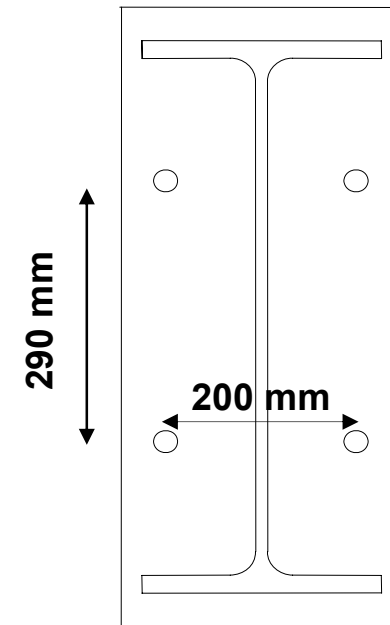
$t = 6..16 \text{ mm}$

S5

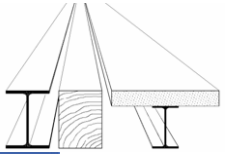


$t = 12 \text{ mm}$

S6

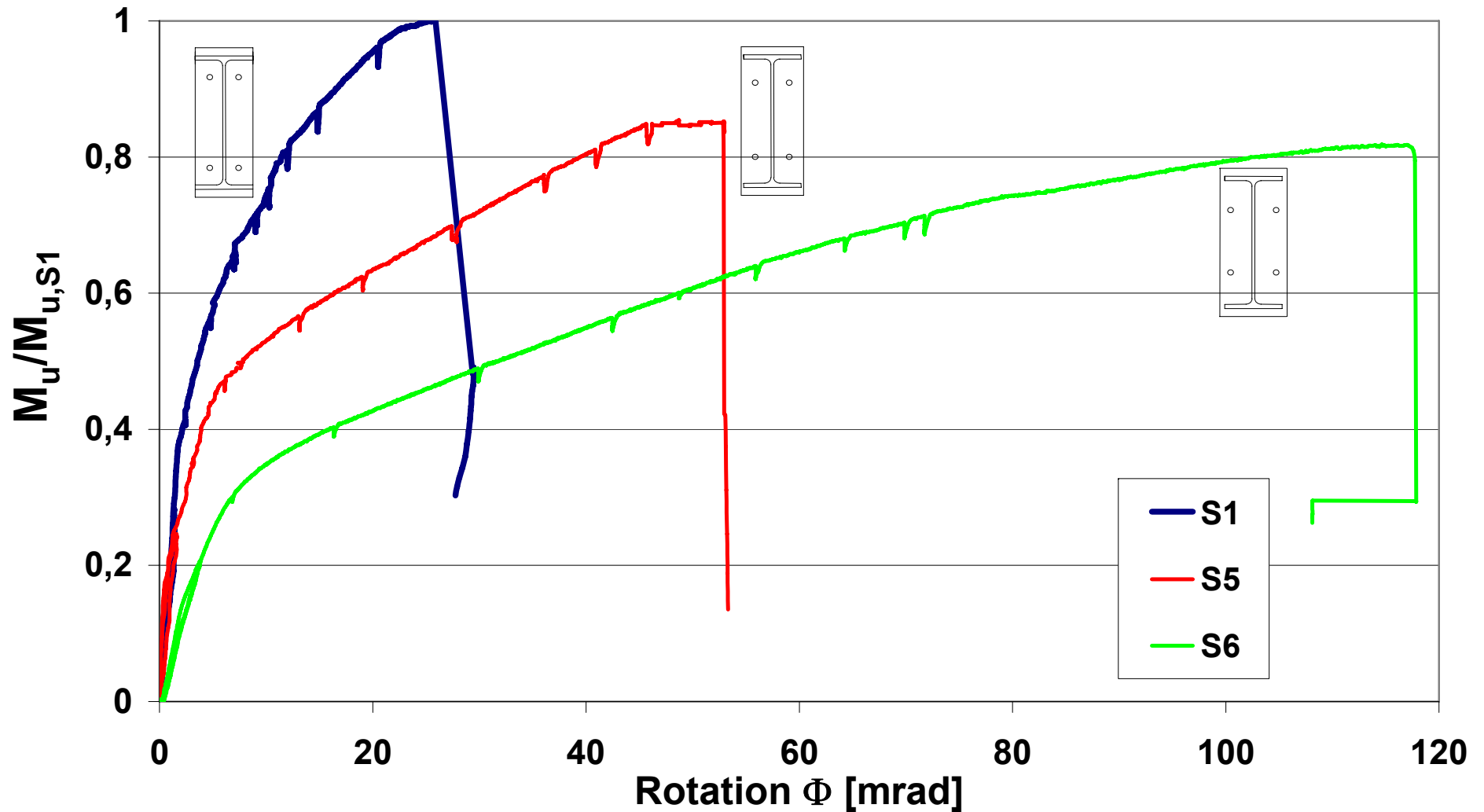


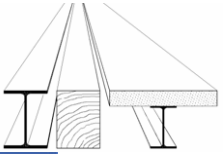
$t = 12 \text{ mm}$



Steel joint tests

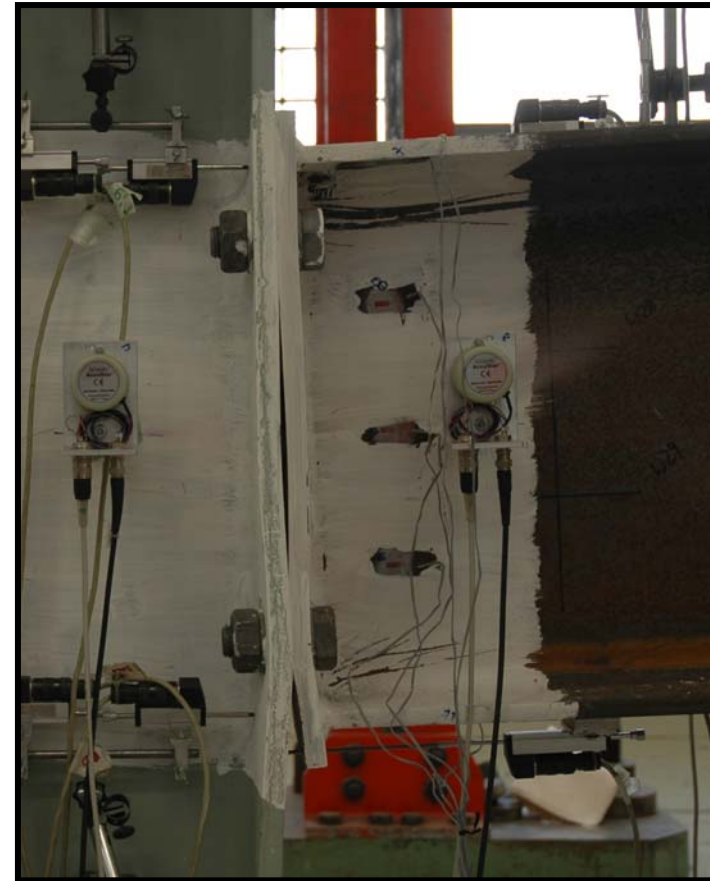
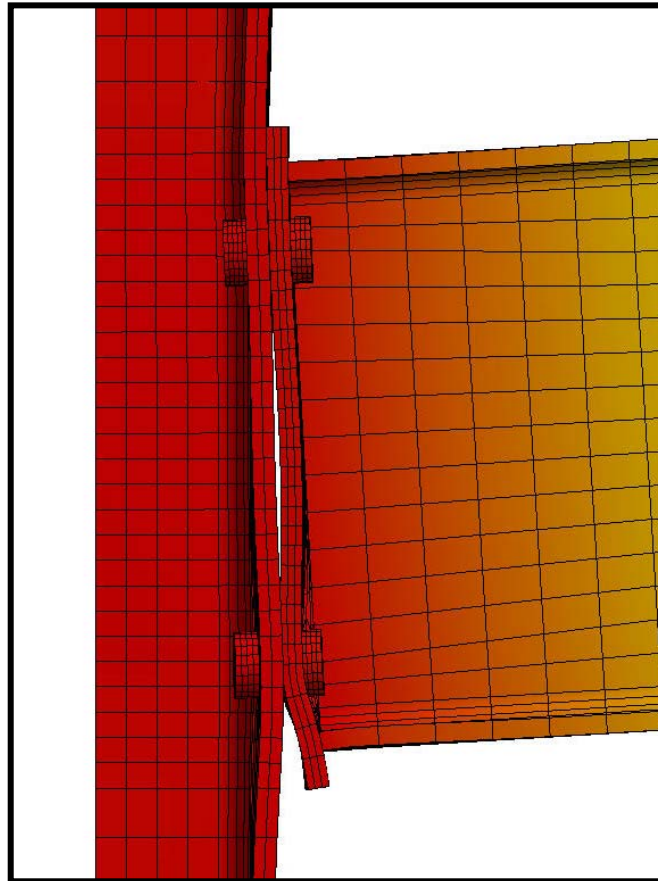
Test Results: Influence of the bolt arrangement



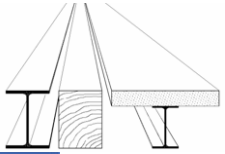


Steel joint tests

Comparison of the deformations:

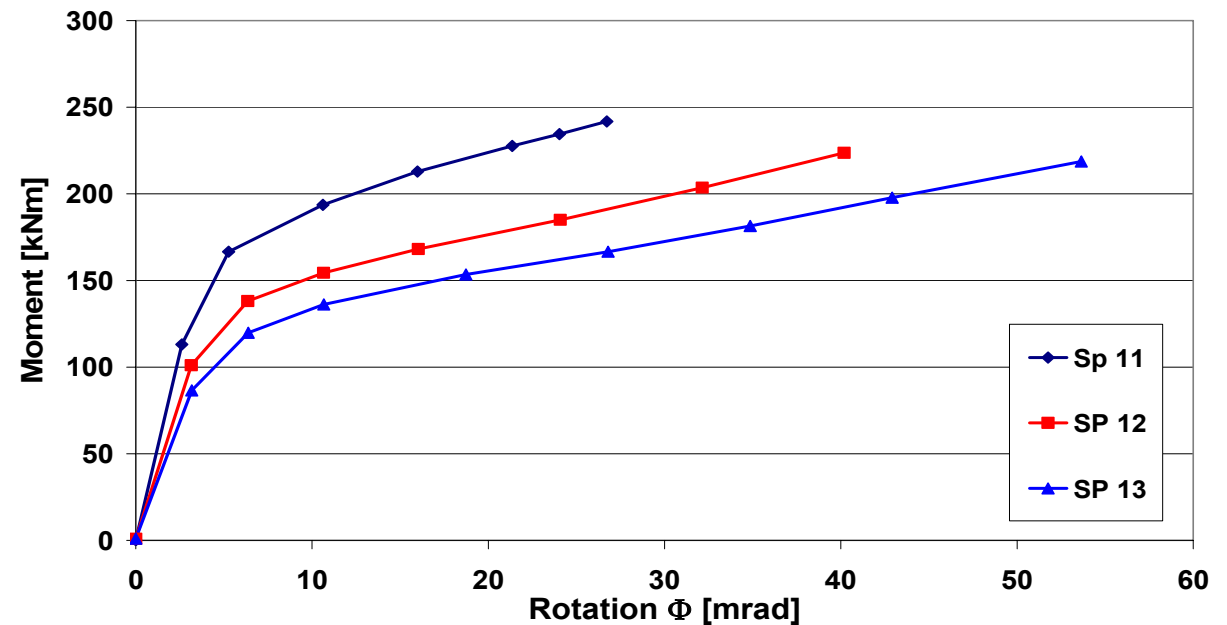
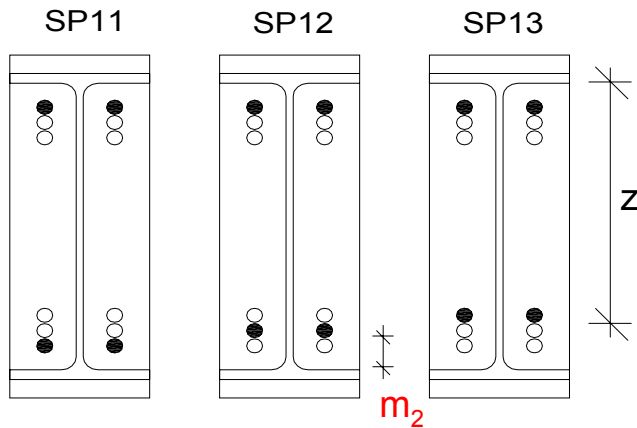


→ *validation of the numerical model by the experimental results*



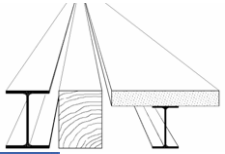
Steel joint tests

Influence of the bolt arrangement - vertical distance -



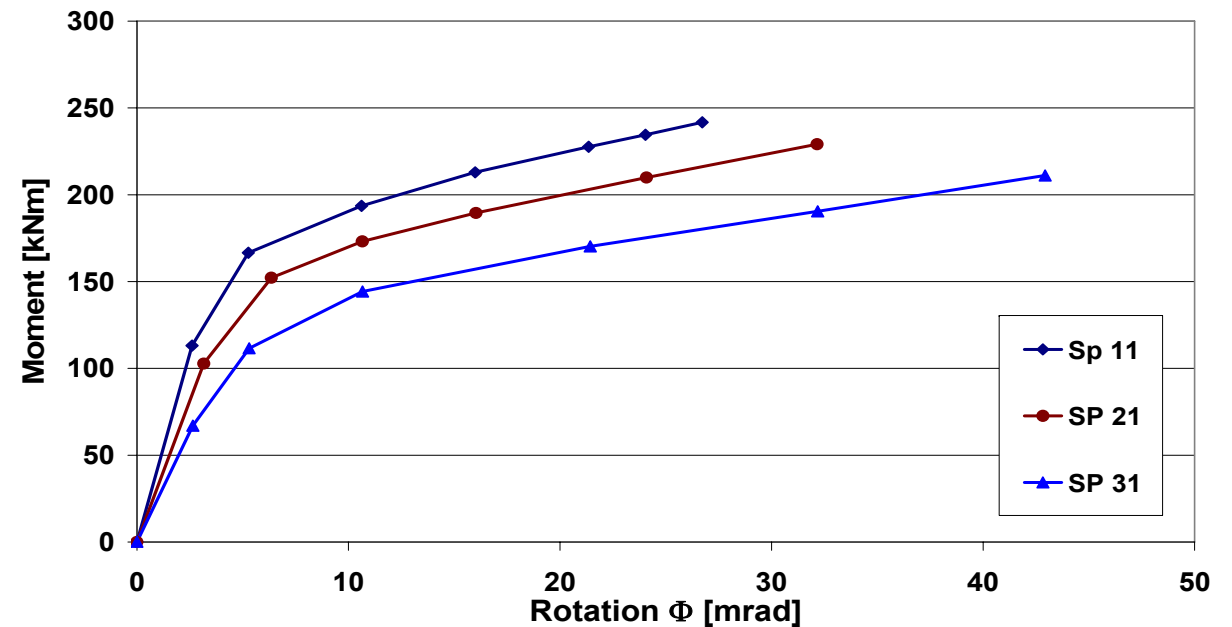
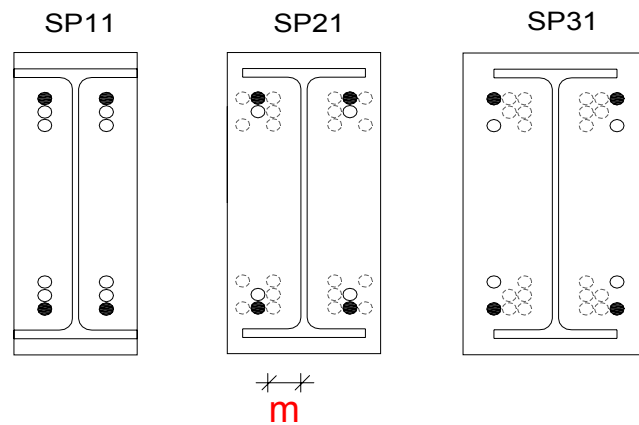
decrease of the inner lever arm z \rightarrow decrease of M_j

increase of the vertical distance m_2 between bolts and beam flange \rightarrow increase of ductility



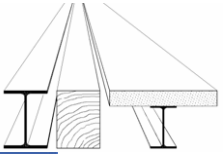
Steel joint tests

Influence of the bolt arrangement - horizontal distance -



increase of “ m ” \rightarrow decrease of effective length and M_j

increase of the horizontal distance between bolts and beam web \rightarrow increase of ductility



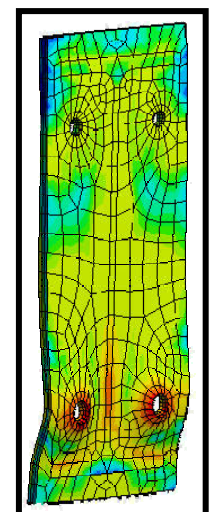
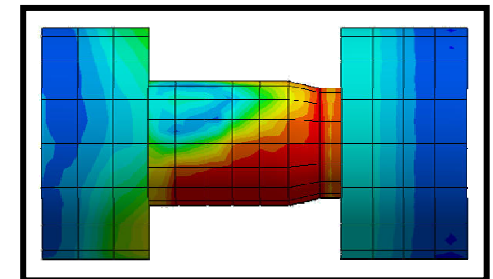
Findings of steel joint tests

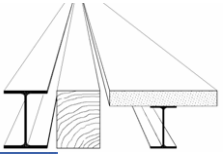
Membrane effects in the endplate were clearly identified:

- **cause over-strength effects in the endplate**
(leads to additional stress of the bolts)
- **ductility criterion acc. EC3 part 1-8 does not sufficiently ensure highly ductile joint behaviour**

By change of the bolt arrangement:

- **ductility has been clearly increased**
by only moderate drop of the bearing capacity
- **ductile and sufficiently strong partial-strength**
(composite) joints may be designed

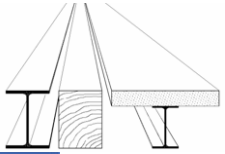




Conclusions

- **Composite joints with „realistic profiles“**
may also reach high rotation capacity (> 100 mrad)
 - *depending on the ductility of the single components*
and their adjustment
- **in these ductile joints membrane forces may be activated**
for redistribution of forces
- **partial-strength joints with ductile design**
are applicable to create redundant structures



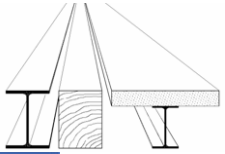


Acknowledgement

*The work presented here is carried out, as a joint research project with a financial grant from the **Research Fund for Coal and Steel (RFCS) of the European Community.***

The authors are grateful for the support!





Robustness

**Thank you very much
for your attention**

Universität Stuttgart

Institute of Structural Design

Fields: steel, timber and composite structures

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[Ice Stadium Bad Reichenhall @ Feuerwehr Berchtesgaden]