Structural Analysis of Bolted L-flange and C1 Wedge Connection for Offshore Wind Turbine Support Structures

Hasan Al Ali – Jeppe Jakobsen – Jonas Klint Junker

Aalborg University

Structural and Civil Engineering

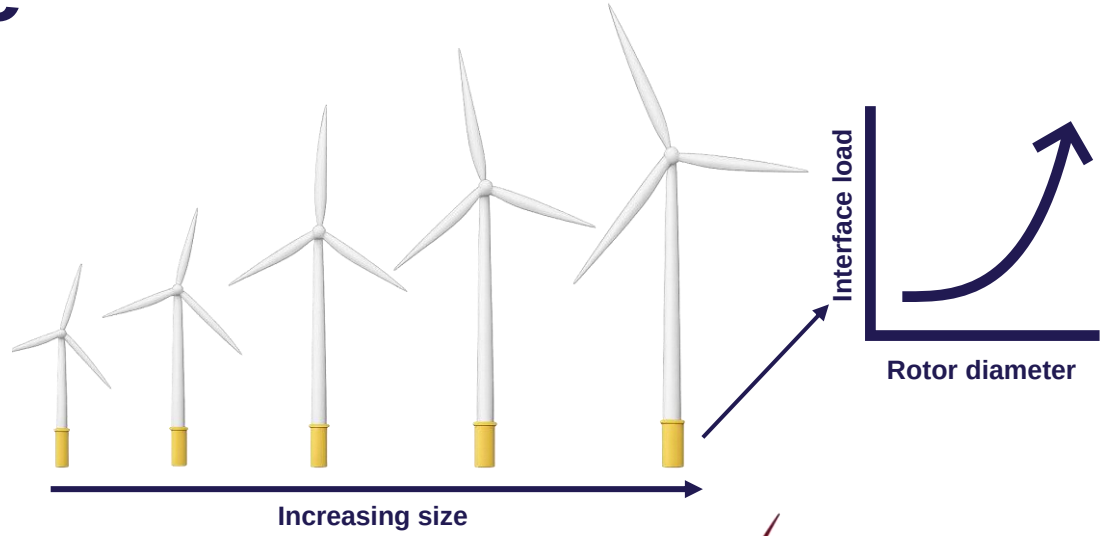
Master Thesis

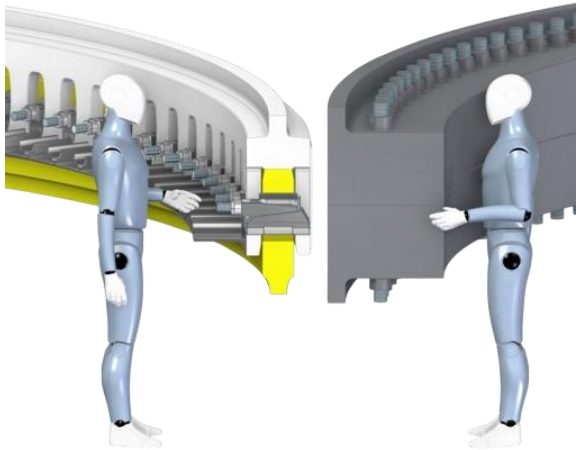
Content

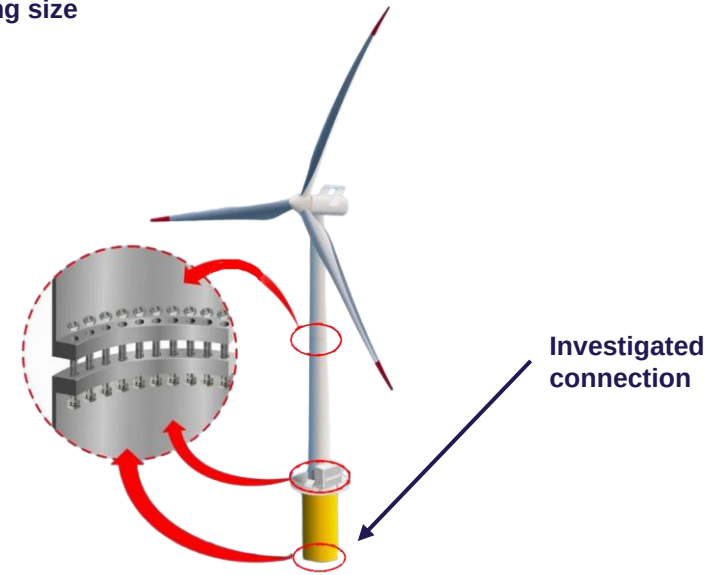
- Motivation and purpose
- Methods
  - Analytical methods
  - FEA
- Results
- Conclusion

Motivation and purpose

- Climate change and global warming
  - Growing demand for sustainable solutions
  - This has led to an expansion
    - Size and loads
    - Requires greater structural capacity
    - On the limit of feasibility
- Compare two flanges at 8 meter outer diameter
  - Bolted L-flange
  - C1 Wedge Connection
- Limit states
  - Ultimate limit state
  - Fatigue limit state

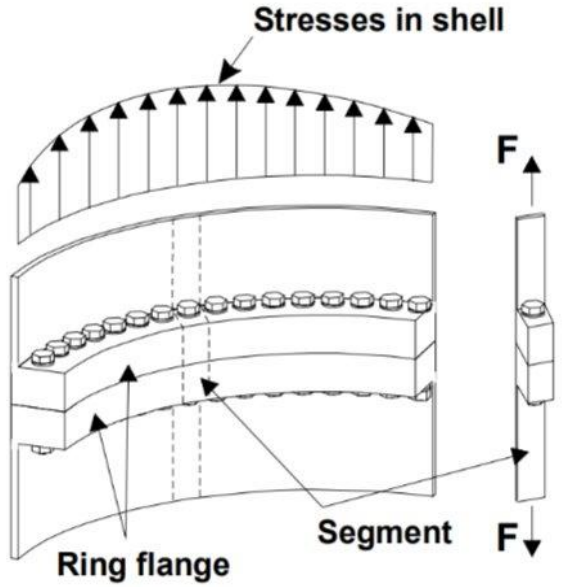


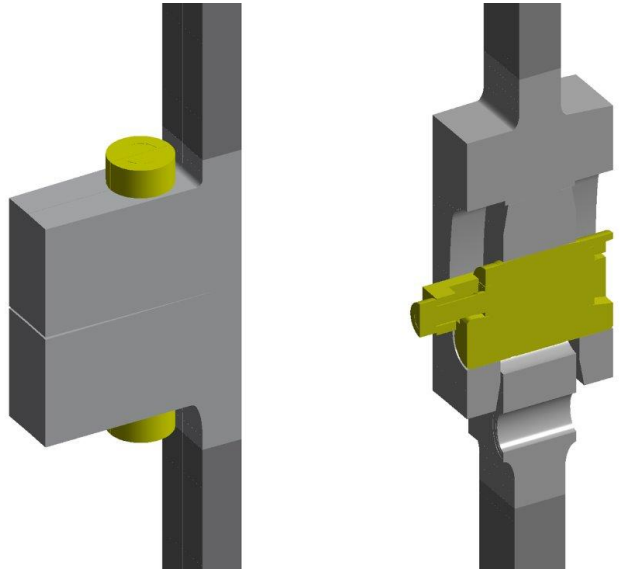




Methods

- Segment model approach
- Ultimate limit state
  - Analytical expressions:
    - Plastic hinge theory for the L-flange using principle of virtual work
    - Yielding of cross-sections in tension for the C1 Wedge Connection
  - Non-linear Finite Element Analysis (FEA)
    - Material models, contact conditions and geometry
- Fatigue limit state
  - Miner's rule based on design equivalent moment (DEM) and stress concentration factors (SCF)
    - SCF’s found by FEA using linear material models

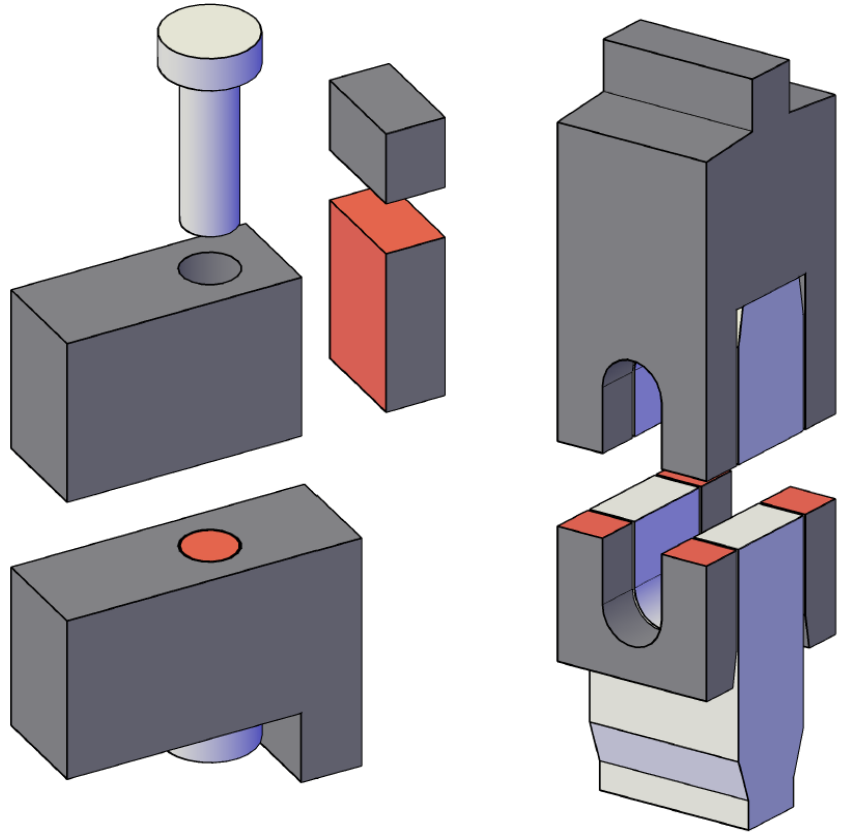




Analytical

Results

- Assumed failure mode:
  - L-flange:
    - Bolt yielding and plastic hinge forming in the can or flange element
  - C1 Wedge Connection:
    - Yielding of upper webs



653 MNm

L-Flange

Analytical Design ULS Capacity

742 MNm

C1 Wedge Connection

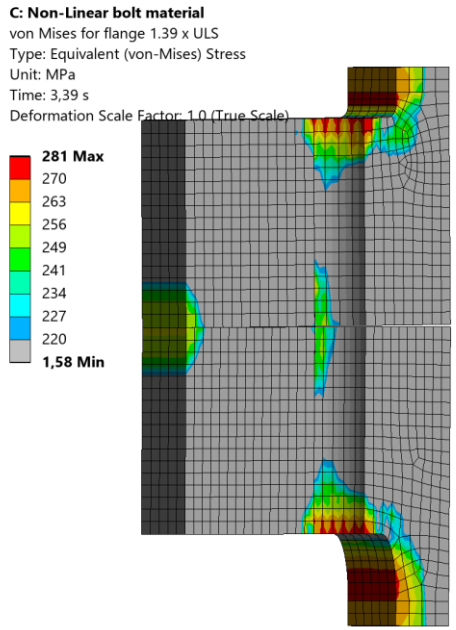
Analytical Design ULS Capacity

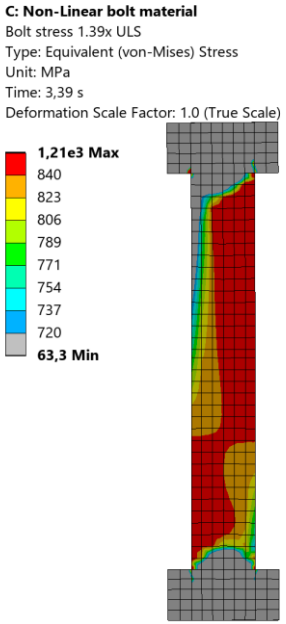
***13.6% greater than L-Flange**

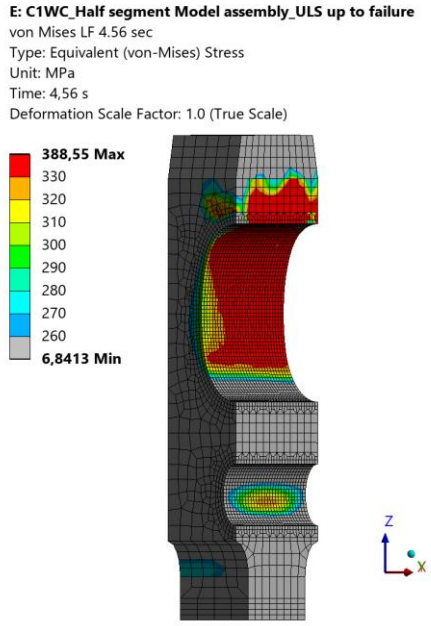
Finite Element Analysis

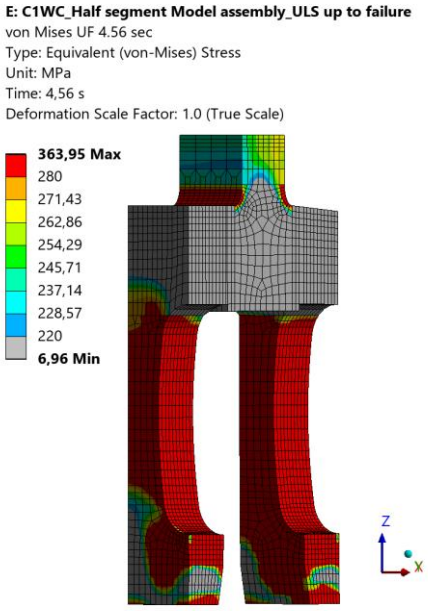
Results

- Expected failure mode:
  - L-flange:
    - Bolt yielding and plastic hinge forming in the can or flange element
  - C1 Wedge Connection:
    - Yielding of upper webs
- FEA verifies the analytical approach









698 MNm

L-flange

Numerical Design ULS Capacity

***6.8% greater than analytical**

973 MNm

C1 Wedge Connection

Numerical Design ULS Capacity

***31.1% greater than analytical**

***39.4% greater than L-flange**

Fatigue

Results

- Design Equivalent Moment of 230 MNm
- SCF and S-N Curves
- Miner’s rule determined the accumulated damage

72%

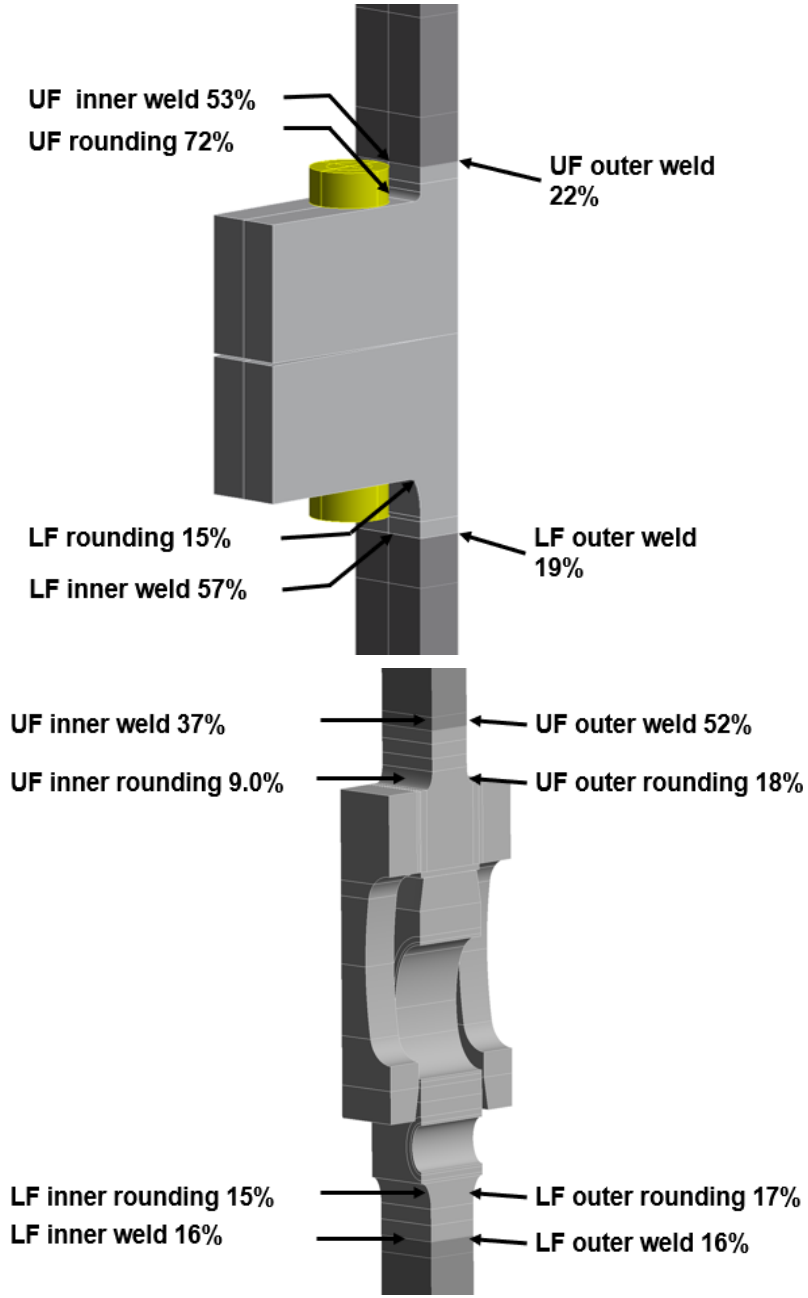
L-flange

Highest accumulated fatigue damage

52%

C1 Wedge Connection

Highest Accumulated fatigue damage



Conclusion

- C1 Wedge Connection
  - Greater capacity at 8 meter outer diameter in both limit states
  - Better scalability for larger turbines
  - Faster on-site installation
- L-flange
  - Easier maintenance if failure occurs
  - Normalized and faster production
  - More practical experience

- Choice should be based on needed capacity and overall cost

Description	Bolted L-flange	C1 Wedge Connection
Analytical design moment (ULS)	653 MNm	740 MNm
Numerical design moment (ULS)	698 MNm	973 MNm
Highest accumulated fatigue damage (FLS)	72% (Rounding)	52% (Weld)
Considerations	Easy maintenance if failure occurs, normalized and faster production, more practical experience, less material usage	Faster on-site installation