Progressive Damage Analysis of Pin Bearing Failure in GFRP Using Continuum Shell FE Modelling Approach

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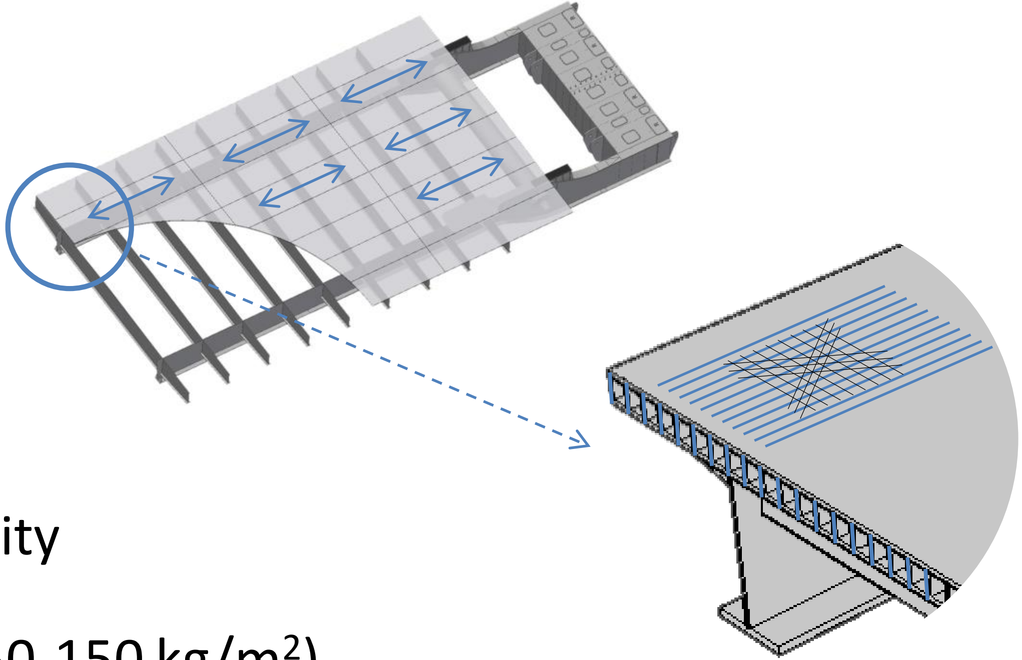
FRP decks offer great potential for renovation and new built bridges!



Steel: large stiffness and ductility

FRP: Lightweight (50-150 kg/m^2)

Fatigue and corrosion resistant

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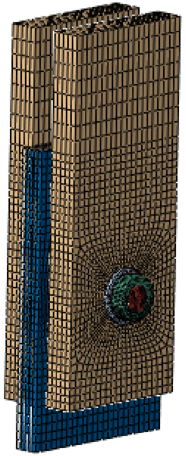
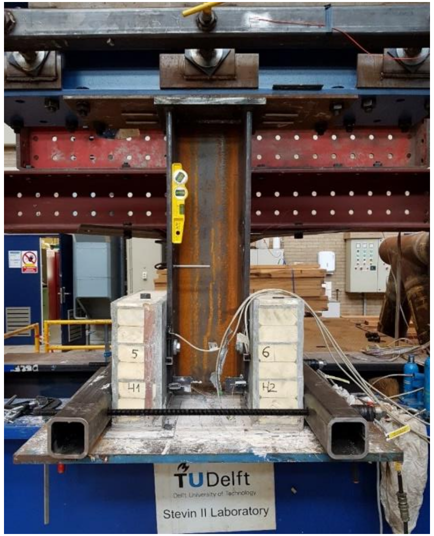
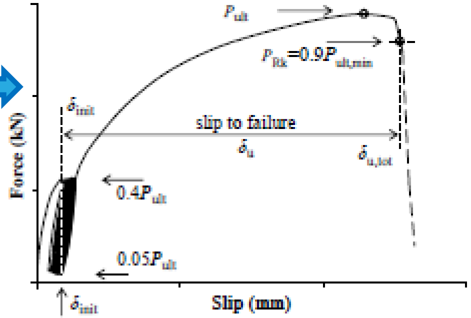
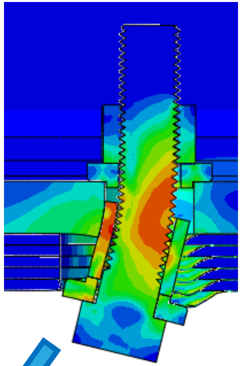
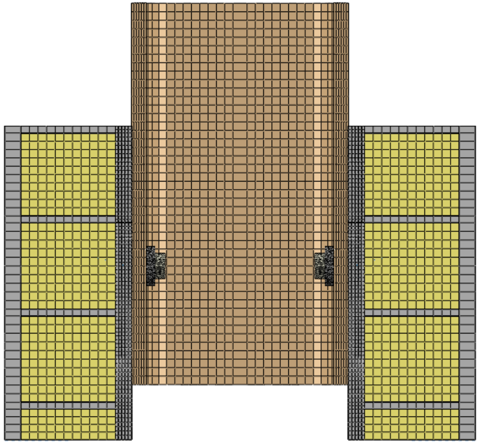
Motivation: accurately predict behaviour and failure modes of bolted connectors for steel-FRP structures at joint/component level.



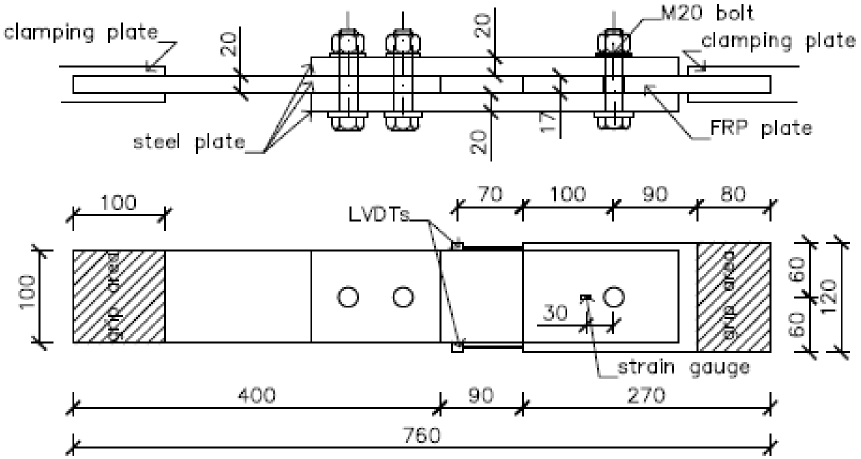








Double-lap shear tests: Compression 0° and 90°



- 7 mm thick GFRP plate (cut from FRP deck)
- S-Glass: UD and Biax
- 0°/75%; 90°/8.4%; ±45°/16.6%
- VARTM: Vf = 52%
- M20 8.8 bolt in a 21 mm hole

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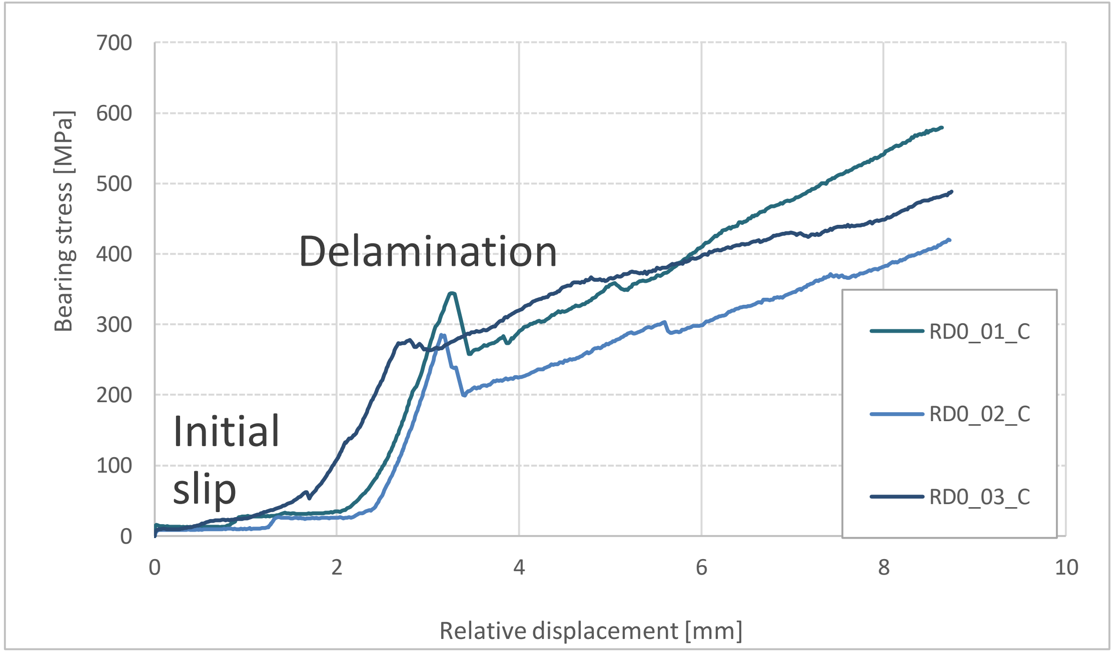
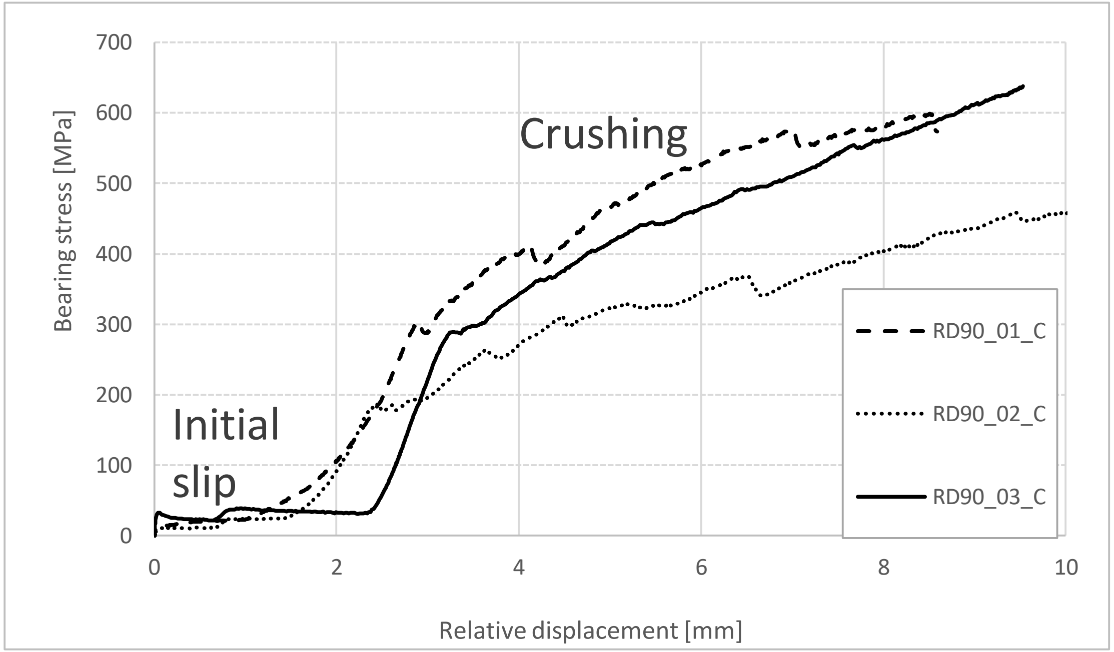
Load in principal direction of laminate: *initial delamination followed by progressive crushing*

RD0º_C



Load in perpendicular direction:
simultaneous progression of delamination and crushing



RD90º_C

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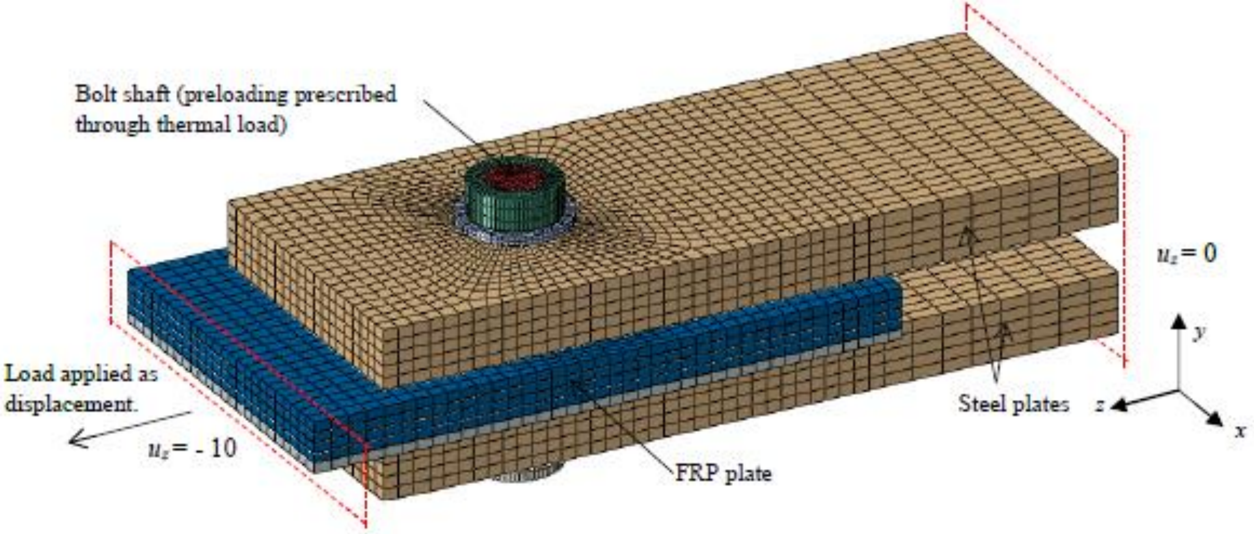
Double-lap shear tests – FE model



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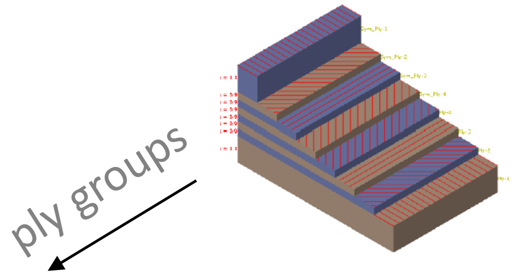
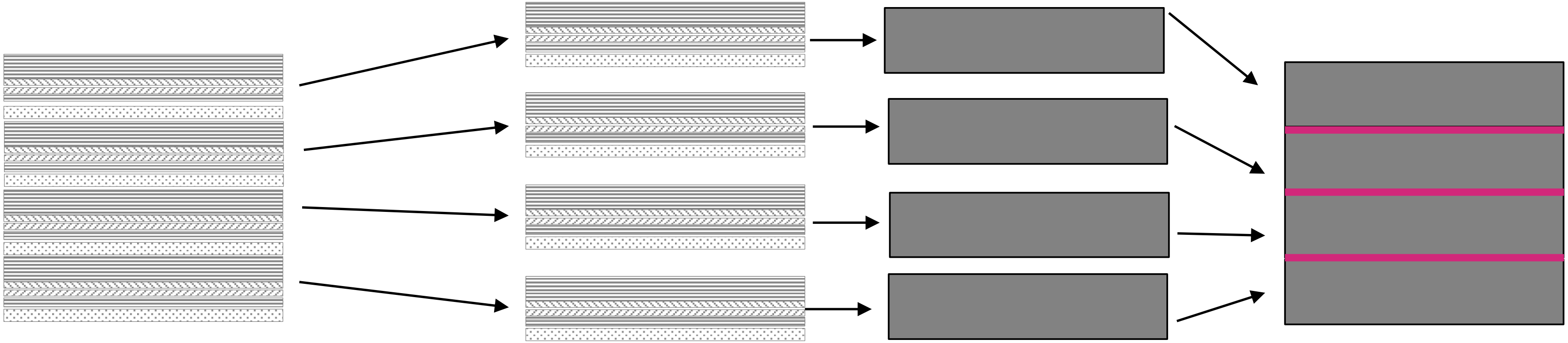
Modelling approach for FRP

- stacked continuum shell elements
- \+ cohesive zone modeling





Lay-up: [0_4/45/-45/0/90/0_4/45/-45/0/90/0_4/45/-45/0/90/0_4/45/-45/0/90/0_4/45/-45/0/90/45/-45]

- Intralaminar damage: Hashin damage model
- Interlaminar damage: cohesive surface int.

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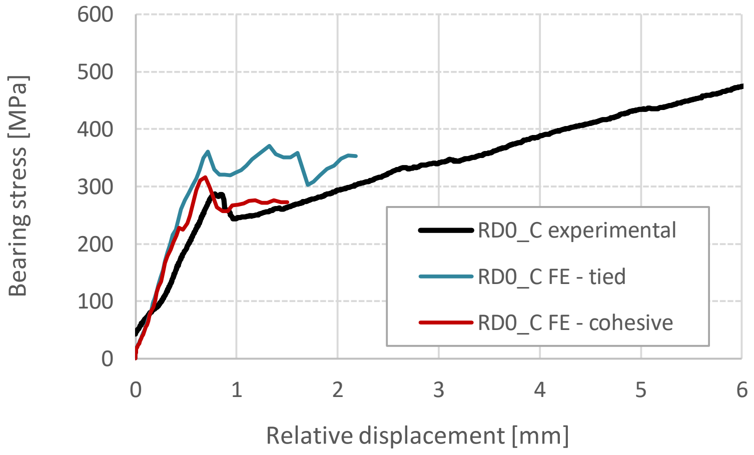
Calibration methodology: parallel to principal direction of the laminate



Modelling the delamination:
18% reduction!

Step 1:

- Start with strength values based on strain limits from literature or UD tests.
- Calibrate fracture energies by comparing bearing Experiment and FEA results.

	Longitudinal tensile	Longitudinal compression	Transverse tensile	Transverse compression
Strength [MPa]	865	700	36	131
Fracture energy [N/mm]	92	80	0.277	0.798

Dominant for bearing in principal laminate direction

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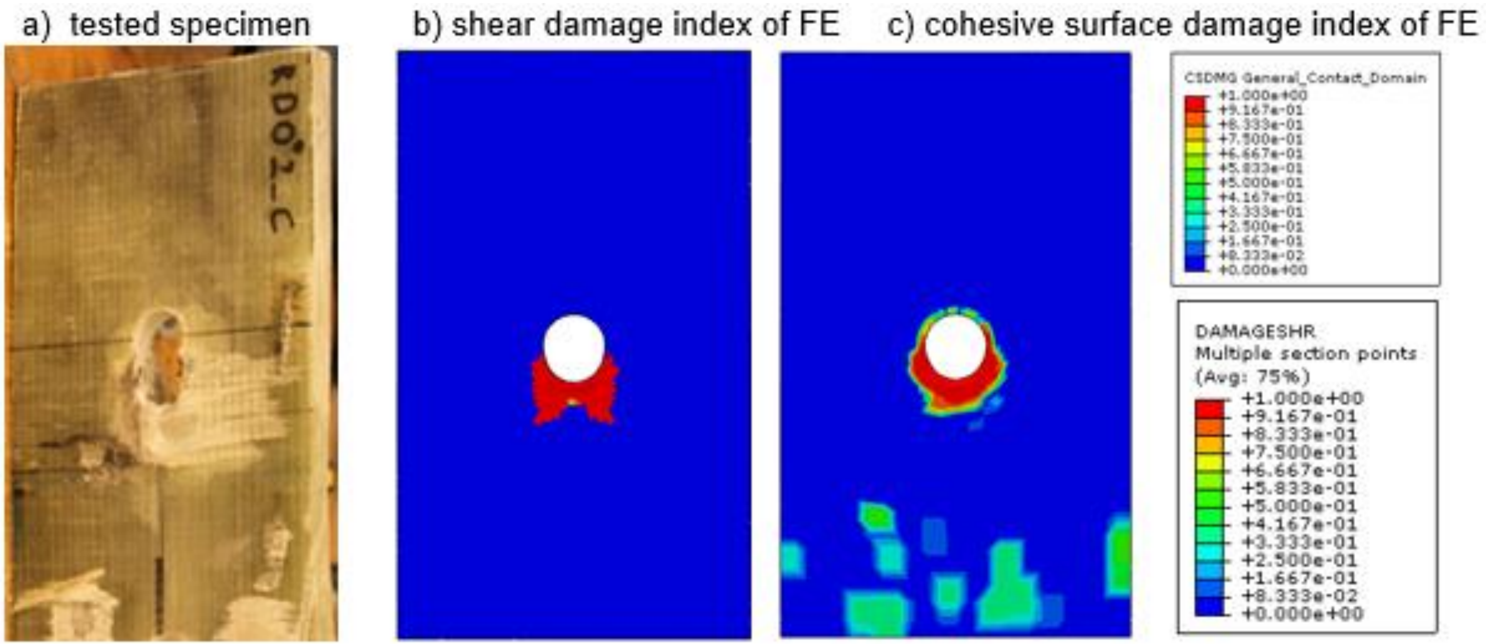
Calibration methodology:
RD0º_C at 1.5 mm relative displacement



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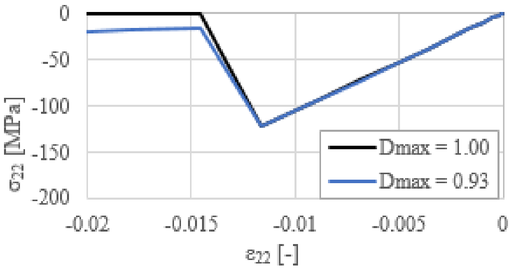
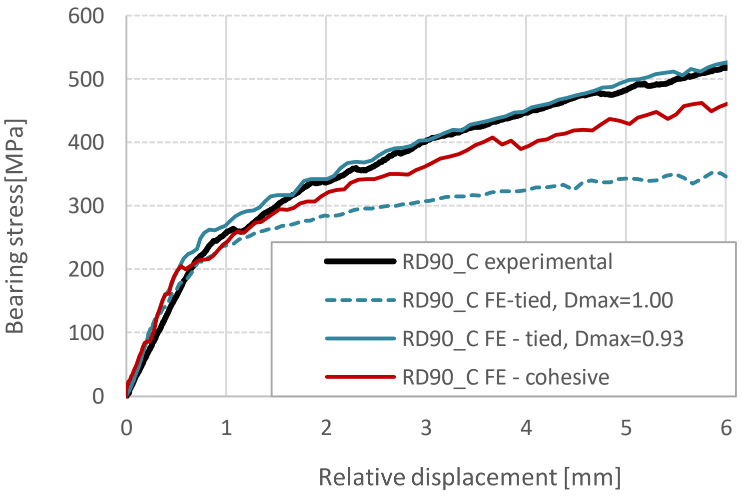
Calibration methodology: perpendicular to principal direction of the laminate

Step 2:

- Improper slope of the load-displacement curve in the progressive crushing stage.
- Problem: total damage of element.
- Adjust maximum damage index (D_{max}) in case of perpendicular direction.
- D_{max} = 0.93 in this study.





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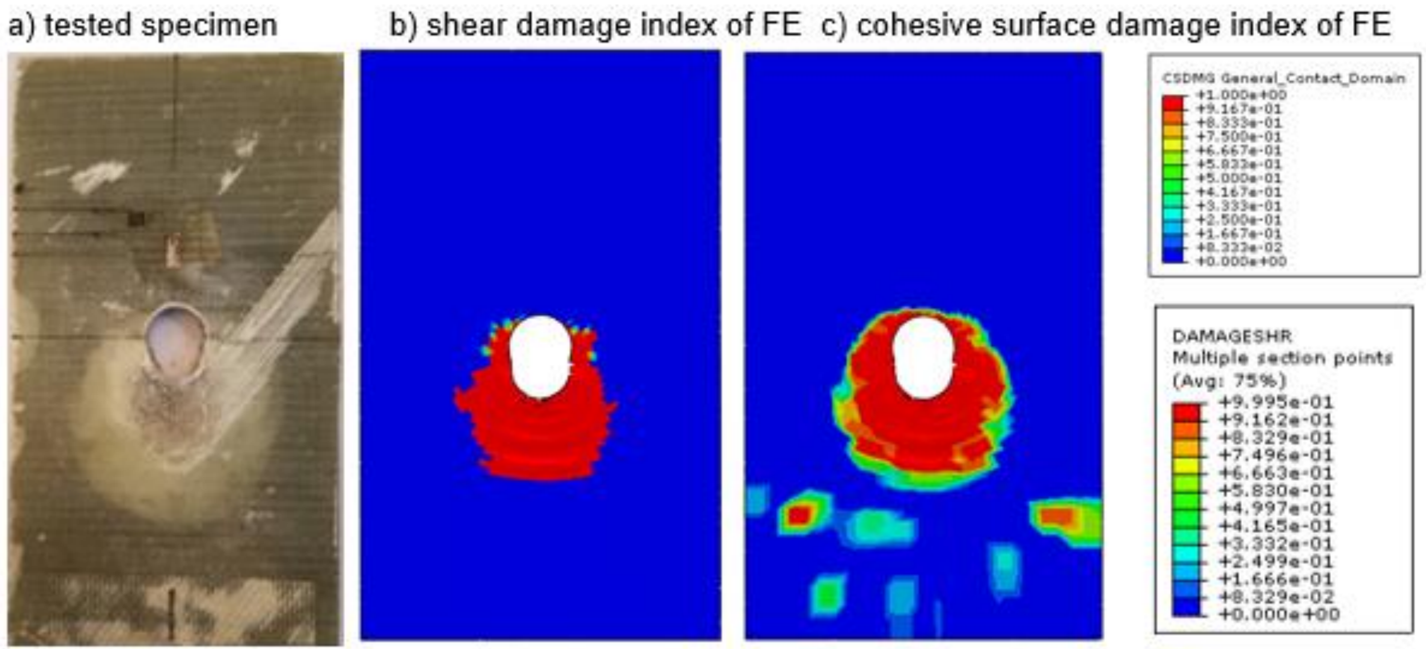
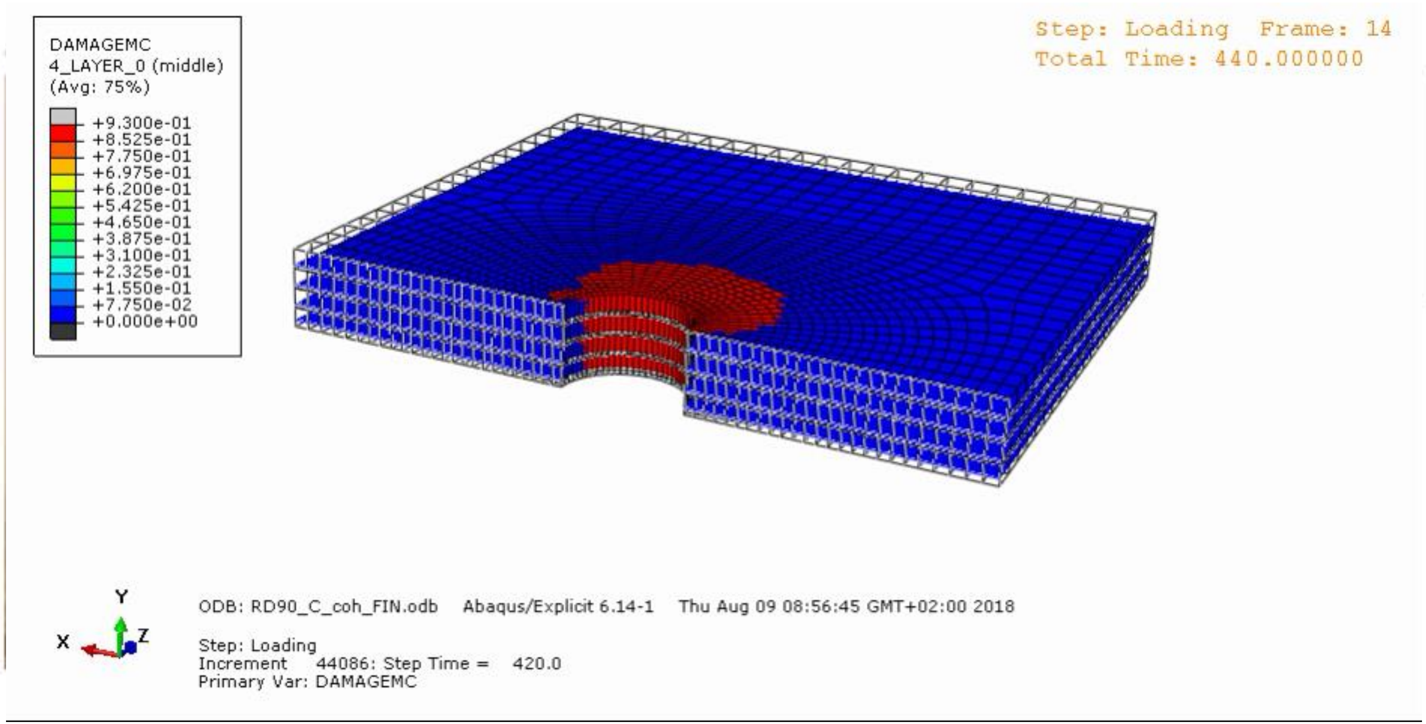
Calibration methodology:
RD90º_C at 6.2 mm relative displacement



Calibration methodology:
RD90º_C - compressive damage in matrix



Conclusion:

- Stacked continuum shell modeling capture relevant failure modes.
- FEA vs. Experiment results within 5% accuracy.
- Possible to model residual stiffness by reduced maximum damage index.
- D_{max} = 0.93 in this study for perpendicular direction of laminate.
- Inclusion of cohesive surface property (i.e. delamination) lead to approximately 18% reduction of resistance.

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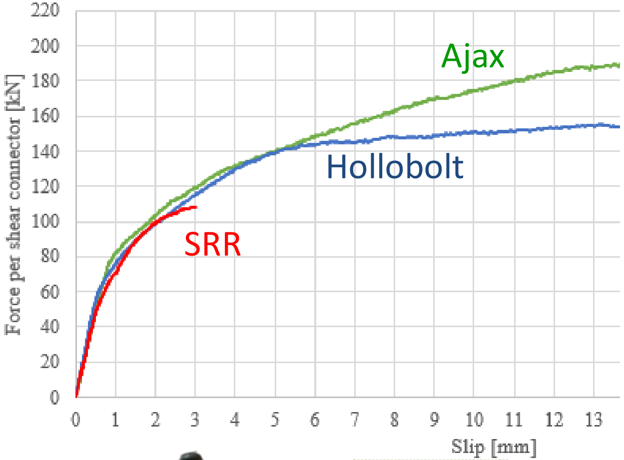
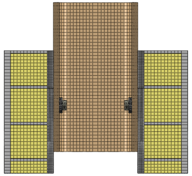
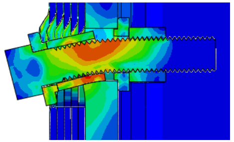
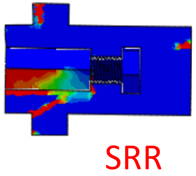
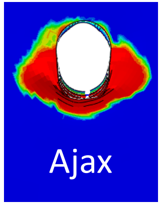
Upscaling: static behaviour of 3 connector types
Sufficient strength and stiffness, demountable

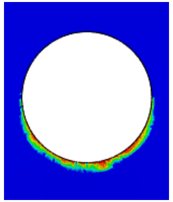


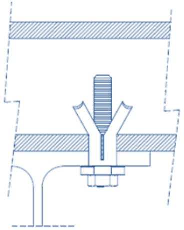


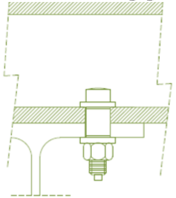


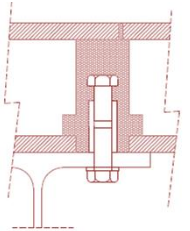


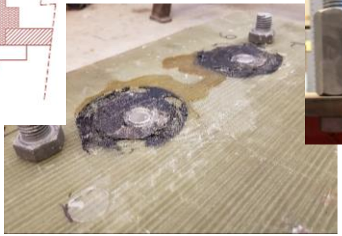








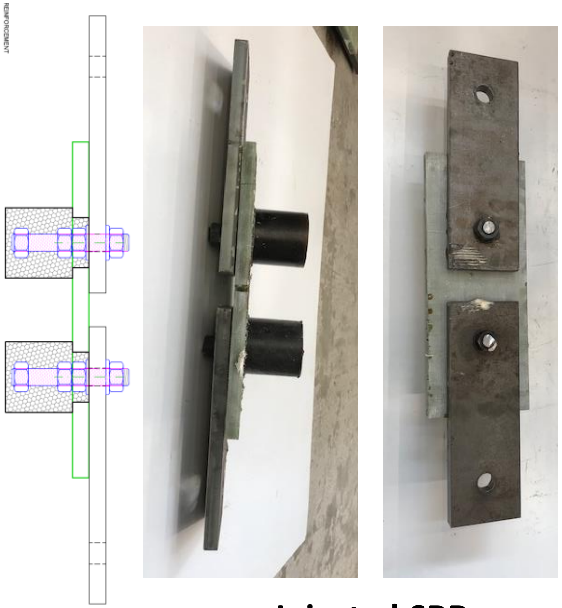




Qualification tests (2019)
Compare fatigue and creep performance

Injected Bolts

Hollow Bolts



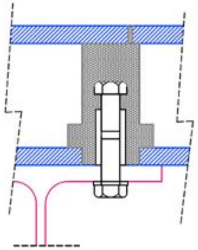
Injected SRR

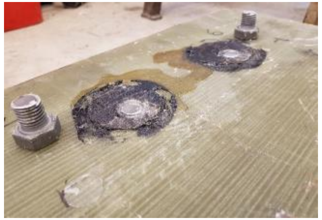
TU Delft · TU Delft · Rijkswaterstaat Ministerie van Infrastructuur en Milieu · Royal HaskoningDHV Enhancing Society Together · FiberCore europe · ARUP

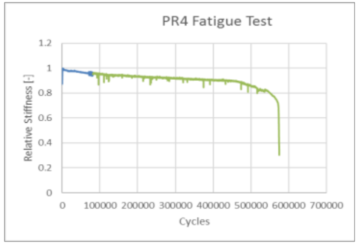
Bolted joints for FRP: Outlook

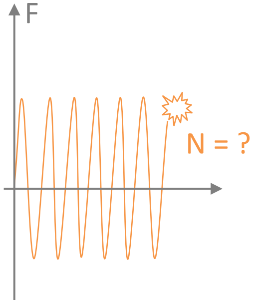
2017/2018 — SRR vs. other → 2019 — Development of SRR4FRP → 2020 …

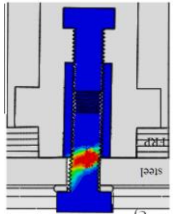
Static behaviour | Fatigue and Creep | Multiple scales, short- and long-term

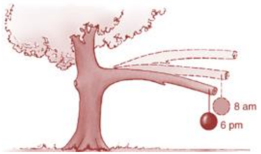


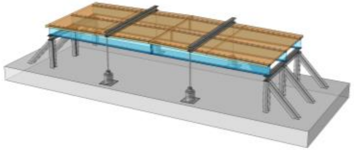


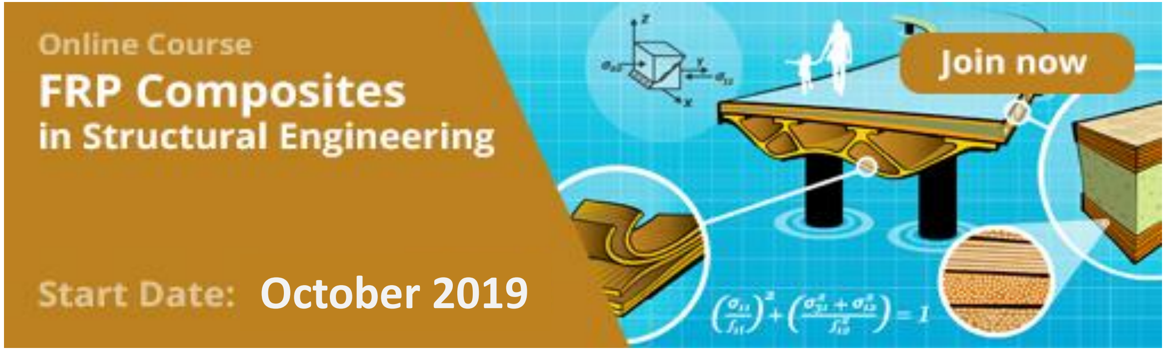












Professional Education Course

Guest lectures:

- Designed for professionals: 9 weeks, 5-6 h/week
- Design, Apply, Analyze
- Material, Joints, Structures
- 50% video lectures & reading; 50% assignments

- Two runs: 40 participants
- **Next run: October 2019**

tudelft.nl/frp-course