“CHS adhesively bonded by GFRP”

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Content

- Wrapped steel joints and promising applications

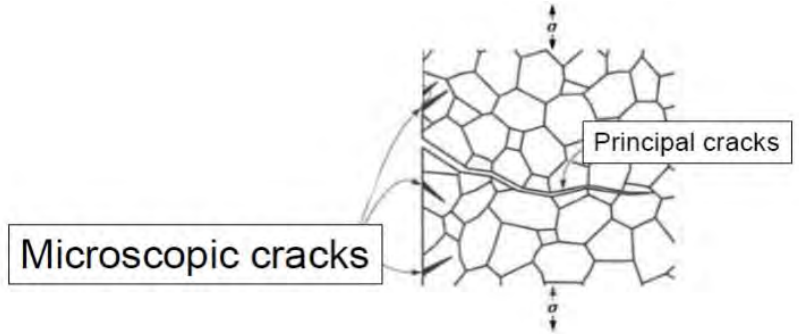
- Preliminary experimental results

- Conclusions and recommendations

Why adhesively bonded steel joints?

Fatigue

- Progressive, localized and permanent structural change of materials
  - Growth only under fluctuating/repeated stresses
  - Culminate into initiation of cracks and leads to final failure



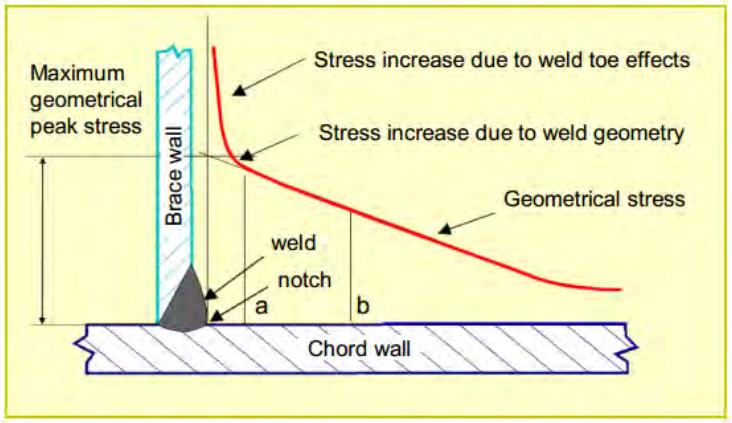
CHS: Steel Circular Hollow Sections

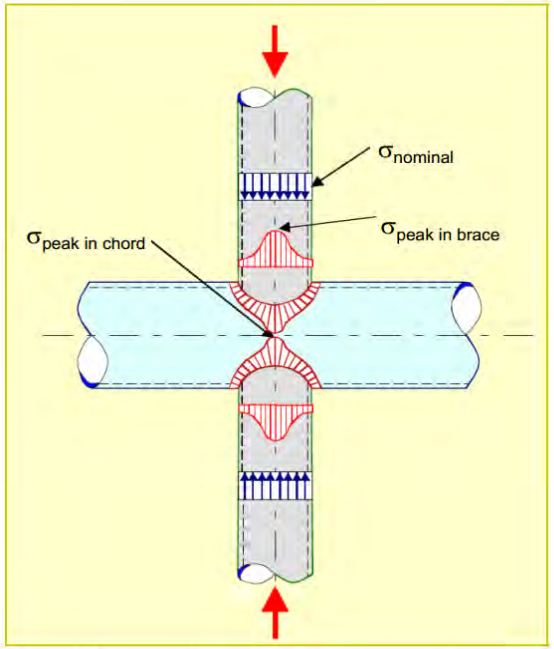
- Cost effective solution for lattice structures
- Applications:

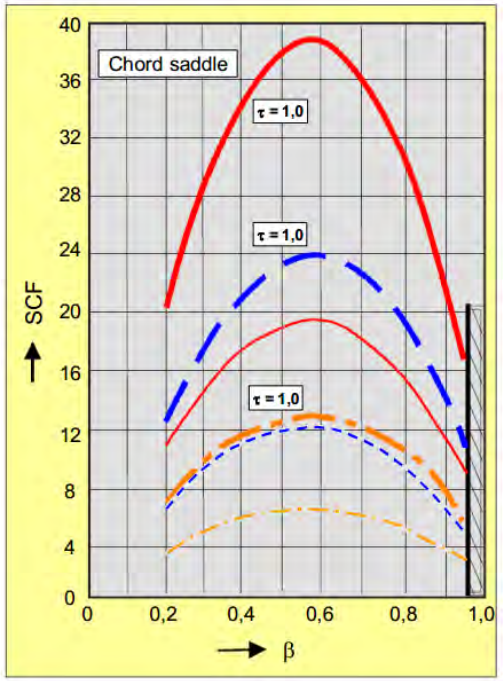
- Main disadvantage: **Fatigue endurance**

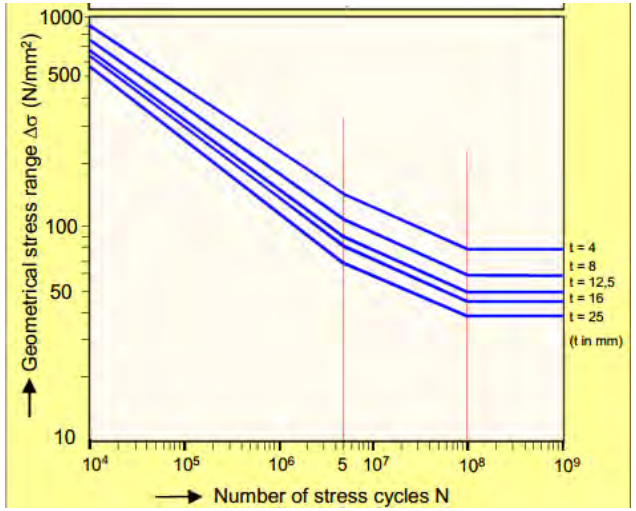
Fatigue: Steel structures

- Welded structures: peak stresses at toes and roots of welds → week point
  - Tubular joints: non-uniform stiffness distribution → week point
    - **SCF ranging from 2 to 40**



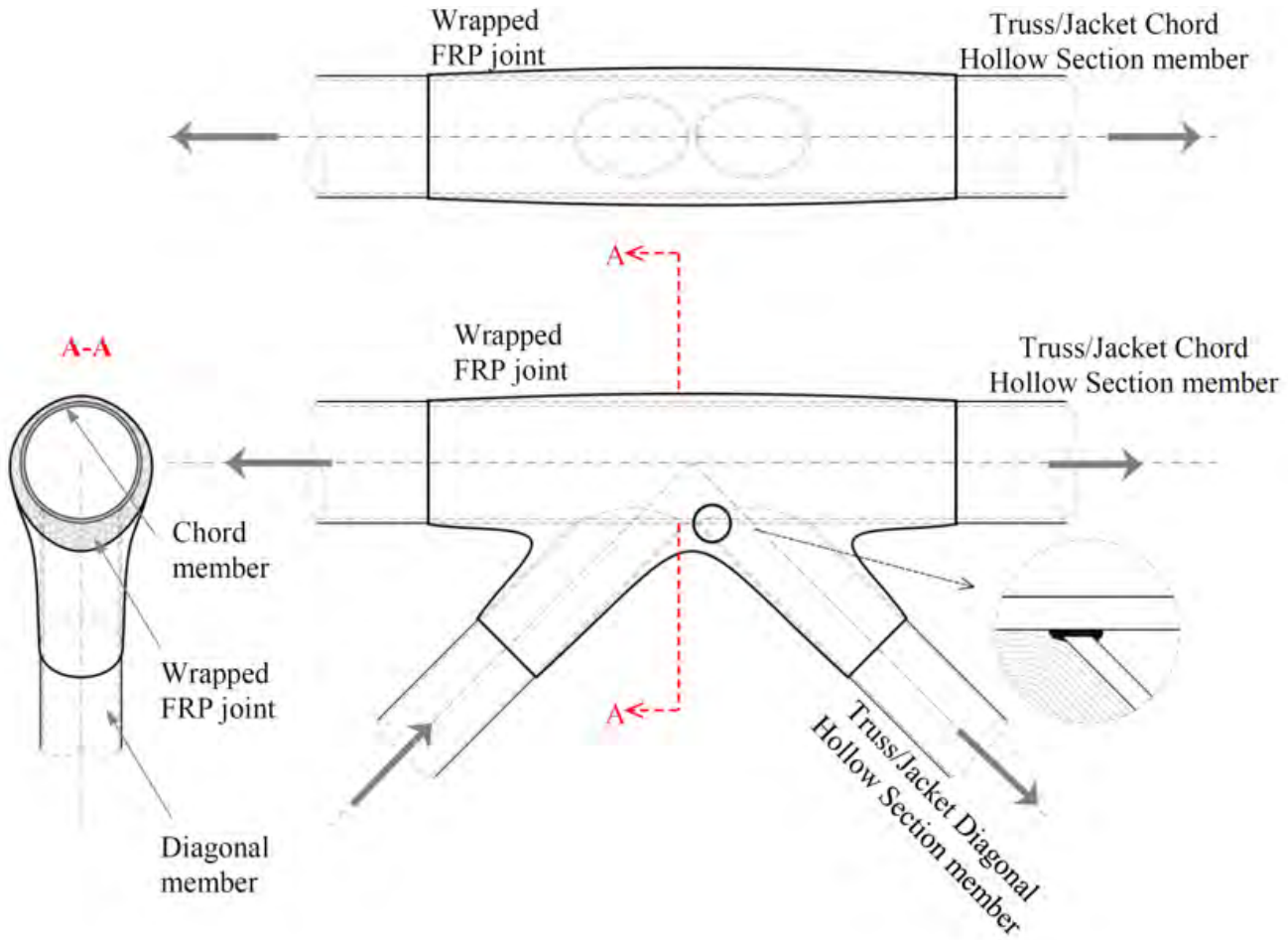






$$SCF_{i,j,k} = \frac{\text{geometrical stress}_{i,j,k}}{\text{nominal stress in the brace}}$$

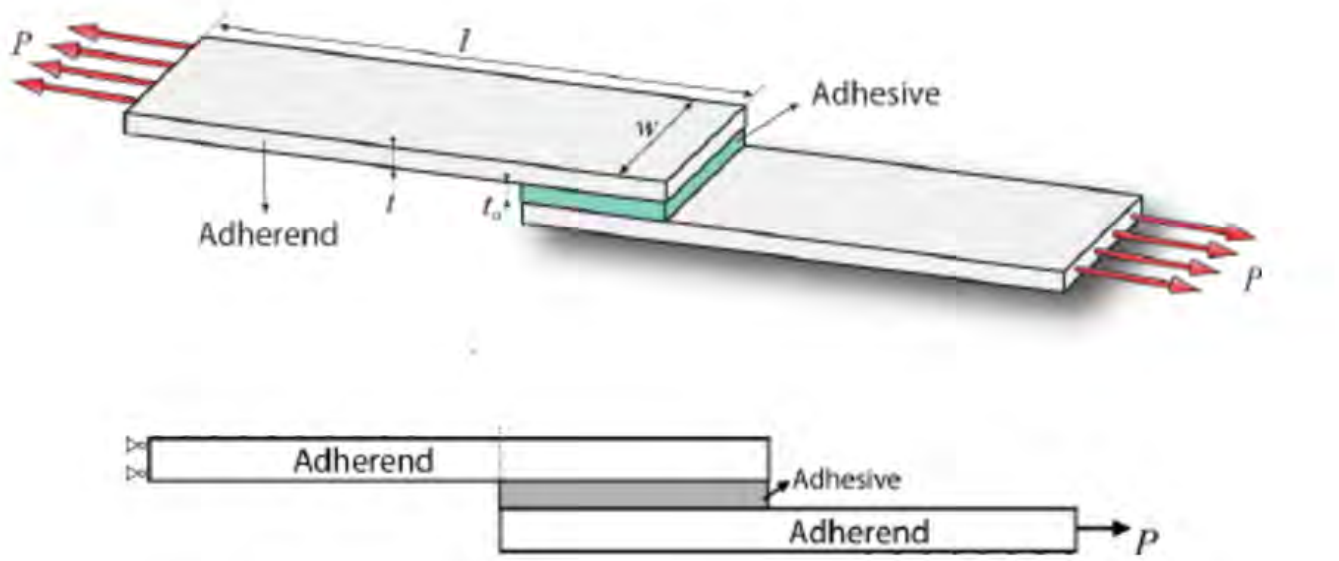
FRP wrapped steel joints



- Diagonals and chord bonded by FRP
- Hand lamination

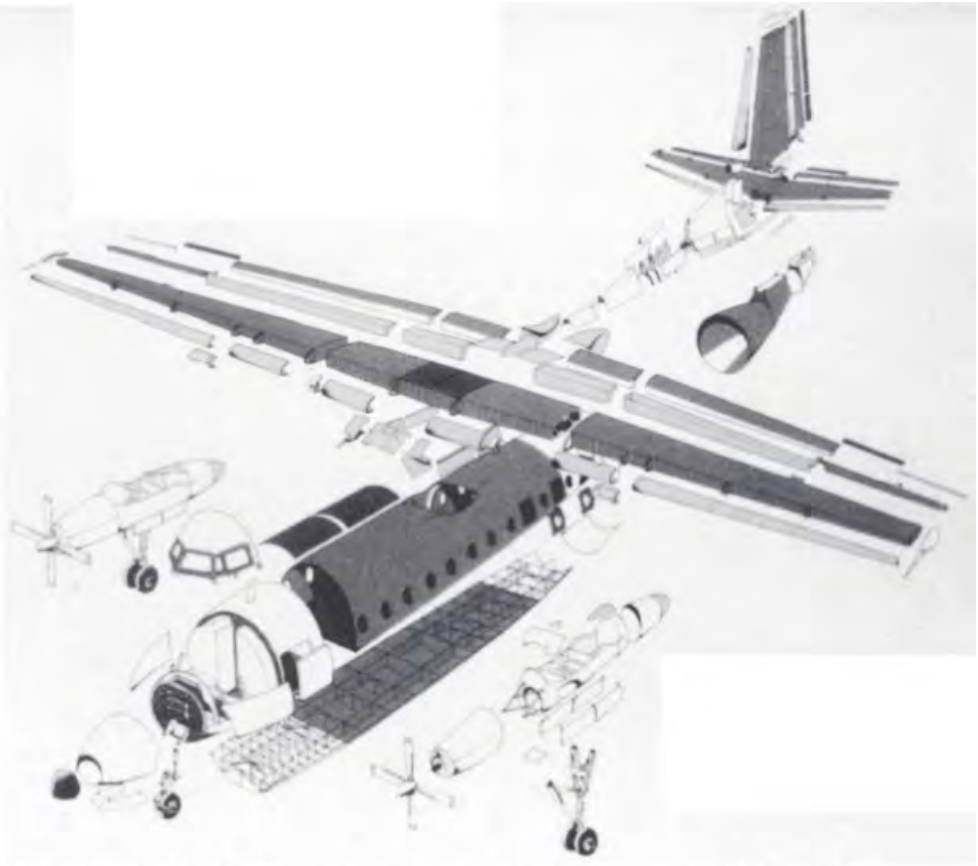
Patent pending
TU Delft

Adhesive Bonding



Adhesive Bonding

- Applications in Aerospace Engineering
- First attempts during the World War II
- Widely used to replace mechanical fasteners
- Increasing applications
- <u>Advantages:</u>
  - Excellent strength-to-weight ratio
  - Ease of application
  - Reduced stress concentrations
  - Stiffness improvements



Bonded components in the Fokker Friendship F27 (1950s)

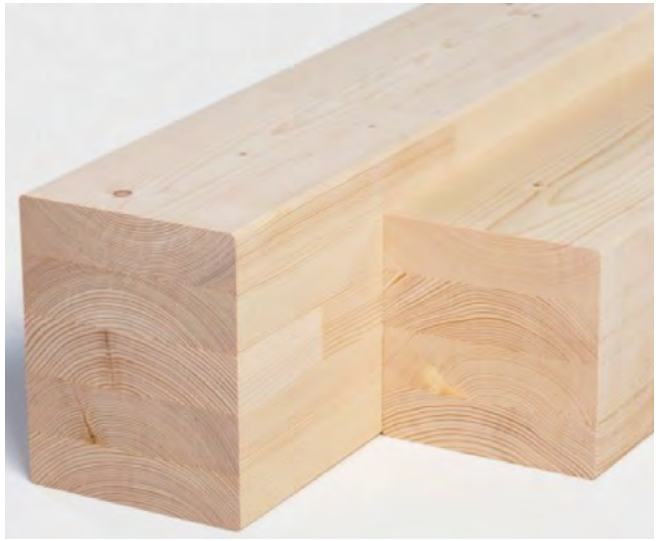
Adhesive Bonding in Civil Engineering

- Limited structural applications

- <u>Examples:</u>

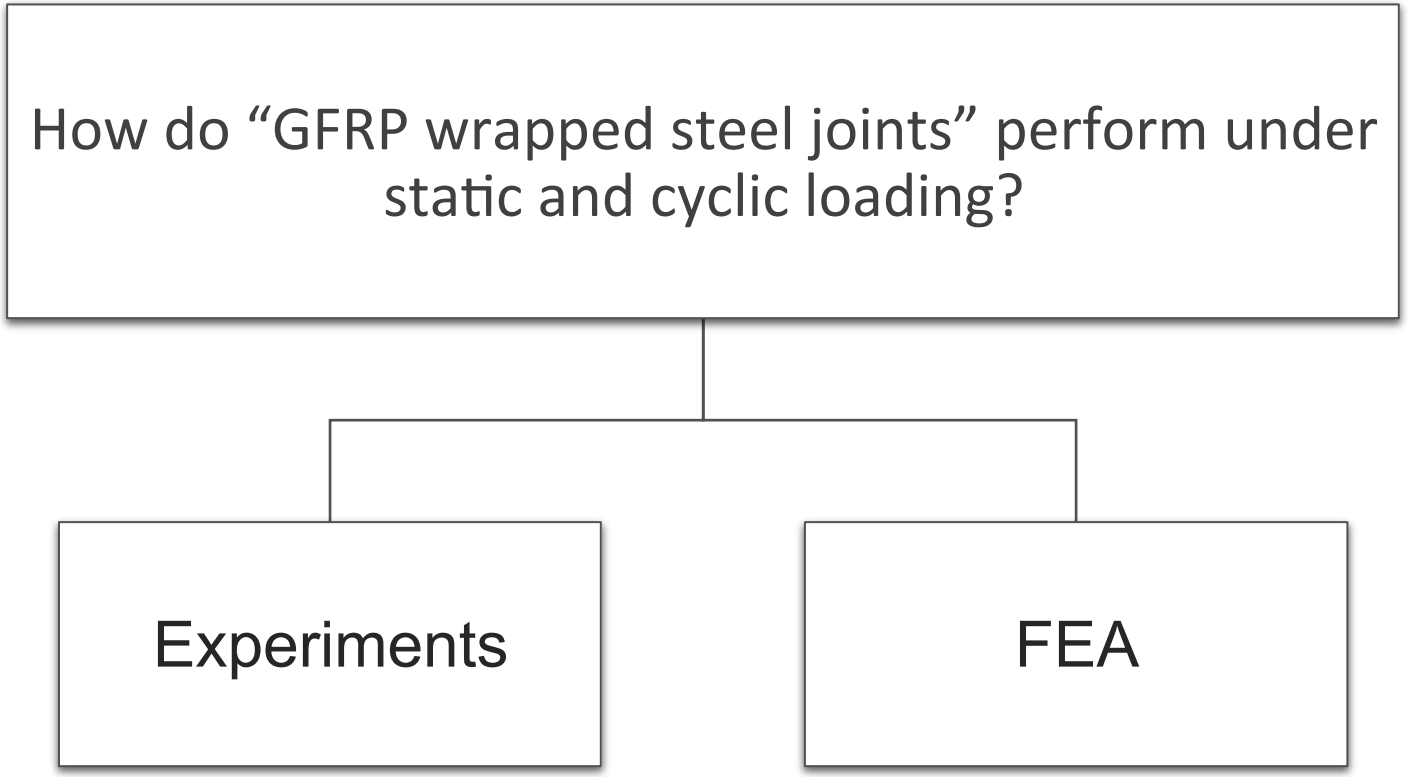
Fiber Reinforced Polymers (FRP)

Glued Laminated Timber



Strengthening of existing structures

Research Question



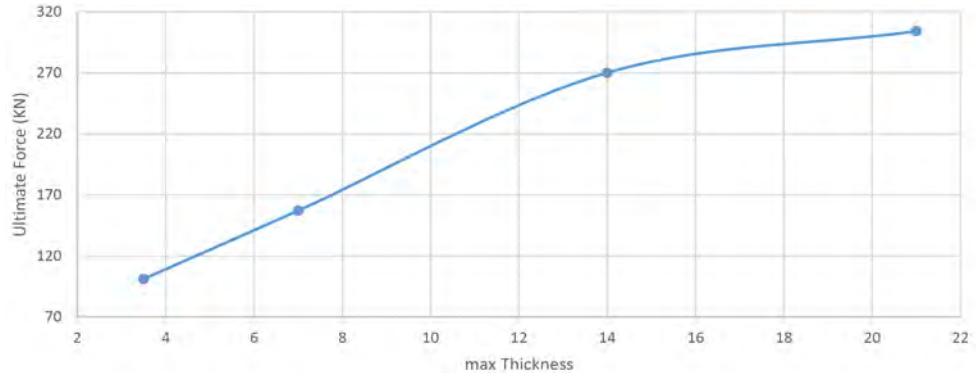
Experiments

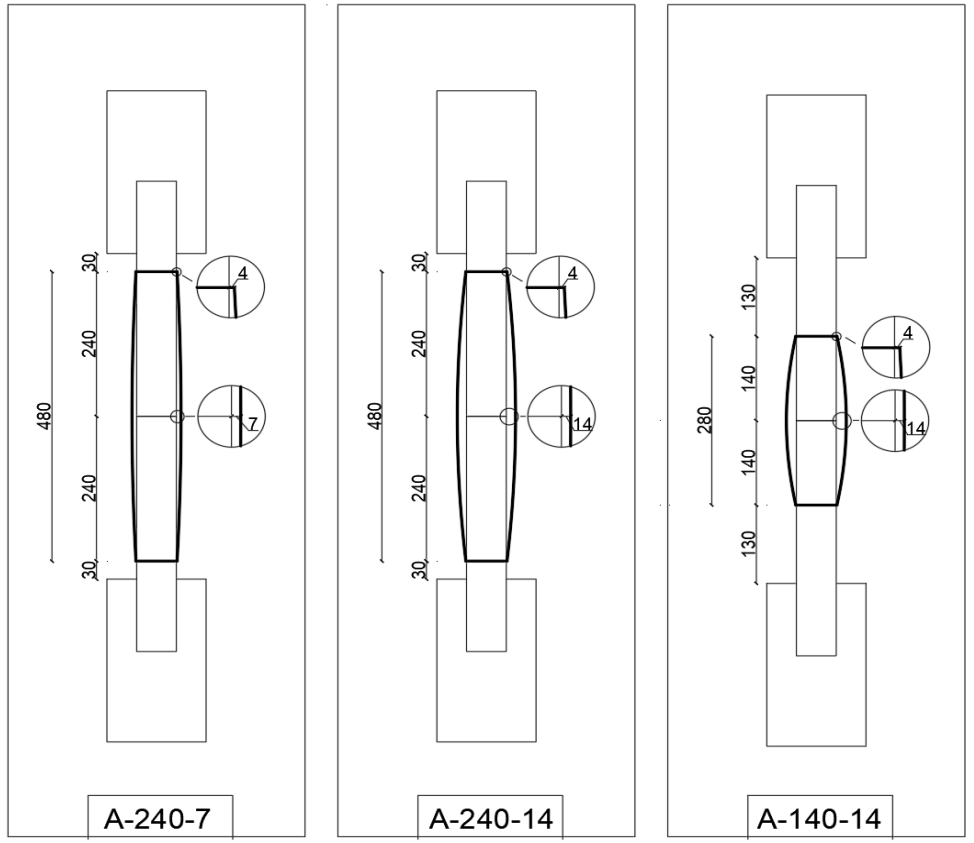
Patent pending
TU Delft

- 12 static tests
- 2 dynamic tests (fatigue loading)

- Axial joints: 3 series

- <u>FRP Dimensions:</u>
  - L=240 mm, t=14 mm
  - L=140 mm
  - t=7 mm

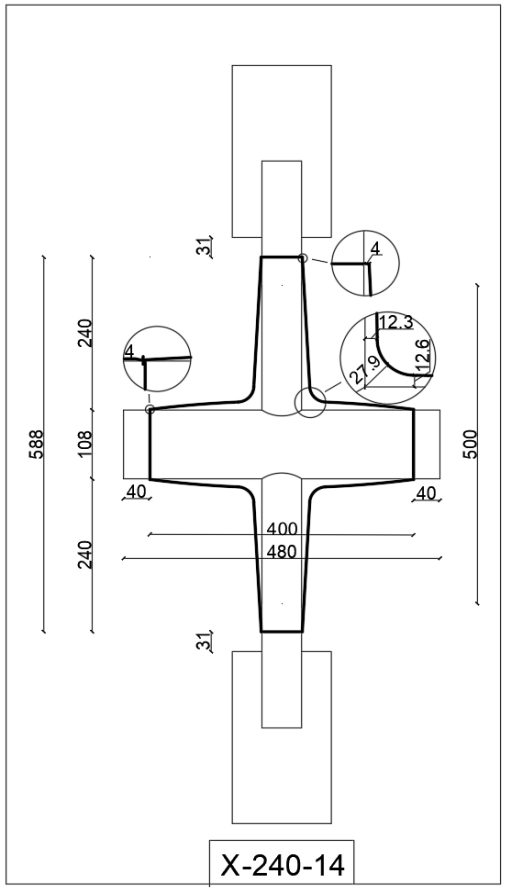




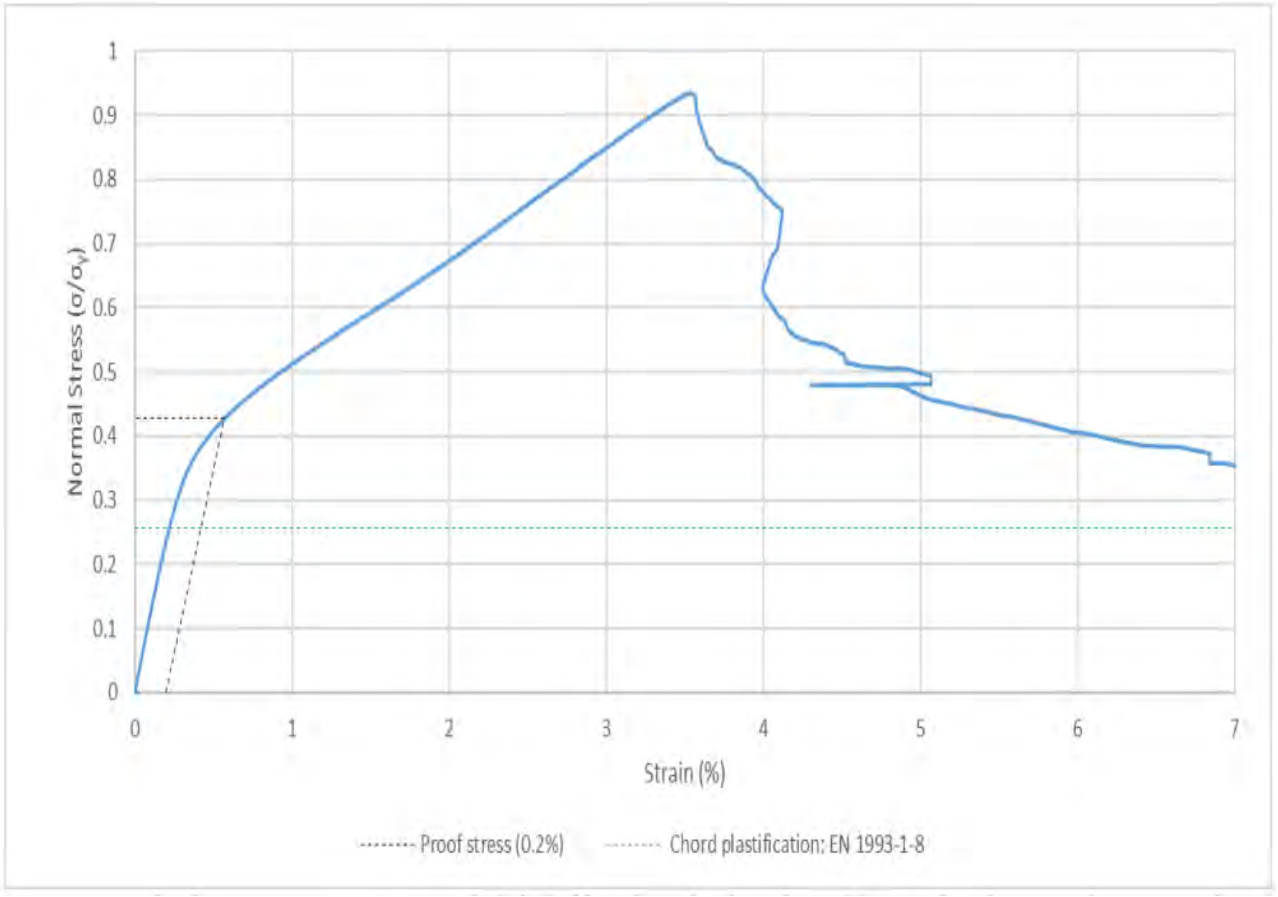
Experiments

Patent pending
TU Delft

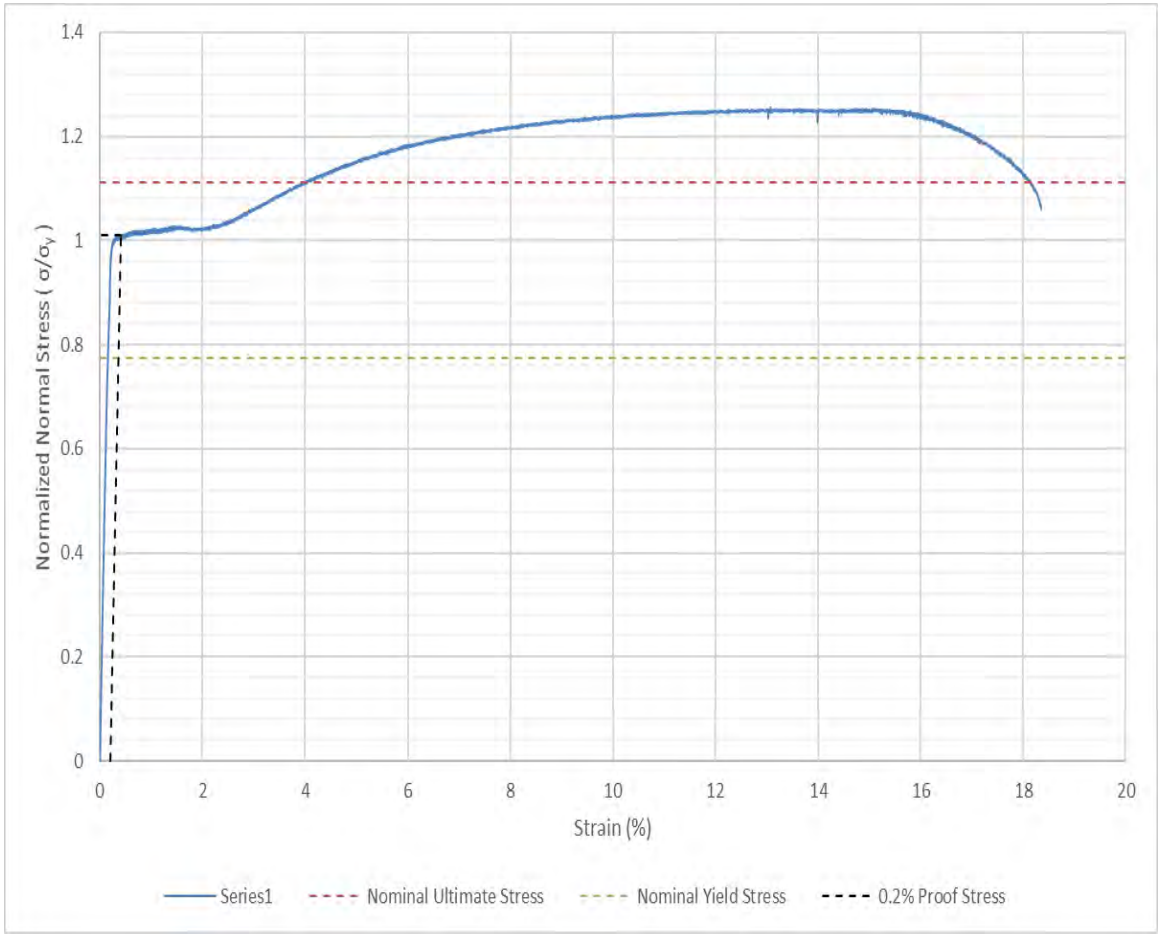
- X-joints: 1 series (of 3 identical specimens)
- Comparison with traditional joints



Experiments: Welded X-Joint

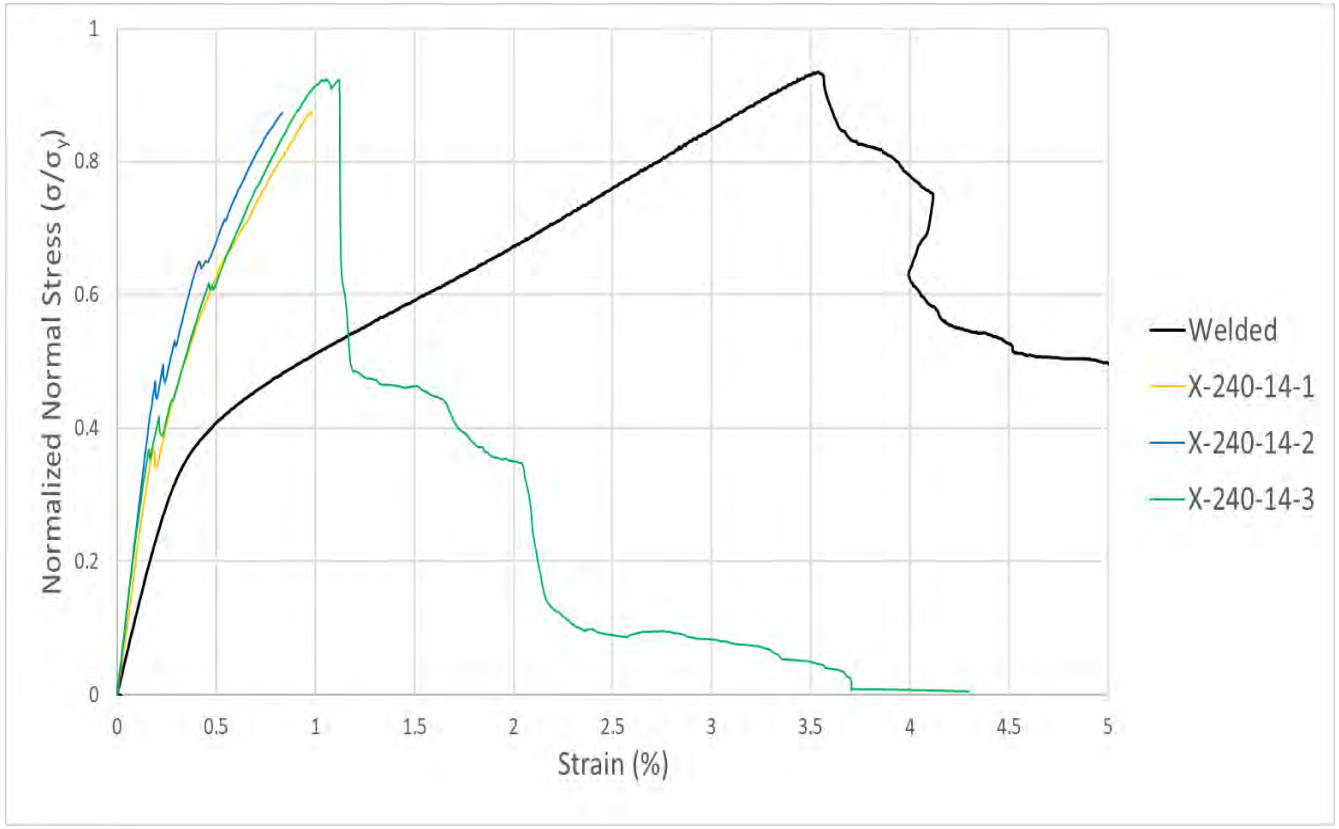


Experiments: Welded Axial



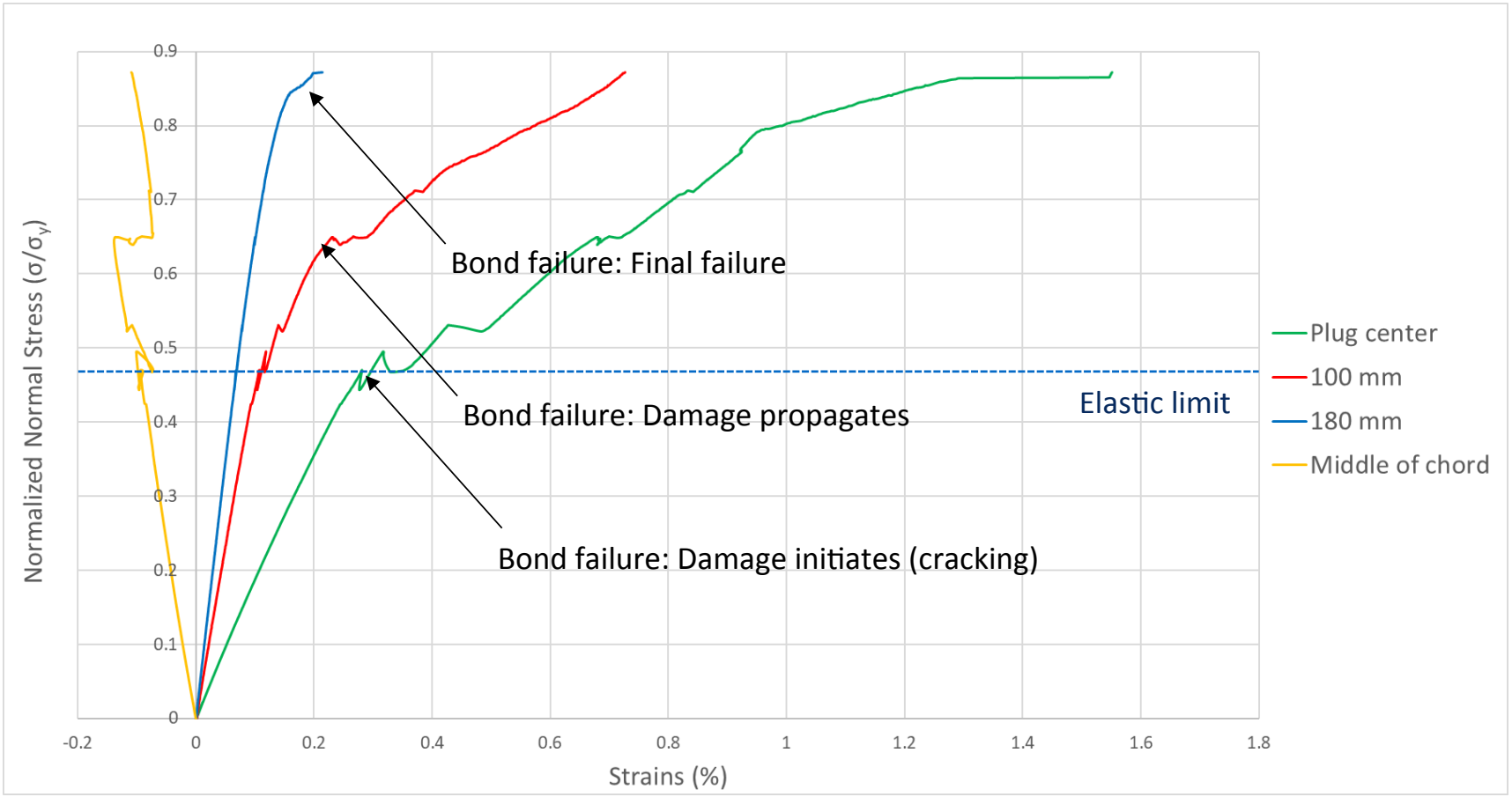
Experiments: X-Joint

Patent pending
TU Delft



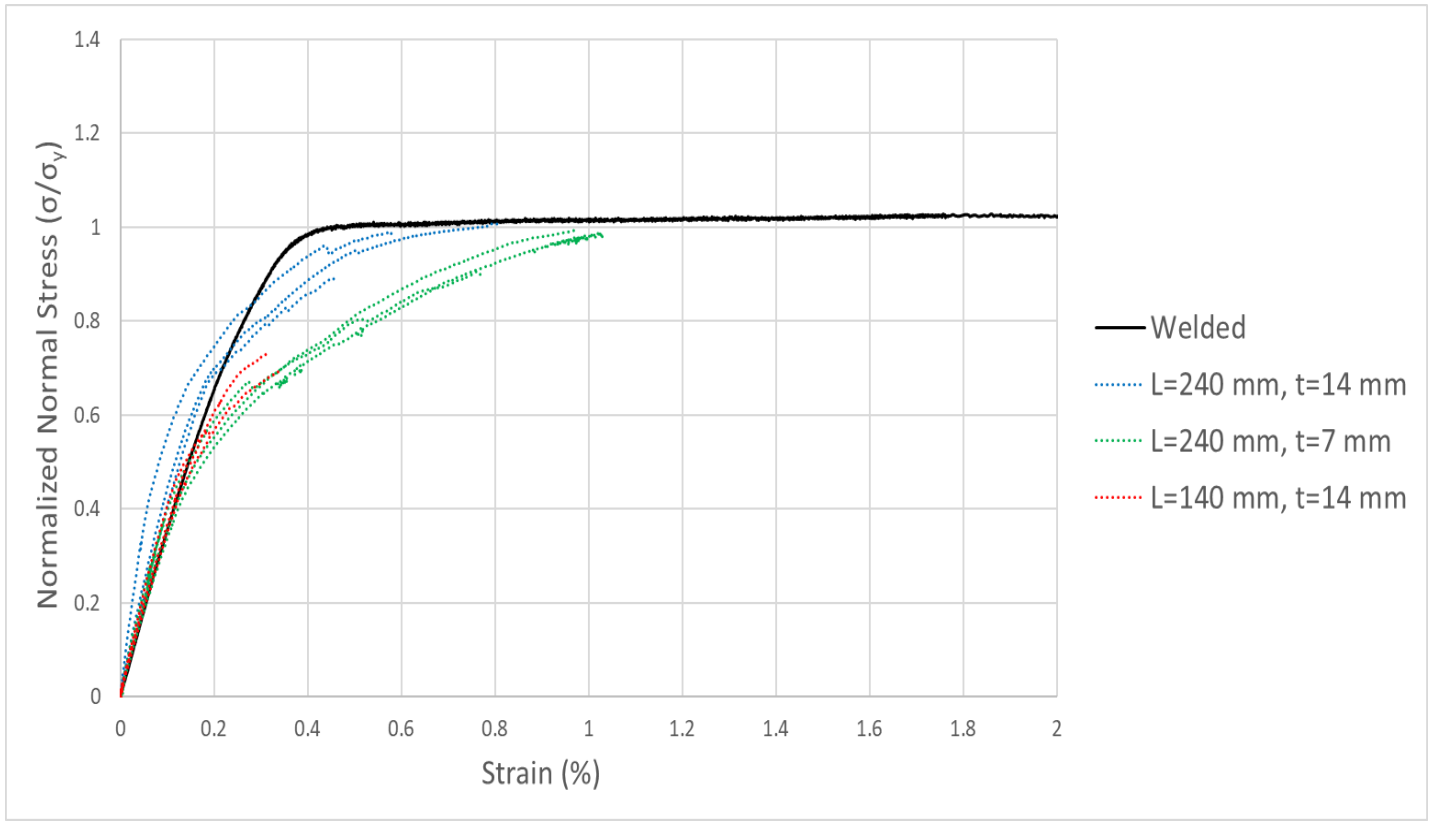
Experiments: X-Joint

Patent pending
TU Delft



Experiments: Axial Joint

Patent pending
TU Delft

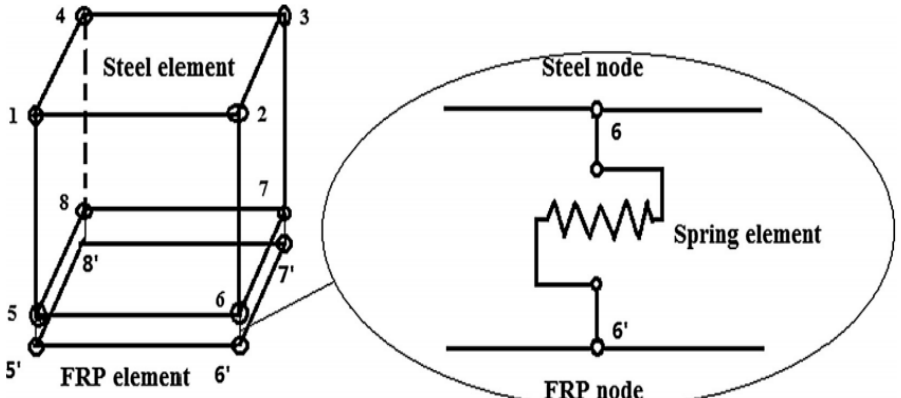


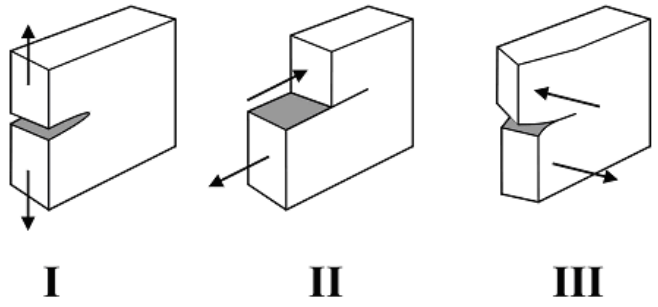
Experiments: Dynamic Test

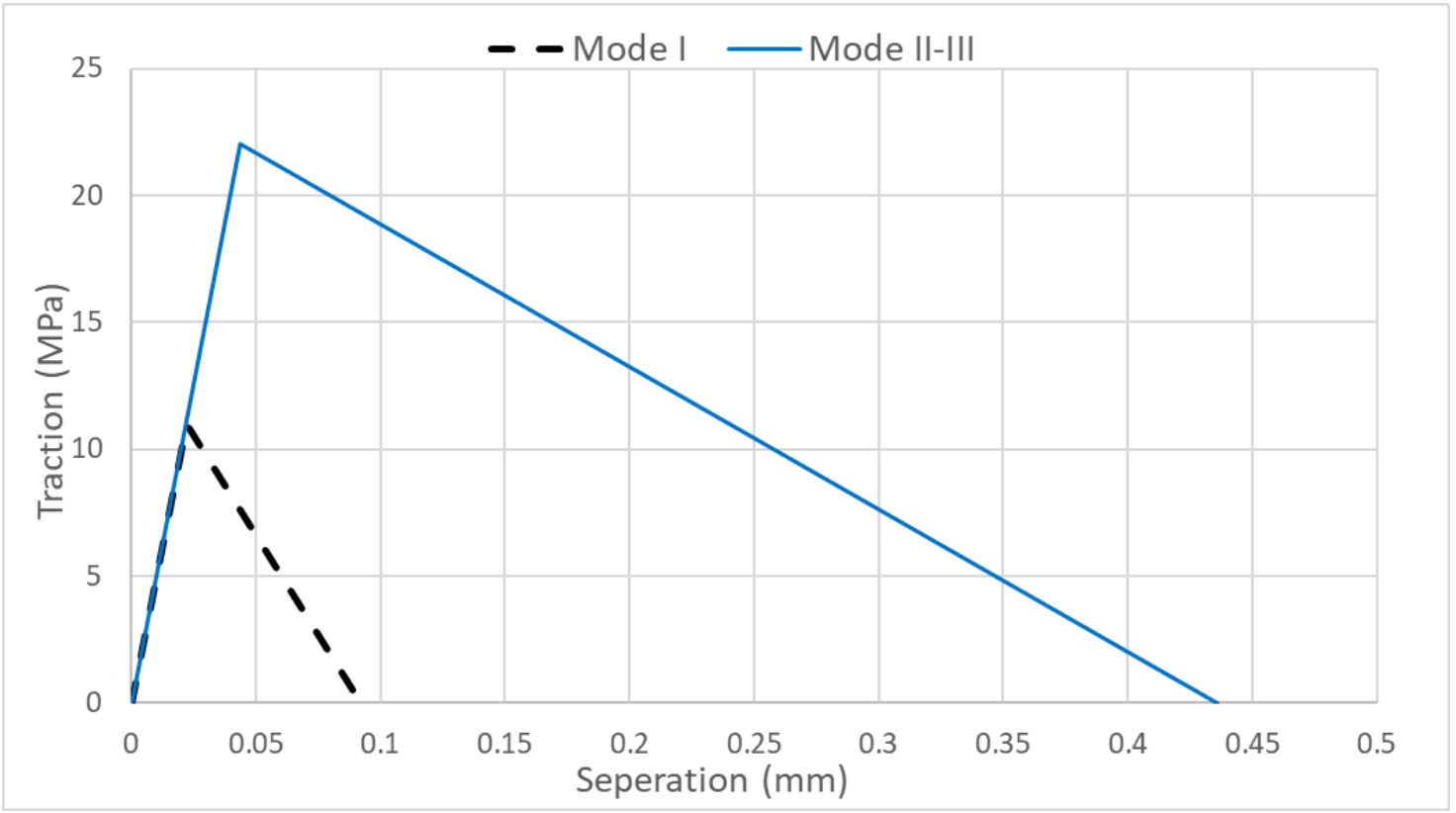
Patent pending
TU Delft

- FRP joint: 960,000 cycles *(ΔF=60 KN, Δσ=142MPa)*
- Steel joint: 29,000 cycles

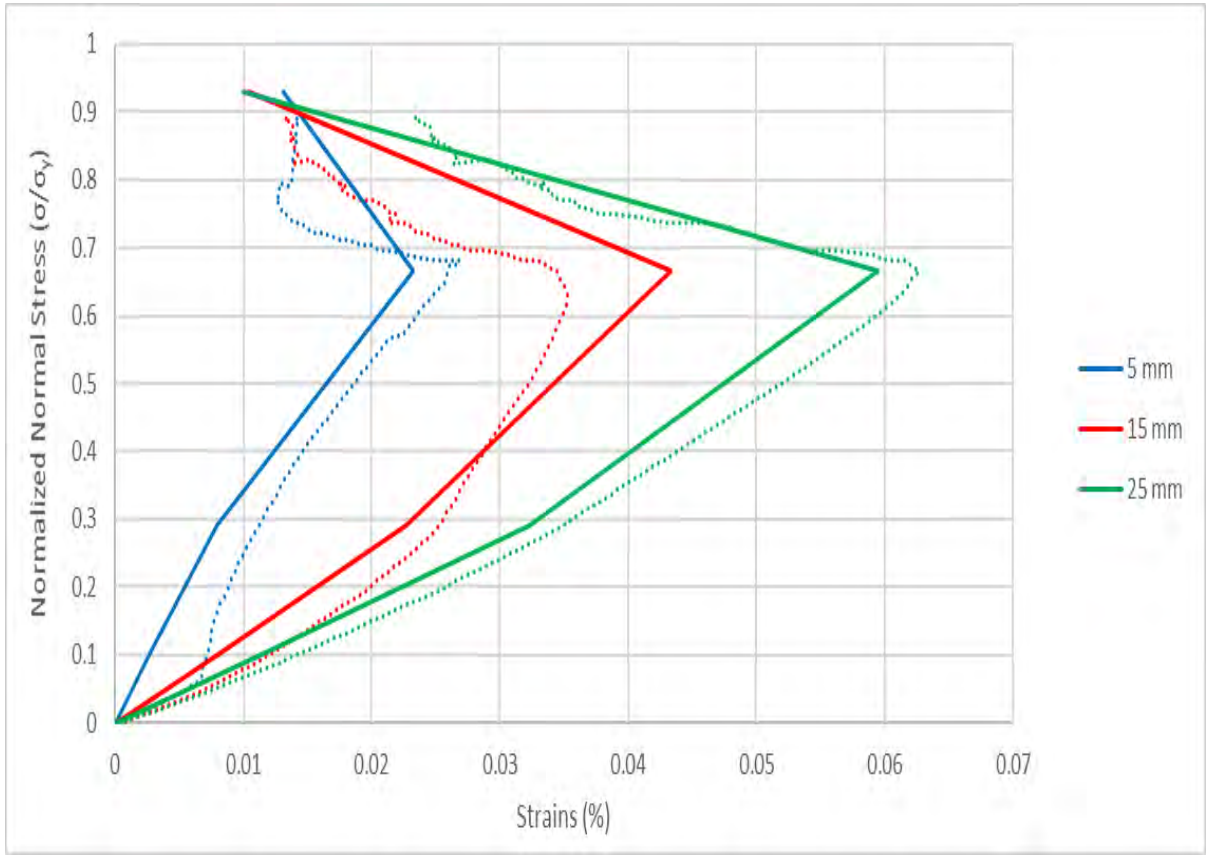
Finite Element Analysis





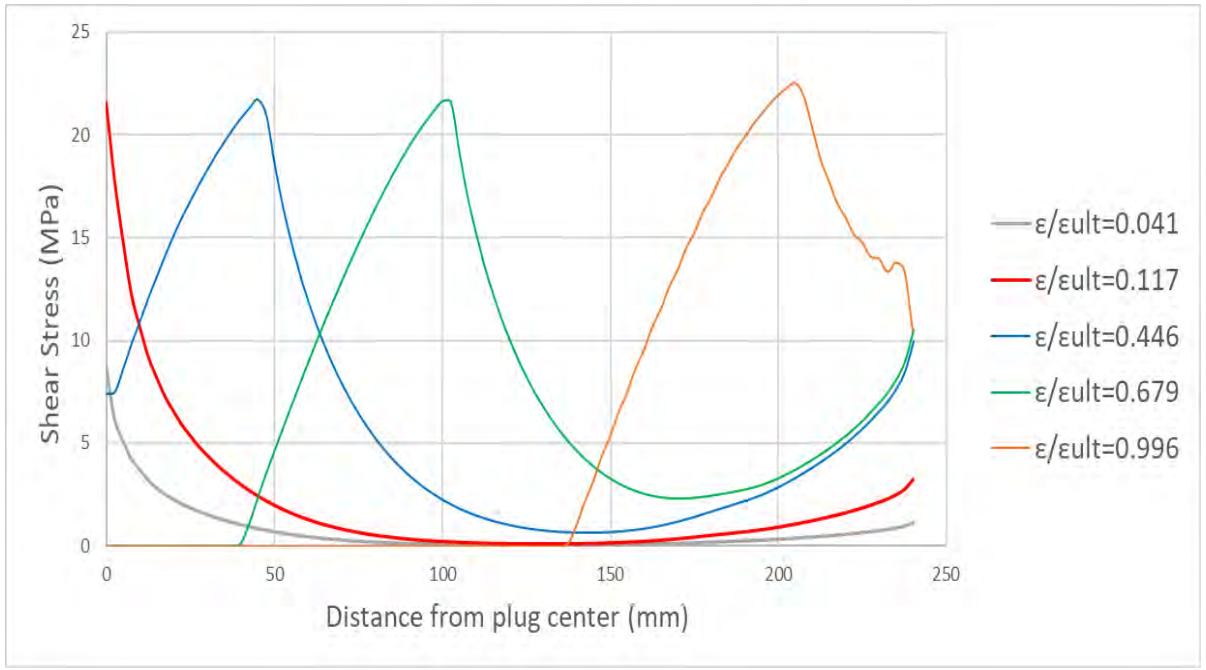


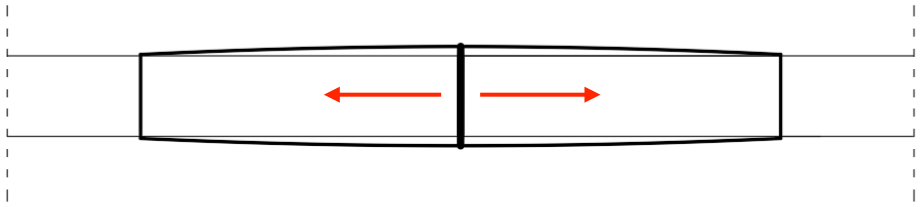
FEA: Comparison with Experiments



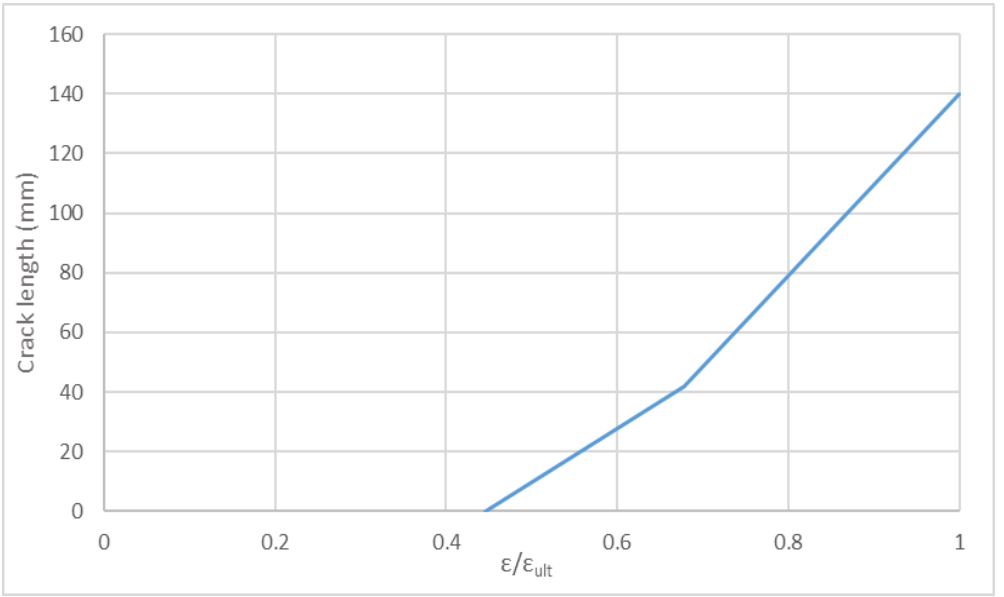
Dotted lines are averaged experimental measurements; solid lines are FEA results.

Failure Mode



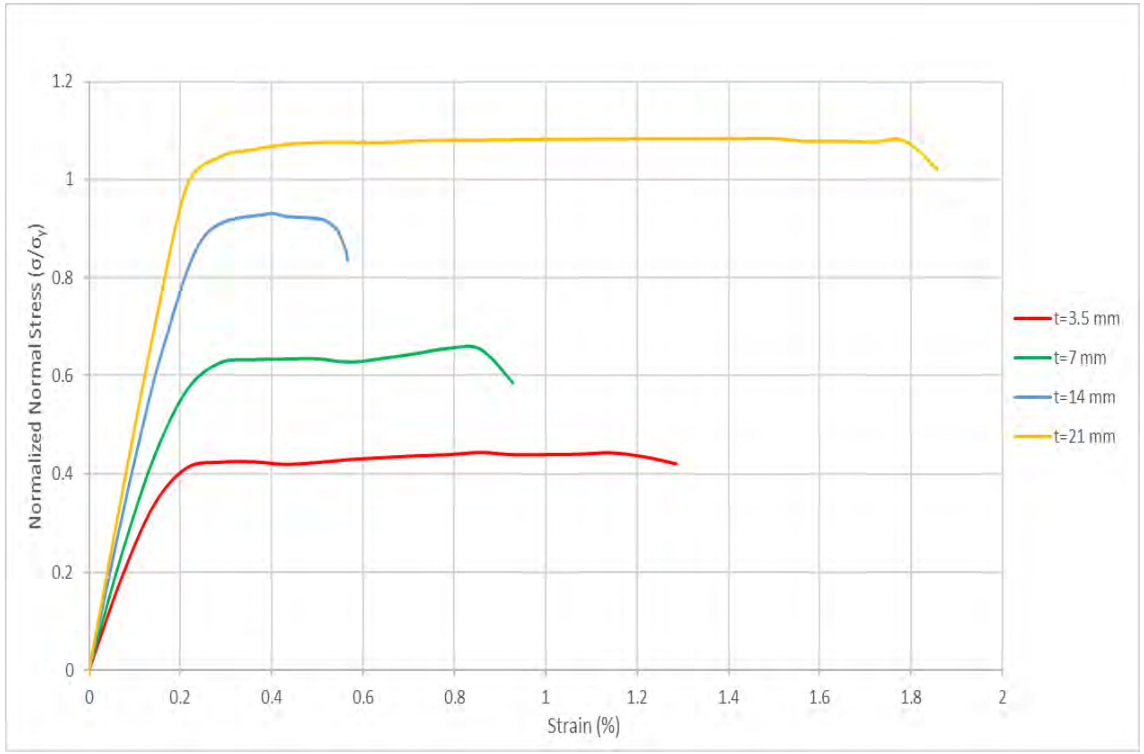


- Large stress concentrations at plug center
- Bond strength is reached
- Damage initiates at the steel-FRP interface
- Propagates until final failure

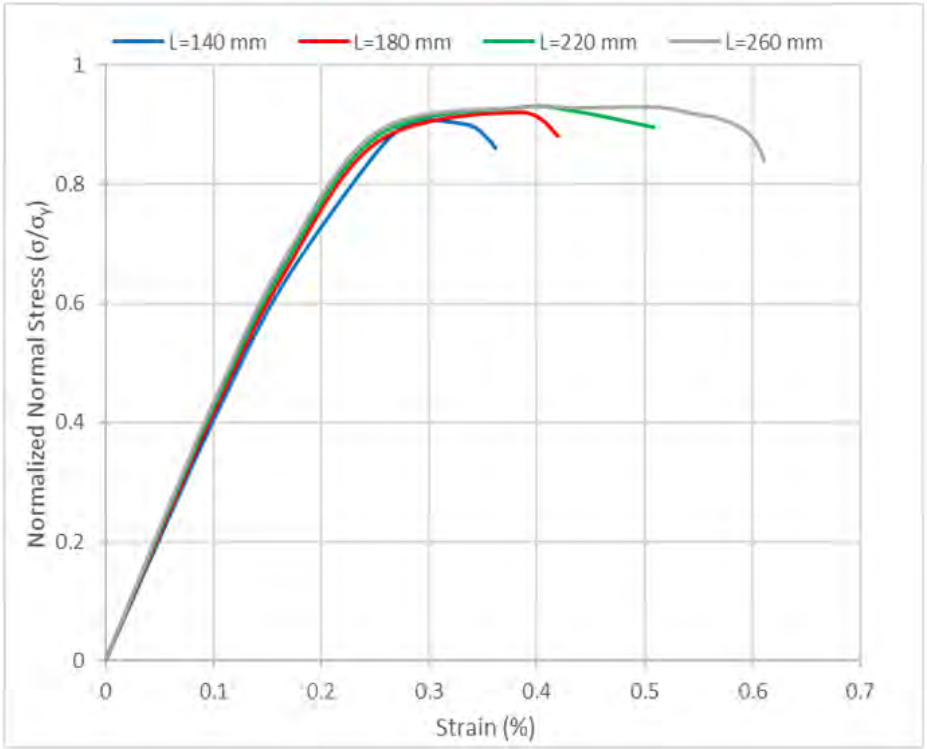


Optimization

- FRP thickness



- FRP Length



- Fabrication quality, FRP stiffness

Challenges

- Environmental conditions
  - Long-term effects
    - Fabrication
- Complex geometry / properties

Conclusions & Recommendations

- FRP wrapped steel joints can achieve almost the same static resistance as the welded joint:
  - X-joint: 88% – 89 % of the yield resistance
  - Axial joint: 71% - 96% of the yield resistance

- Indication of greatly increased fatigue life:
  - FRP joint: 960,000 cycles
  - Welded joint: 29,000 cycles

- The resistance of the joints can be optimized by:
  - Length and thickness of the wrapping
  - Fabrication

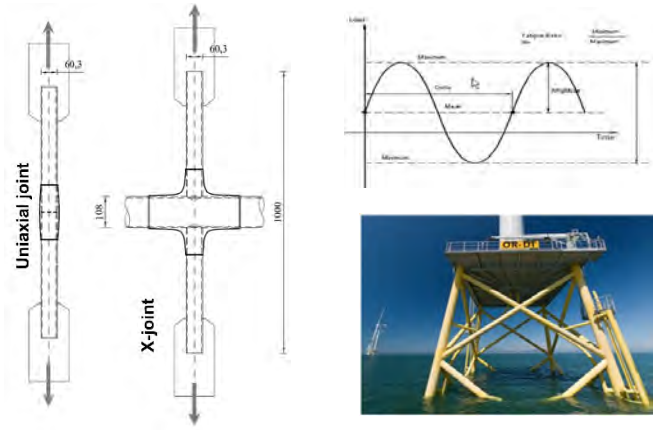
OUTLOOK

2017 2018 2020 2022

15% of the full size

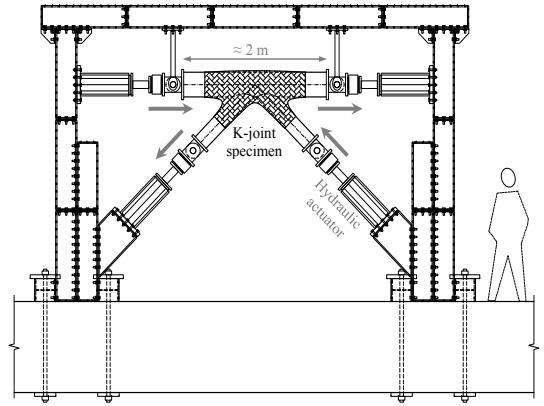
Preliminary tests
Proof of concept

downscaled to 50% size



Demonstration
Upscaling (24 exp.), Fatigue (32),
Creep (12), Accelerated aging (21)

100% - full size experiments



Full scale
Complex geometry
Certification, Production

Research objectives: Understanding, Prediction models, Optimization

Planned by Dr. M. Pavlovic

The patent pending joining technology by Wrapped FRP joints has been developed at TU Delft – Faculty of Civil Engineering and Geosciences. For further information contact Assist. prof. dr. Marko Pavlovic

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End of presentation