COMITÉ FRANÇAIS DE MÉCANIQUE DES SOLS ET DE GÉOTECHNIQUE

Journée parrainée par

Recommandations pour les reconnaissances géotechniques

Thierry Denois (EDF-re)

Soil investigations for floating offshore windfarm

Agenda :

- Specific purpose of Soil Investigation for FOW
- Investigation tools and methods
- From geological to ground model
- Investigation planning
- Investigation content
- Challenges of FOW investigations

Thierry Denois (EDF-RE) : thierry.denois@edf-re.com

Specific purpose of SI for FOW

Sediment mobility

Overall slope stability

Scour potential

Need of sea floor preparation

Liquefaction analysis

Overall site conditions

Ultimate capacity

Permanent displacements

Cyclic degradation

Cyclic displacements

Soil reactions

Resistance/ geometry of buried chain part

Anchor penetration

Pile installation (driveability, vibrodriving)

Skirts penetration (suction anchor, GBS)

Anchor

Cables burial

ISSUE	PARAMETERS
Ultimate strength	Monotonic shear strength under various stress paths (strength anisotropy) Cyclic shear strength under various combinations of average stress and cyclic amplitude for triaxial or simple shear stress paths Sand: Peak effective angle of friction (ϕ’), critical angle or phase transition angle, constant volume friction angle (ϕ'_{cv})
Permanent displacements	Compressibility Permeability Permanent strains and pore pressures generated under various combinations of average stress and cyclic amplitude for triaxial stress paths or simple shear Compressibility after cycles
Cyclic displacements	Cyclic shear strain versus cyclic shear stress for triaxial or simple shear stress paths Initial cyclic shear modulus
Foundation stiffness	Cyclic shear strain versus cyclic shear stress for triaxial or simple shear stress paths Shear modulus at very small distortion (G_o or G_{max}) and evolution with distortion level Damping
Soil reactions	Monotonic and cyclic shear strength Compressibility under virgin loading and reloading Permanent and cyclic strains and permanent pore pressures under various combinations of average stress and cyclic amplitude for triaxial or simple shear stress paths Sea floor topography and morphology, presence of anomalies on the sea floor
Skirt penetration	Undrained shear strength Remoulded shear strength (or sensitivity) Drained angle of friction (ϕ’) - Sand Residual sand-steel or sand-concrete interface angle (δ_r) Cone resistance (q_c) Sea floor topography and morphology, presence of anomalies on the sea floor Presence of blocks in the soil

Table 5.2: Additional parameters that might be required for specific issues

ISSUE	PARAMETERS
Pile installation	Shear strength Young’s modulus (E_{50}) or shear modulus (G_{50}), or strain at 50% of ultimate strength (ε_{50}) - Clays Cone resistance (q_c) Unconfined compressive strength (UCS = σ_c) - Rocks Abrasiveness Clay sensitivity Pile wall rugosity (d)
Liquefaction potential	CPTU data (q_c or q_t, R_f, B_q) Grain size and fines content Atterberg limits (w_L and w_P) and water content Shear waves velocity (V_s)
Scouring and erosion	Grain size for sands Permeability Shear strength for clays
Cable burial	Cone resistance (q_c) - Sands and clays Density Grain size and permeability – Sands Rock abrasiveness Thermal conductivity Electrical resistivity Velocity of compression (V_p) and shear (V_s) waves

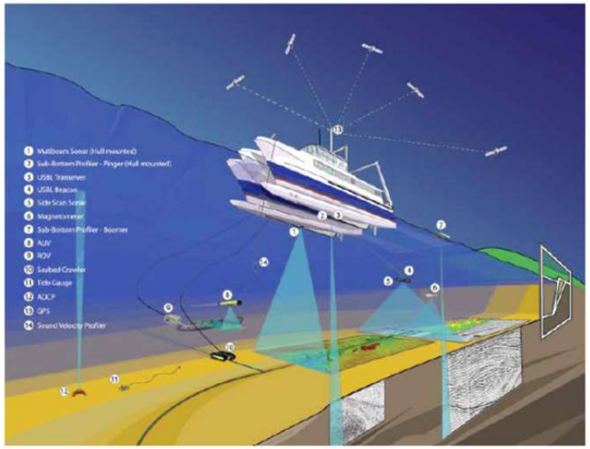
Investigation tools and methods

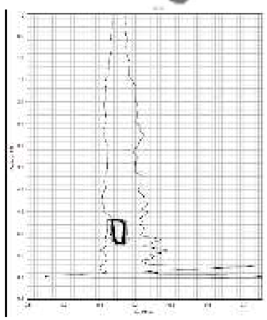
Geophysical

Geotechnical

- **Seabed mapping**: MBES, SSS
- **Sub-Seabed mapping**: SBP, Single or multichannel Seismic reflection, MASW Refrac
- **In-situ testing Geophysical**: PSSL, Check Shot, Gamma Nat, Video / ACTV
- **In-situ testing**: CPT, Elec resistivity CPT, VST vane shear test, T-Bar / Ball probe, PMT HPDT
- **Seabed coring or sampling**: VC, Piston, Seabed drill, Grab
- **Conventional drilling coring and sampling**
- **Lab-testing**
  - Characterisation
  - OEdometer
  - Triaxial
  - Etc ......
  - Thixotropic
  - Interface test

Wider use for FOWT



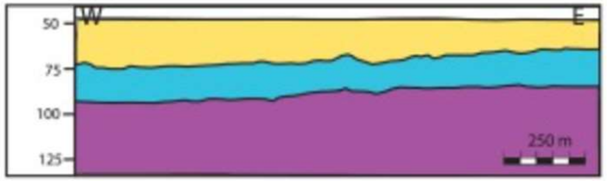


edf renouvelables

From geological to ground model

Initial geological model → **Seismo-stratigraphic model** → **Site geological model** → **Geotechnical model**

From DTS: general stratigraphy and lithology of the main geological formations; tectonic elements; main geological hazards and constraints

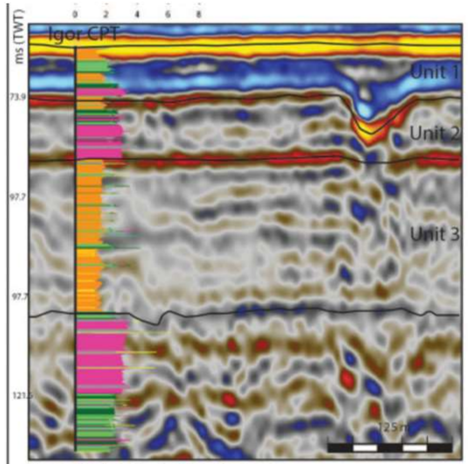


From preliminary Gphy : bathymetry digital ground model, stratigraphic model based on seismic **with hypothesis on Vp**.

=> definition of area of similar nature guidance for BH location

=> seismic feature DTS

Integrate result of preliminary geotech : **improved velocity model;** lithological characterization of layers; draft of soil province ; assign prelim geotech parameters

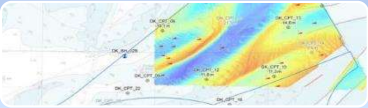


Normalized soil behaviour type zones

Define geotechnical units (gather layers of similar geotech parameters, distinguish internal variations inside seismic unit as weathering), **define geotechnical design profiles, including OCR, Ko, Gmax …)**

γ_d	[kN/m³]	13
γ_{sat}	[kN/m³]	18
k	[m/sec]	1e⁻⁴
ν	[-]	0.3
c	[kPa]	0
φ	[°]	35

Investigation planning



Pre-project	Project First phase	Project Second phase	Installation	Operation
Conceptual design	Basic design to FEED	Detailed design	Follow-up	Inspection
Bid preparation survey DTS	1st Gphy 1st Geotech	2nd Gphy Cable 2nd Geotech	Monitoring	Inspection survey
			Seabed clearance, footprint, as built, as laid surveys	Scour monitoring, cable free span …

Ground modelling

- DTS → Initial geological model
- Initial geological model → Seismo-stratigraphic model
- 1st Gphy → Seismo-stratigraphic model
- Seismo-stratigraphic model → Site geological model
- 1st Geotech → Site geological model
- Site geological model → Geotechnical model
- 2nd Geotech → Geotechnical model

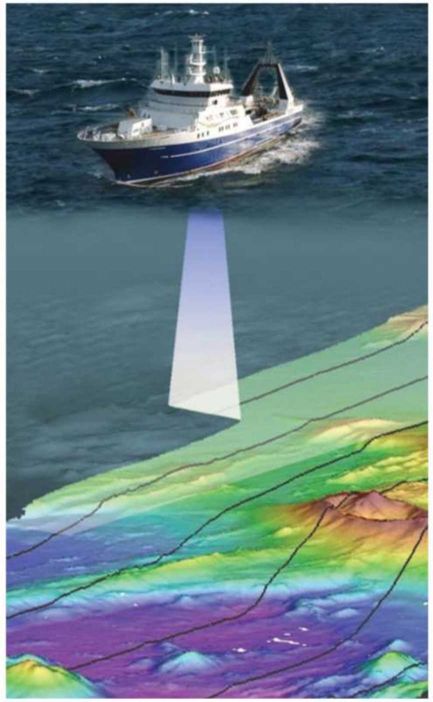
cfms

Investigation content

TARGET PENETRATION

1st Gphy	MBES, SSS (50 to 100% overlap) Single or mulittrace seismic (boomer sparker, typically 250m interline Sub-bottom profiles	2nd Gphy Grid refinement	MBES, SSS (100% overlap) Single or mulittrace seismic (boomer sparker, 30-50min Sub-bottom profiles, Pinger or chrip Option for seismic réfraction	Typically 50m for seismic,
1st Geotech	Seabed CPT, vibrocore , BH with in-witu testing : typically on 20 to 30% WTG, at least one BH by geological province , 30 to 50m depth depending soil/anchor type	2nd Geotech	DRAG ANCHOR : 1 CPT per anchor location, if heterogeneity: 1 CPT on penetration path 1 sampling per anchor cluster	Design penetration + max (20% ; 0,5 width)
			ANCHOR PILE : 1 CPT per pile 1 CPT+1 BH per anchor cluster Or 1BH with alternate sampling/CPT	Design penetration + 2 pile diameter
			SUCTION PILE : 1 CPT per pile 1 Tbar + 1 VST (vane shear test) + 1 BH (sampling) per anchor group	Design penetration +0,5 caisson diameter
			GRAVITY PILE : 1 CPT per location 1 BH with sampling per group	1,5 anchor diamter and > 2m below skirt

Challenges of FOWF investigation



- High water depth :
  - Above #200m: spacing between MBES/SSS lines shall be reduced with waterdepht (increase survey lenght)
  - Below #200m : MBES/SSS resolution can become too low for feature detection. Would need deep fish or AUV.
  - Often more geohazard on continental slope (slope instability, prograding canyon…)
  - Conventionnel drilling becomes even more expensive with water depth (time for drillstring setting and tool handling). Only few seabed drilling unit can reach 30-50m in soil and are heavy/complex to deploy.

- Mulitple anchor layout variants : late project knowledge of anchor locations
- Risky development : temptation to limit preliminary geotech to vibrocore/piston core : limited penetration (#10m) .
- Often normally consolidated and sensitive soil, more difficult to sample and test without disturbance
- Effect of thin soil layer on buried chain geometry / resistance : what parameter to consider ?
- [geotechnical design] Multidirectional loading still not fully addressed in design method

No specifically adressed in current recommendations … still room for improvement