Scour monitoring around offshore jackets and gravity based foundations

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Sometimes, long-term measurements can become a bit boring…
... but other times you can not wait to see the result!
The C-Power wind farm
Phase 1: the GBFs
  Monitoring 2009 - 2012
Phase 2: the jackets
  The foundations
  Installation
  Predicted scour pits
  Actual scour pits
Conclusions
The C-Power wind farm

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Involvement of IMDC

• Owners engineer
• Design basis + scour & scour protection
• Supervision of the works
• Monitoring program

G. Dewaele → C-Power
J. De Winter, W. Goossens → supervision
A. Bolle, P. Haerens → design issues
Phase 1: Gravity based foundations (GBFs)

The GBF is a concrete cylindrical/conical structure, held in place by its own gravity.

Static scour protection has been placed:

- details in Bolle et al. 2009 & 2010

Operation and Maintenance program:

- discussed previously in IMDC (2010) and Whitehouse et al. (2011)
- multi-beam surveys at least every 6 months
- comparison with monitoring lines: alarm, intervention and danger line
Phase 1: Gravity based foundations (GBFs)

Observations

- Armour layer is stable
- No damage observed
- No significant edge scour
- No interventions needed
- Monitoring continues
Phase 2: Jacket foundations

The jacket foundation is a steel structure with four legs connected to each other with braces.

The legs are grouted to pinpiles, which are driven into the sea soil.

The main advantages compared to GBFs:

- serial production: faster fabrication & better quality control
- easier logistics: less harbour space & marine preparation works needed
- only 2 types of installation vessels are required: pre-piling & jacket installation
- more cost-effective (steel price evolution!)
- easier decommissioning
Phase 2: Jacket foundations

2. The installation
Phase 2: Jacket foundations

3. The predicted scour pits

**global scour depth**
- $S_G = 0.37 \times D_{\text{calc}}$
- based on a 2x2 pile group (Sumer and Fredsoe, 2002)
- $D_{\text{calc}} = $ pile diameter incl. marine growth (DNV, 2007)

**global scour extent**
- radius $r_G = S_G / \tan \alpha$
- with $\alpha = \text{equal to } \phi/2$ and $\phi = $ the friction angle of the soil [°]

No global scour if the distance between the pile centres is more than $6 \times D_{\text{calc}}$ (Breusers, 1972 and Hirai and Kurata, 1982)
Phase 2: Jacket foundations

3. The predicted scour pits

**local scour depth** $S_L$
- expected value
  \[ S_{L,e} = 1.3 \times D_{\text{calc}} \] (DNV, 2007)
- maximum value
  \[ S_{L,m} = 2 \times D_{\text{calc}} \] (Sumer et al., 2002)

**local scour extent** $r_L$
- expected radius
  \[ r_{L,D} = \frac{1}{2} D_{\text{calc}} + S_{L,e} / \tan \alpha \]
- maximum radius
  \[ r_{L,D} = \frac{1}{2} D_{\text{calc}} + S_{L,m} / \tan \alpha \]

with \( \alpha_{\text{downstr}} = 0.5 \times \alpha_{\text{upstr}} \)

- applied all around the piles (Hoffmans and Verheij, 2007)
- inclined members and secondary structures increase the turbulence
Phase 2: Jacket foundations

3. The predicted scour pits

**total scour depth**
- expected total scour depth
  \[ ST,e = SG + SL,e = 2.6m \]
- maximum total scour depth
  \[ ST,m = SG + SL,m = 4.1m \]

**total scour extent**
- expected radius
  \[ r_{T,e} = \frac{1}{2} D_{calc} + S_{T,e} / \tan \alpha = 9.4m \]
- maximum radius
  \[ r_{T,m} = \frac{1}{2} D_{calc} + S_{T,m} / \tan \alpha = 13.9m \]

→ In this case the total scour depth and extent equals the local values, since no global scour has been found.
Phase 2: Jacket foundations

3. The predicted scour pits

RSBL = Reference Seabed Level or the lowest expected level over the lifetime, without structures
PDTDL = Pile Design Tolerance Dredging level or the lowest value of RSBL & dredged level
alarm = expected scour depth
danger = maximum scour depth
Phase 2: Jacket foundations

Available measurements

- Multi-beam surveys: from 6 up to 16 datasets per jacket
  - before dredging: August 2010 – March 2011
  - after dredging: March – April 2011
  - after pre-piling: June – September 2011
  - during cable installation: October – December 2011
  - during the first winter: December 2011 – February 2012
  - spring and summer 2012

- Hydrodynamic data
  - from the Flemish banks monitoring network
Phase 2: Jacket foundations

4. The actual scour pits

Evolution from dredging level
Phase 2: Jacket foundations

2.5 months after pre-piling, before jacket installation

- distinct circular scour holes
  - $S_{av} = 1.3m$ (0.65D)
  - $S_{max} = 2.4m$ (1.2D)
  - fully developed scour after 1 month
    (DNV, 2007; Sumer and Fredsoe, 2002)

- 4 piles only, pile-stick-up = 1.5m
  - effect of the pile height
    (DHI & Snamprogetti, 1992)
  - $S_{exp} = 0.9m$ (0.45D vs. 0.65D)
  - $S_{max} = 1.4m$ (0.7D vs. 1.2D)
  - lower than the observed values!
Phase 2: Jacket foundations

4. The actual scour pits

After jacket installation: October 2011 – February 2012

Observed scour:
- The depth increases instantly
  - $S_{av} = 1.4$ to $1.9m$ ($0.7 – 0.95D$)
  - $S_{max, av} = 1.7$ to $2.7m$ ($0.85 – 1.35D$)
- The width increases during time

Predicted scour depths:
- $S_{exp} = 2.6m$
- $S_{max} = 4.1m$
Phase 2: Jacket foundations

4. The actual scour pits

Observed scour depths

- Danger level
- Intervention level
- Alarm level
- Insurvey
- Postdredging
- Monitoring 1
- Monitoring 2
- Outsury ASB
- Incable
- Outcable
- Incabletrench
- Outcabletrench
- Cablepoststormdec2011
- CableJan2012
- CableFeb2012
- CableFeb2012b
- CableMarch2012
- CableMay2012
Conclusions

**GBFs:** the monitoring went on the last years, and no damage of the scour protection was observed.

**Jacket foundations:** comparison theoretical & observed scour

- Design made for the maximum expected scour for a pile group
- The observed scour pits are close to the theoretically expected scour (or alarm level)
- Observed scour is somewhat deeper than the (average) values from literature

Monitoring continues.
Recommendations

- Be careful when applying formulas (also DNV guideline)
- Continue monitoring & compare with data from other sites
- Combine observations with hydrodynamic conditions to obtain a new formula