TIDAL TURBINE FOUNDATION OPTIMISATION

RAMBOLL ENERGY

- RORY SINCLAIR

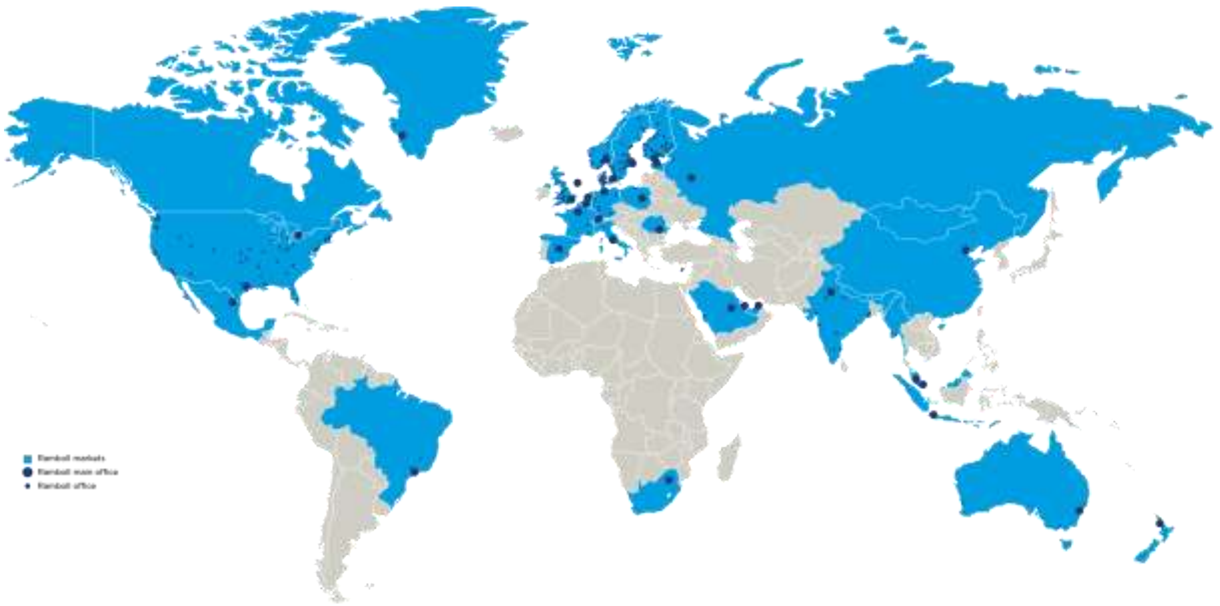
Presentation Contents

- Introducing Ramboll
- Tidal Turbine Foundations
- Our Experience with Fatigue in:
    - Gravity Bases
    - Floating
    - Bottom-Fixed (Jacket/Monopile/Duopod)
- Looking Ahead
- Summary

INTRODUCING RAMBOLL

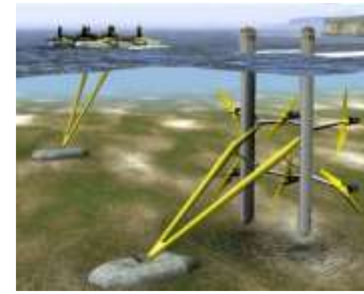
INTRODUCING RAMBOLL

- Ramboll: leading engineering consultancy company founded in Denmark in 1945
- Today, we employ more than 13,000 expert engineers and consultants
- 300 offices in 35 countries
- EUR 1.1 billion revenue
- Owned by Ramboll Foundation



INTRODUCING RAMBOLL

- O&G employees began first offshore wind project in 2001
- Since then…70% of all the world’s offshore wind turbines now rise from foundations engineered by Ramboll
- Separate wind/tidal department set up 10 years ago
- 5 offshore offices: Denmark, Germany & UK
- London office next to waterloo



RAMBOLL

TIDAL TURBINE FOUNDATIONS

TIDAL FOUNDATIONS

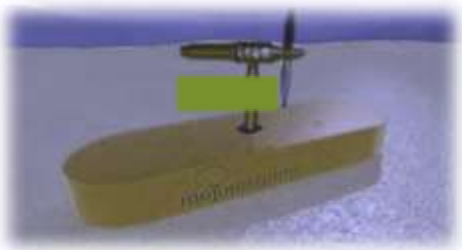
- Tidal energy faces huge challenges:
  - Installation costs
  - High current speeds
  - Rocky seabed
  - Uneven seabed
  - Limited access
- At present foundations are trials and so are not suitable for mass production
- The next stage is a repeatable structure

RAMBØLL

TIDAL FOUNDATIONS

General Comments

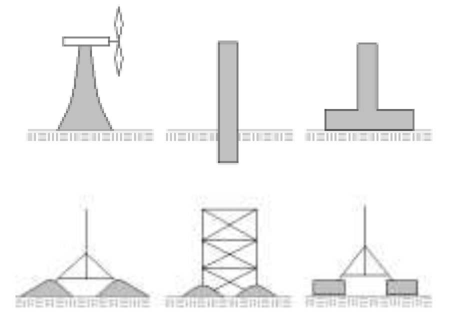
- Progress your foundation design at earliest opportunity
- Design for fatigue, don’t make it an afterthought
- Hire specialists if experience is not in-house
- Installation and foundation design are intertwined

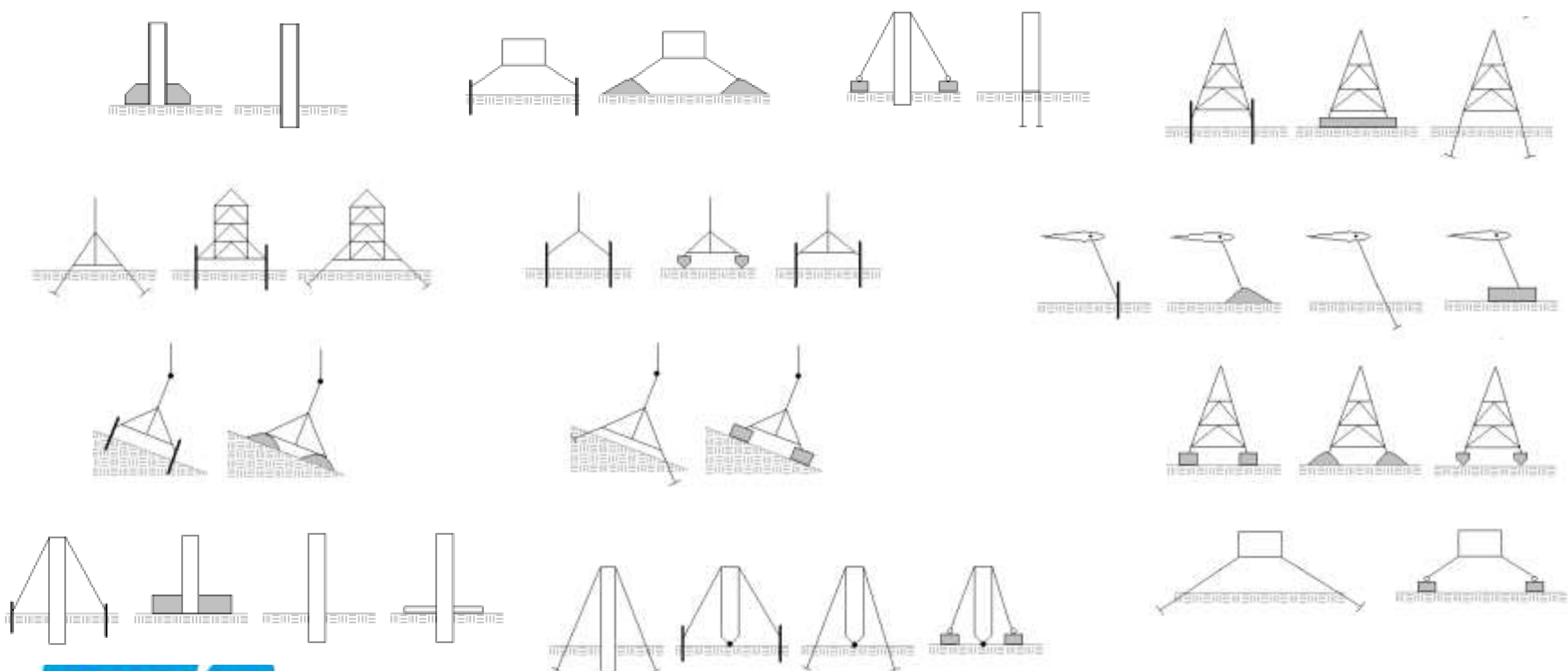



RAMBOLL

TIDAL FOUNDATION CONCEPTS

- **Gravity Base**
- **Floating**
- **Bottom-Fixed**

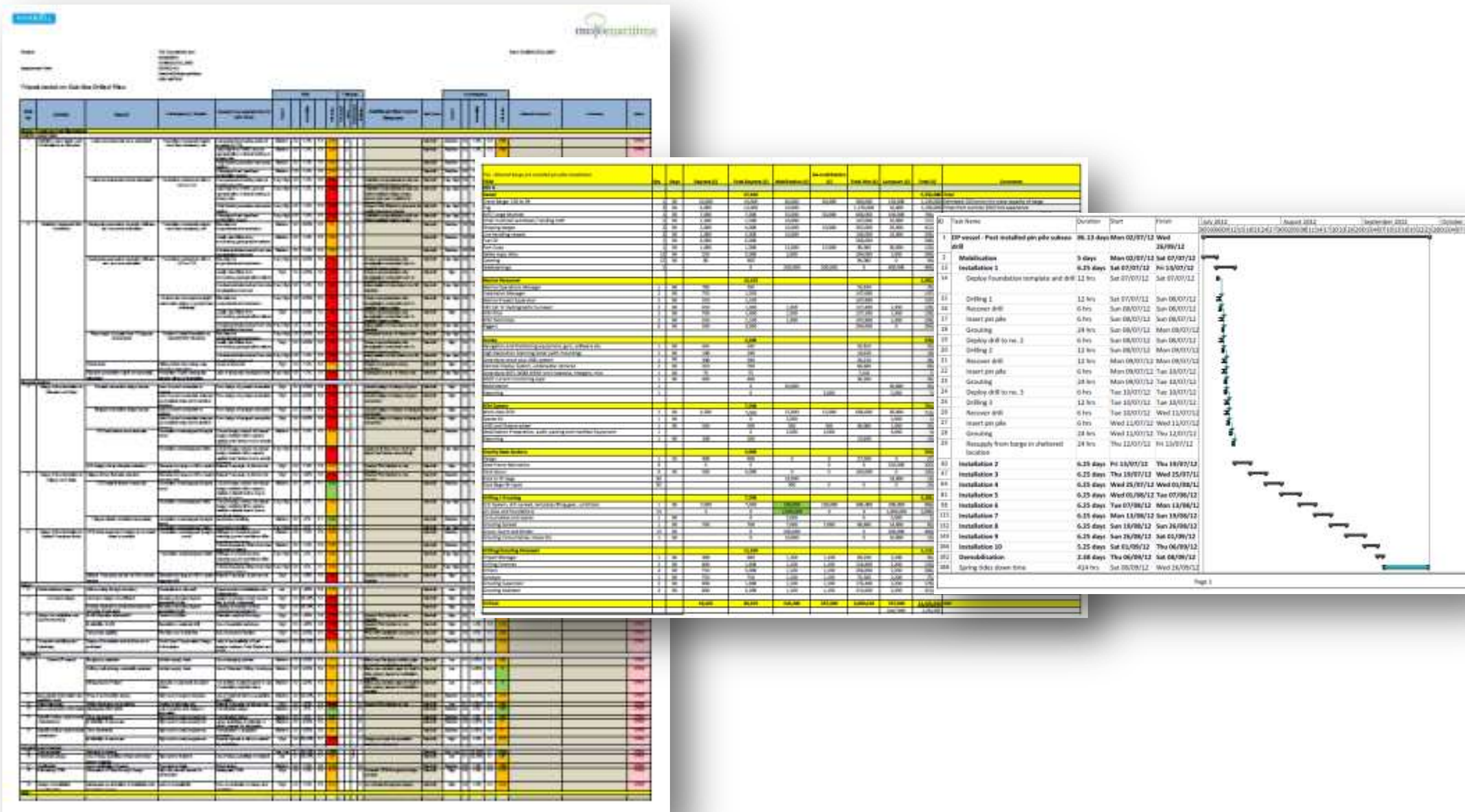




RAMBØLL

CONCEPT ELIMINATION PROCESS

Early-stage study of risk, cost and schedule

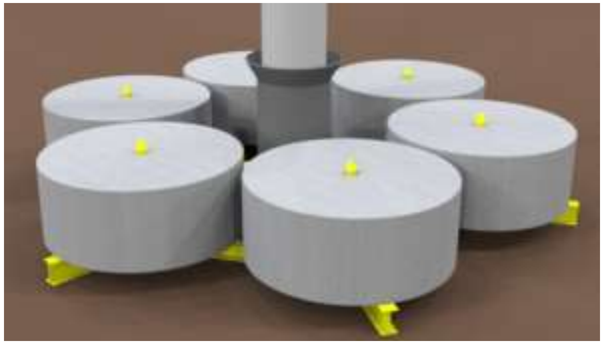


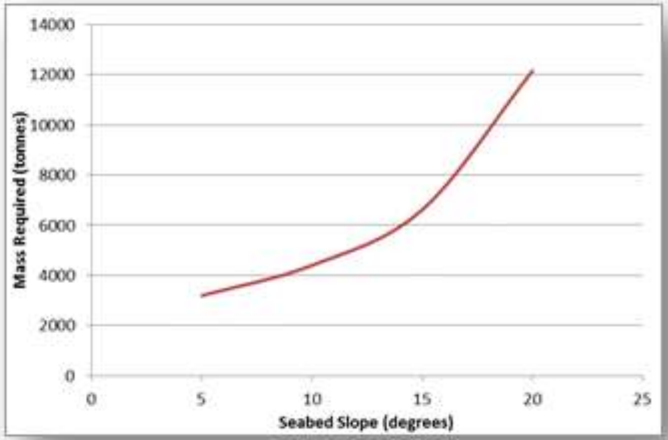
GRAVITY BASE

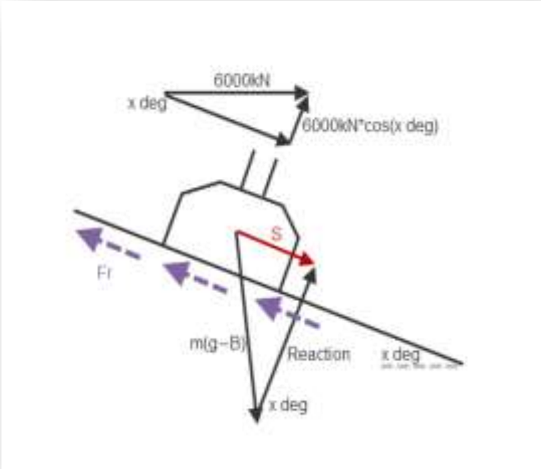
GRAVITY BASE

Problems:

- Substantial ballast mass required – v. expensive
- Carbon footprint large for ingots of steel/concrete
- Sensitive to seabed slope
- Bathymetry of tidal sites rarely flat







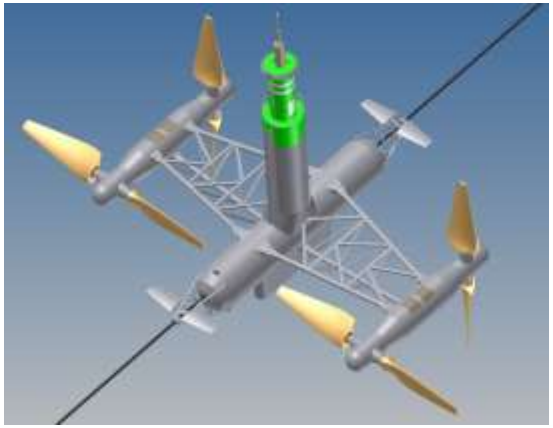
RAMBØLL

FLOATING

FLOATING

Pro's:

- Removes significant installation cost – hugely attractive solution economically
- Obvious O&M benefits



Other Thoughts:

- Still requires fixation by seabed anchor or rock socket (fixed)
- Introduces additional complexity:
  - Dynamic platform – impact on turbine efficiency
  - Dynamic export cable
  - Additional spacing requirements due to cables

RAMBOLL

MONOPILE

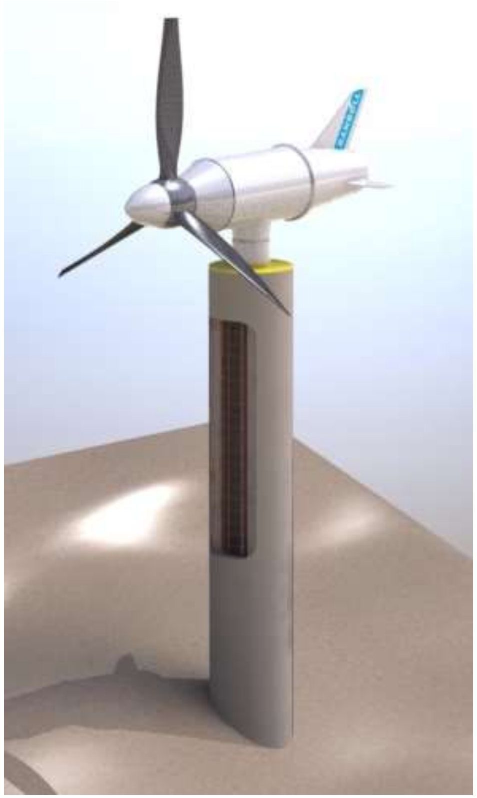
MONOPILE – DESIGN

General

- Simple design, proven concept
- Simple fabrication, weld automation

Fatigue Considerations

- Material thickness/diameters governed by fatigue
- ULS utilisation ratios are low
- No fatigue sensitive joints
- Pile diameter at upper limit of drilling capability…



RAMBØLL

MONOPILE - INSTALLATION

Subsea Drilling

- Most tidal sites have rock ground conditions – this requires drilling
- Current drilling diameter limit of ~ >2.8m (installed pile less than that)
- For 1MW+ device, MP's may struggle to work in fatigue at this diameter

MONOPILE - INSTALLATION

Topside Drilling

- No such diameter limits BUT requires a stable platform e.g. a jack up barge:
    - Successful application of jack ups in tidal races is limited (stability & VIV issues)
    - Jack up owners reluctant to deploy in tidal races
    - Susceptible to weather downtime
    - Expensive day rates
- Bottom line:
    - If "no" to jackups → it's a "no" to topside drilling
    - For 1MW+ → very possibly a no to MP's

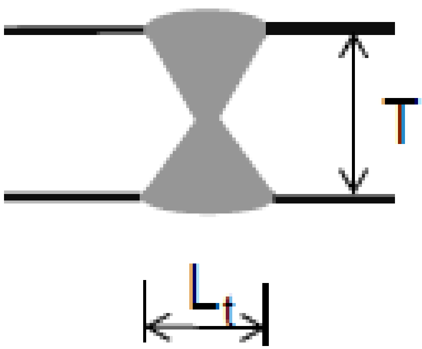
RAMBOLL

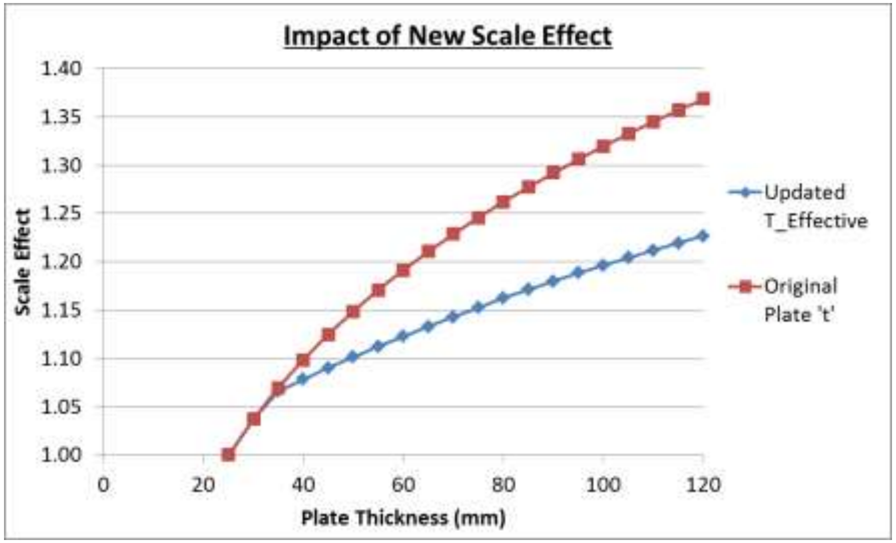
MONOPILE – A REVIVAL?

Updated Scale Effect

- SN curves derived using test plate thickness 25mm
- Scale effect used to account for actual plate thickness (basically a factor applied to the stress term)
- Formulae changed to depend upon weld width

$$\log N = \log \bar{a} - m \log\left(\Delta\sigma\left(\frac{t}{t_{ref}}\right)^{k}\right)$$





RAMBOLL

MONOPILE – A REVIVAL?

Updated SN Curves

- Current SN Curves:
  - Based on decades old research
  - Questionable representation of modern materials
  - Questionable representation of advances in modern fabrication techniques
  - Questionable representation of current member geometries (7m + diameter!)
- Structural Lifetime Industry Collaboration (SLIC):
  - Joint-industry project
  - Develop the existing SN curves
  - New testing being carried out using modern materials/practices/geometries
- Potential for improvement in fatigue performance of MP (or otherwise…)

RAMBOLL

MONOPILE – VIABLE?

Summary:

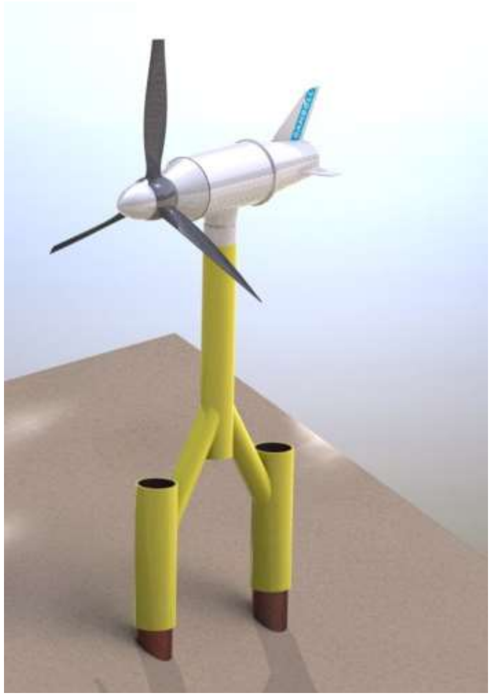
- Current diameter restrictions severely limits application of the MP
- < 1MW devices (prototype?) – likely to be viable
- > 1MW devices - potentially going to have fatigue issues
- Codes are changing as we speak, FLS failure not necessarily the case in the future…
- If MP's can be made to work in fatigue with OD limits they may be 'the solution'

RAMBOLL

DUOPOD

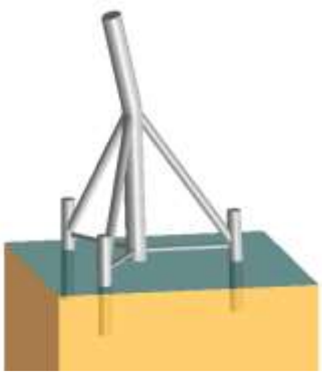
DUOPOD

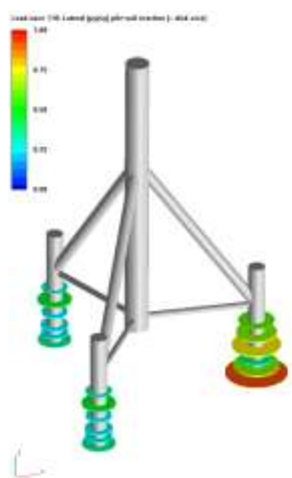
- Significant reduction in pile diameter due to:
    - X2 load paths to support (soil)
    - Forces are more 'axial'
    - Capacity of soil to 'take' axial load greater than lateral load
- Problems:
    - Joints introduced – suddenly much more complicated for fatigue
    - If significant out-of-plane bending loads at joints - fatigue issues
    - More expensive to fabricate than MP
- Are there better solutions?



TRIPOD

TRIPOD





- Main advantage of duopod without going all the way to a jacket
- 3rd leg reduces out-of-plane bending forces in joints
- Potentially thinner sections than with duopod
- Advantage of on-bottom stability
- More expensive to fabricate than MP
- The solution we often settle upon

JACKET

JACKETS

Key Points

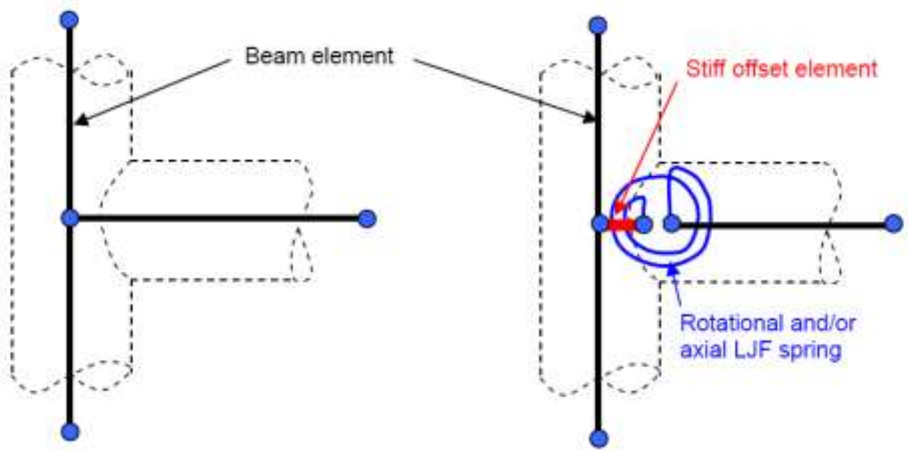
- Lever arm to load not sufficient to 'require' a jacket
- Multiple piles -> increased installation complexity
- Lots of members -> fabrication complexity & cost (very much)
- Probably not the economic answer
- May be deployed at deeper water sites in future

RAMBØLL

LOOKING AHEAD

Super-Elements & Influence Matrices

- Simple Beam Element Model (BEM) simplifies stiffness @ joints (below left)



- Local Joint Flexibility (LJF) introduced at simple joints as more accurate representation of joint stiffness
- Involves insertion of offset (very stiff element) and a spring to model joint stiffness
- EFTYMOI parametric equations empirically derived to determine LJF
- Generally (though not always!) results in improvement in fatigue performance

Super-Elements & Influence Matrices

- Equations are not suitable/reliable for complex joints e.g. offshore substation girder joint

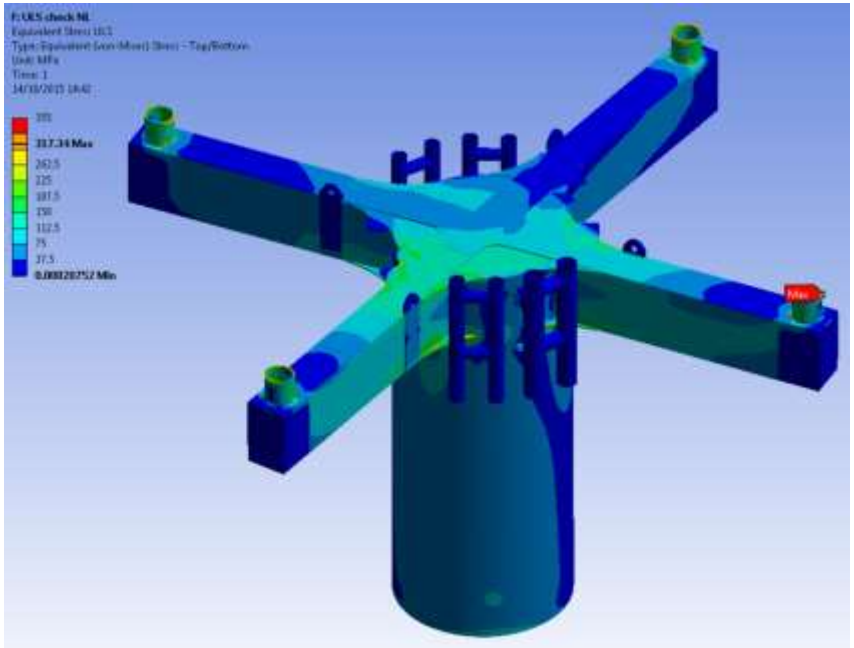
- We use super-elements instead!

- What is a super-element:

    - We create accurate model of our complex geometry in FE software

    - Extract stiffness & mass matrix and insert into same old (simple) beam element model

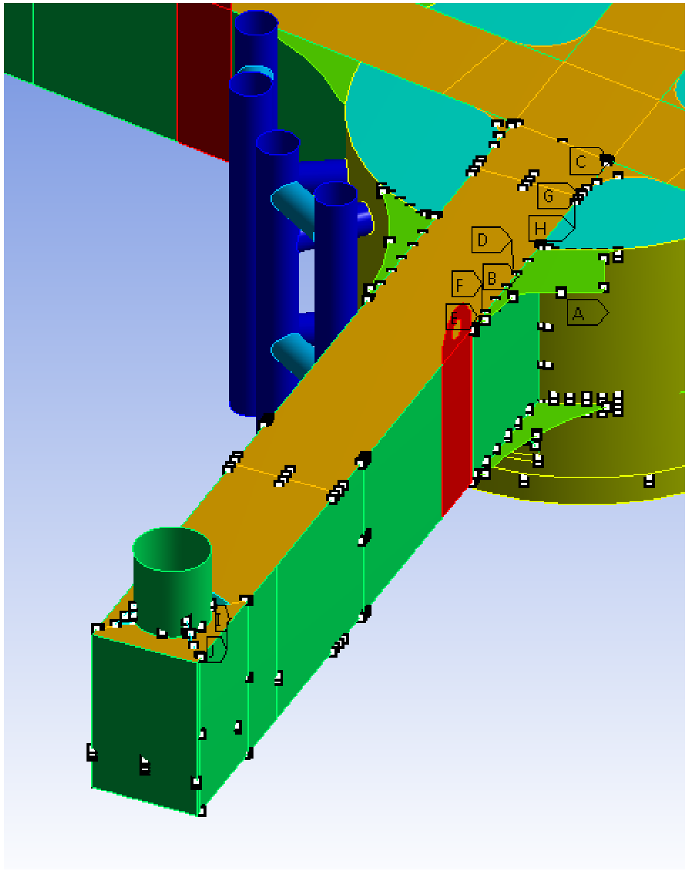
    - Seamless integration with BEM software



RAMBØLL

Super-Elements & Influence Matrices

- Influence Matrices:
  - Relates forces in simple BEM with forces inside the super-element ‘black box’
  - Basically a large matrix of numbers
- A few years ago influence matrices mainly used in very complex joints
- Their use is no-longer exceptional:
  - We’re now inserting influence matrices wherever we see a benefit
  - Even within applicability limits of EFTYMOI equations
  - Getting joints to ‘work’ that we just couldn’t get working



RAMBOLL

SUMMARY

Summary

- Foundation design and installation intertwinned, foundation design impacts installation – a major project cost driver

- Tidal foundations are almost always governed by fatigue

- There is no one foundation solution, we don't subscribe to the 'universal foundation' concept:

  - When you progress a detailed design at array scale, one size fits all isn't economic

  - Turbine & site-specific variables easily justify expense of optimised foundation

  - Cluster foundations at array scale

  - Our fee is negligible ☺

RAMBØLL

THANK YOU