海床条件和基础

Seabed conditions and foundations

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概况Overview

场址调查

Site investigations

- 必要性

  Why are they necessary?

- 如何处理

  How do you do them?

基础

Foundations

- 选项

  Options

- 影响因素

  Influences on selection

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场址调查的必要性
The need for site investigations

基础设计
Foundation design

- 基础可能占工程成本的20－30％
  Foundations may comprise up to 20-30% project cost
- 测海学
  Bathymetry
- 基础设计－地质/地理学条件
  Foundation design - geotechnical/geophysical conditions
- 结构流体动力载荷（海洋气象学）
  Hydrodynamic loading of structures (met ocean)

环境影响评估
Environmental impact assessment

- 对自然环境的影响
  Physical
  - 基准数据
    Baseline data
- 对生物的影响
  Biological
- 对社会经济和文化的影响
  Socio economic / cultural

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—M Latham（1994）

“没有哪个建筑项目是没有风险的，风险可以被克服、被减小、被分担、被转移或者承担，但是不能被忽视”

“No construction project is risk free. Risk can be managed, minimised, shared, transferred or accepted. It cannot be ignored” M Latham (1994)

在项目早期进行，计划完善的，场址调查是必须的，以确保能把由于不可预测的现场自然条件引起的潜在危险降到最低。

Well planned site investigations, carried out early in the project timescale are essential to ensure the potential risks associated with the occurrence of unexpected physical site conditions are minimised.

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地质/地理学的调查
Geotechnical / geophysical investigations

分阶段的方法
Phased approach

- 资料收集研究
  Desk top studies
- 地质地理初步调查
  Preliminary geophys survey
- 项目初步安排
  Preliminary project layout
- 现场调查计划编制
  SI planning
- 现场调查
  On site investigation
- 实验室测试
  Laboratory testing

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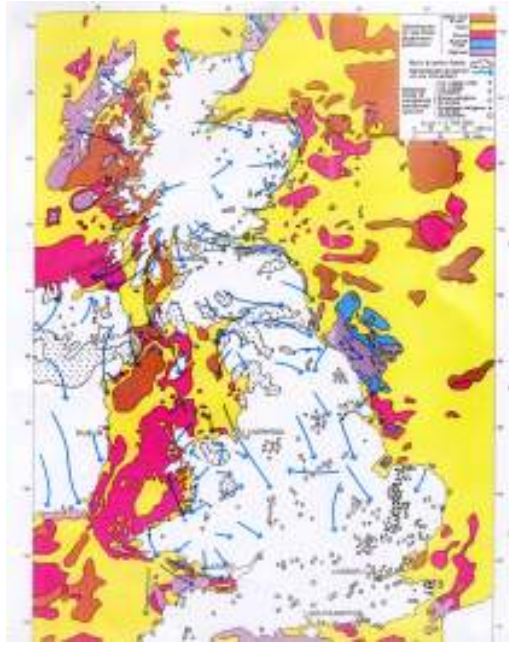
地质/地理学的调查
Geotechnical / geophysical investigations

资料收集研究Desk top studies

- 现有信息的来源Sources of existing information
  - 地质地图Geological Maps
  - 英国地质勘测British Geological Survey
  - 以前的工作Previous works
    - 建设工程Construction works
    - 电缆/管道铺设Cable/pipeline laying
    - 油/气勘探Oil/Gas exploration
  - 英国水文地理部门UK Hydrographic Office
  - 空中摄影Aerial Photography
  - 当地信息Local Knowledge
- 核对及比较现有的信息Collate and compare all existing information
  - 找出现有信息的状态Define the current state of knowledge
  - 找出有关现场未知的信息Highlight what is not known about the site



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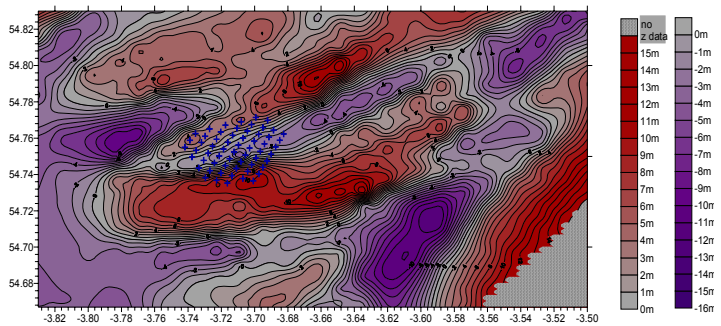
地质/地理学的调查
Geotechnical / geophysical investigations

- 项目初步安排(基于资料收集研究)
  Preliminary project layout (based on desk top studies)

- 自然限制Physical constraints
  - 对比海床高度历史—时间序列Historical comparison of bed levels - time history
  - 水深Water depths
  - 并网连接Grid connection
  - 生态学限制Ecological constraints

- 场址初步布局Preliminary site layout
  - 场址面积site area
  - 可能的风机布局possible turbine layout
  - 可能的电缆路线likely cable route



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地质/地理学的调查
Geotechnical / geophysical investigations

现场调查计划SI planning

- 风险与成本的对比研究Risk vs cost
  - 首先为初步设计提供足够信息Initially sufficient information for preliminary design
  - 足够的数据范围Adequate coverage
  - 数据的可靠性－选择钻孔或地震Reliability of data - borehole vs seismic
- 气候/现场可达性－夏季为好Weather/accessibility - summer preferable
- 调查步骤Programme
- 可选择的承包商Contractor availability / 船只的选择vessel choice
- 调查的范围Range of investigations
  - 基于资料收集研究的结果Based on results of desk top study
    - 地质学的/地理学的Geotechnical/geophysical
    - 海洋气象学Metocean

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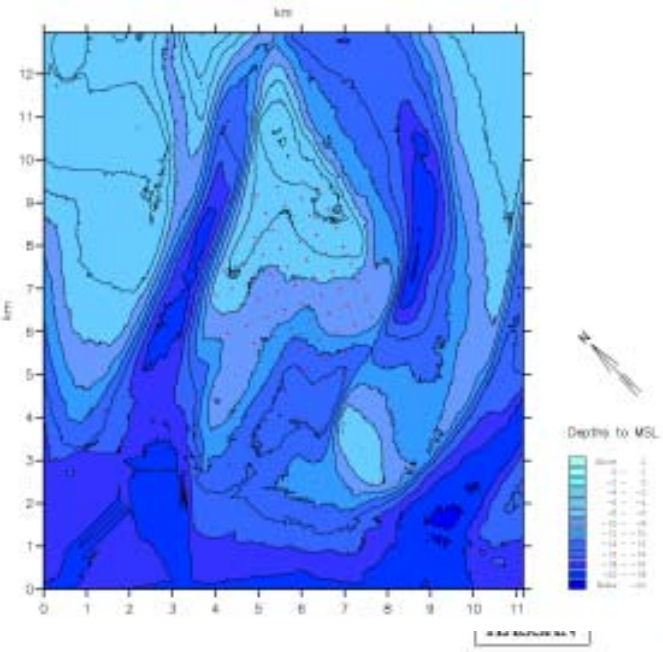
地质/地理学的调查
Geotechnical / geophysical investigations

现场调查－测海学On site investigations - bathymetry

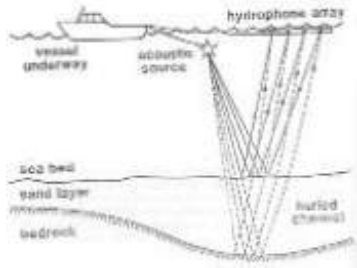
- 声纳探测Sonar survey
  - 包括风机的区域和周围区域Cover turbine area and surrounding sea
  - 在主要区域采用小间隔纵横交错的声纳探测-100至 150 m Closely spaced orthogonal survey runs on main area - 100 to 150 m
  - 在偏远的地区可用更大的间隔进行测量Surveying can be more widely spaced on more remote areas
  - 以最低成本，覆盖大的区域Large areas covered at min
  - 补充打孔之间的区域'Fills in' areas between boreholes
  - 应计划好包括打孔的位置Should be planned to coincide w
- 应与海岸加工的研究相结合Linked into coastal processes stud

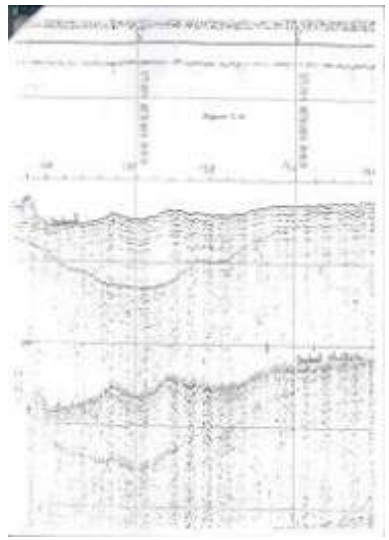


地质/地理学的调查
Geotechnical / geophysical investigations

现场调查－地理学方面
On site investigations - geophysical

- 海底剖面Sub bottom profiler
  - 应用数字全球定位系统进行排列布置
    Towed array with DGPS positioning
  - 提供关于地层剖面信息
    Provides information on sub-bed stratigraphy
  - 基于地震剖面解释的结果
    Results based on interpretation of seismic profile
  - 以最低成本，覆盖大的区域
    Large areas covered at minimal cost
  - 补充打孔之间的区域
    ‘Fills in’ areas between boreholes
  - 应计划好包括打孔的位置
    Should be planned to coincide with borehole locations

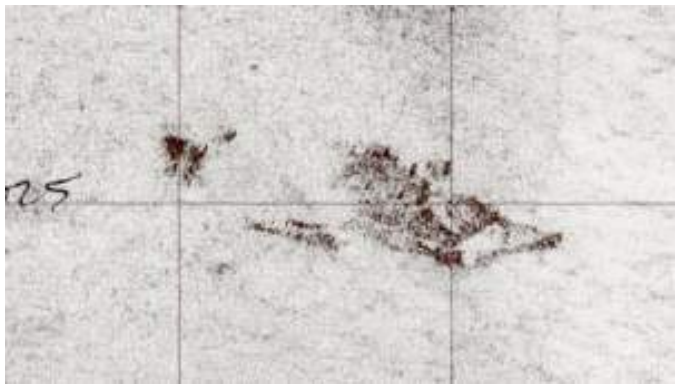


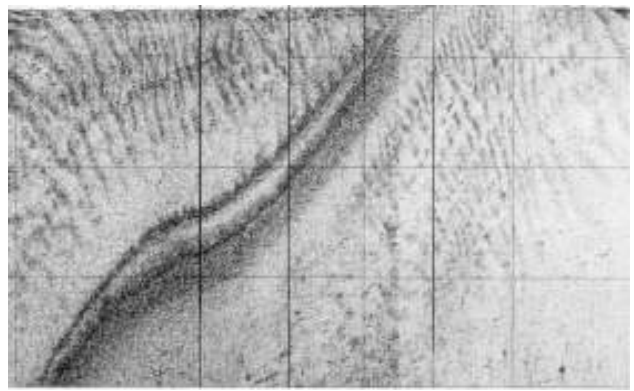


地质/地理学的调查
Geotechnical / geophysical investigations

现场调查－地理学方面On site investigations - geophysical

- 扫描声纳侧面Side scan sonar
  - 应用DGPS进行排列布置Towed array with DGPS positioning
  - 提供关于地层剖面信息Provides information on bed profile
  - 确定砂波的尺寸和方向Identifies size and direction of sand waves
  - 应用于考古学识别残骸/异物Used by archaeologists to identify wrecks / anomalies





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地质/地理学的调查
Geotechnical / geophysical investigations

现场调查—地理学方面
On site investigations - geophysical

- 地磁仪
  Magnetometer
  - 应用DGPS布置进行排列
    Towed array with DGPS positioning
  - 提供金属异物的信息
    Provides information metallic anomalies
  - 应用考古学识别残骸/异物
    Used by archaeologists to identify wrecks/anomalies

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地质/地理学的调查
Geotechnical / geophysical investigations

现场调查－地理学方面On site investigations - geotechnical

- 打孔Boreholes
  - 壳钻/旋转钻探Shell and auger / rotary drilling
  - 打孔网格根据当地情况的进行修改－钻孔的数目取决与调查的目的和项目开发的阶段
    Grid pattern modified as required by local features - number of holes will depend on the purpose of the investigation and the stage of the project.
  - 一般的深度是30－40mDepths typically 30-40 m
  - 使用自升式钻塔平台钻孔
    Drilled from jack-up platform
  - 根据实际情况及时分析调整
    Flexibility through prompt reporting
  - 取样/测试的范围
    Range of sampling/testing
    - 描述/记录
      Description/logging
    - 无干扰和受干扰的取样
      Undisturbed and disturbed sampling
    - 锥形穿透测试
      Cone penetration testing
    - 礁石样品
      Rock coring

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海上风机的基础选择
Offshore Foundations

- 类型
  Types
- 对选型和设计的影响
  Influences on selection and design

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至今海上风机基础选择
Offshore foundations to date

位置 Location	试运行时间 Date of Commissioning	与海岸距离 Distance from Shore (km)	风机数 No of turbines	风机类型/额定功率 Turbine type & rating	水深 Water depth (m)	基础类型 Foundation type
Vindeby, Denmark	1991	1.5 > 3.0	11	Bonus 450 kW	2.5 > 5	混凝土重力式 Concrete gravity
Lely, Netherlands	1994	1	4	Nedwind 500kW		单根钢桩式 Steel monopile
Tuno Knob	1995	6	10	Vestas 500kW	3 > 5	Concrete gravity
Dronten, Netherlands	1997	0.4	28	Nordtank 600kW	5	Steel monopile
Bockstigen, Sweden	1998	4	5	Wind World 500kW	6	Steel monopile
Utgrunden, Sweden	2000	8 > 12.5	7	Enron Wind 1500kW	7.2 > 10	Steel monopile
Blyth, UK	2000	0.5	2	Vestas 1800 & 2000kW	7.5	Steel monopile
Middlegrunden, Sweden	2000	2	20	Bonus 2000kW	2 > 5	Concrete gravity
Yttre Stengrund Sweden	2001	6	5	Neg Micon 2000kW	9	Steel monopile
Horns Rev, Denmark	2001	17	80	Vestas 2000kW	6.5 > 13.5	Steel monopile
North Hoyle, UK	2003	7 > 8	30	Vestas 2000kW	10 > 15	Steel monopile
Nysted, DK	2004	12	72	Bonus 2.3MW	10	Concrete gravity
Arklow Bank, Ireland	2004	14	7	GE 3.6 MW	5 > 8.5	Steel monopile
Scroby Sands, UK	2004	2.5	30	Vestas 2MW	4 > 12	Steel monopile
Kentish Flats	2005	12	30	Vestas 3MW	5	Steel monopile
Barrow	2006	8	30	Vestas 3MW	20	Steel monopile
OWEZ	2006	10-18	36	Vestas V90	22	Steel monopile
Beatrice	2007	25	2	REpower 5M	45	四桩式 Quadropod
Burbo	2007	6	25	Siemens 3.6	8	Steel monopile

风机基础类型
Foundation types

单桩式
Monopile

重力式
Gravity

多桩式
Multi-pile

沉箱式
Suction

漂浮式
Floating

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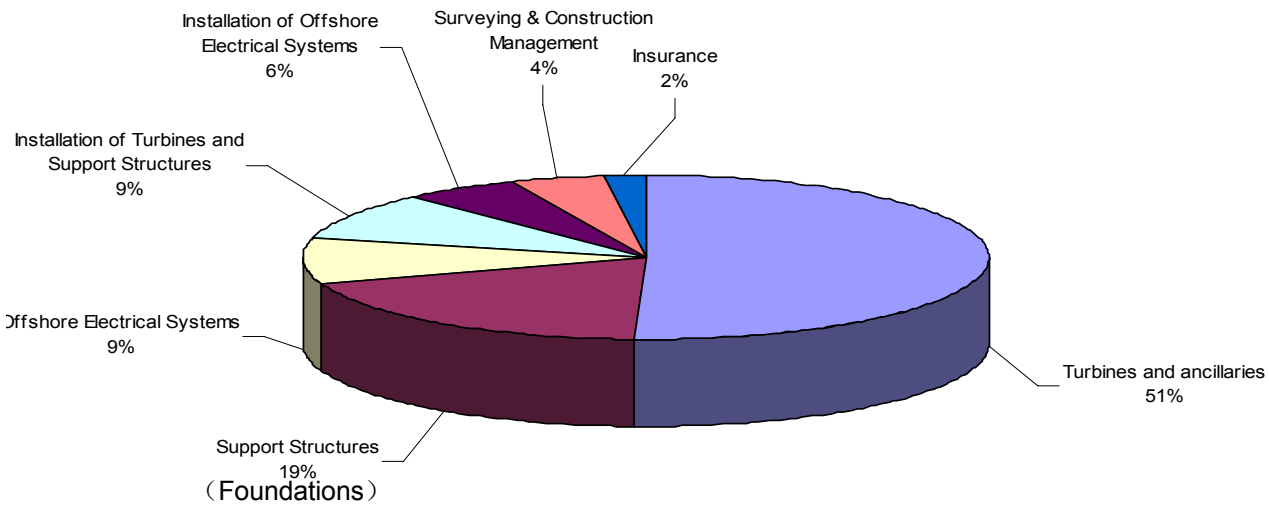
基础的重要性？
Why are foundations important?

在成本中占有较大的比重
Large proportion of capital costs

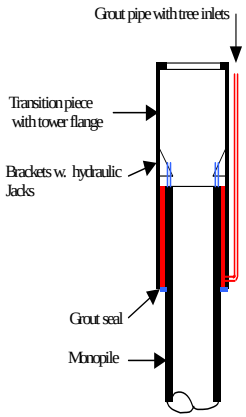
主要的成本风险和规划风险
Major risk for cost and programme

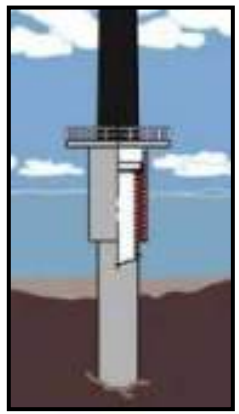
图：海上风机成本比例

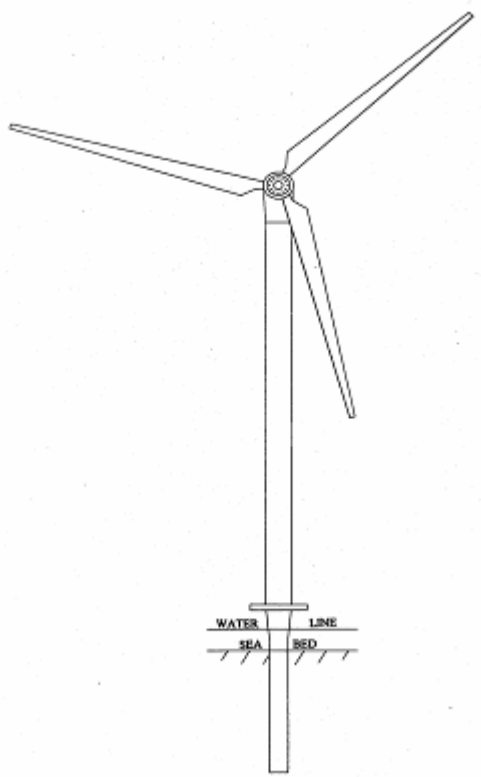


基础类型－单桩式
Foundation types - Monopile

- 钢管Steel Tube
- 通常 直径4.5－5m Typically 4.5 - 5 m dia
- 厚度30－60mm Thickness 30 - 60 mm
- 打入/钻孔 Driven/drilled
- 需要一个过渡段固定在桩上部
  Transition piece grouted to top of pile







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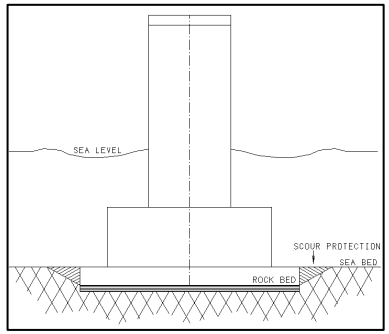
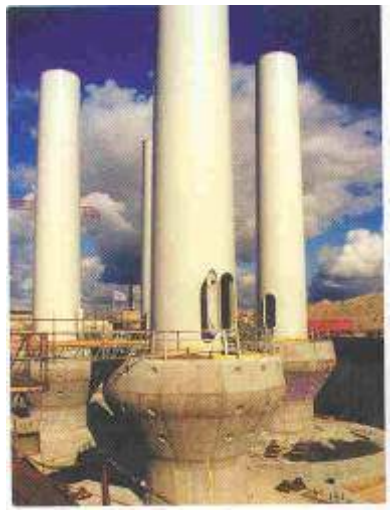
基础类型－重力式
Foundation types - Gravity

- 钢或者混凝土
  Steel or concrete
- 依靠基础的重力抵抗倾覆力矩
  Relies on weight of structure to resist overturning
- 需要压舱物
  Ballast may be required
- 海床准备非常重要
  Seabed preparation essential
- 对海浪冲刷比较敏感
  Can be susceptible to scour
- 适应于水浅的场址
  Better suited to shallower sites





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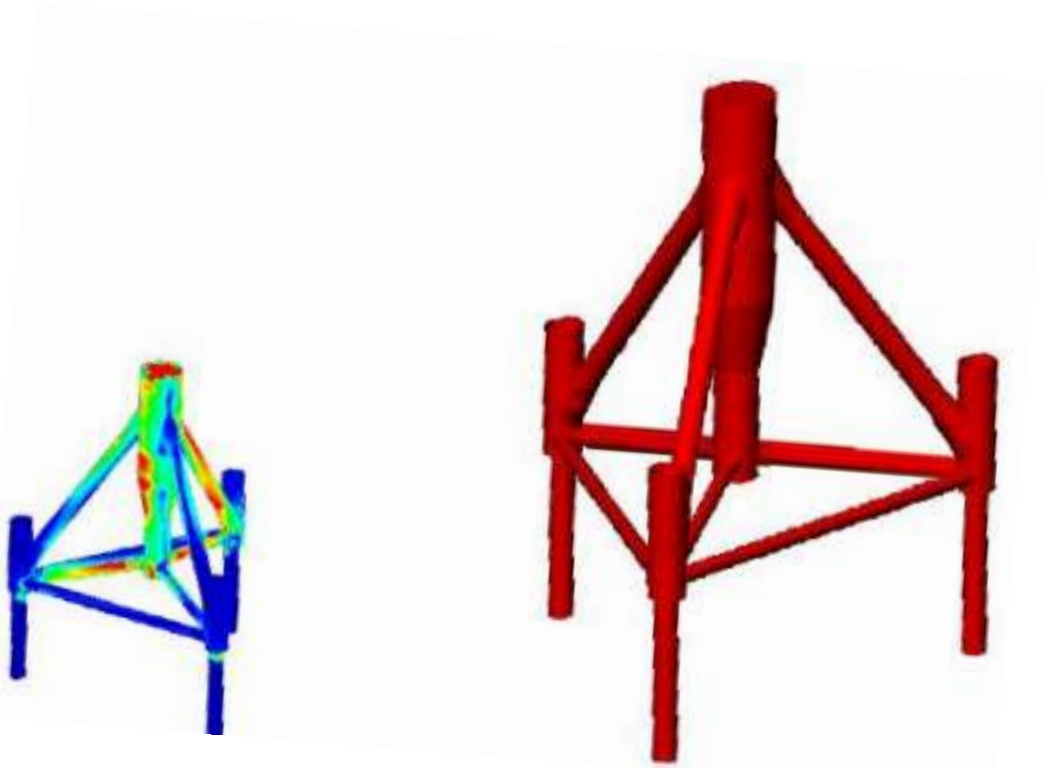
基础类型—多桩式
Foundation types - Multi-pile

- 小直径钢桩
  Small diameter steel piles
- 管状钢结构
  Tubular steel superstructure
- 填塞或者成型连接
  Grouted or swaged pile connections
- 适合水深的地区
  Suitable for deeper water
- 目前还没有应用
  No installations to date



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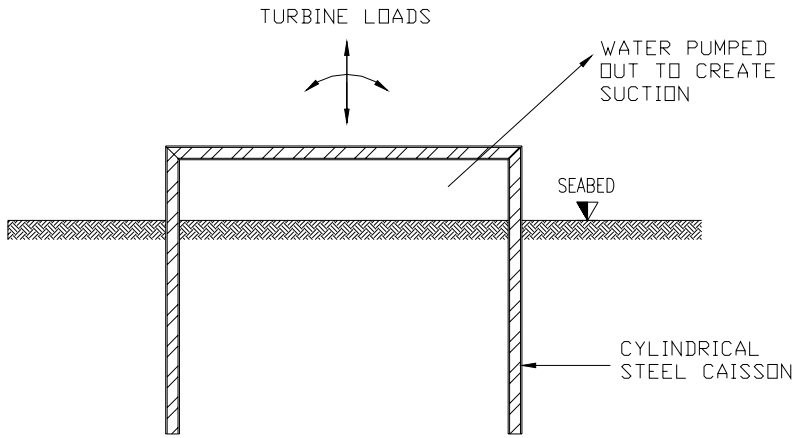
基础类型—沉箱式
Foundation types - Suction

- 钢箱结构
  Steel skirt caisson structure
- 沉箱靠重力插入海床
  Penetrates into seabed under self weight
- 抽出箱内海水以产生压力
  Trapped water pumped out to produce suction effect
- 以用于海上平台安装的锚泊固定
  In use as mooring anchors for offshore installations
- 目前处于可行性研究阶段
  Feasibility stage at present for turbine foundations



漂浮式基础
Floating Foundations

好处：

Benefits:

- 可应用于新的场址和国家

  Expands potential to new sites & countries
  - 挪威、美国、西班牙、日本

    Norway, USA, Spain, Japan…
- 概念选择范围广

  wide choice of concepts
  - 依据：参见各种建议

    evidence: see variety of proposals
- 成本与固定海底方式差不多

  Similar cost as bottom-mounted
  - 这些概念有待被证实

    once concepts are proven
- 在建设和安装步骤上有比较大的弹性

  greater flexibility of construction & installation procedures
- 容易移动/拆卸

  easier removal / decommissioning

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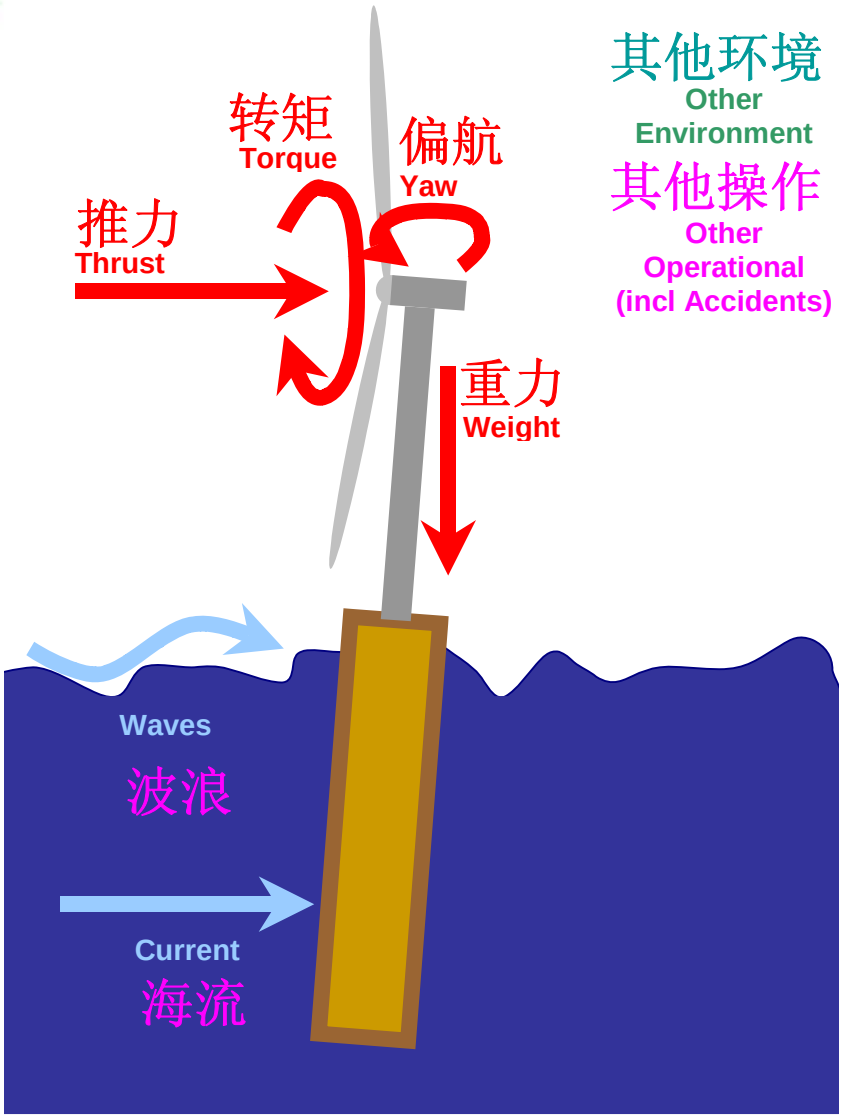
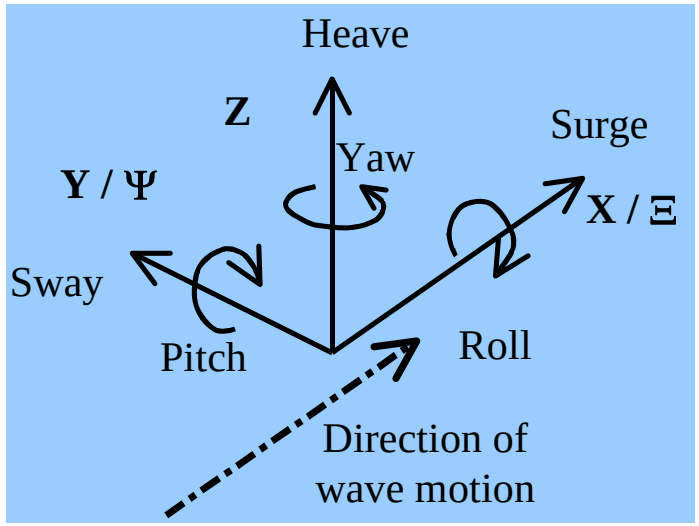


设计支配因素
Design Drivers

- 风机的推力
  turbine thrust
- 上风风机的偏航稳定性
  upwind yaw stability
- 波浪（载荷以及引起的运动;固有周期）
  Waves (loads and induced motion; natural periods)



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全世界海上风机场址
Worldwide Sites

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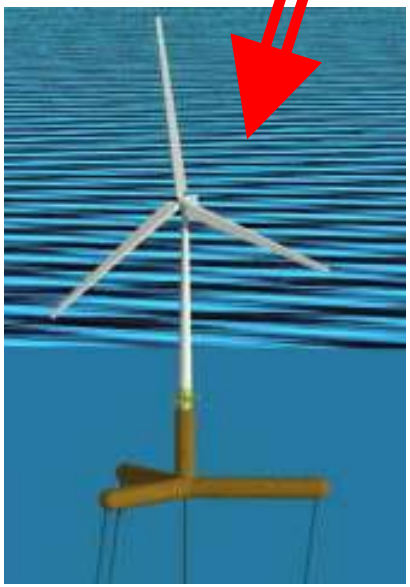
漂浮式基础：3种概念类型
Floating Foundations: 3 Classes of Concept

要达到稳定性Achieving Stability

1. 流体静态平衡Hydrostatic (water piercing area)
2. 重力摆锤式Mass (pendulum effect)
3. 水下锚系式Moorings (tensioned)



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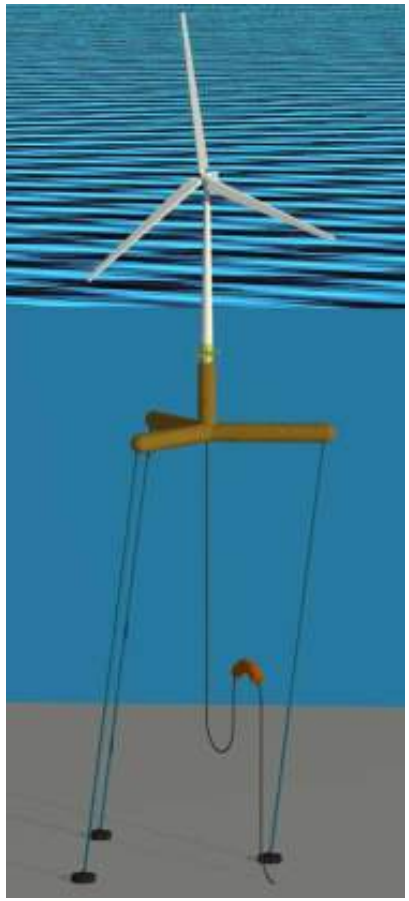
候选概念： TLP
Candidate Concepts: TLP

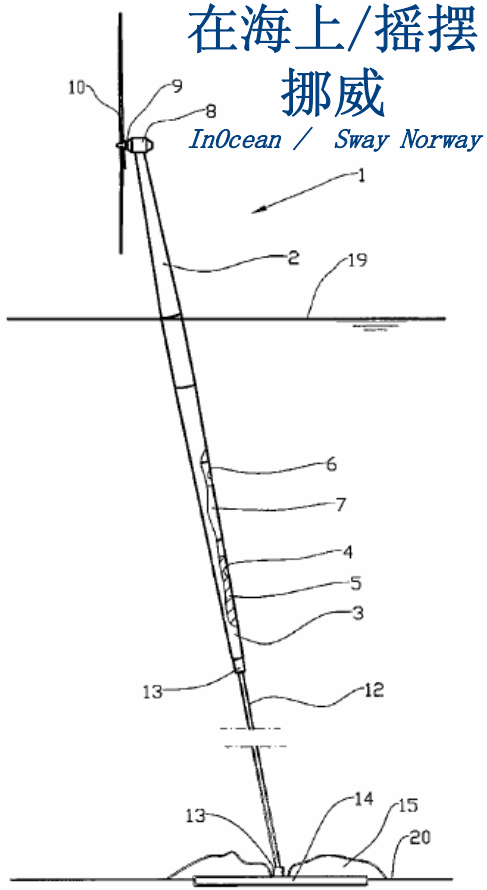
- 小运动
  Low motion
- 系泊的成本
  Cost of moorings
- 安装和拆卸的困难
  Difficulty of Installation / removal



在海上/摇摆

挪威

InOcean / Sway Norway



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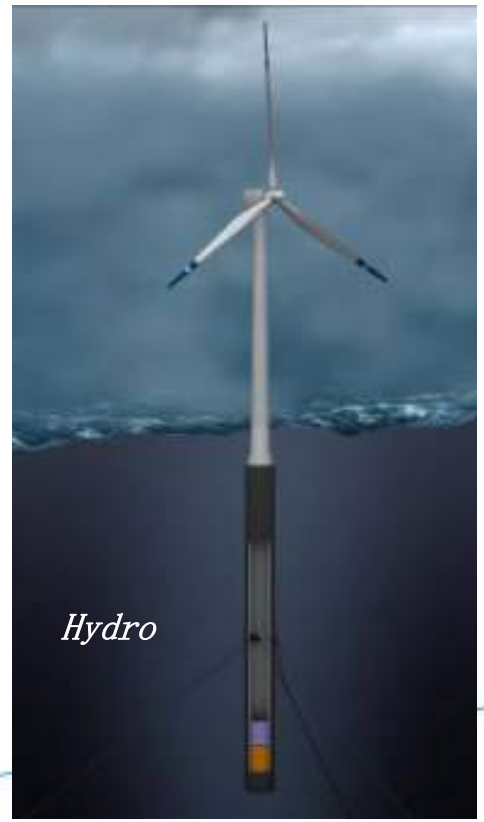
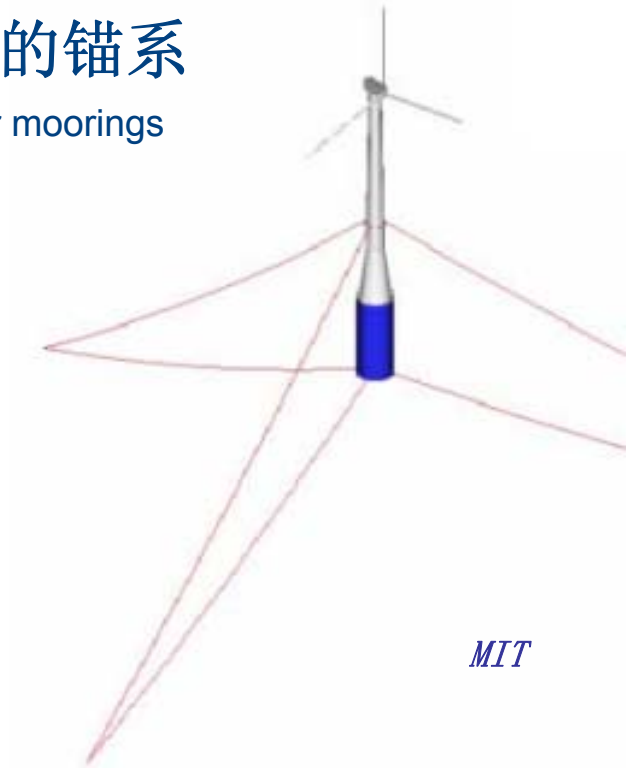
候选概念：柱形浮筒
Candidate Concepts: Spar Buoy

- 大的平均和动态运动响应（与其他概念对比）
  Large mean and dynamic motion response (c.f. other concepts)
- 短的浮筒需要一个重的圆盘或者坚固的锚系
  Shorter buoy would require a heave-suppression disc or firmer moorings





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候选概念：三浮箱
Candidate Concepts: Tri-Floater

- 需要阻尼板增加固有周期
- （从而减小运动响应）

  Damping-plates needed to increase natural periods (and hence reduce motion response)

- 浅水（<50m）

  Shallow Waters (< 50m)

- 相对于TLP设计：减小了风险但增加了成本

  c.f. TLP: less risky but more expensive

- 风机在角上→需要更重的结构

  Turbine at corner
  → heavier structure

- 四浮箱→结构更重

  4-Floater
  → heavier structure

对基础类型选型的影响
Foundation types - influences on choice

- 水深
  Water Depth
- 土壤和海床条件
  Soil and bed conditions
- 环境载荷
  Environmental loading
- 建设方法
  Construction methodology
- 成本
  Cost

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水深的影响
Influences - Water Depth

- 随着水深的增加倾覆的可能性增加
  Increased overturning with increased depth
- 支持相同的风机需要比较大的结构
  Larger structures required to support same turbine
- 工作环境更加困难
  More difficult working environment

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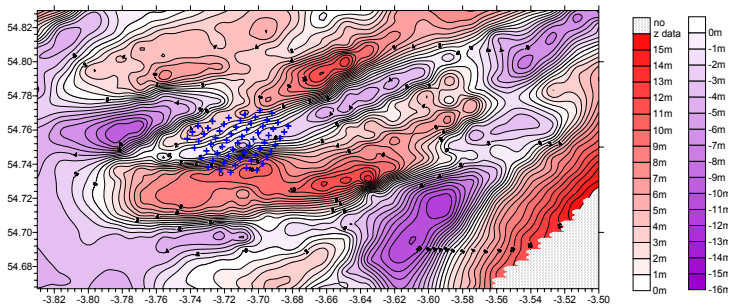
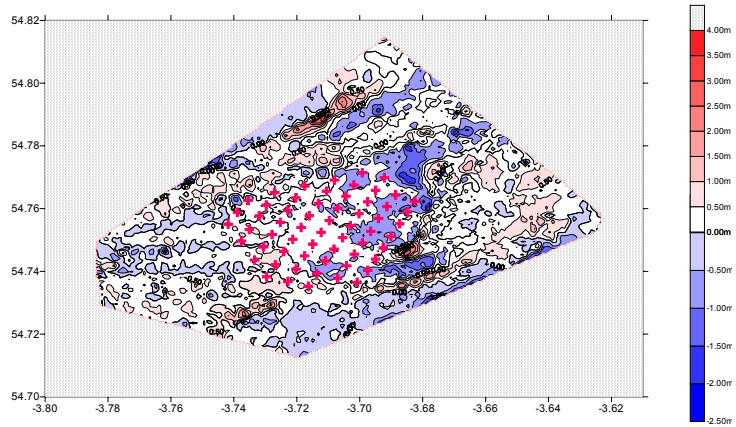
海底土壤和海床的影响
Influences - Soil and Bed Conditions

- 地层学
  Stratigraphy
- 土壤强度
  Soil strength
- 岩表深度
  Level of rock head
- 海床迁移率
  Bed mobility
  - 全体迁移
    Overall bed movement
  - 当地冲刷
    Local scour





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环境载荷的影响

Influences - Environmental loading

- 风机的风载
  Wind Loading from Turbine
- 波浪高度和周期
  Wave Height and Period
- 破碎波条件
  Breaking Wave Conditions
- 海流速度
  Current Speed
- 冰载
  Ice
- 海洋生物附着生长
  Marine Growth

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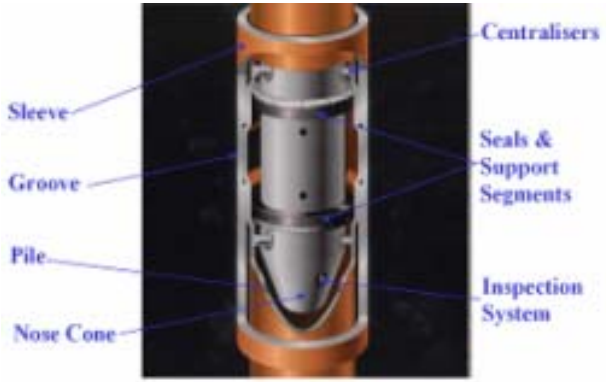
建设方法的影响
Influences - Construction methodology

- 装配/海岸设施
  Fabrication/Shore Side Facilities
- 可利用的安装设备
  Available Installation Equipment
- 基础的运输
  Transport of Foundations
  - 尺寸
    Size
  - 重量
    Weight
- 基础的连接
  Foundation Connections
  - 安装速度
    Speed of Installation
  - 临时支撑必需吗？
    Temporary propping required?
  - 安装期间需要监护？
    Attendance required?



Hydra-Lok® Swaged Connection

安装的影响
Influences - Installation

- 可利用的装备/资源Available equipment/resources
  - 顶起/钻井浮船Jack-up/Floating barge
  - 打桩设备Piling equipment
  - 放缆Cable laying

- 当地后勤限制Local logistical restrictions
  - 海港/海岸设备Harbour/shore side facilities
  - 水深/潮汐限制Water depth/ tidal restrictions
- 法律允许的条件Conditions of Statutory Consents
- 气候的限制Weather

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成本的影响
Influences - Cost

- 制作成本Fabrication
  - 原料成本Raw material cost
  - 位置－尽可能设在港口Location - at port if possible
  - 运输－整体尺寸/重量Transport - overall size/weight
  - 制造形式Form of fabrication
- 安装成本Installation
  - 需要监护Attendance required
  - 从港口的运输Transport from port
  - 在现场的时间/可能的延误Time on site/potential for delay
    - 允许公差Tolerance
    - 天气窗口Weather windows
- 拆除成本Decommissioning
- 风险Risk

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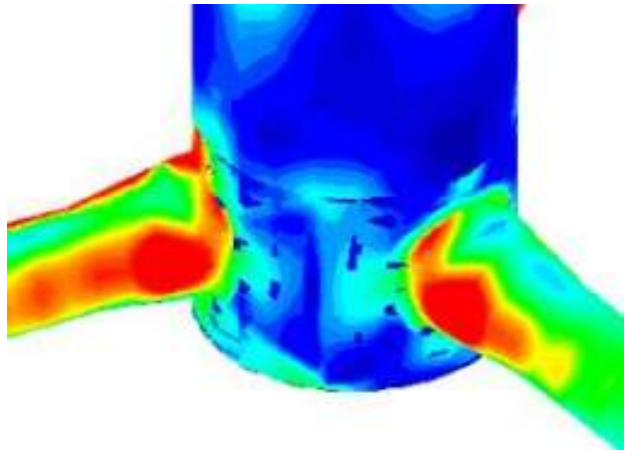
基础类型－详细设计需注意事项
Foundation types - detailed design considerations

- 风和波浪的组合载荷Combined wind and wave loading
- 动力载荷Dynamic loading
- 疲劳（有限元分析）Fatigue (FE analysis)
- 共振（固有频率）Interaction with turbine (natural freq.)
- 进入方式Access
- 电缆连接－J型管Cable connections - J tubes
- 防腐蚀保护Corrosion protection
- 冲刷保护Scour protection
- 可建造性Constructability
- 成本Cost
- 拆除Decommissioning



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回顾Overview

场址调查

Site investigations

- 必要性

  Why are they necessary?

- 如何处理

  How do you do them?

基础

Foundations

- 选项

  Options

- 影响因素

  Influences on selection

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