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Civil, Structural, Geotechnical, Offshore, and Wind Engineering
Optimisation of structures for offshore wind farms

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List of Technical Abilities
Design of Foundations and Superstructures for Offshore Wind Turbines/Wind Energy Converters

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- **General**
    - This list of Technical Abilities contains general information on the technical knowledge relating to the design of a typical monopile foundation for the support of an offshore wind turbine
    - Aspects covered vary from initial site evaluation and determination of metocean parameters to full structural and fatigue analyses and member sizing

- **Detailed design and design criteria**

    - Summary of detailed design
        - Input data - determination of water depths, metocean parameters, turbine operating characteristics, etc.
        - Loadings - separate and combined wind and wave loading
        - Structural analyses - extreme and fatigue loadings
        - Dynamic response - to both turbine loads and wave loads
        - Fatigue critical - combination of wind and wave loading
        - Member checks and sizing
        - Optimisation of design - economy and ease of installation

    - Design criteria
        - Safety - design for fatigue usually critical
        - Elegance - simple structures with minimal risk during installation and minimum number of operations on site
        - Economy - design fully optimised for minimal cost

    - Other important criteria
        - Response of structure to turbine operating characteristics - soft-soft or soft-stiff designs
        - Fine tuning of design to achieve optimum modal characteristics
        - Lifting and transportation limitations - position of grouted joint and use of optimum diameter/plate thickness
        - Foundation installation method - site constraints


- **Determination of metocean data**

  - Determination of water levels
    - Relationship between MSL (CD) and MSL (OD)
    - Tidal ranges and storm surge, e.g., LAT, HAT, and HSWL
    - Crest level of waves, including breaking waves
    - Extent of splash zone
    - Design water depths for 50 year life

  - Determination of platform level and hub height
    - Minimum platform level to suit clearance over waves
    - Minimum hub height to suit blade clearance over platform
    - Minimum hub height to suit blade clearance over vessels

  - Determination of wave parameters
    - Extreme wave height and period (50 year return period), including the effects of shallow water and seabed slope, e.g., spilling or plunging breaking waves
    - Extreme currents (50 year return period)
    - Fatigue waves and wave scatter diagram, generated either from published data, site data, or European Wave Model and including selection of wave theory

  - Determination of wind parameters and other parameters
    - Extreme gust wind speed at hub height (50 year return period)
    - Variation of wind speed with height
    - Variation of turbulence intensity with height
    - Marine growth
    - Ice loading
    - Air and sea temperatures

- **Dynamic behaviour and response**

  - Natural frequency and avoidance of resonance
    - Soft-soft or soft-stiff designs
    - Calculation of upper and lower bounds of natural frequency (1^{st} and 2^{nd} modes) and establishment of forbidden zones
    - Effect of non-linear ground conditions (p-y springs etc.)
    - Effect of added mass - marine growth, entrapped water, and entrained water
    - Effect of lateral pile loading (thrust loading)

  - Dynamic response
    - Dynamic analyses performed for either extreme or fatigue loadings
    - Incorporation of non-linear waves for both extreme and fatigue loadings and non-linear ground supports for extreme loadings
    - Effect of aerodynamic and hydrodynamic damping, wind turbine availability, and wind and wave directionality
    - Wind loading - incorporation of rotor loads, including time histories, from wind turbine manufacturer
    - Wave loading - steady state or transient time history analyses including generation of time histories
    - Combined wind and wave loading - simple superposition of loads to full combination of time histories

- **Structural analysis - extreme loading**

  - Extreme wave loading
    - Generation of wave loading, including non-linear waves up to stream function 10^{th} order
    - Incorporation of marine growth (increased diameter), non-linear supports (p-y springs etc.), effects of currents, and variation with water depth
    - Calculation of C_d and C_m including the effects of wake encounter at low Keulegan-Carpenter numbers (i.e., large diameters)
    - Inclusion of J-tubes or other significant appurtenances
    - Calculation of forces due to static response (stepped wave) or dynamic response (steady state or transient time history analysis)
    - Generation of water particle kinematics
    - Member checking (local and overall buckling) including appurtenances

  - Extreme wind loading
    - Incorporation of turbine loadings provided by wind turbine manufacture, e.g., from certification loading document
    - Wind loading from turbine tower and/or superstructure provided by wind turbine manufacturer or calculated directly
    - Member checking

- **Structural analysis - fatigue loading**

    - Fatigue wave loading
        - Generation of individual wave height and periods from wave scatter diagrams
        - Effect of non-linear waves
        - Use of linear spring supports (rather than clamp) to give exact match of 1st and 2nd modes
        - Inclusion of J-tubes or other significant appurtenances
        - Calculation of C_d and C_m including the effects of wake encounter at low Keulegan-Carpenter numbers (i.e., small waves)
        - Calculation of fatigue spectrum using static response (stepped wave) or dynamic response (steady state analysis)
        - Fatigue life assessment calculated using the following wave energy spectrums: deterministic, Pierson-Moskowitz, or Jonswap

    - Fatigue wind loading
        - Incorporation of fatigue spectrums or damage equivalent loadings provided by wind turbine manufacture, e.g., from certification loading document
        - Fatigue life assessment calculated at all critical points

- **Combination of wind and wave loading**

    - Combined extreme wind and wave loading
        - Incorporation of combined turbine loadings and wave loadings provided by wind turbine manufacture, e.g., from certification loading document
        - Extreme wave combined with reduced wind, and vice versa
        - Otherwise, separate time history generated for wave loading and combined with time history for turbine loads provided by wind turbine manufacturer in order to give overall response
        - Member checking

    - Combined fatigue wind and wave loading
        - Incorporation of combined wind and wave fatigue spectrums or damage equivalent loadings provided by wind turbine manufacture, e.g., from certification loading document
        - Alternatively, separate time history generated for wave loading and combined with time history for turbine loads provided by wind turbine manufacturer in order to give overall response
        - Determination of length of time history simulations and correlation of wind speed and wave height
        - Method of combining time histories, e.g., response spectra method for in-phase and out-of-phase random vibrations
        - Rainflow counting performed on combined time history to give combined wind and wave fatigue spectrum
        - Fatigue life assessment calculated at all critical points

- **Value engineering**

  - Overall optimisation
    - Overall aim is to achieve minimum fabrication costs within constraints imposed by design and installation
    - Optimisation of design to suit turbine location and water depth
    - Fine tuning of design to achieve optimum modal characteristics and therefore minimise dynamic response
    - Use of optimum D/t ratios for monopile (to suit pile driveability) and transition piece/turbine tower (for minimum fabrication cost)
    - Variation of embedment length with turbine location and ground conditions
    - Fatigue critical - avoid poor details with SCF's, e.g., metal-to-metal contact within grouted joint
    - Fatigue critical - avoid poor details around areas of peak/high stress, e.g., position of appurtenances at top and bottom of grouted joint and at mudline
    - Consider reducing corrosion protection on areas of good fatigue life and vice versa

  - Fabrication costs and materials
    - Limit plate thickness to 60mm (consider using larger diameter)
      - Relatively easy availability
      - Seam welds not excessive
      - Pre-heat not required
      - Cheaper J2G3 steel can be used instead of offshore grades
    - Optimise length of items to suit maximum plate rolling widths
    - Fabrication details - detail of attachments to main shell to be chosen to maintain optimum plate thickness, and not vice versa

- **Scour protection and overall seabed movement**

  - Assistance with assessment of seabed levels due to
    - Local scour
    - Sand waves
    - Overall seabed movement - long term (tidal & littoral processes)
    - Overall seabed movement - short term (storm action)

  - Scour protection strategy and design considerations
    - Cost benefit analysis - long term design life (no repairs) versus medium term design life with periodic repairs
    - Assistance with preparation of requirements for physical or numerical modelling
    - Installation sequence of scour protection and effect of temporary scour during pile installation
    - Effect of presence of scour protection on breaking wave type
    - Determination of design water depths
    - Specification for scour protection layout and materials

- **Foundation installation**

  - Selection of pile installation method
    - Drive
    - Drill and drive
    - Drill and socket

  - Design considerations
    - Assistance with interpretation of ground conditions and recommendations for site investigations
    - Risks and options associated with hard driving conditions
    - Optimisation of installation method to suit site conditions and equipment available to Contractor

  - Determination of embedment length
    - Optimisation across site to suit turbine location and water depth
    - Extreme conditions - safety requirements
    - Operating conditions - modal and deflection criteria

  - Detailed design
    - Derivation of p-y, t-z, and q-w soil springs
    - Pile driveability analysis
    - Pile tip integrity and permitted D/t ratio
    - Fatigue damage during driving

- **Design of grouted joint and appurtenances**

    - Design of grouted joint
        - Preliminary assessment of peak hoop stresses and axial stresses using empirical formulae
        - Detailed assessment of grouted joint using 3D solid element finite element analysis
        - Determination of position and minimum length of grouted joint to suit design loadings and preferred methods of installation
        - Prevention of slip, debonded design, with inclusion of shear keys
        - Provision of mechanical safety
        - Selection of grout material

    - Detailing of grouted joint
        - Determination of thickness of grout to suit installation method and misalignment tolerances
        - Optimisation of design, including avoidance of poor fatigue details associated with areas of peak stresses and SCF's associated with metal-to-metal contacts (e.g. angle stop rings)
        - Methods of installation, including temporary support of transition piece and detailing of grout skirts, etc.

    - Appurtenances
        - J-tubes, including provision for installation and transportation
        - Boat landings; rigid or with fenders
        - Main platform, secondary platforms, and internal platforms, including attachments and mounting points
        - Landing points for installation of transition piece and lifting eyes

- **Corrosion protection**

    - Determination of corrosion allowance for following zones
        - Internal and external buried
        - Internal and external submerged
        - Internal airspace within monopile and within tower
        - External splash zone and external atmospheric

    - Specification for corrosion protection
        - Recommendations for coating selection including J-tubes and other appurtenances
        - Recommendations for cathodic protection including direct mounting or remote systems

    - Optimisation of overall design for cost
        - Consider reducing corrosion protection in lieu of increased corrosion allowance and corrosion pitting on areas of good fatigue life and vice versa
        - Cost benefits of increased plate thickness versus reduced corrosion protection, and vice versa

- **Weld specifications and fabrication details**

  - Weld specifications
    - Design of welded connections
    - Plate profile and weld details
    - Weld quality and permissible imperfections
    - Optimisation of weld spec with requirements for fatigue design

  - Fabrication details and specifications
    - Preparation of fabrication details
    - Permissible fabrication tolerances
    - Optimisation of fabrication spec with requirements for design

- **Certification of designs**

  - Certification of designs to following international certification bodies
    - Germanischer Lloyd WindEnergie GmbH (GL Wind)
    - Det Norske Veritas (DNV)
    - American Bureau of Shipping (ABS)

- **Calculations to various international codes of practice:-**

  - Calculation of fatigue damage to any of the following codes of practice
    - Eurocode 3 1993-1.1 and 1993-3.1
    - British Standard BS 7608
    - Germanischer Lloyd Regs
    - API RP 2A-WSD
    - UK HSE Guidelines
    - International Standard ISO 19902
    - NORSOK Standard N-004
    - ESDU Data Items
    - Dansk Standard DS 449

  - Calculation of thin walled buckling of steel shells to following codes of practice
    - ECCS European Recommendations
    - Eurocode 3 1993-1.6 and 1993-3.1
    - API RP 2A-WSD
    - NORSOK Standard N-004