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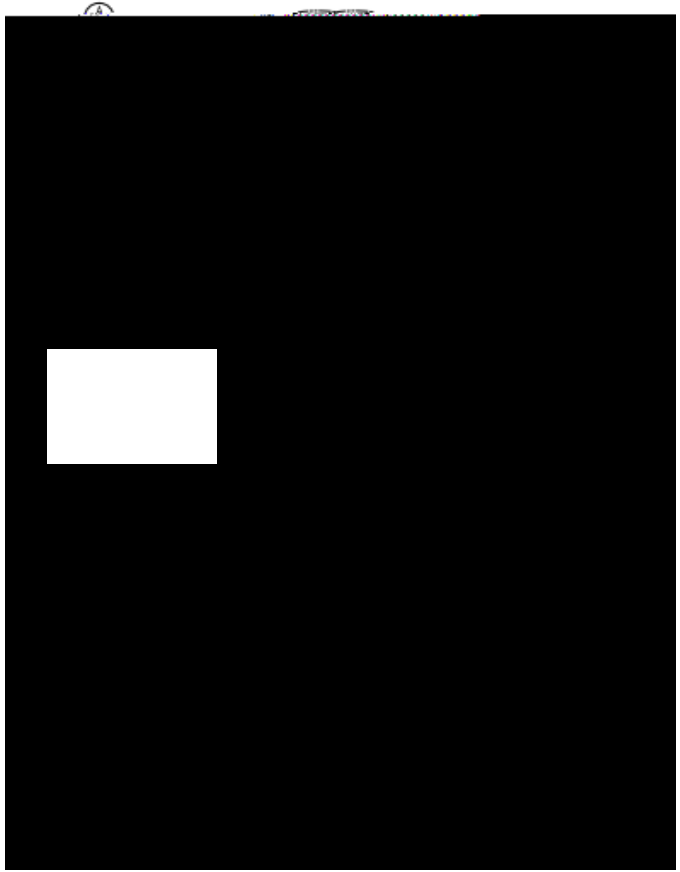
Jacket Design Experience



FEED of 67 Galloper offshore Wind Farm and FEED of suction bucket jackets at Dudgeon

Detailed Design of 84 jacket substructures (and 2 OTMs) for the Beatrice offshore wind farm

Floating Wind Turbine Structures

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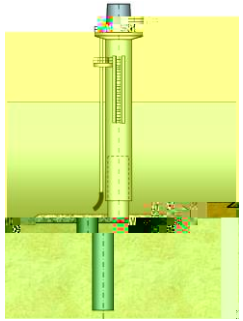
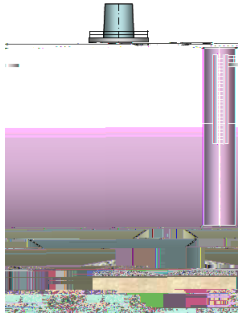
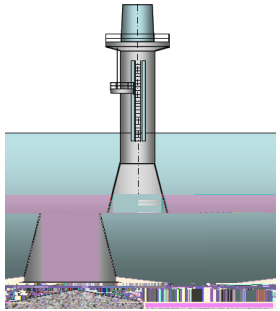
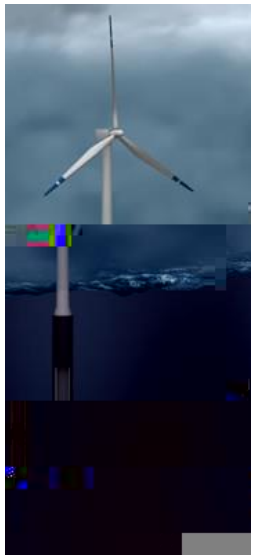
Challenges and Solutions

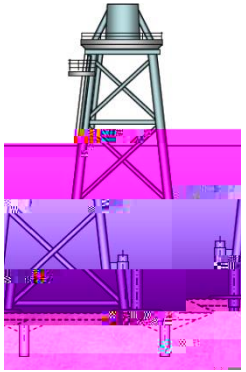
- Holistic Wind Farm Design
- Geotechnical Considerations
- Bespoke vs Clustered Design
- Design Integration
- Secondary Steel and Appurtenances
- Fatigue Design Improvements
- Fabrication Efficiency
- Transportation and Installation Issues
- Monitoring and Design Feedback











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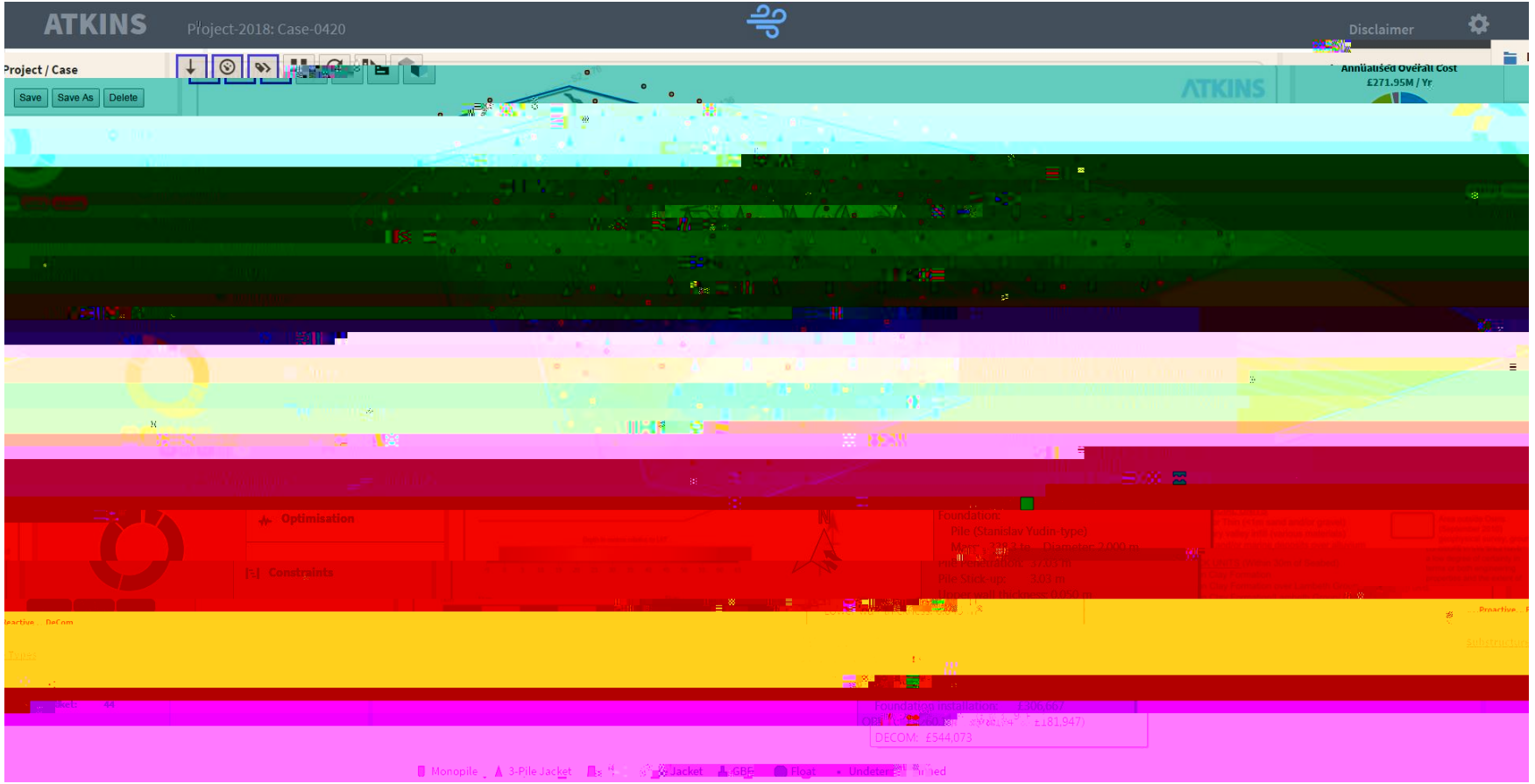
Holistic Approach – Virtual Wind Farm



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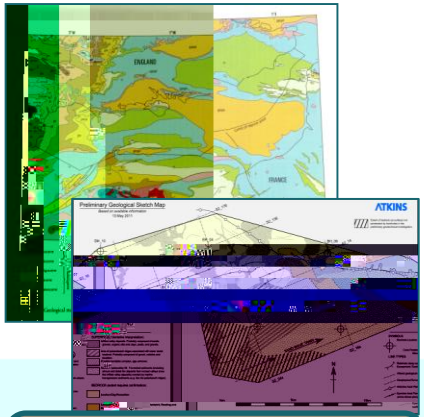
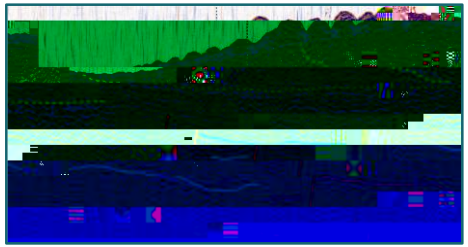


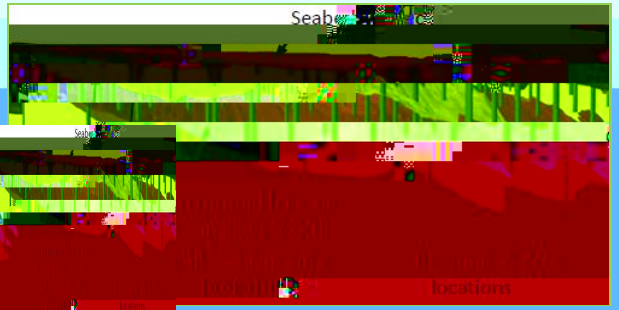
Desk study, geological info



Interpretation of geophysics profiles

Geotech. data , logs & lab test results

Data integration & analysis



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Geotechnical Design Considerations

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Geotechnical data available in stages

- Progressive confirmation of design?
- Not the most efficient process

Site wide study of pile response

- Identify relative stiffness of piles (stick up / soil)
- Define bounding conditions (upper and lower bounds)

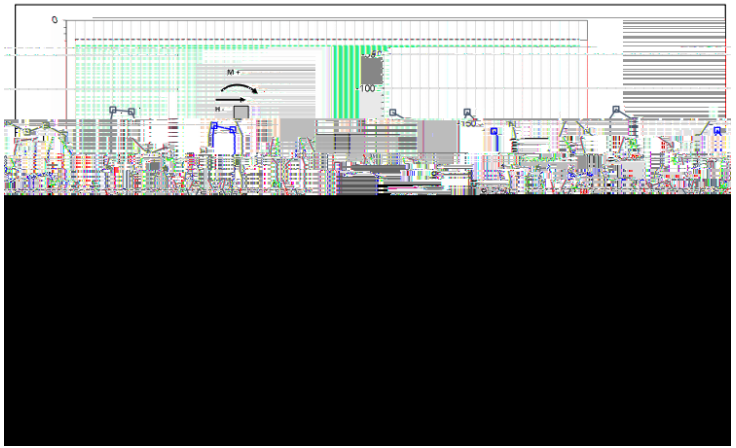
Seabed variability and uncertainty

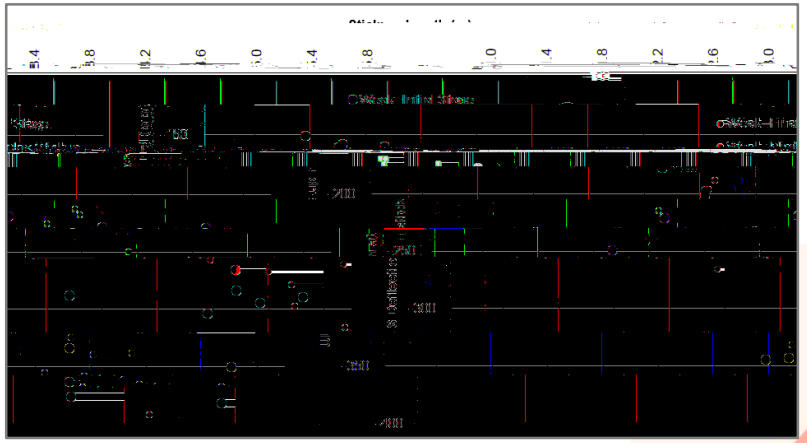
Pile driving design

- Drivability, strength, fatigue, buckling, contingency for refusals

Designs based on worst case (bookend approach)

- Not efficient for the design of most locations





Bespoke vs Clustered Design

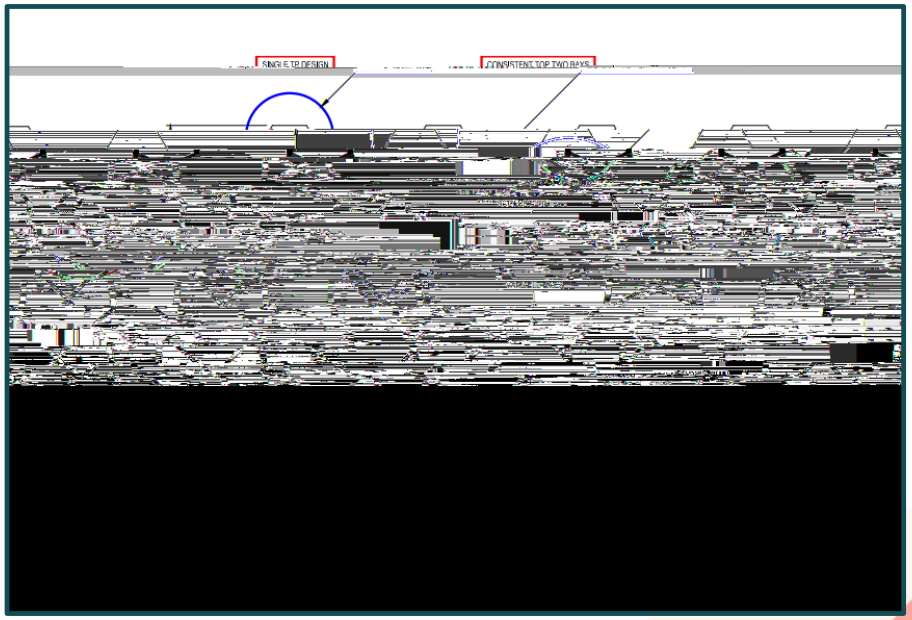
Clustering principles:

- As much similarity as possible across site
  - Despite water depth variation over site and significant soil variability
- Consistent upper structure & Transition Piece, common foot print for single standard jacket piling template and seafastening
- Design and fabrication efficiency and
- but at cost – design must be for the worst case across the cluster/site

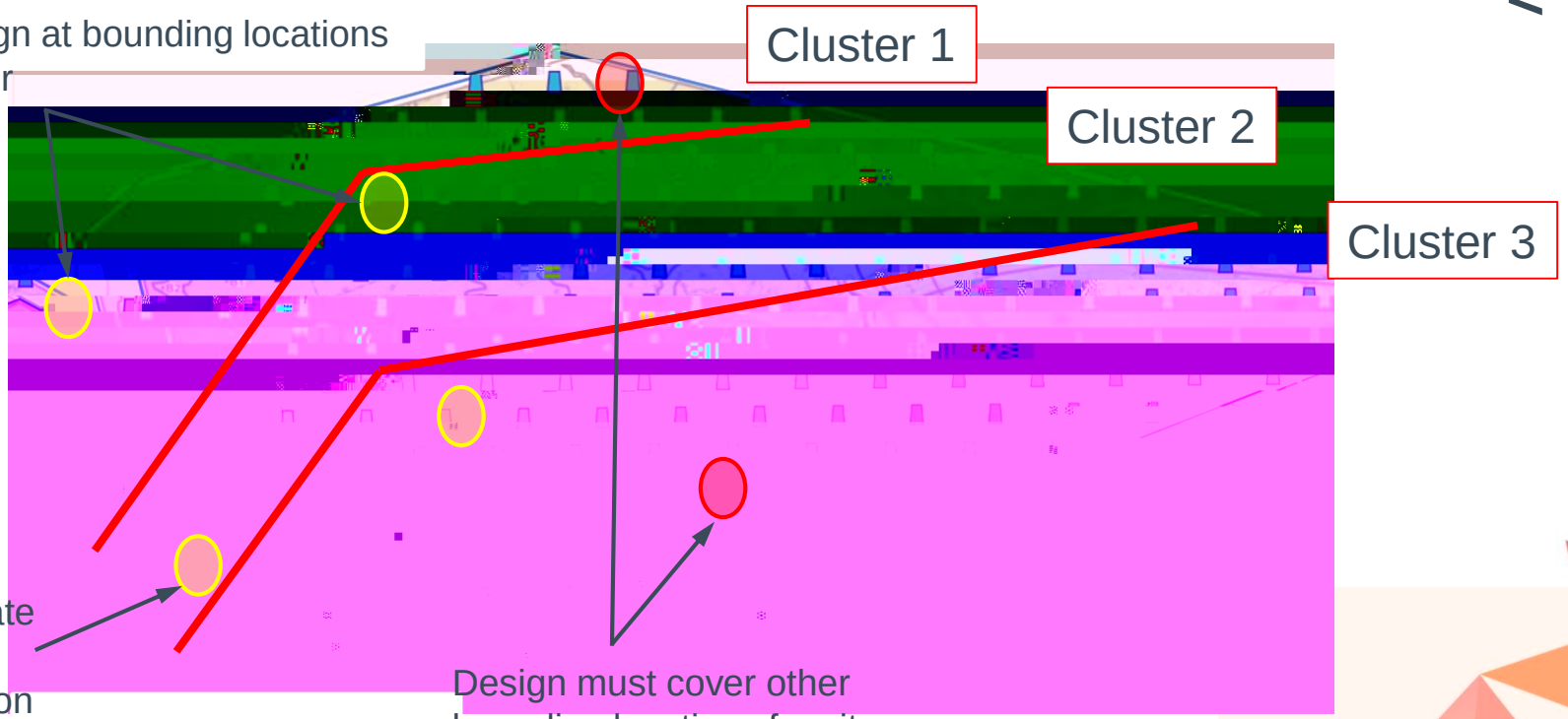
Bespoke Design:

- Greater weight efficiency can be achieved, but is this an improvement on clustering
- What is the optimum balance?

Design of structure in distinct “clusters” with variable pre-piling stick-up at mudline

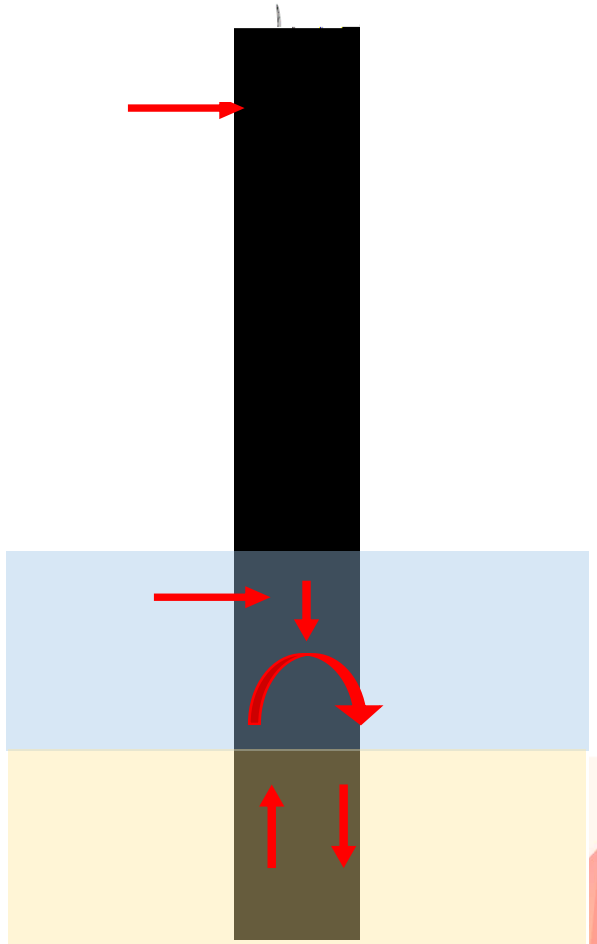


Example of Clustering and Design Efficiency



Design Integration

- Design efficiency depends on the integration of wind and wave loading
- Traditional approach is still based on onshore turbines where the interface is at the base of the tower
- The substructure designer is presented with a “fait accompli”, the tower design is frozen
- Greater design efficiency could be offered by integration of the substructure and tower
- Design loading is also developed based on the wind first principle, wave loading is related to it
- GBFs, larger diameter monopiles and parts of jackets are increasingly dominated by wave effects, not so much wind
- Design improvements may be offered by integrated, wave-first design
- Tower design different to monopiles, more efficient, lessons to learn?



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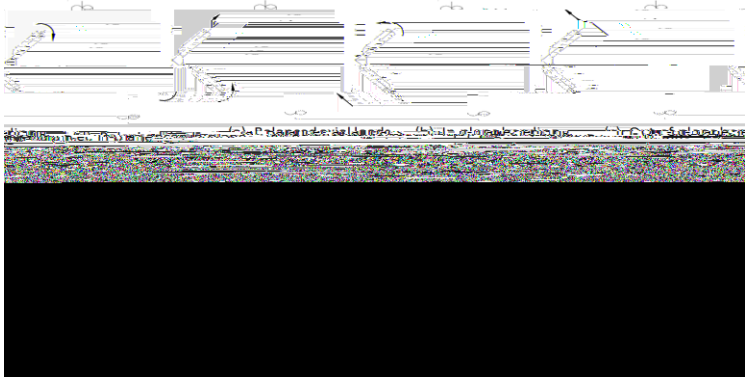
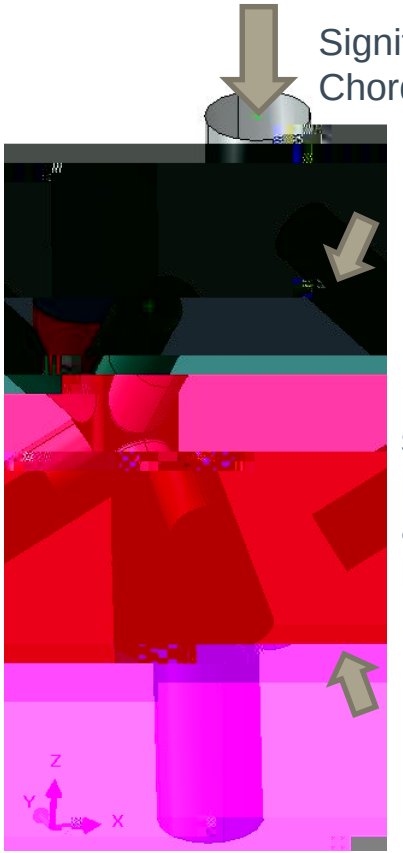
Fatigue Design Improvements

Fatigue is normally the key driver in WTG support structure design

- Rules and guidance typically based on oil and gas structures and loading (not axial in chord)
- Update of empirical Stress Concentration Factors for WTGs?
- Bespoke Stress Influence Functions based on FEA required for design efficiency, but slows design
- Ongoing large scale joint tests under way for development of SN curves



Significant Axial Chord Forces



Lower magnitude but still important brace axial and bending loads

Fabrication Efficiency

Design for specific fabricator or keep options open?

Options for construction of jacket:

- Vertical construction and assembly
- Horizontal construction in shed
- Subsequent upending to vertical

Options for member sizes:

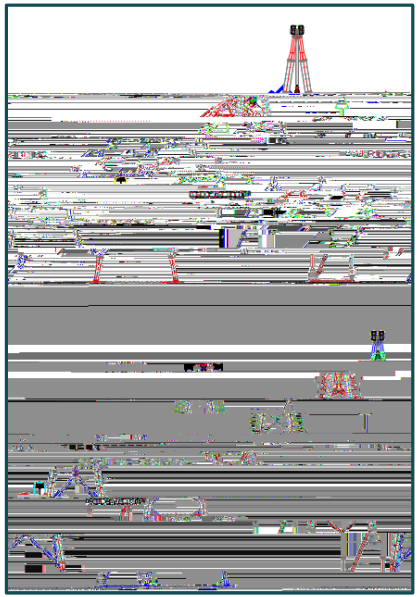
- Standard or fabricated sections?
- Preferred rolled sizes differ
- D/t limits for rolled sections

Options for welded assembly:

- Point to point or nodal construction?
- Automated node welding available?
- Single or double-sided joint welds?
- Location of closure welds in legs?

Image: Smulders

Vertical Assembly



Upending to Vertical

Designing an efficient structure for one fabricator is not necessarily efficient for others

Transportation and Installation Issues

Vertical transportation and lift

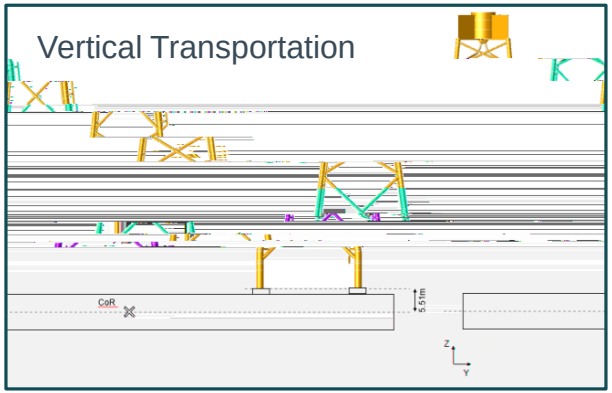
- Preferred if lift vessel hook heights permit
- Care with barge stability and jacket design stresses
- Onerous seafastening design
- More efficiency / automation needed

Horizontal transportation and upending

- Required if hook height insufficient
- Option more expensive than vertical transportation

Other Issues

- Simple Noble Denton transport criteria conservative
- Based on oil and gas, better guidance for WTGs?
- Pile driving fatigue prevents attachment of appurtenances on monopiles
- Blue hammer technology?



Upending from Horizontal to Vertical

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