Transcendent foundation solutions

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Transcendent foundation solutions

***Cross pollination of
scientific and industrial disciplines
to overcome
economic and technical challenges
in foundation of large bridge structures***

COWI contribution to Jubilee Volume, 75th anniversary of K. Terzaghi's "Erdbaumechanik"

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Introduction - Outline

- **Why this topic?**
  - beyond the long words
- **Geotechnical challenges**
  - exemplified by major Fixed Links & bridge structures
- **Case histories of challenges**
  - practice runs at home
  - backbone for global involvement
- **Conclusion**

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Why transcendent foundation solutions?

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Why transcendent foundation solutions?

- **Basics still "Terzaghian"**
- **Operational environment changed dramatically**
- **Every decade changes in**
  - field testing
  - laboratory testing
  - numerical & physical modelling
  - constitutive modelling
  - monitoring
  - construction techniques
  - ITC

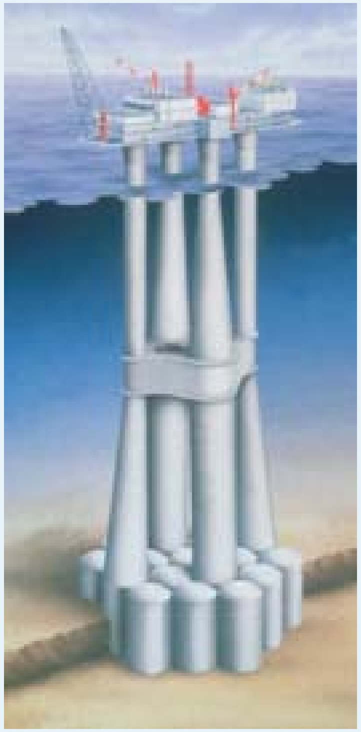
Why transcendent foundation solutions?

- Changes in role and Society
  - increasing competitiveness & complexity
- Buzz words
  - "fast tracking" - "turn key projects"
  - "DBO" - "PPP"
- Geotechnical - structural
  - roles and persons merge/separates
  - cross border knowledge and understanding
  - creative use of lateral thinking
  - cross pollination of disciplines & technologies
- Fixed Links & landmark bridges

Geotechnical challenges

- **Do not forget the interfaces**

Soil - Water - Structure interaction



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Fixed Links and Landmark structures exemplify challenges

- by nature often cross border
- ability to grasp & communicate
  - non-tech issues
  - "soft demands" to sustainable solutions
- Feasibility studies demonstrate need for cross pollination
  -geo, -structural, -hydraulic, -environmental,
  -surveyors, -architects, -traffic planners,
  -biologists, -bankers, -economists, -lawyers,
  -3D animators, -NGO's, -politicians
- But we must ask:

Are we blindly accepting "natural" trends?

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- are we amenable to new outlooks?

From outside

From inside

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Concept to track record for Fixed Links

- **Practice runs with internal Links**

Little Belt
1970

600 m
42 m

Farø Bridges
1985

260 m
26 m

Great Belt
1998

1624 m
65 m

Concept - track record

- **Practice runs with internal Links**
- **Trans-national Links**
- **Backbone for new challenges**

Øresund 490 m
2000 57 m

Femern Belt
***2017? 700-2000* m**

Concept - track record - new opportunities

at truly international scope & scale

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4 examples of challenges & solutions

- Great Belt Link -West Bridge (Denmark)
- Great Belt Link -East Bridge (Denmark)
- Bangabandhu Bridge (The Jamuna River, Bangladesh)
- Offshore wind turbine foundations (Denmark, Belgium)

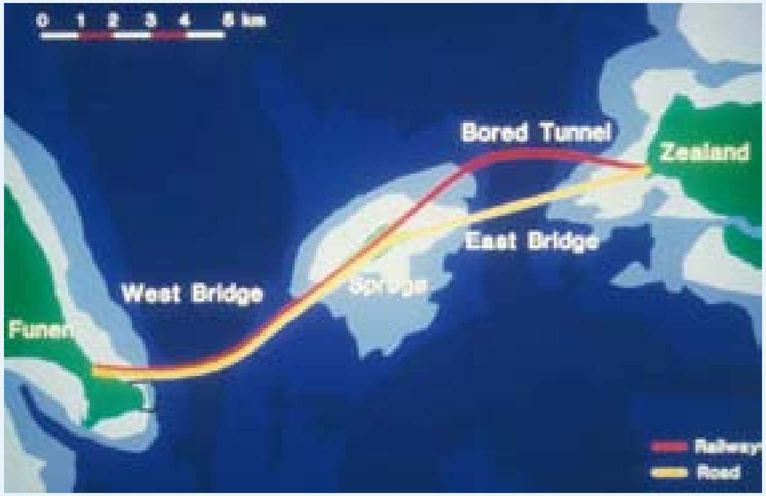
Great Belt Link - West Bridge

Challenge

- Deep waters - clay till
- Fast track project

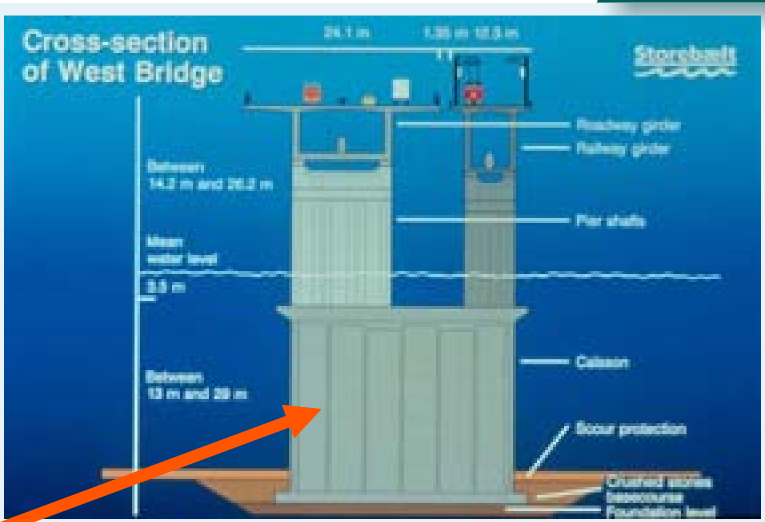
Solution

- Reduce risky offshore operations (open dredge or pneumatic caissons)
- Mega-size onshore pre-fabrication



Great Belt - West Bridge

- **6.6 km multi-span concrete bridge**
  51 spans 110.4 m;
  12 spans 81.75 m
- **Box girders on pier shafts**
- **Common gravity based caisson foundation**
- **Levelled stone beds**



Great Belt - West Bridge

- **Pre-fab. Yard**
- **Erection by "Svanen"**
  (Purpose built heavy lift 6400 t)
- **Multi-purpose jack-up**

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4 examples of challenges & solutions

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Great Belt - East Bridge

- **6.8 km suspension bridge**
  1624 m main span;
  534 m side spans & approach bridges
- **Steel box girders**
- **Concrete box girders**
- **Gravity based caisson foundation**
- **Stone beds on clay till**

Great Belt - East Bridge

- Two new separate dry docks
- Towing of caissons up to 50 000 t
- Stone beds

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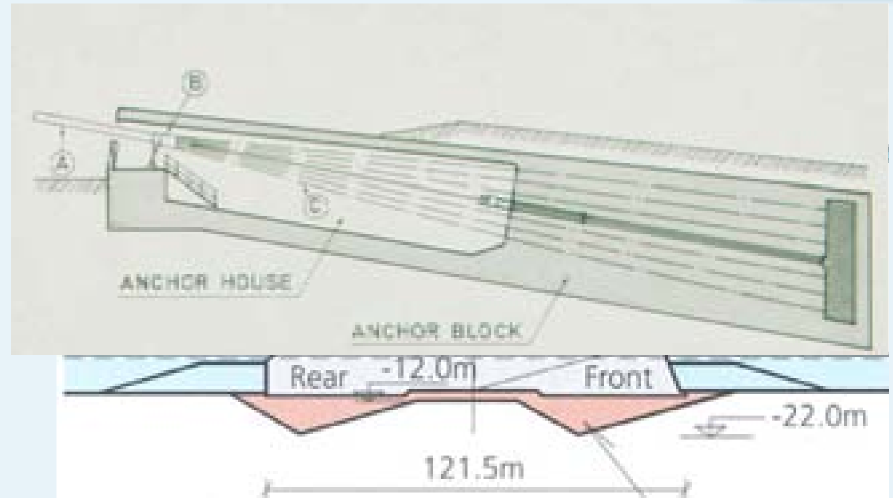
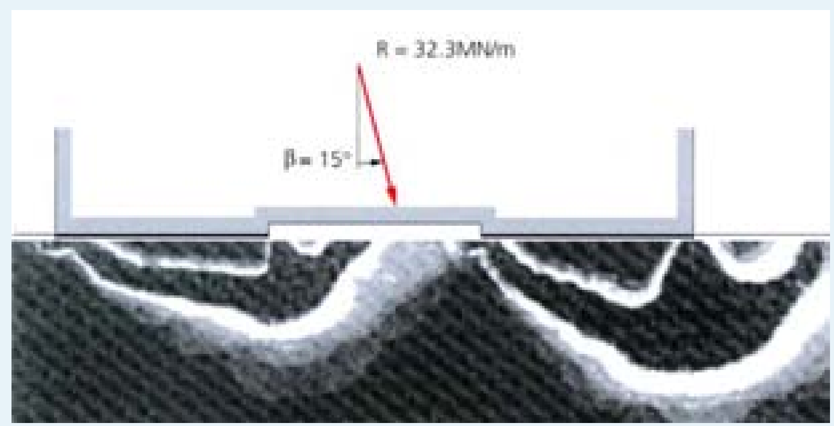
Great Belt - East Bridge

- Inspiration from Little Belt
- Reduce effect from H = 505 MN by stone wedges
- Large scale sliding tests
- Comprehensive soil-structure interaction analysis





4 examples of challenges & solutions

- Great Belt Link -West Bridge (Denmark)
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- **Bangabandhu Bridge (The Jamuna River, Bangladesh)**
- Offshore wind turbine foundations (Denmark, Belgium)

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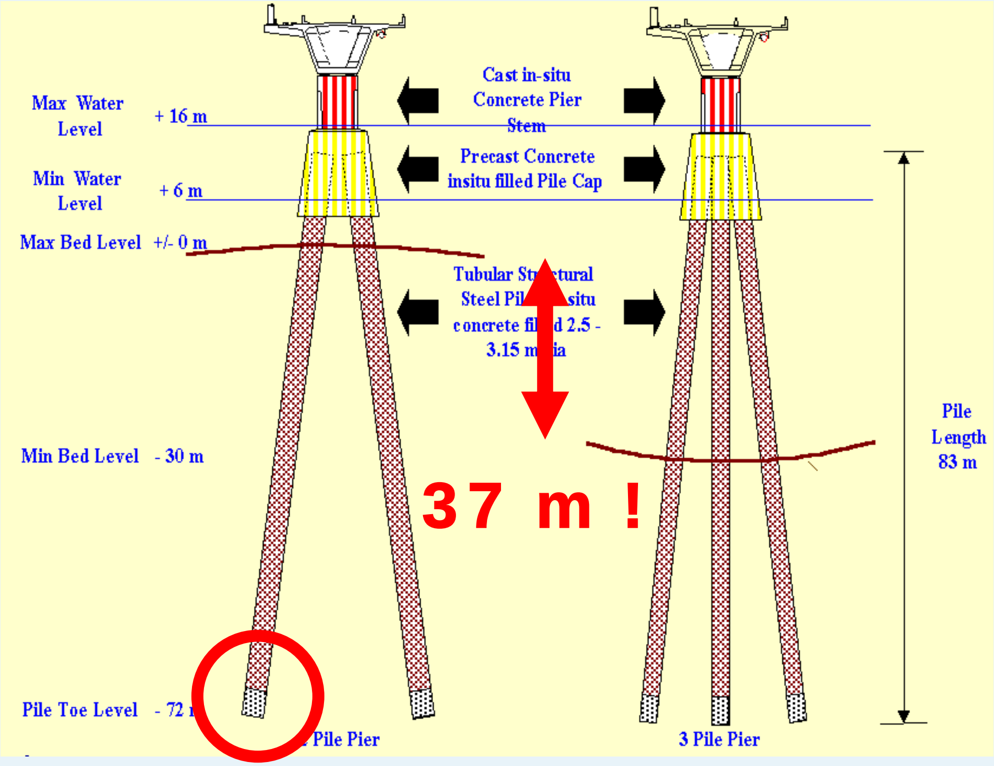
Bangabandhu Bridge

- Crossing of unpredictable Jamuna River
- World Bank study 70'es:
  - traditional long suspension spans
  - 20-40 m open dredge concrete caissons
  - 80 m foundation depth
- 1 billion US$ - prohibitive
- Issue re-opened in 1980'es
- Off shore piling matured
  - driving of 3 m piles to 10 000 t capacity
- Recession in offshore oil market

Bangabandhu Bridge

- Piled solution viable
- 83 m Ø3.15 m piles grouted at bottom



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Bangabandhu Bridge

- Conical in situ cast pile caps
- Cantilevered concrete box girders
- Advantages
  - low cost
  - improved lateral stiffness
  - transparent design (scour - liquefaction)
  - 121 piles installed (2 month before low water)

4 examples of challenges & solutions

- Great Belt Link -West Bridge (Denmark)
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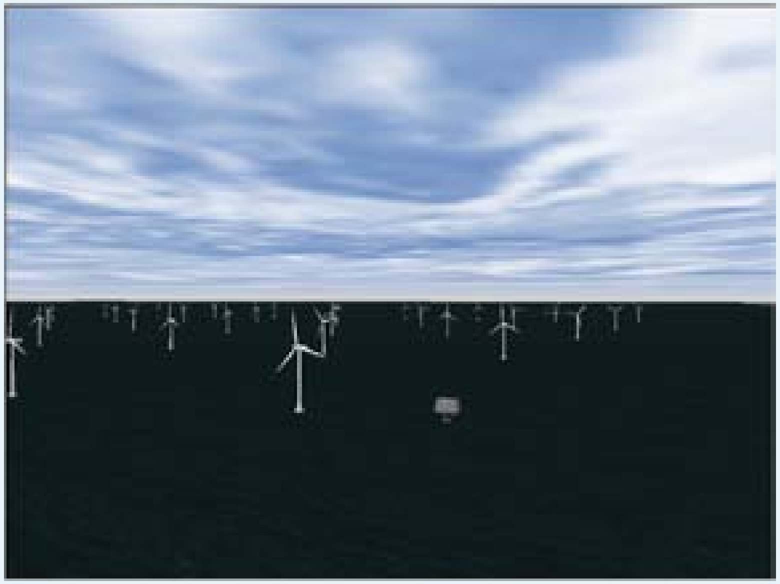
- **Offshore wind turbine foundations (Denmark, Belgium)**

Offshore wind turbine foundations

Building on bridge experience

- Gravity base foundations
- State-of-the-art design for reinforced concrete shell structures



Special challenges

- Soil-foundation-wind turbine dynamic
- Loads depend on system response
- Soil stiffness nonlinear - iterations a must
- Dominant horizontal loads
- High ballast dead weight - minimum structural dead weight
- Cost of foundation decisive for viability of wind farm development

Nysted windfarm - Denmark

- **Nysted Offshore windfarm Denmark**
  world record: 72 Bonus 2.3 MW turbines
  10 m water depth; clay till with boulders
- **Mono-pile not feasible**
- **1300 t pre-fabricated caissons**

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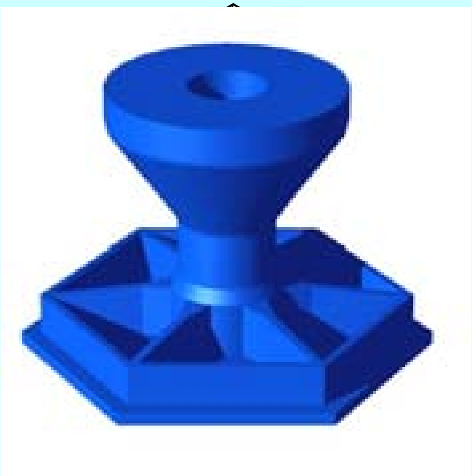
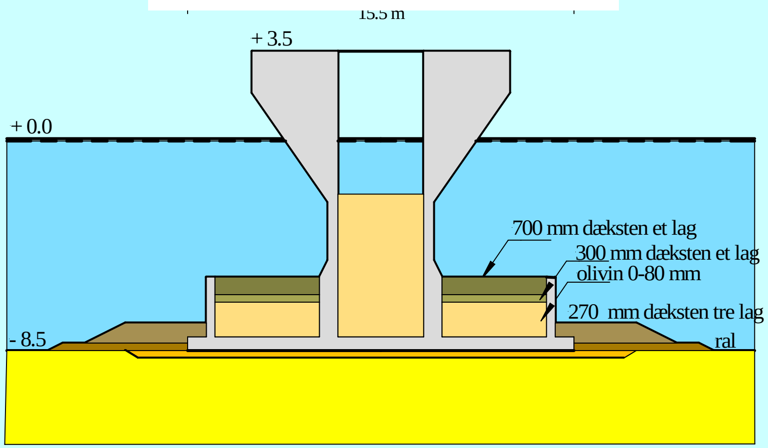
Nysted windfarm - Denmark

- COWI designer for
  - contractor Per Aarsleff
  - Client DONG Energy
- Foundation design
- Conical shape due to ice





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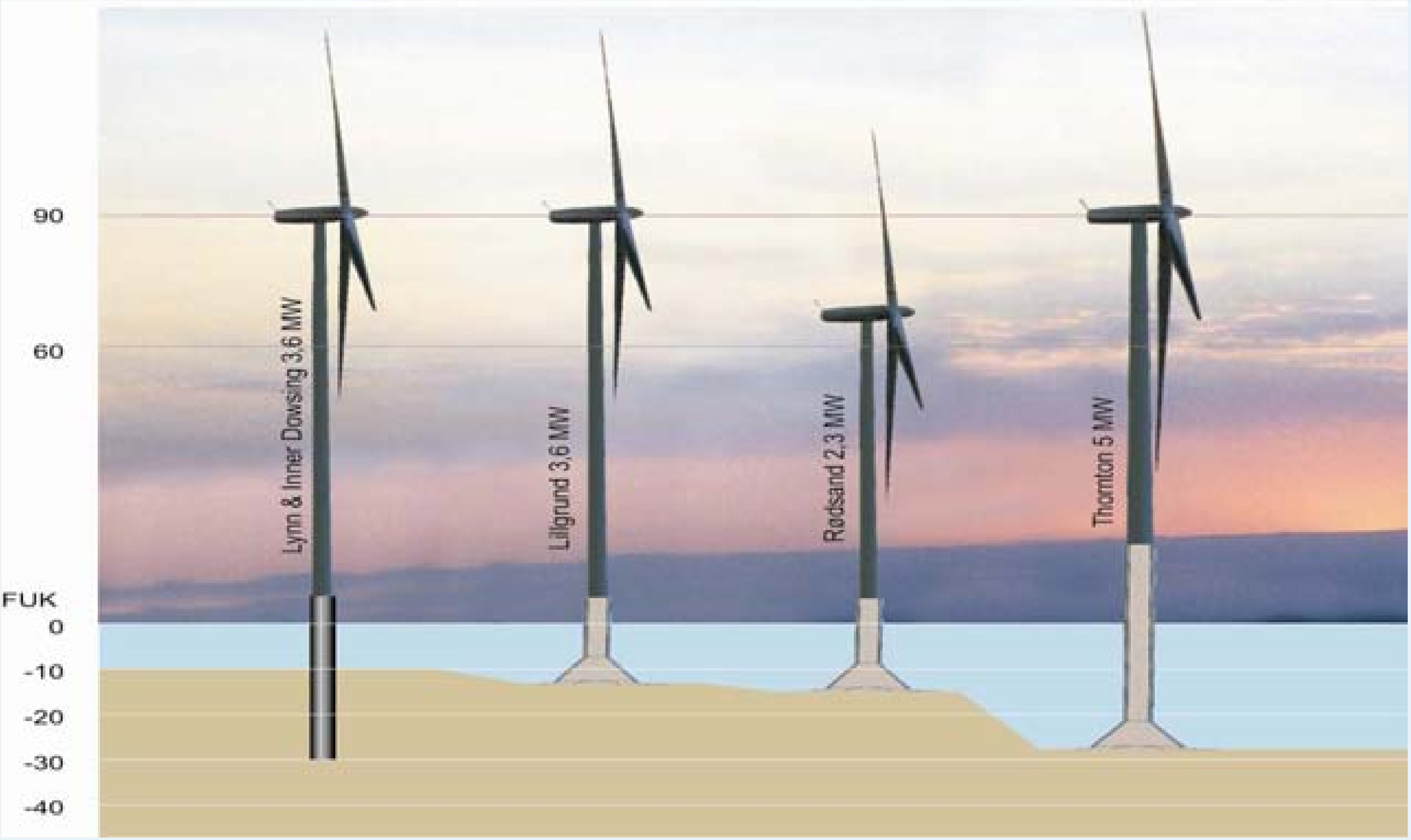
Nysted windfarm - Denmark

- COWI designer for
  - contractor Per Aarsleff
  - Client DONG Energy
- Foundation design
- Conical shape due to ice
- **Transport on 10 000 t barge**
- **Installation by purpose-built crane**
- **4 foundations per 10 days**
- **Successful symbiosis**

Trend: Bigger and deeper



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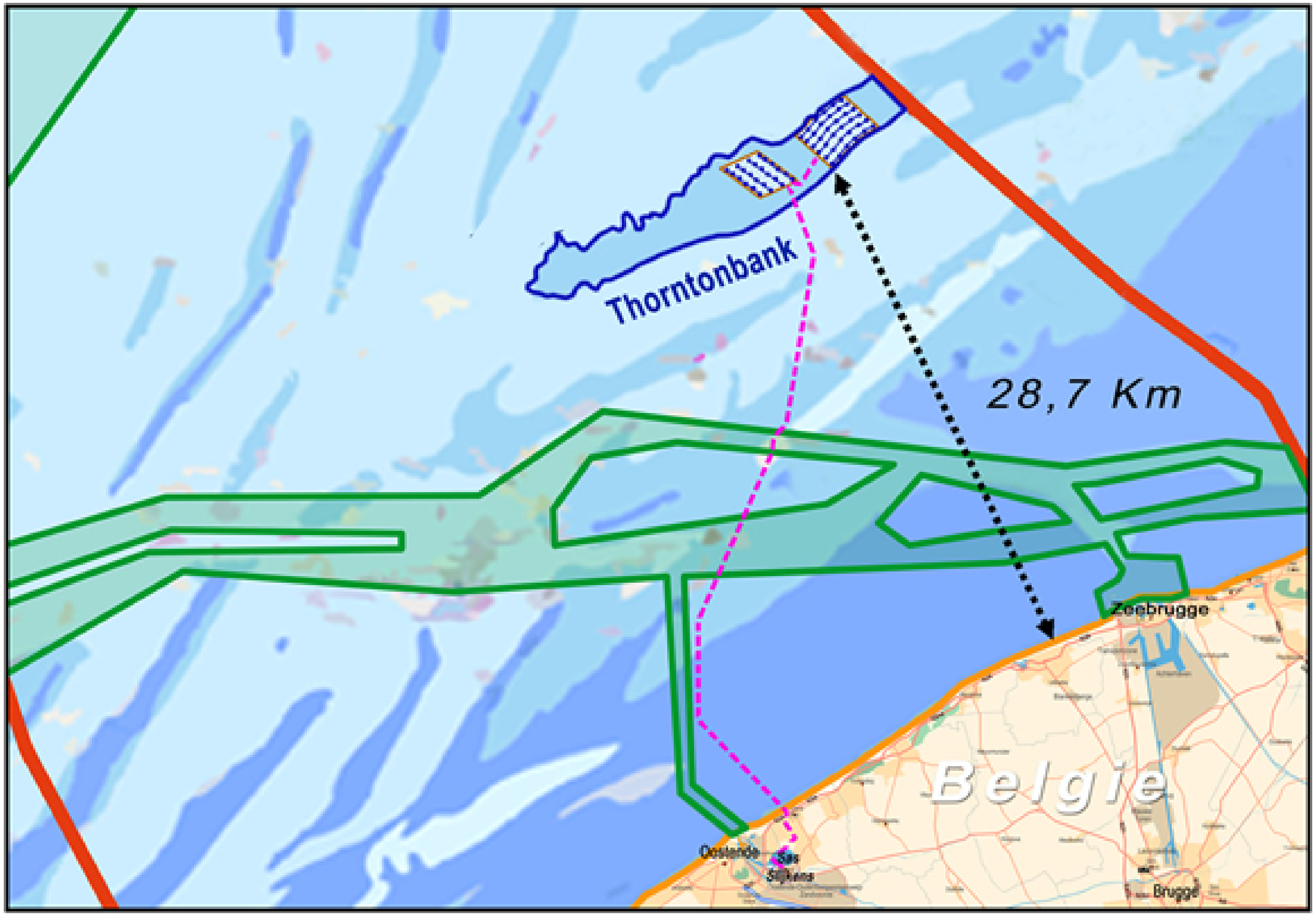
Thornton Bank offshore windfarm - Belgium



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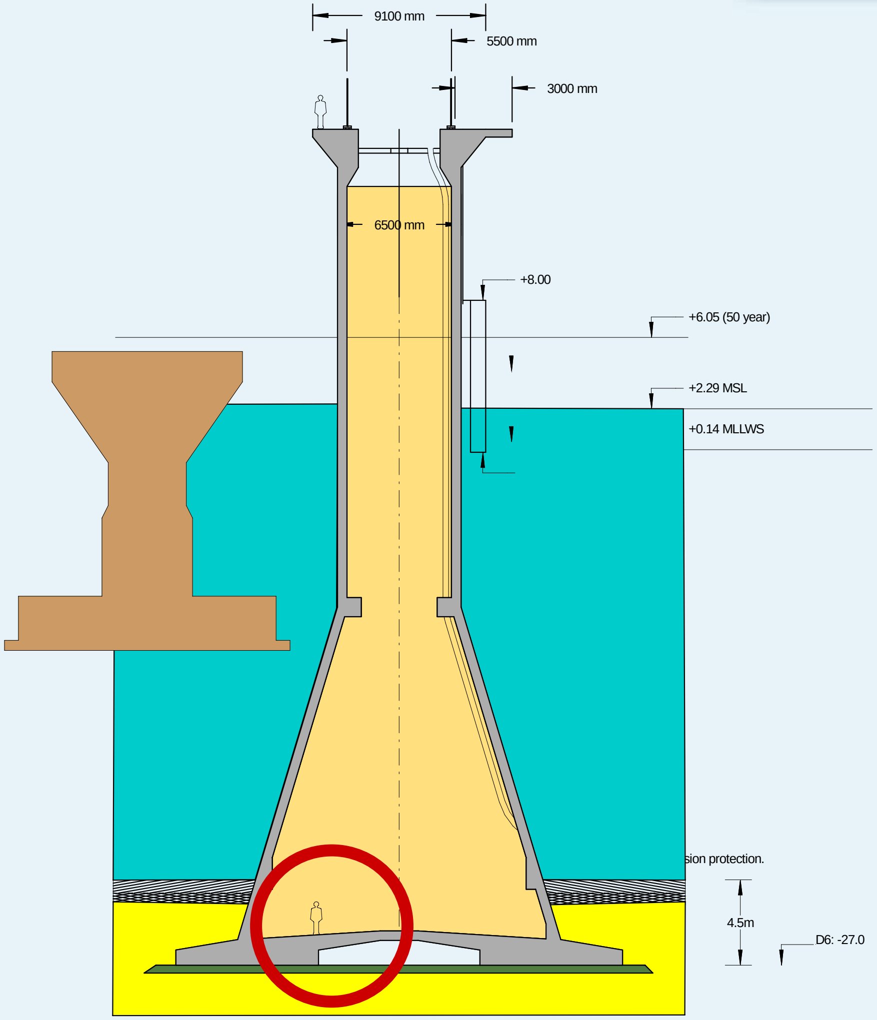
Thornton Bank offshore windfarm - Belgium

Project on-going based on track record

- Owner: C-Power n.v., Belgium
- Turbine supplier: REpower, Germany
- Marine contractor :
  Dredging International, Belgium
- Designer: COWI, Denmark
- 60 wind turbines (5 MW)
  (first phase 6)
- Rough North Sea conditions
  water depth > 25 m

Thornton Bank offshore windfarm - Belgium

- Offshore wind turbine foundation real geotechnical challenge
- Involves many disciplines
- Requires cross pollination and lateral thinking
- Due to organisation set-up designs need to be generic!



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Conclusion

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- Facing challenges in geotechnical engineering we learn from
  - Mistakes (not just our own!)
  - Precedents
  - Colleagues, competitors, mentors
- And gain insight from
  - other disciplines (cross pollination)
  - lateral thinking
  - open-mindedness
- Behaving in this manner we act in the spirit of Krebs Ovesen

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