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Hybrid angle members. FRP-materials and design rules

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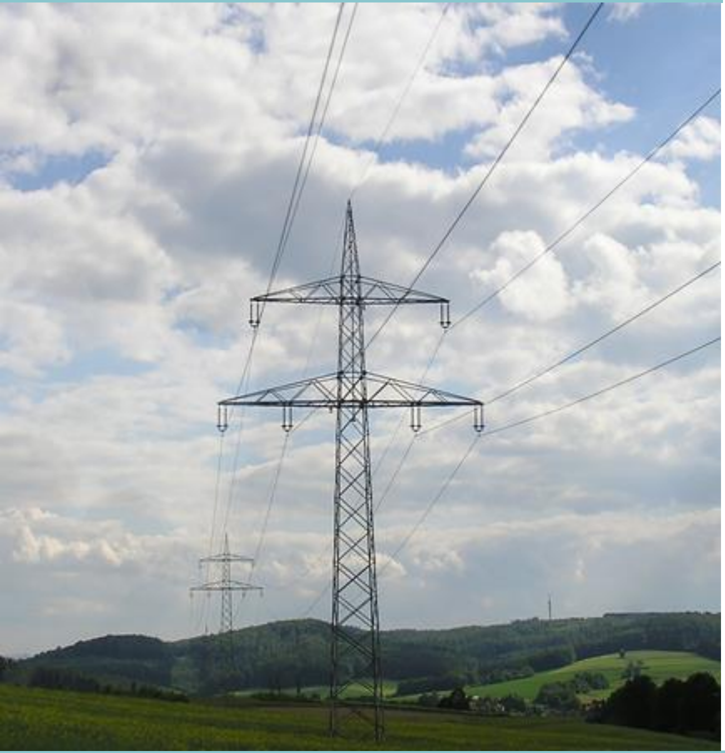

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Research Fund for Coal & Steel

8 December 2020 – Innovative Developments and Solutions for Steel Lattice Towers

Use of FRP materials

- Before construction…

Aeronautic & aerospace

Maritime

Automobile & transport

Sports

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State of the art : concrete strengthening
buildings



Slab




Beam



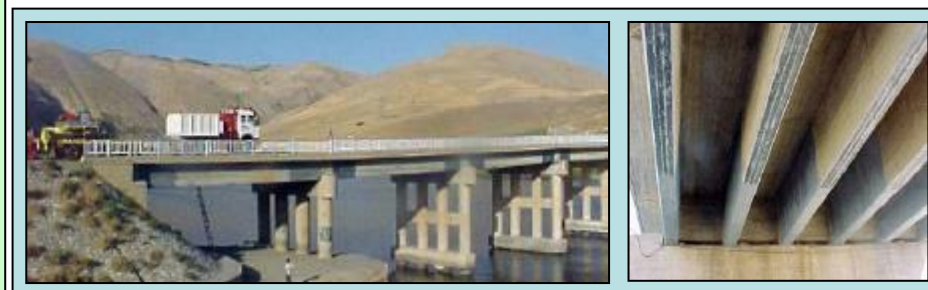

Openings in slab, beam




column, joints

State of the art : concrete strengthening
bridges

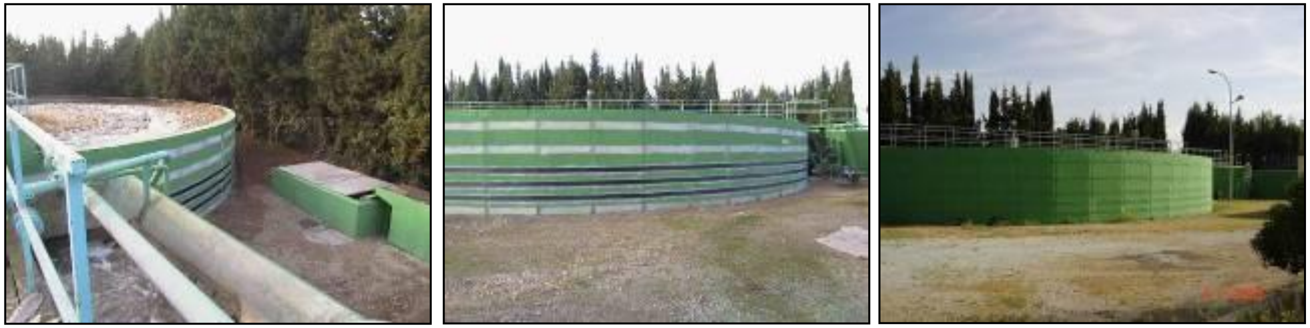
slab



beam

Pile

State of the art : concrete strengthening
other civil engineering structures



Tanks

Waste water tank

Silos

What are composites?

- Composite = mixture of a hardened matrix and a reinforcement
- In traditional construction (reinforced concrete)
  - Matrix = Concrete
  - Reinforcement = Reinforcing Bar

- In Fibre Reinforced Polymer (FRP)
  - Matrix = Polymer Resin
  - Reinforcement = Fibre

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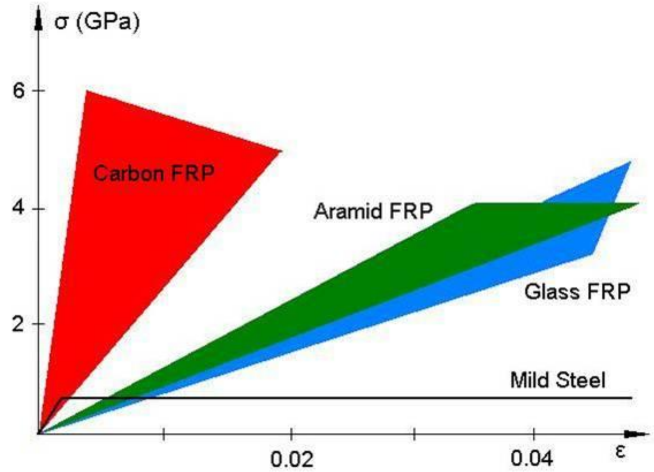
Various fibres on the market

- **Glass** – low stiffness, low strength, not very useful for structural application

- **Aramid** – absorb water, tough, good in impact situation (energy absorber), good in vibration, sensitive to humidity

- **Carbon** – high stiffness, high tensile strength, high durability, inert to most chemical, very low creep, the most brittle fibre.



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Appropriate fibre for structural application

- The literature highlights **<u>that carbon fibres are the best solution</u>** for structural steel strengthening as it is for concrete structure.

    - High strength,
    - High E modulus,
    - Excellent fatigue properties,
    - High durability

- Appropriate matrix: epoxy

- Combination: **Carbon Fibres Reinforced Polymers (CFRP)**

Products for the application

- FRP material and adhesive:
  - CFRP to strengthen steel members: **Sika CarboDur laminates**

  - Epoxy structural adhesive to bond CFRP on steel: **Sikadur-30**

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Geometrical properties of the laminates

- Sika CarboDur geometrical properties:

Type	Width (mm)	Thickness (mm)	Cross Section (mm^2)
Sika CarboDur S512	50	1.2	60
Sika CarboDur S812	80	1.2	96
Sika CarboDur S1012	100	1.2	120
Sika CarboDur S1512	150	1.2	180

- Due to steel angles dimensions (L 70x70x7mm): **Sika CarboDur S512**

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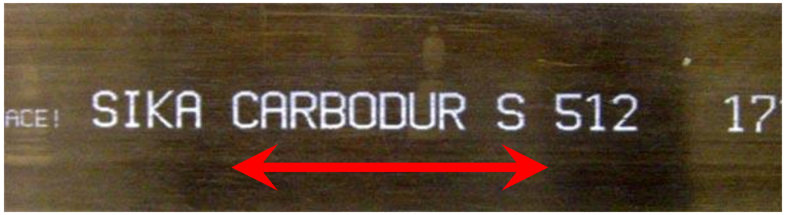
Mechanical properties of the laminates

- Sika CarboDur S mechanical properties:

Laminate Tensile Strength	Mean value	**3 100 MPa**	(EN 2561)
	5% fractile-value	**2 900 MPa**	
Laminate Modulus of Elasticity in Tension	Mean value	**170 GPa**	(EN 2561)
	5% fractile-value	**165 GPa**	
Laminate Elongation at Break in Tension	Mean value	**1.8%** Values in the longitudinal direction of the fibres	(EN 2561)



Uni-directionnal fibres orientation

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Packaging of the laminates

- Available in rolls, unlimited length
  - 10, 25, 50 m in cardboard box
  - 250 m in wooden box

Properties of the resin: Sikadur 30

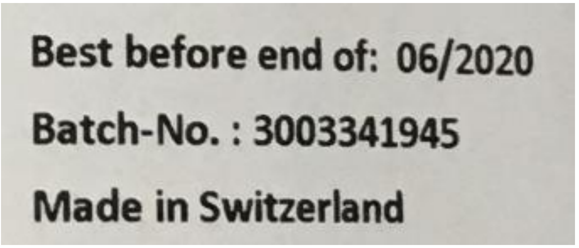
- Epoxy Adhesive
- 6 kg unit
- Ready to use
- 2 components
- Pasty and thixotropic resin
- CE Marking: EN 1504-4

General recommendations for application

Safety gloves

Safety glasses

- Store in original unopened, sealed and undamaged packaging in dry conditions at temperatures between +5°C and +30°C.
- Protect from direct sunlight.
- Shelf life: 24 months from date of production (“best before” on the label)
- Note the batch number of products (traceability)


Best before end of: 06/2020

Batch-No. : 3003341945

Made in Switzerland

Example of label

Sandblaster

Sikadur helix

Application roller

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Steel substrate preparation

- Epoxy Sikadur 30 adhesive can bond to degreased galvanized substrate, but it depends on the targeted bond level that we want to reach.
- Best alternative solution:
  - Prepare the steel substrate by **sandblasting with a grade of 2.5** (or by grinding)
- If angles are painted, the sandblasting (or grinding) preparation will remove paint and galvanization.

Sa 2½

Based on rust grade C, Mill scale, rust, paint coatings and foreign matter are removed. Any remaining traces of contamination shall show only as slight stains in the form of spots or stripes.
Standard cleaning grade for method 11.2 “Barrier coating” according EN 1504-9.

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Steel angle preparation for tests

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Sikadur 30 resin preparation

- Mix components A+B together for at least 3 minutes with a mixing spindle attached to a slow speed electric drill (max. 300 rpm) until the material becomes smooth in consistency and a uniform grey color.

- Avoid air inclusion while mixing.

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Sika CarboDur laminate preparation & application

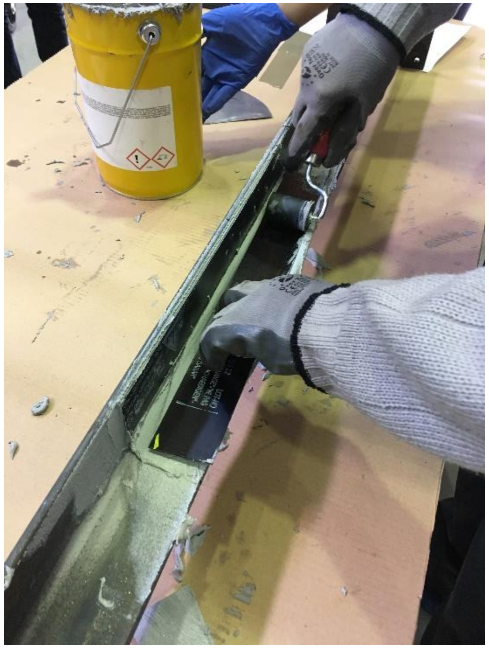
- Just before the application, the Sika CarboDur plate must be cleaned with an impregnated rag of Sikadur Colma Cleaner.
- With the trowel, apply a layer of Sikadur 30 on the Sika CarboDur plate, around 1 – 1.5 mm (not on the face with the name of the product).
- With the trowel, apply a layer of Sikadur 30 on the prepared substrate, around 1 mm.



Sika CarboDur laminate preparation & application

- Once the Sika CarboDur plate installed, use the application roller to remove on each side the air enclosed and the excess of resin.
  - Ensured to have a good contact between substrate / resin / plate and no air enclosed.

- Remove the excess of resin on each side of the plate, do not re use it.



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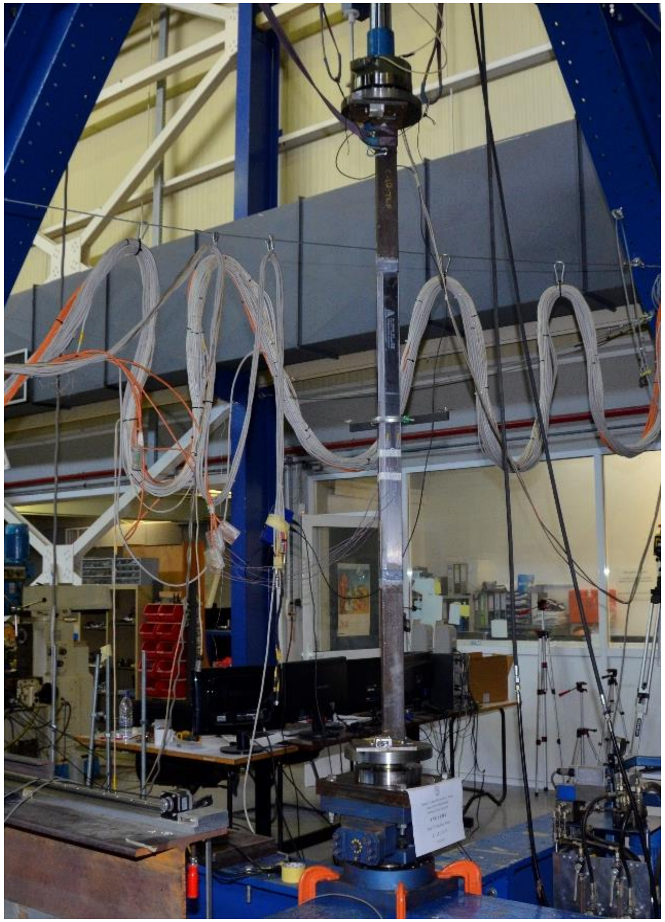
Hybrid angle members – Design rules

Experimental validation

Tests on hybrid members performed at NTUA

- 5 bending tests
- 16 compression (buckling) tests
  - ➢ 2 pure compression
  - ➢ 14 compression + bending



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Hybrid angle members – Design rules

Types of failure

FRP under tension – fracture of the fibers

FRP under compression – plate breaking
Detachment of the FRP plate due to shear strain

Buckling of the hybrid member

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Hybrid angle members – Design rules

Design resistances of hybrid cross-section

1. Tension

$$N_{t,Rd} = A_s \cdot \frac{f_y}{\gamma_{M0}} + A_f \cdot \frac{\eta \cdot f_f}{\gamma_f}$$

2. Compression

$$N_{c,Rd} = A_s \cdot \frac{f_y}{\gamma_{M1}} + A_f \cdot \frac{\eta \cdot k \cdot f_f}{\gamma_f}$$

k = 0.5 reduction factor for pure compression

3. Moment resistance to strong axis bending

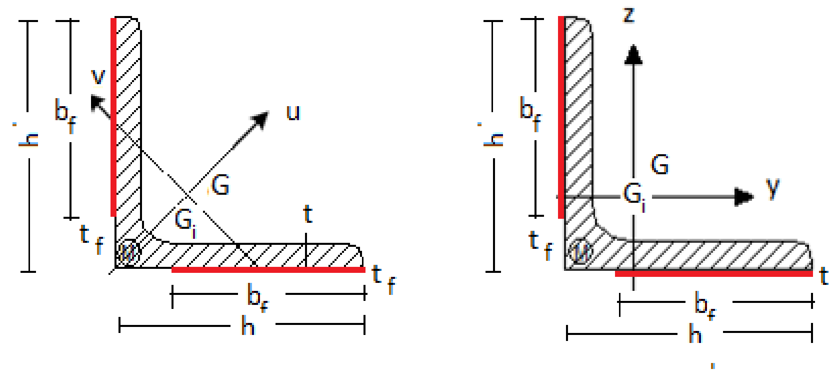
$$M_{u,Rd} = M_{u,pl,s,Rd} + \frac{\eta \cdot f_f \cdot t_f \cdot b \cdot (2b-h)}{3\sqrt{2} \cdot \gamma_f}$$

where $M_{u,pl,s,Rd}$ is the design moment resistance of steel sestion

4. Moment resistance to weak axis bending

$$M_{v,Rd} = \frac{f_y \cdot t}{\sqrt{2} \cdot \gamma_{M0}} \cdot \{(h-x_0)^2 + x_0^2\} + \frac{2 \cdot \eta \cdot f_f \cdot t_f}{3 \cdot \sqrt{2} \cdot (h-x_0) \cdot \gamma_f} \left\{(h-x_0)^3 + \left[x_0 - (h-b_f)\right]^3\right\}$$

where: $x_0 = \frac{\frac{b}{2} - \sqrt{(b/2)^2 - ac}}{a}$, $a = 2 f_s t$, $b = 3 f_s t h + f_f t_f b_f$, $c = f_s t h^2 - f_f t_f b_f \left(\frac{b_f}{2} - h\right)$



Notation, principal and geometric axes for hybrid section

G_i centroid of hybrid section, G centroid of steel section

As area of steel section, Af area of FRP plate

Iui , Iiv Second moments of area for the hybrid section

f_y yield strength of steel , f_f tensile strength of FRP

γ_{M0} , γ_f material safety factors

η is the conversion factor for FRP

Resistances are calculated for the hybrid section

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Hybrid angle members – Design rules

Design resistances of hybrid members

1. Buckling Resistance

Critical buckling loads

$$N_{cr,u} = \frac{\pi^2 \cdot E_s \cdot I_{ui}}{l^2}, \quad N_{cr,v} = \frac{\pi^2 \cdot E_s \cdot I_{vi}}{l^2}$$

Reduction factors χu, χv as derived from buckling curve **b**

$$N_{bu,Rd} = \chi_u \cdot N_{c,Rd}, \quad N_{bv,Rd} = \chi_v \cdot N_{c,Rd}$$

2. Combined effects - Compression and bending

Strong axis bending

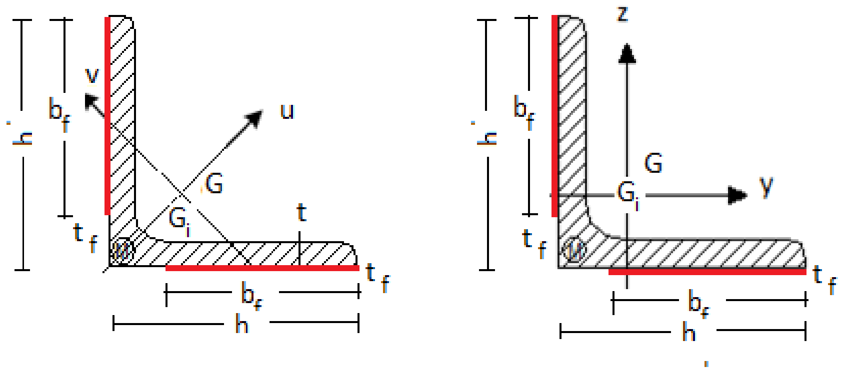
$$\left(\frac{N_{Ed}}{N_{bu,Rd}} + k_{uu}\frac{M_{u,Ed}}{M_{b,Rd}}\right)^{\xi} + k_{uv}\frac{M_{v,Ed}}{M_{v,Rd}} \leq 1$$

Weak axis bending

$$\left(\frac{N_{Ed}}{N_{bv,Rd}} + k_{vu}\frac{M_{u,Ed}}{M_{b,Rd}}\right)^{\xi} + k_{vv}\frac{M_{v,Ed}}{M_{v,Rd}} \leq 1$$

Factors $\xi = 2$

$k_{uu} = \frac{C_u}{1-\frac{N_{Ed}}{N_{cr,u}}}$, $k_{uv} = C_v$, $k_{vu} = C_u$, $k_{vv} = \frac{C_v}{1-\frac{N_{Ed}}{N_{cr,v}}}$, $C_u = 0{,}6+0{,}4\psi_u$ $-1 \leq \psi_u = \frac{M_{2u}}{M_{1u}} \leq 1$, $C_v = 0{,}6+0{,}4\psi_v$ $-1 \leq \psi_v = \frac{M_{2v}}{M_{1v}} \leq 1$



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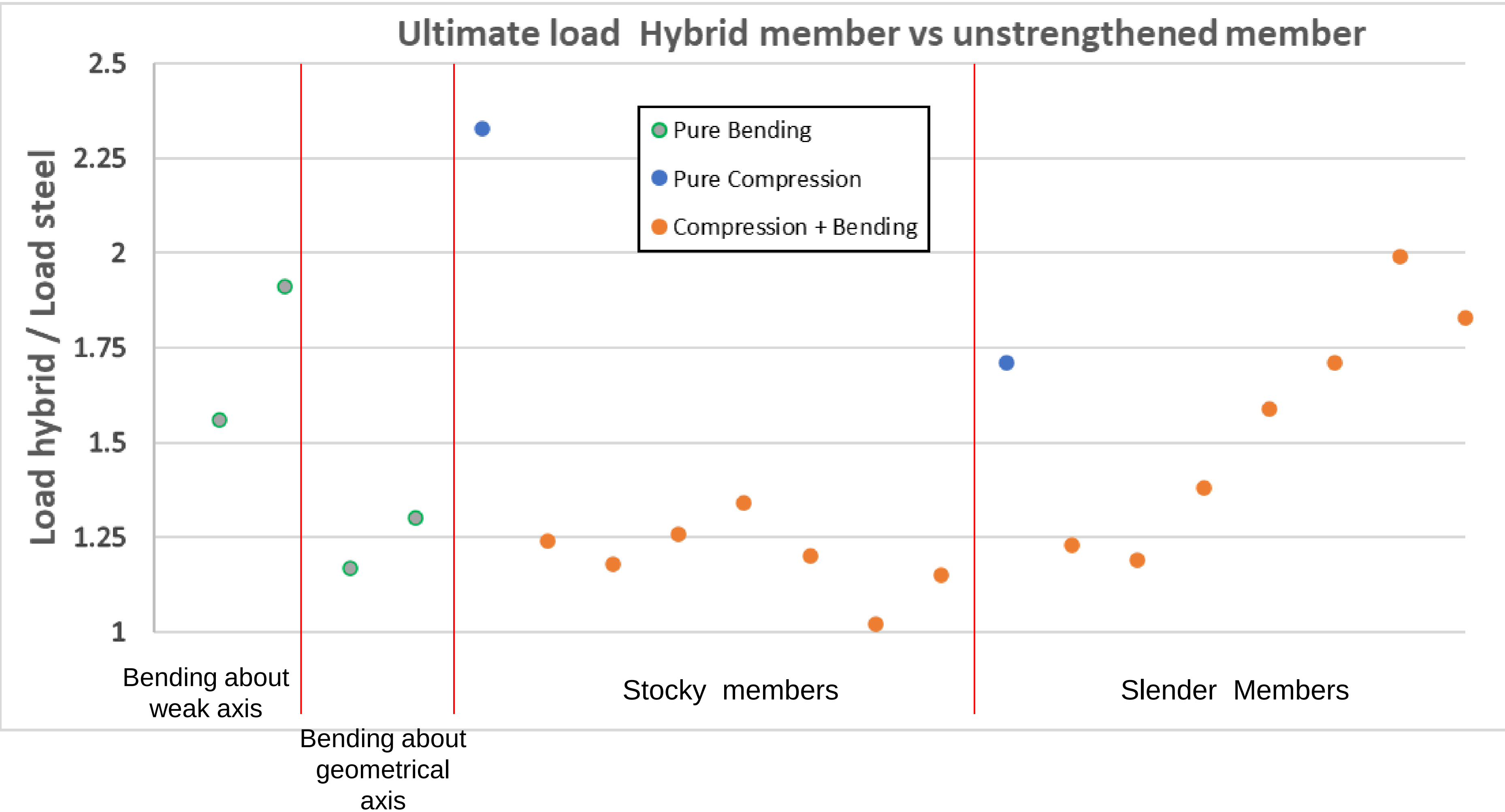

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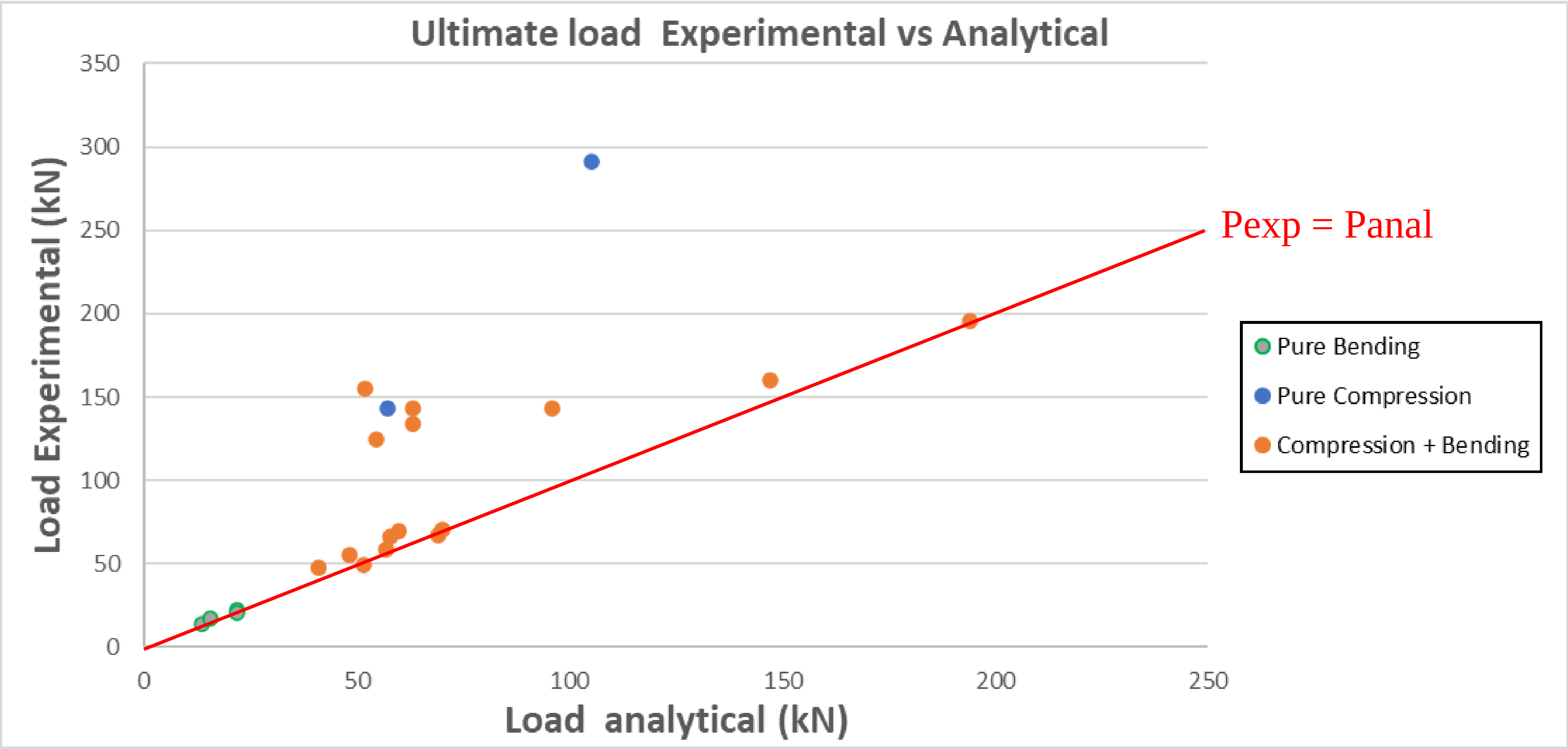
Hybrid angle members – Design rules

Experimental validation



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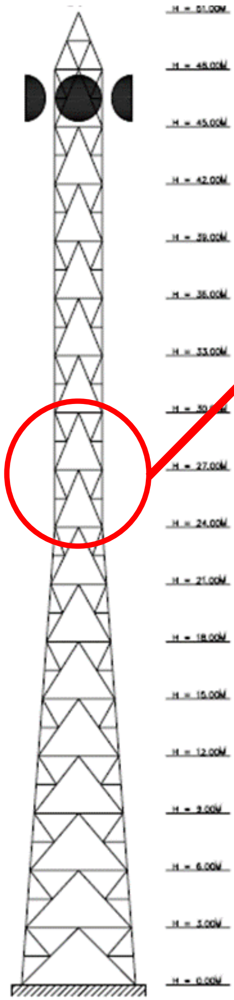
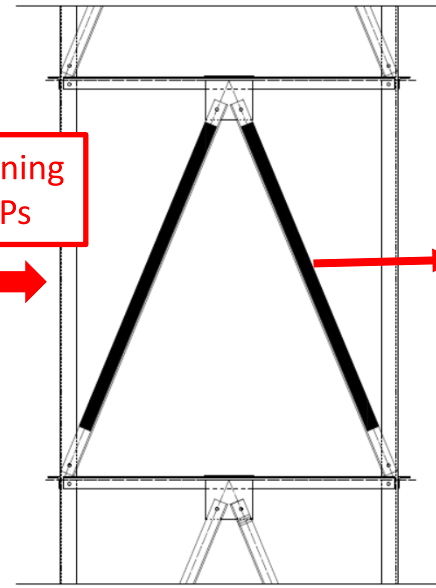
Application of FRP strengthening to steel lattice tower (example)



Typical failure - Braces' failure

Strengthening with FRPs



Brace member L70.7	
$N_{t,RD}$	$N_{b,RD}$
168.79 kN	77.97 kN

Brace Hybrid member L70.7 + FRP	
$N_{t,RD}$	$N_{b,RD}$
540.79 kN	115.43 kN

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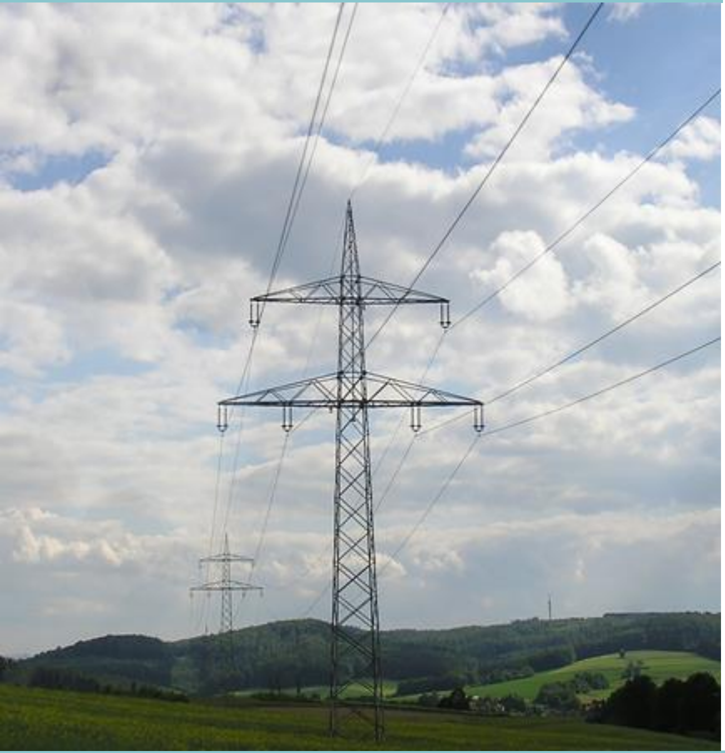
Thank you for your attention…



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