"ANGELHY"

Title: **ANGELHY – Innovative solutions for design and strengthening of telecommunications and transmission lattice towers using large angles from high strength steel and hybrid techniques of angles with FRP strips**

Fund: Research Fund for Coal and Steel (RFCS-2016)

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Summary

Angle sections are extensively used in lattice towers and masts for telecommunication or electricity transmission. In addition, single or built-up sections made of angles are used in a wide field of civil engineering applications including buildings, bridges or for strengthening existing structures. However, there is a lack of consistent European rules for design for members made of angle profiles. Recent developments have led to a wider application of large angle sections made of high strength steel, for which European design rules are missing. Due to increasing loads, strengthening of existing towers, especially for communication, is an issue faced in everyday practice. However, design codes cover only one specific configuration. The objective of this project is the development of design rules that exploit the carrying potential of angle sections, including large angles from high strength steel, the improvement of existing rules for built-up sections and the incorporation of innovative types of built-up sections composed of two angles with unequal sections. In addition, hybrid profiles composed of angle sections and FRP plates will be investigated and relevant design rules will be developed. Such hybrid members provide innovative and cost-effective solutions for strengthening existing lattice towers. Experimental and numerical investigations will be performed at the level of cross sections, members, as well as of structural tower subassemblies to incorporate the influence of realistic connection conditions, existing eccentricities and load shedding between tower walls. Case studies will be examined and a performance-based assessment of the actual system safety will be conducted incorporating uncertainties in loads, material and geometry. A comprehensive evaluation of the reliability infused by the new design rules will be made. The proposed rules will be integrated in design software for towers.

Market Analysis -Case studies – Code review

Within the framework of the program the following have been conducted:

- Market analysis and identification of structural typologies for telecommunication towers and transmission towers
- Analysis and design of six case studies:
    1. Prototype telecommunication tower
    2. Conventionally strengthened prototype telecommunication tower
    3. FRP strengthened prototype telecommunication tower (Figures 1 and 2)
    4. Transmission tower conventional linear analysis
    5. Transmission tower non-linear static analysis
    6. Lattice girder in structural application made of single and built-up angle sections
- Critical assessment of EN rules for lattice towers and design assisted by testing

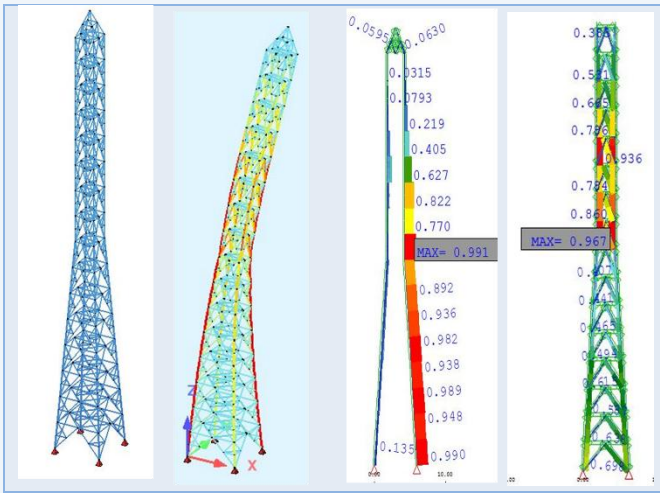

Fig. 1: Numerical analysis of a telecommunication tower

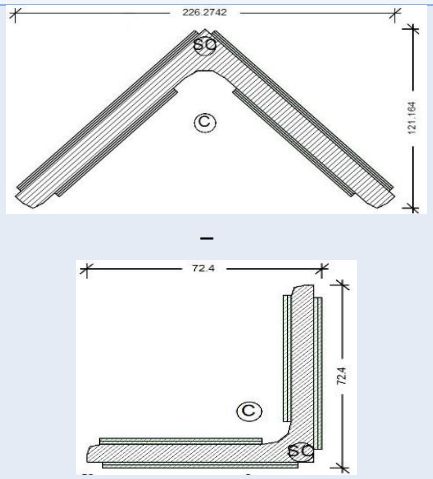

Fig. 2: Sections strengthened using CFRP plates

Experimental investigations

The following tests are planned to be performed:

- Compression tests on large angle columns from high strength steel
  - 12 Compression tests on large angle columns from high strength steel (S460)
  - two eccentricity values and two length values
  - two sections (L150x150x18, L200x200x16)
- Tests on hybrid angle members strengthened with CFRP plates (Figure 3)
  - 16 compression tests on angles columns (L70.7)
    - two length values (1750, 2300 mm)
    - two values for CFRP thickness
    - two values for strengthening length
    - five load eccentricity values
  - 5 three-point bending tests on angles (L70.7)
    - one length value (1750 mm)
    - two values for CFRP thickness
    - one value for strengthening length
    - Different loading axes (u and v)
- Full scale tests on telecommunication tower's segments (Figure 4)
  - six full scale tests on tower's segments, two of them on towers strengthened with CFRP plates
    - two loading directions (orthogonal and diagonal)
- 16 laboratory buckling tests on closely spaced built-up members (Figure 5)
  - six buckling tests on back-to-back connected angles
  - six buckling tests on star battened angles with equal sections
  - four buckling tests on star battened angles, each one with different sections

Fig. 3: Buckling tests on hybrid angle columns

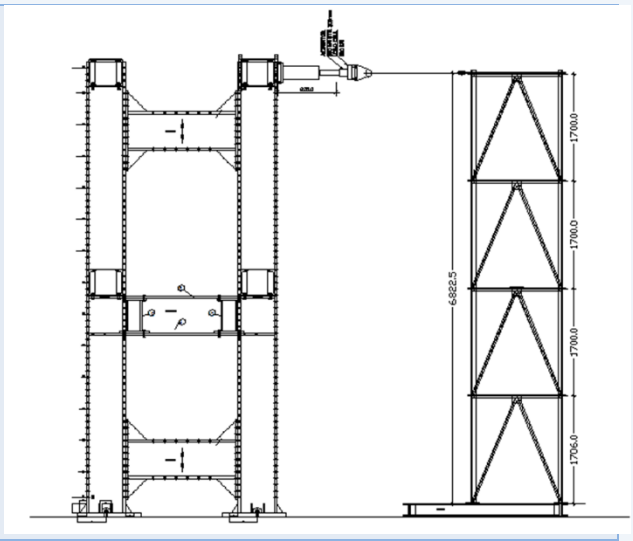

Fig. 4: Testing set-up for full scale tests

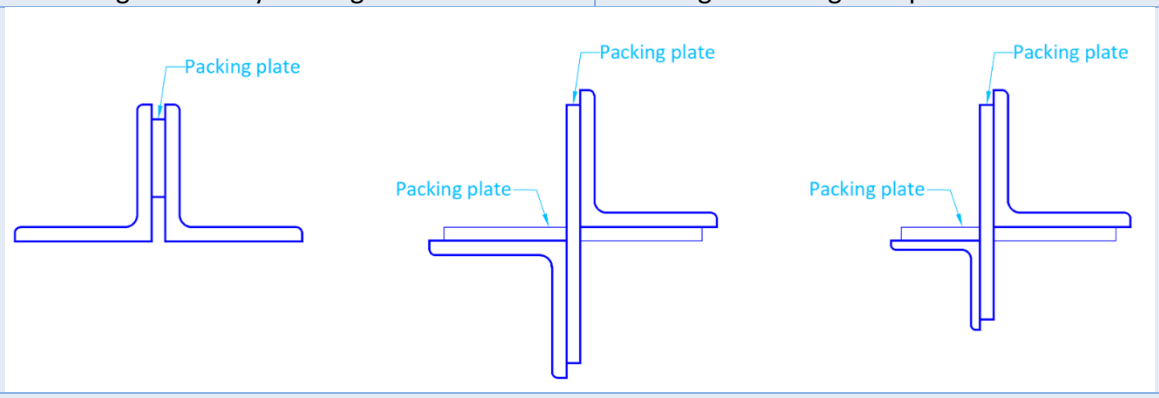

Fig. 5: Configuration of built-up members

Numerical investigations

The following numerical investigations are planned to be performed:

- numerical investigation of buckling and three-point bending tests for single angle members (Figure 6)
- numerical investigation of buckling and three-point bending tests for hybrid angle members strengthened with CFRP plates
- alternative numerical models for lattice telecommunication towers
- numerical investigation of built-up members

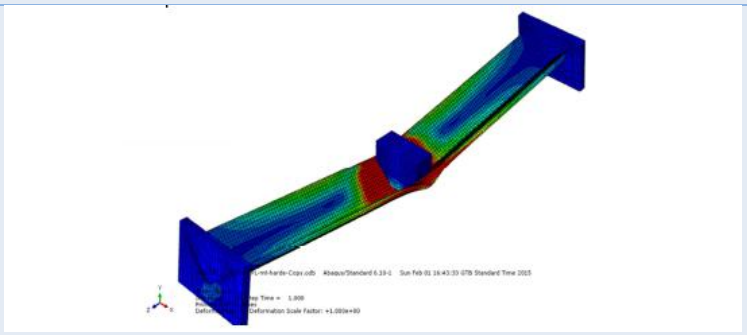

Fig. 6: Numerical shell element model

Validation and design rules

Based on the numerical and the experimental results the following design rules are planned to be developed:

- design rules for members composed of single angle sections
- design rules for hybrid angle members with FRPs
- design rules for closely spaced built-up members (angles connected through packing plates and

angles connected through battens in two perpendicular planes), including built-up members with unequal sections.

Also, parametric models of case studies and loads are planned to be formed for both telecommunication and transmission towers. Based on them:

- probabilistic analyses are going to be performed for towers
- a performance-based approach will be formulated for estimating the reliability level of towers subject to probabilistic wind, ice and temperature climatic loads under the influence of ageing
- cost/benefit analyses will be performed to discern the improvements brought on by the new design recommendations
- the proposed design rules for high strength angles and FRP-steel hybrid members will be verified and, where necessary, calibrated to offer the required reliability at the component and system level.

A general design guide (containing design recommendations) is planned to be proposed on the design of lattice towers and structures with high-strength angle sections as well as for application and design of strengthening measures in existing towers by addition of a second angle or by FRP strips

Codification and Dissemination

After the completion of the research and the extraction of the basic conclusions and design rules, they are planned to be issued:

- Proposals for Code amendments (EN 1993-3-1, EN 1993-1-1 and EN 54341)
- Recommendations for design and construction of hybrid members composed of steel sections and FRPs
- Dissemination and implementation of the project results, including publications, workshops, presentations, updated versions of software etc.