By Dr Martin Kelm
Technical Director

# FOWPI Foundation Design

# OWF Gujarat

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# Agenda

1. Introduction to COWI
2. Foundation types
3. Introduction to foundation design
4. Basis of design
5. Advisory foundation design

# 1. Introduction to COWI

Founded in 1930 by

**C**hristen **O**stenfeld

**W**riborg **J**ønson

# Introduction to COWI

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## COWI IN NUMBERS

798 MILLION EUR IN TURNOVER

MORE THAN 85 YEARS OF HISTORY

WORKING IN 124 COUNTRIES

OVER 6,600 EMPLOYEES



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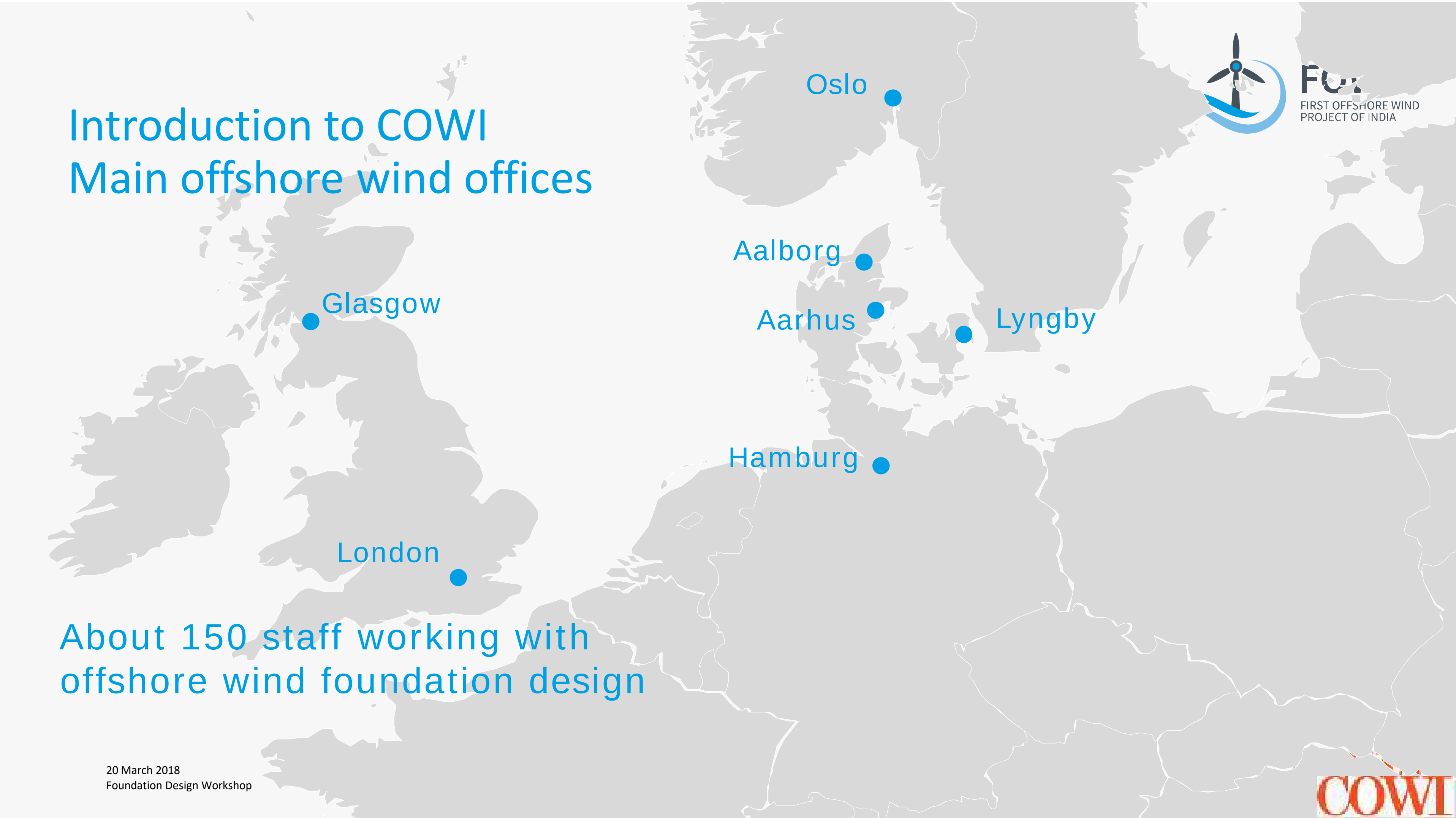
# Introduction to COWI
# Marine offices

# Introduction to COWI
# Main offshore wind offices




About 150 staff working with
offshore wind foundation design



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# 2. Foundation types

Due to its site-specific character, offshore wind foundations represent a significant part of a project's capital expenditure, and therefore optimization of its structure might lead to substantial savings.

# Foundation types

# Foundation types Investigated

- Steel jackets
- Concrete gravity based foundations
- Monopiles

# Foundation types
## Concrete gravity based foundations

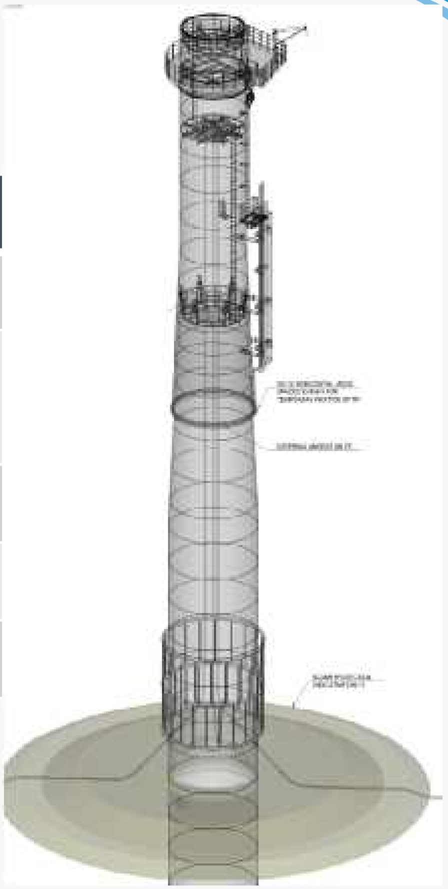
| Pros | Cons |
|---|---|
| + cheap construction | - heavy |
| + local construction | - difficult to install |
| + versatile | |

# Foundation types
## Steel jackets

| Pros | Cons |
| --- | --- |
| + widely used | - relatively expensive |
| + relatively light | |

# Foundation types
# Monopiles

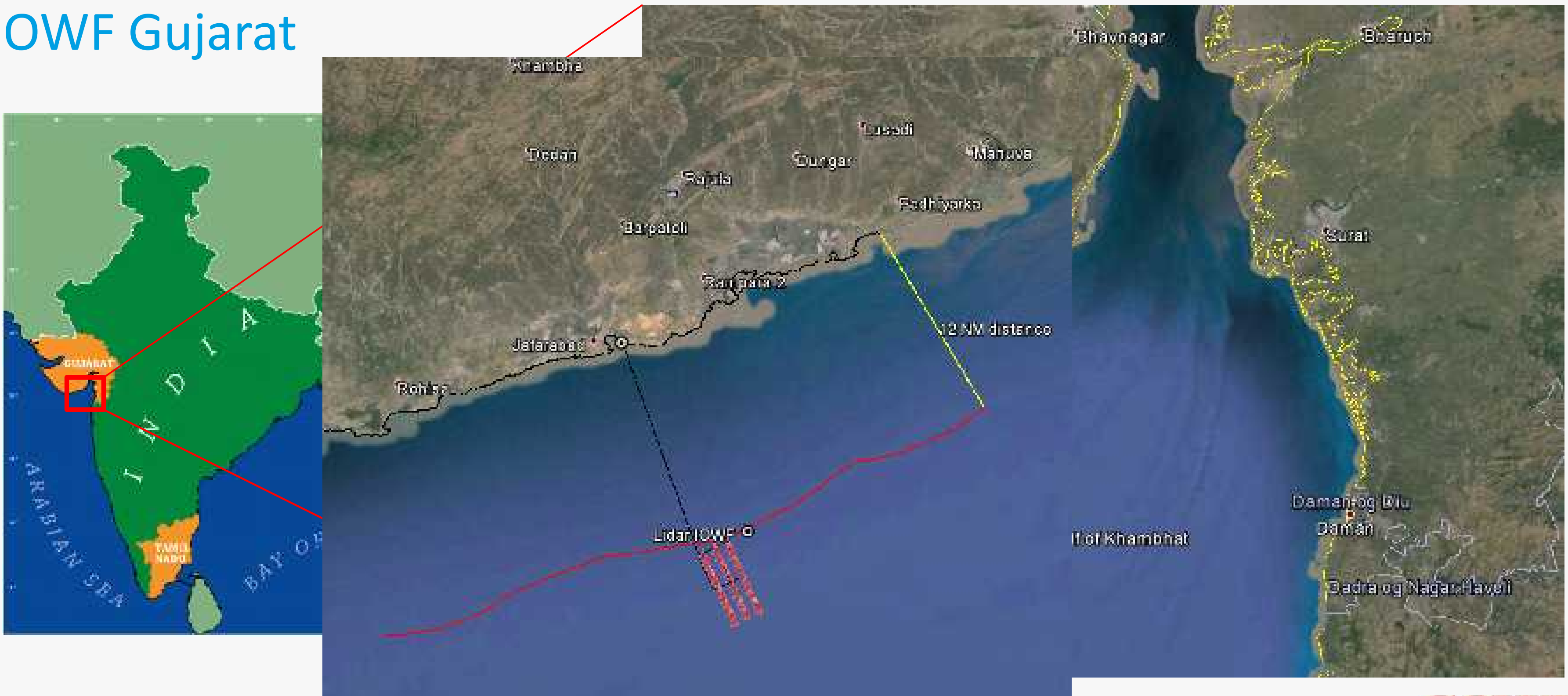
| Pros | Cons |
| --- | --- |
| + widely used | - relatively heavy |
| + supply chain | - special equipment needed |
| + fast to install | |
| + relatively cheap | |
| + versatile | |



# Foundation types
# Selection criteria

- Water depth
- Wind turbine MW class
- Costs
- Ground conditions
- Installation vessels availability
- Local fabrication facilities

# Foundation types
# OWF Gujarat



# Foundation types
# Selection OWF Gujarat

- Water depth -> 14 to 18 m w.r.t. LAT
- Wind turbine MW class -> 3 to 6 MW
- Costs
- Ground conditions -> Clay and sand
- Installation vessels availability
- Local fabrication facilities

# Foundation types
# Selection OWF Gujarat

| Criterion | Gravity | Jacket | Monopile |
|---|---|---|---|
| Water depth | 0-40-> + | 30-50 -> - | 0-40 -> + |
| Wind turbine MW class | + | + | + |
| Costs | ++ | - | + |
| Ground conditions | - | + | + |
| Installation vessel | - | + | + |
| Local fabrication | + | 0 | 0 |
| Sum | 3 | 1 | 5 |

# Wind turbine technology

| Available Turbine Models | Rated Power (MW) | IEC Class | Rotor diameter (m) |
|---|---|---|---|
| MHI Vestas V164-9.5MW | 9.5 | IEC S | 164 |
| MHI Vestas V112-3.3MW | 3.3 | IEC IB | 112 |
| Senvion 6.3 M152 | 6.33 | IEC S | 152 |
| Siemens SWT-8.0-154 | 8.0 | IEC IB | 154 |
| Siemens SWT-3.6-130 | 3.6 | IEC IB | 130 |

# Wind turbine technology
# Risks

**Project-Price grows with risk:**

- New Models mean higher risk
- OEM's inexperienced with offshore environment mean higher risk
- Adapted onshore models mean higher risk

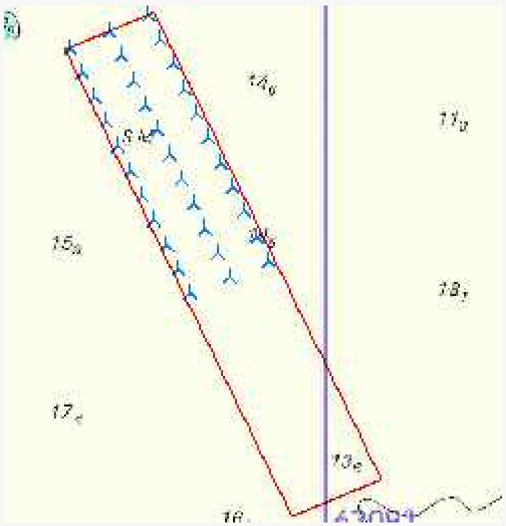
=> Lower Project-Risk with proven offshore wind turbines
e.g. Siemens 6MW, Siemens 4MW, MHI Vestas 3 MW

# Wind turbine technology Selection OWF Gujarat

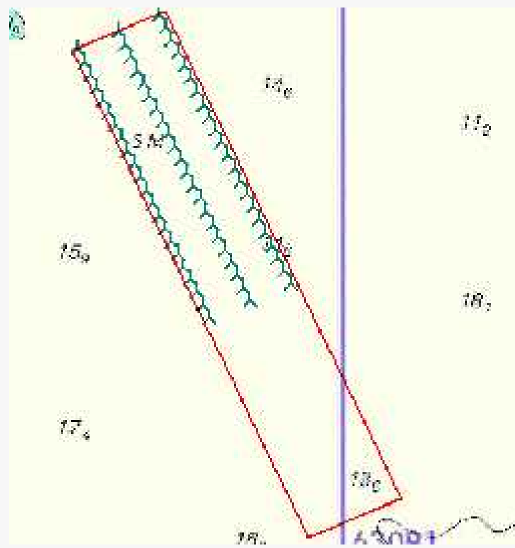
| Reference Turbines | Rated Power (MW) | Hub Height (m) | Rotor diameter (m) |
|---|---|---|---|
| Generic 6 MW | 6 | 107 | 154 |
| Generic 3 MW | 3 | 86 | 112 |

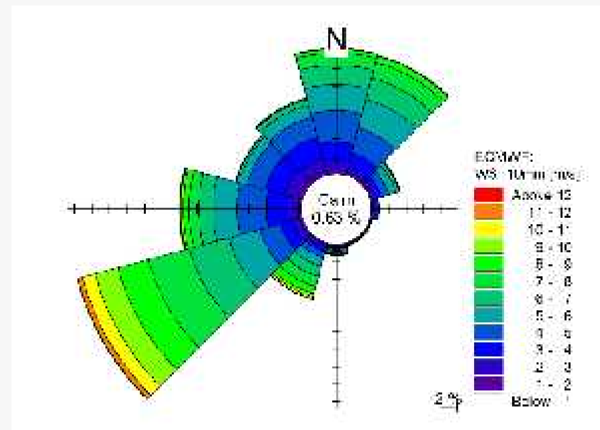
# Wind turbine technology
# Layout OWF Gujarat

6 MW: 3 x 11, 1500 x 1000 m




3 MW: 3 x 22, 1500 x 500 m



# Layout Optimization

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- Increased distance between turbines

  => reduced wake loss – and higher cable costs

- 2 lines of turbines compared to 3 lines

  => reduced wake loss – and higher cable costs.



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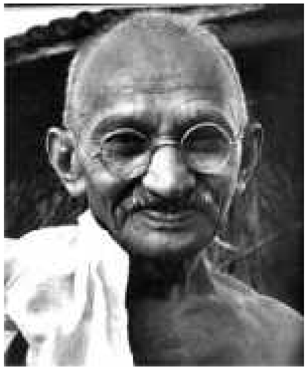
# 3. Introduction to foundation design



**“I do not want my house to be walled in on all sides and my windows to be stuffed. I want the culture of all lands to be blown about my house as freely as possible. But I refuse to be blown off my feet by any”**

Mahatma Gandhi

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# Introduction to foundation design
# Design basis

- Codes and standards
- Foundation concept
- Design lifetime and further Employer's requirements
- Design conditions
  - Soil conditions
  - Environmental conditions:
    - water depths and water levels
    - wind, typhoons
    - waves, currents
    - earthquakes
    - temperatures etc.
- Design processes, methodologies and loads

Compiled in "Design Basis" document



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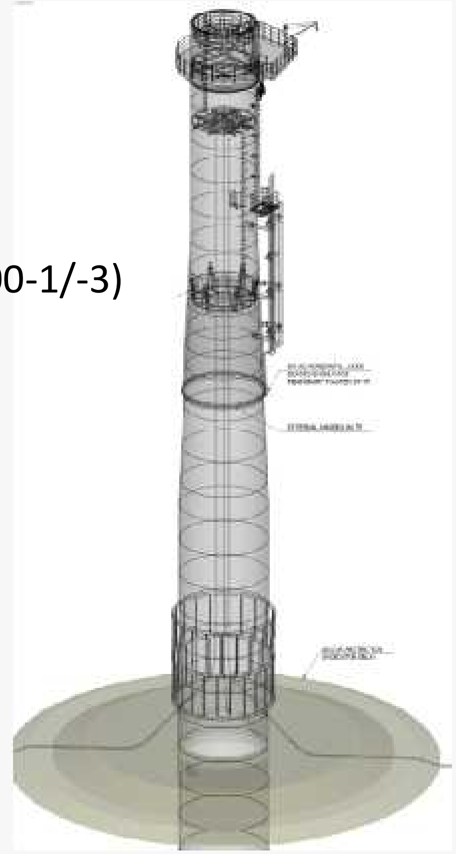
# Introduction to foundation design
# Codes and standards

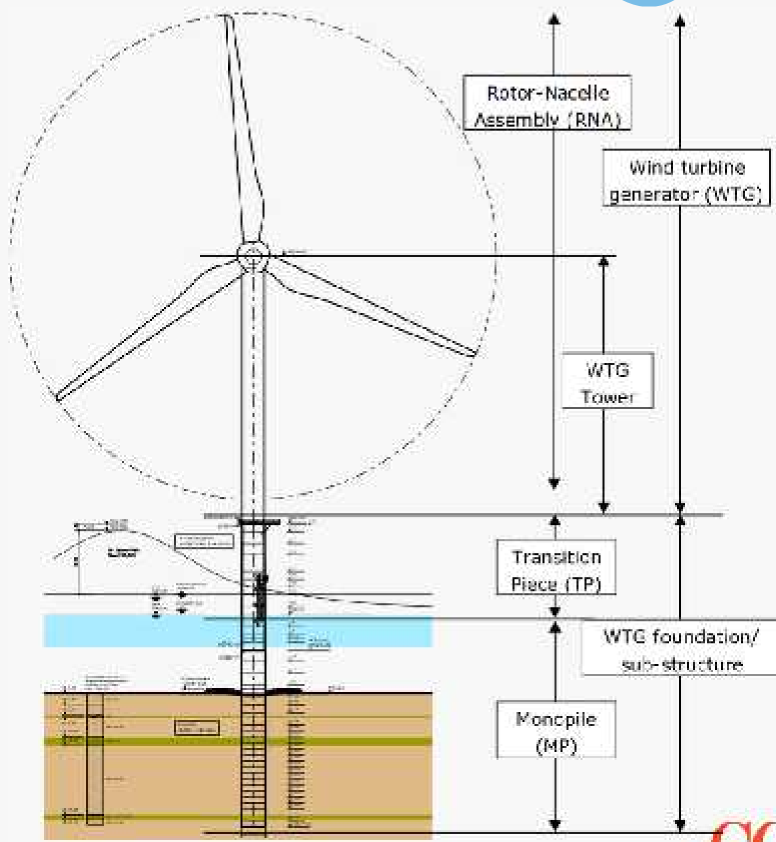
DNVGL family of standards:

- Governing standard: DNVGL-ST-0126
- Standards for loads: DNVGL-ST-0437 (alternatively IEC 61400-1/-3)
- Guidelines for steel design:
  - DNV-RP-C202: Buckling Strength of Shells
  - DNVGL-RP-C203: Fatigue design of offshore steel structures
- Corrosion: DNVGL-RP-0416
- Grout: DNVGL-RP-0419



# Introduction to foundation design
# Basic components

- Wind turbine generator (WTG):
  - Rotor-Nacelle-Assembly (RNA)
  - WTG tower
- WTG foundation or sub-structure:
  - Primary structures, also referred to as **Primary Steel**: monopile (MP) and transition piece (TP)
  - Grouted connection between MP and TP
  - Secondary Steel components of the foundation, also referred to as appurtenances or **Secondary Steel**
  - Scour protection on the seabed



# Introduction to foundation design
# Basic components - foundation

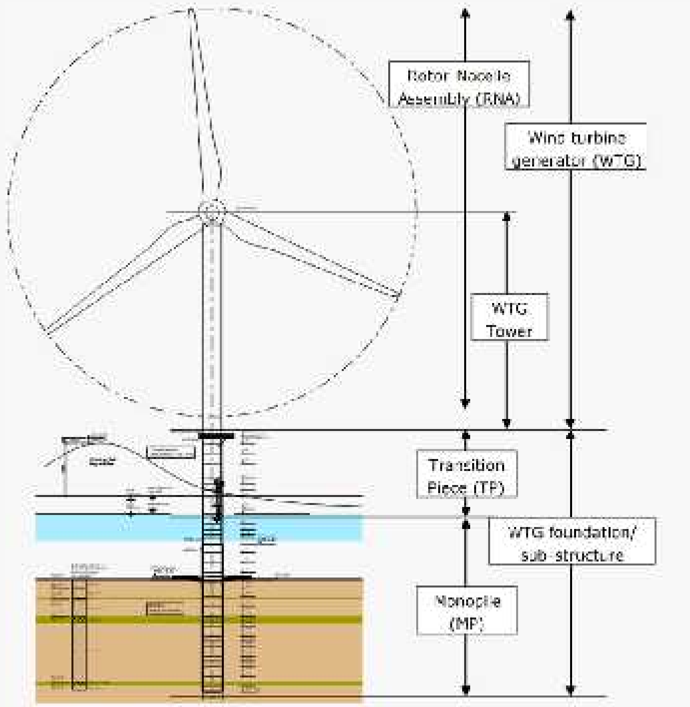
Structural components from design point of view:

- **Primary Steel**:
  These are components which are participating in the overall integrity of the structure or which are important for operational safety. Structural parts where failure will have substantial consequences.
- **Secondary Steel**:
  These are components of no significance for the overall integrity of the structure. Structural parts where failure will be without significant consequence.
- **Special Steel**:
  These are components which are essential to the overall integrity of the structure and exposed to particularly arduous conditions. Structural parts where failure will have substantial consequences and are subject to a complex stress condition. Special structural members are a subset of the Primary Steel.

# Introduction to foundation design
# Design process

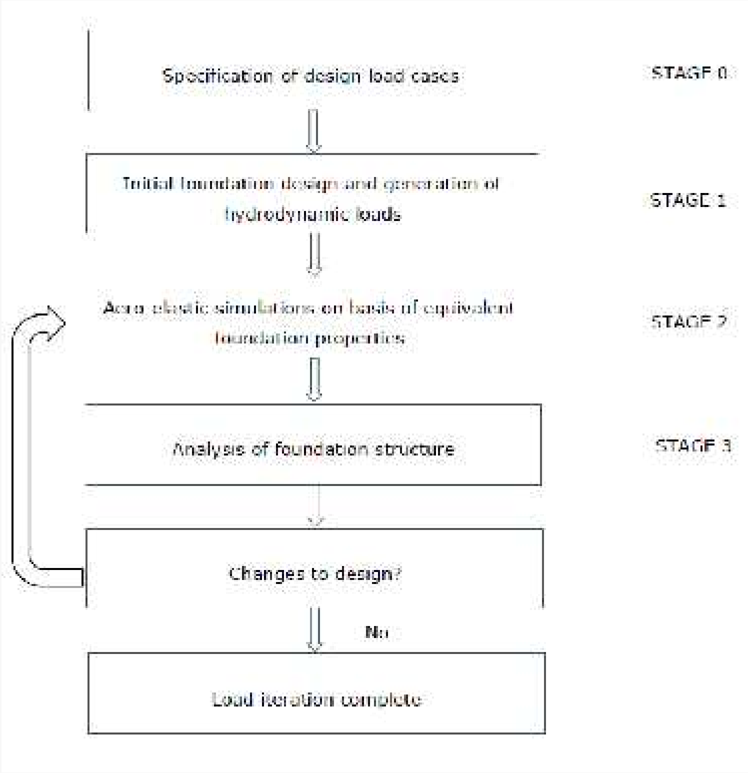
Dynamic system

- Wind and turbulence on the WTG
- Wave loads acting on the foundation
- Design checks:
  - ULS (50-year wind and wave)
  - FLS (over the design life time)
  - NFA (limits for WTG, to avoid resonance)
  - ALS (e.g. ship impact)
  - SLS (e.g. deformation limits)



# Introduction to foundation design
# Design process – load iteration

Iterative process



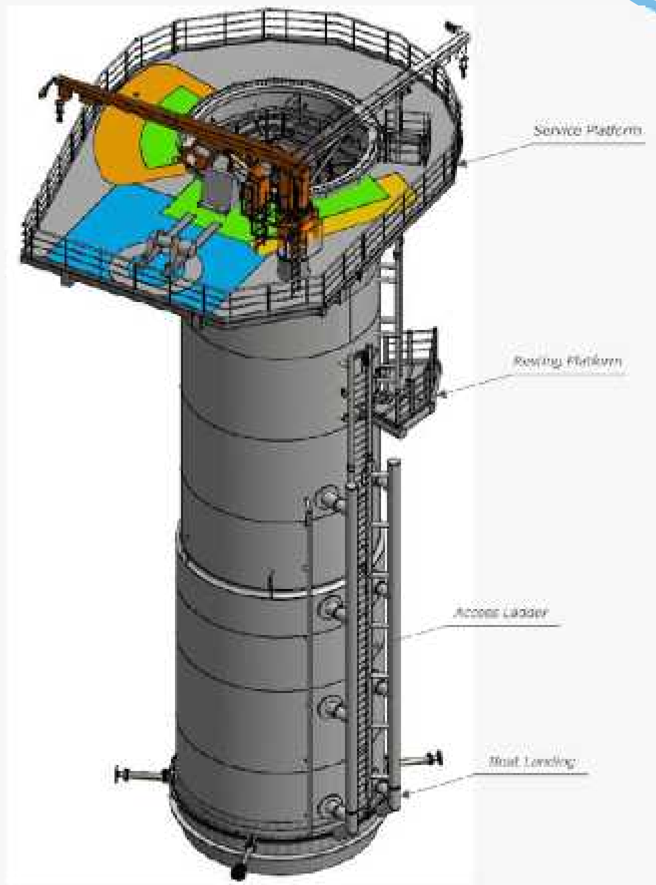
# Introduction to foundation design
# Appurtenances

External:

- Access system:
    - Boat landing
    - External resting platforms
    - Access ladders
- External working platform / service platform

Technical:

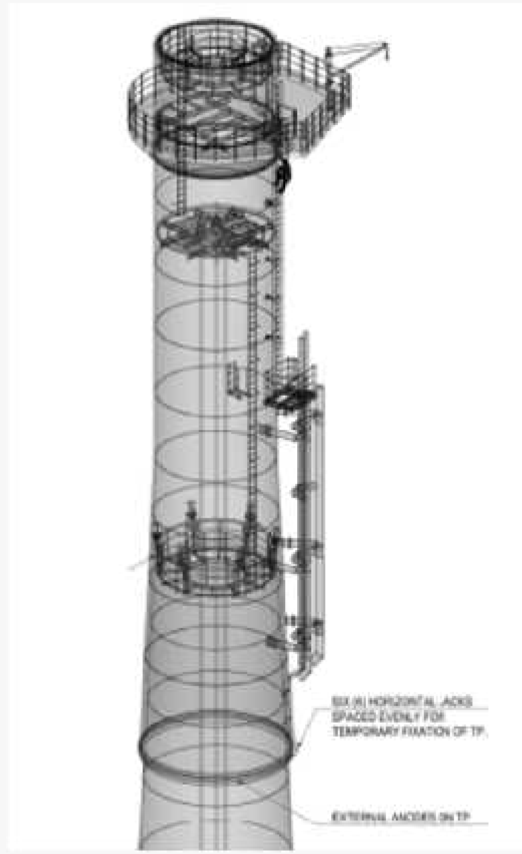
- Corrosion protection components
- Cable protection system
- Grout lines etc.



# Introduction to foundation design
## Appurtenances

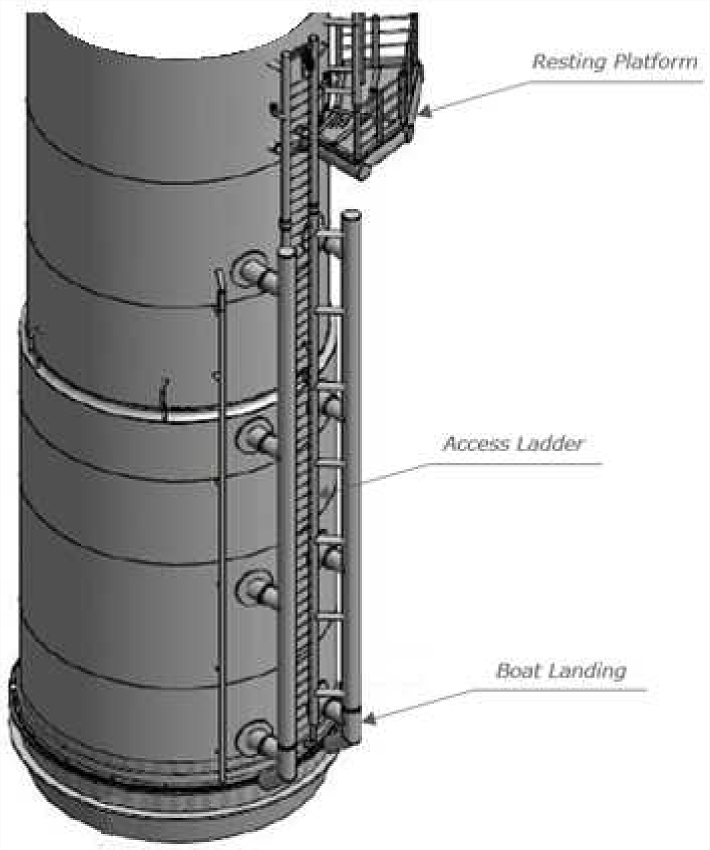
Internal:

- Bolting platform
- Switch gear platform
- Airtight deck
- Internal working platform
- Internal ladders

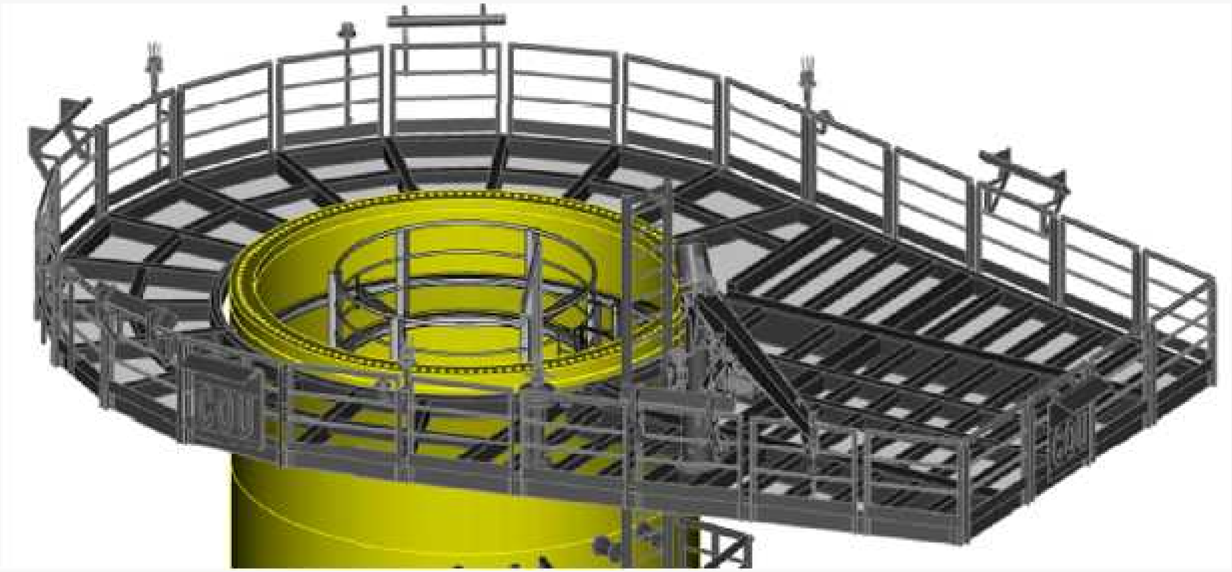


# Introduction to foundation design
# Appurtenances – Access system

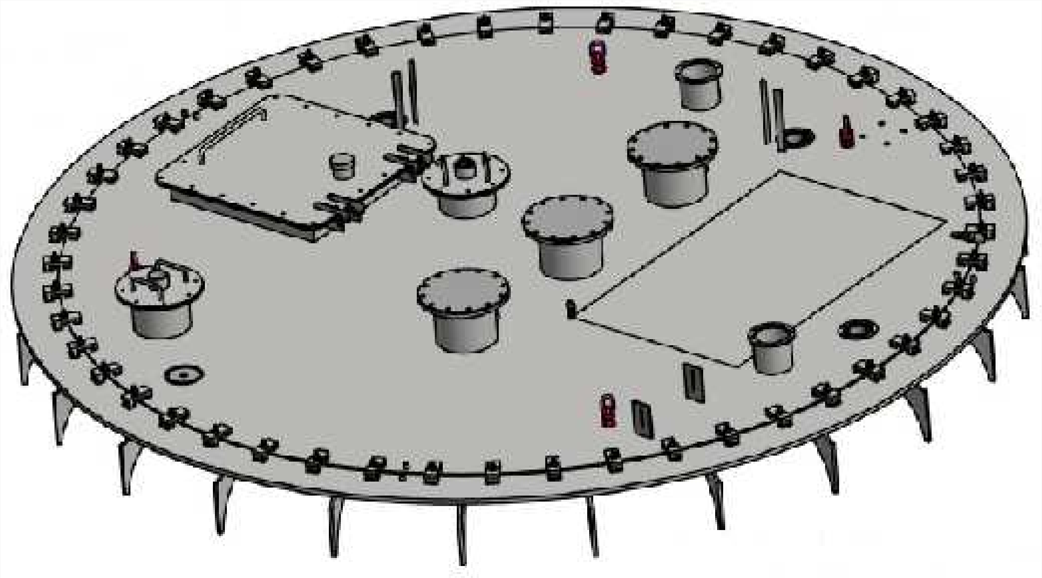
- Boat landing
- External resting platforms
- Access ladders



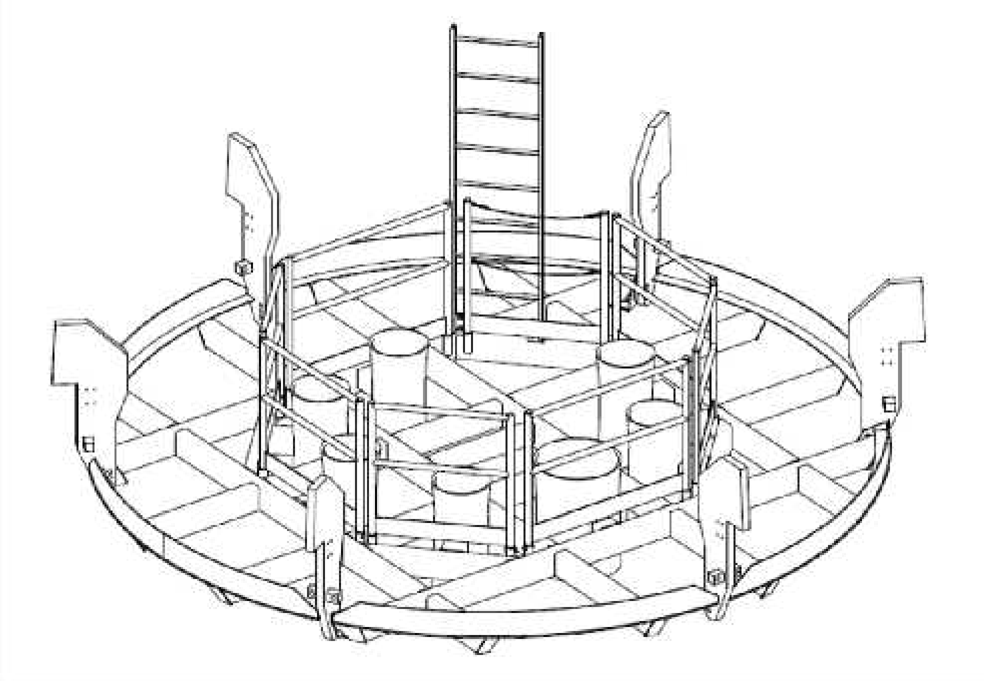
# Introduction to foundation design
# Appurtenances – Service platform



# Introduction to foundation design
# Appurtenances – Airtight deck



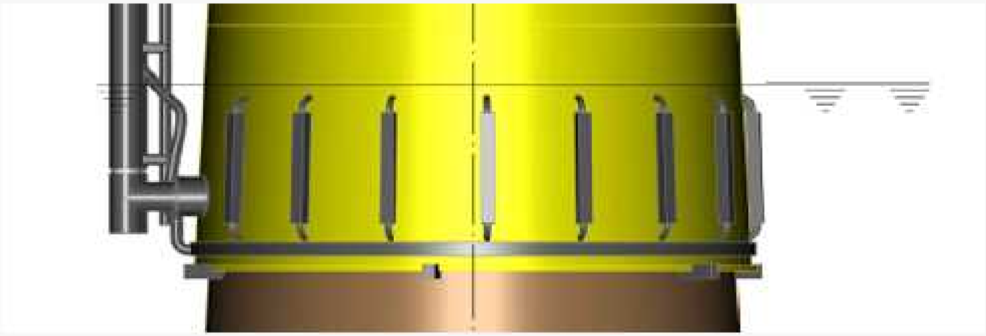
# Introduction to foundation design
# Appurtenances – Internal working platform



# Introduction to foundation design
## Appurtenances – Corrosion protection system

ICCP

GACP

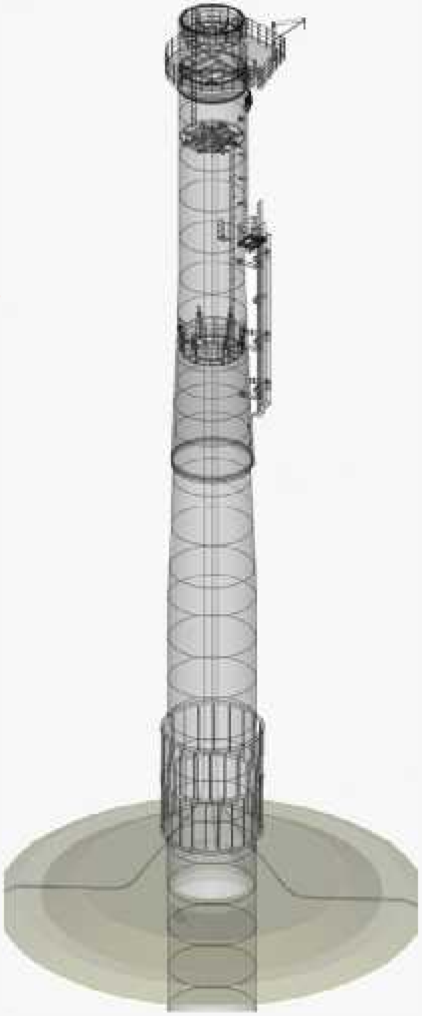


# 5. Basis for design

The site conditions for OWF Gujarat

# Basis of Design Overview

- Codes and standards -> DNVGL family of standards and guideline
- Foundation concept -> Monopile with grouted connection
- Design lifetime
- Design conditions
  - Soil conditions
  - Environmental conditions:
    - water depths and water levels
    - wind, typhoons
    - waves, currents
    - earthquakes
    - temperatures etc.
- Design processes, methodologies and loads



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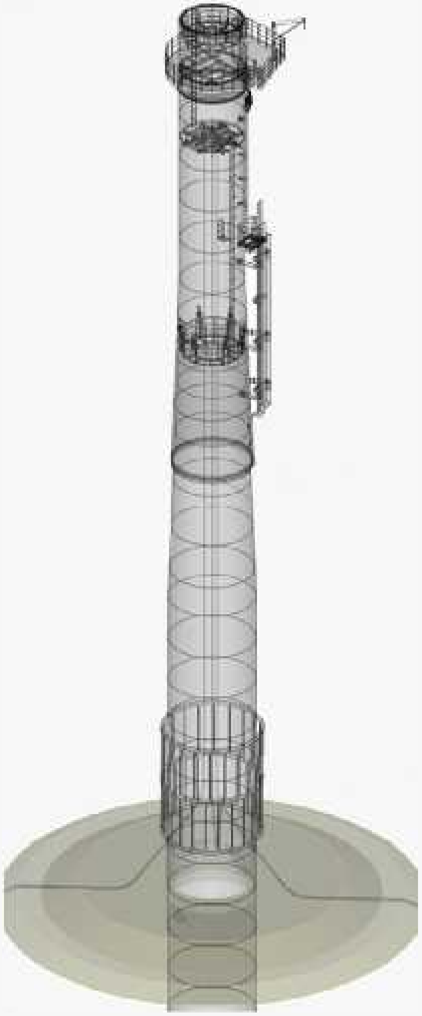
# Basis of Design
# Design lifetime

- Operation lifetime -> 25 years
- Installation period -> 6-12 months
- Commissioning of WTG -> 6 months
- Decommisioning -> 6 months
- Design lifetime -> 27 years



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# Basis of Design
## Soil conditions

| Top of layer | Soil type | Consistence | γ' | φ | $c_u$ |
|---|---|---|---|---|---|
| [m below sb] | - | - | [kN/m³] | [°] | [kPa] |
| 0.00 | Clay | Very soft | 6 | | 3 |
| 2.50 | Clay | Very soft | 6 | | 6.2 |
| 5.00 | Clay | Very soft | 6 | | 6.8 |
| 7.50 | Clay | Very soft | 6 | | 7.2 |
| 9.50 | Sand | Very dense | 10 | 41 | |
| 10.50 | Clay | Stiff | 10.5 | | 111 |
| 11.50 | Sand | Very dense | 10 | 35 | |
| 14.00 | Sand | Very dense | 10 | 41 | |
| 15.50 | Sand | Very dense | 10 | 37 | |
| 20.00 | Sand | Very dense | 10 | 38 | |
| 21.50 | Sand | Very dense | 10 | 37 | |
| 23.00 | Sand | Very dense | 10 | 39 | |
| 24.50 | Sand | Very dense | 10 | 36 | |
| 26.00 | Sand | Very dense | 10 | 41 | |
| 27.50 | Sand | Very dense | 10 | 37 | |
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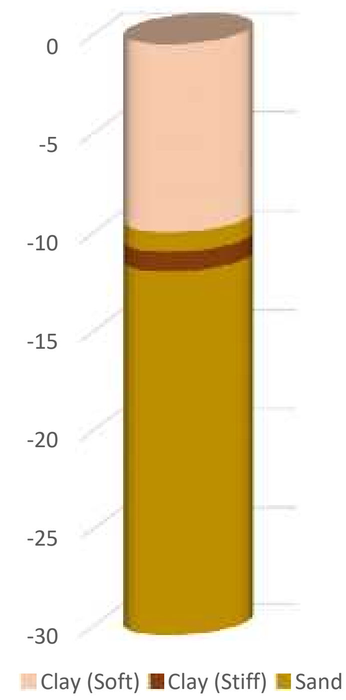

# Basis of Design
# Environmental conditions – water depths and levels

- Water depths range between 14 an 18 m w.r.t. LAT for OWF Gujarat -> 16 m w.r.t. LAT
- Extreme values for typhoon conditions:

| Return period (years) | 50 |
|---|---|
| Highest sea water level (m LAT) | + 7.80 |
| Storm surge (m) | 3.26 |
| Significant wave height Hm0 (m) | 9.5 |
| Extreme (design) wave height (m) | 17.7 |
| Extreme (design) wave crest (m) | 13.8 |
| Highest wave level (m LAT) | + 21.60 |

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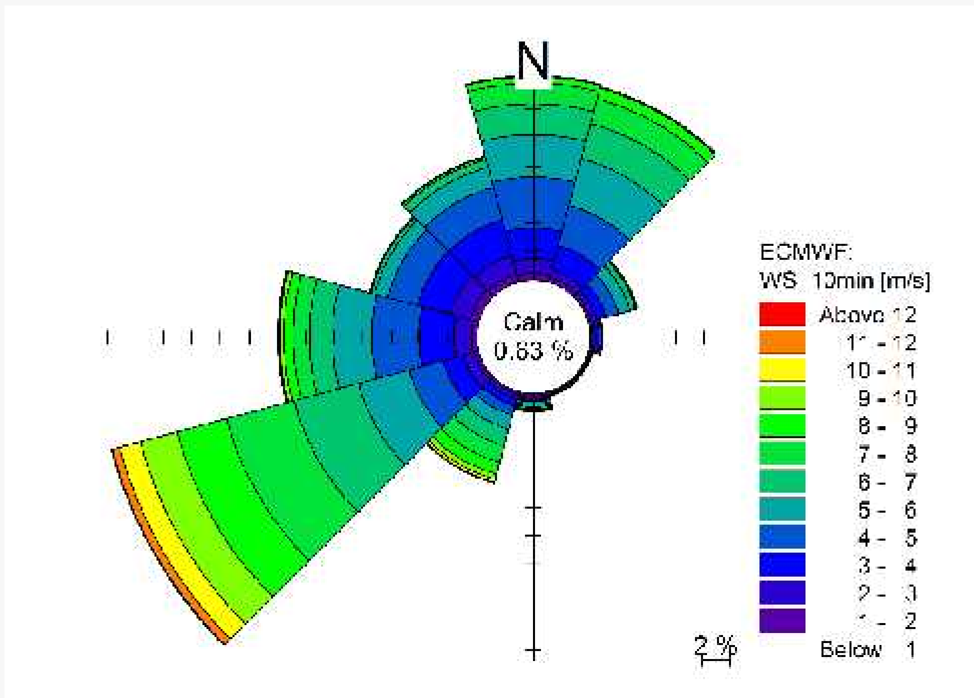
# Basis of Design
# Wind conditions – wind speeds



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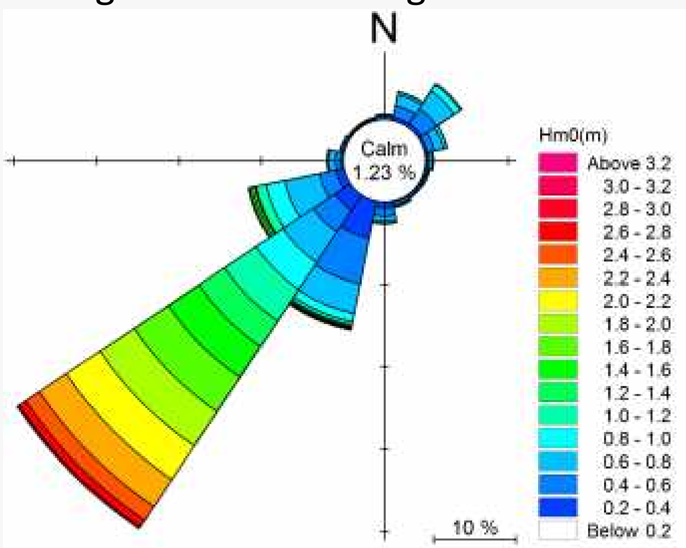
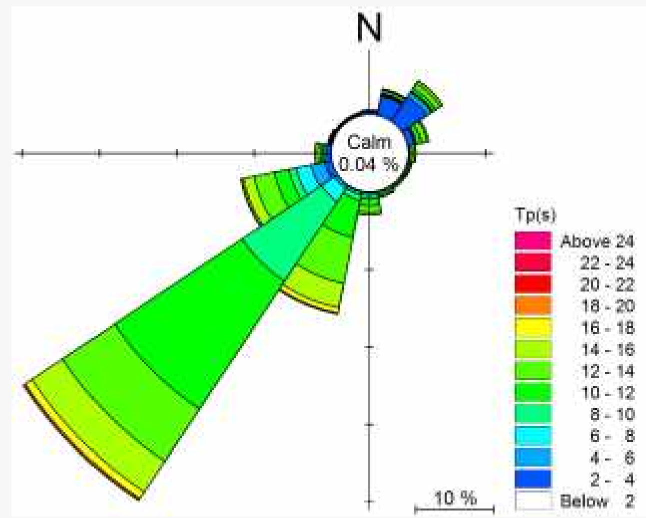
# Basis of Design
# Wave conditions – normal conditions

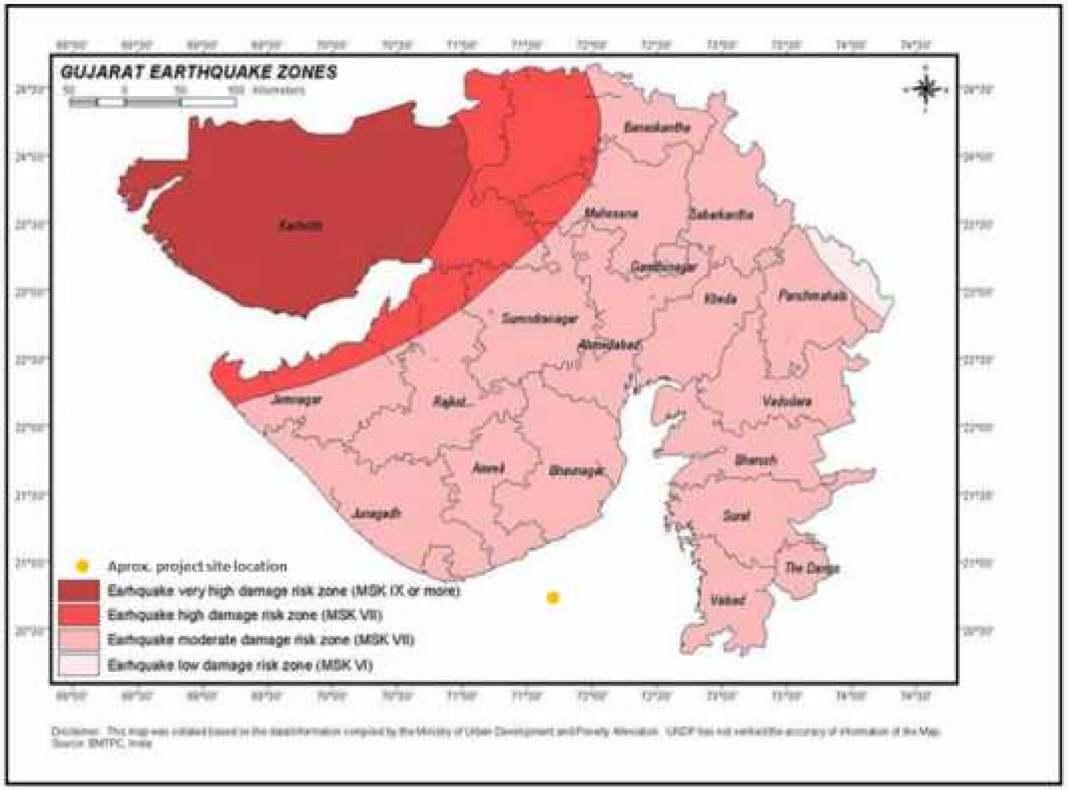
Significant wave height




Peak wave period



# Basis of Design
# Earthquakes

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# Basis of Design Summary

- **Design lifetime:** 27 years

- **Environmental conditions**

- Water Depth: **16m**
  - Highest sea water level**: +7.80m LAT**
  - Wind and wave loads: according to **Metocean study**
  - Maximum design wave level: **+21.60m LAT**
  - Splash zone: **-1.50m** to **+7.00m LAT**
  - Marine growth: according to **ISO 19901-1:2005**
  - Earthquakes: 1 time **bottom diameter of MP** added to pile length
  - Scour protection assumed

- **Design loads:** FLS and ULS

- **Soil conditions**

| Top of layer | Soil type | Consistence | $\gamma'$ | $\varphi$ | $c_u$ |
|---|---|---|---|---|---|
| [m below sb] | | | [kN/m³] | [°] | [kPa] |
| 0.00 | Clay | Very soft | 6 | | 3 |
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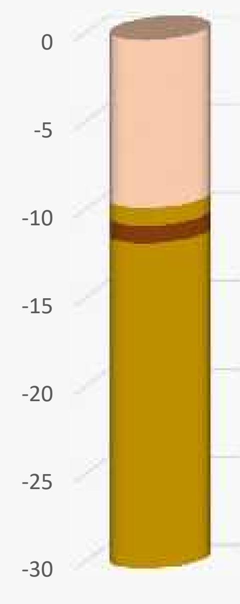
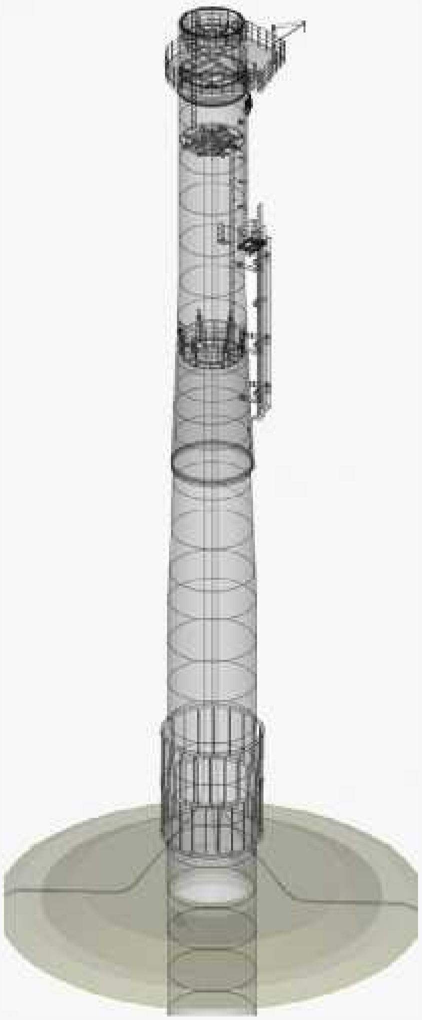


# 5. Advisory Foundation Design

# Advisory Foundation Design
# Concept Design

- **Monopile foundation** recommended for the site
  - **Most common foundation type** in offshore wind farms
  - **Suitable** for a wide variety of **soil conditions**
  - **Rapid fabrication and installation**
  - **Lower costs** compared to other foundation types

- Challenges are
  - **Heavy lift crane** for installation
  - **Hydraulic hammer** for installation
  - **Fabrication facilities** for huge piles and TPs



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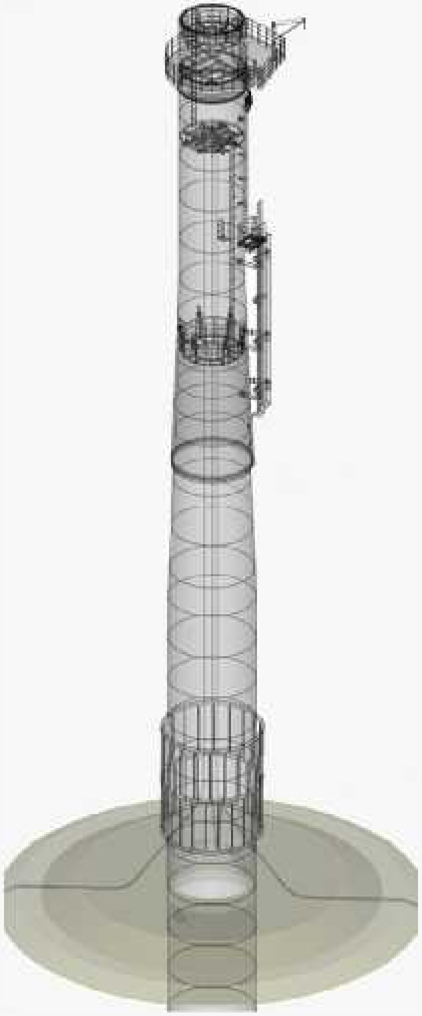
# Advisory Foundation Design
# Main Features

- **Conical grouted connection** between MP and TP
- **Interface level** between TP and Tower at **+24m LAT**
- **Top of MP** at **+6 m LAT**
- **Bottom of TP** at **-4m LAT**



# Advisory Foundation Design Results

- ULS and FLS design checks fulfilled.
- NFA:

| Turbine Model | [-] | 3 MW | 6 MW |
|---|---|---|---|
| Frequency (ULS model/LB) | [Hz] | 0.294 | 0.245 |
| Frequency (FLS model/BE) | [Hz] | 0.295 | 0.247 |
| Frequency (Upper Bound/UB) | [Hz] | 0.298 | 0.248 |

# Advisory Foundation Design Dimensions

| Turbine model | [Unit] | 3 MW | 6 MW |
|---|---|---|---|
| Mass of TP | [MT] | 191 | 306 |
| Length of TP | [m] | 28 | 28 |
| Top diameter of TP | [m] | 4.5 | 6.0 |
| Bottom diameter of TP | [m] | 5.5 | 7.0 |
| Wall thickness of TP | [mm] | 55-65 | 60-90 |
| Mass of MP | [MT] | 530 | 870 |
| Length of MP | [m] | 58 | 63 |
| Embedment length of MP | [m] | 36 | 41 |
| Top diameter of MP | [m] | 4.4 | 5.9 |
| Bottom diameter of MP | [m] | 5.5 | 7.0 |
| Wall thickness of MP | [mm] | 55-80 | 60-100 |
| Length of cylindrical section of MP | [m] | 42 | 47 |
| Length of conical section of MP | [m] | 16 | 16 |

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Thank you very much for your attention!
Any questions?



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