

Geotechnical Considerations for OFFSHORE WIND TURBINES Along the U.S. East Coast



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GEOTECHNICAL CONSIDERATIONS

OBJECTIVES:

- Review Regulations and Guidelines
- Present Key Aspects of East Coast Geology
- Present Components of Geophysical and Geotechnical (G&G) Survey
- Present Data Interpretation and Design Parameter Evaluation



TYPICAL SITE CONDITIONS (WATER DEPTH):

- Maine: 300 ft or Greater
- Mass/RI/NY: 10 ft to 130 ft
- Mid Atlantic: 100 ft or Less



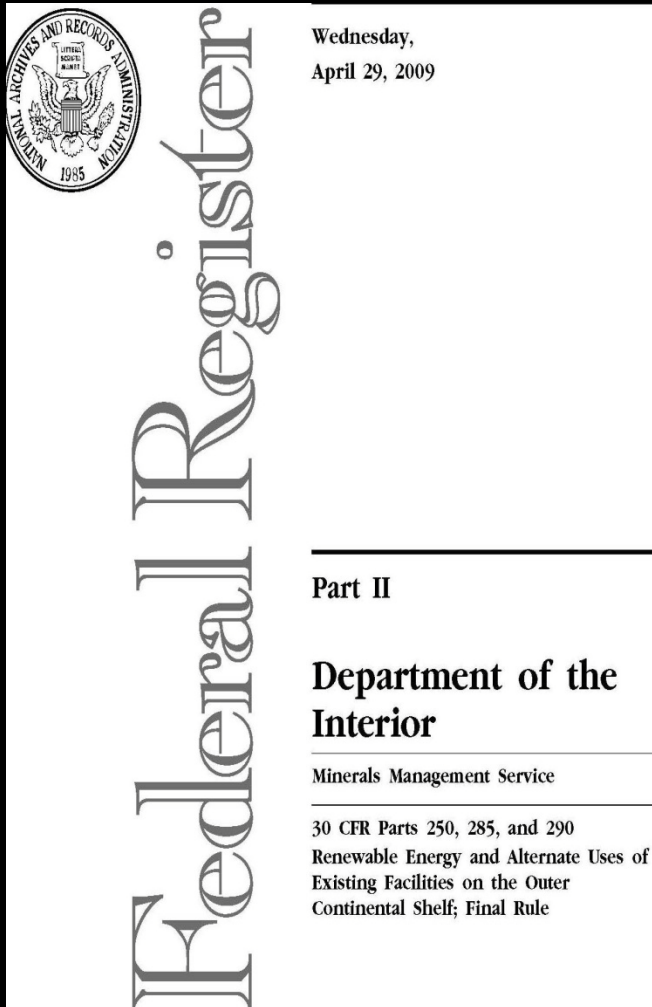
TYPICAL FOUNDATION TYPES:

- Maine: Floating
- Mass/CT/NY: Monopile, Jacket, & Gravity
- Mid Atlantic: Monopile, Jacket, & Gravity



Regulations and Guidelines (US)

- **Federal Register CFR 30 Subpart 285**
 - Subparts F&G
 - Site Assessment Plan
 - Construction Operation Plan
 - Final Design Report
- **BOEM, “Guidelines for Providing Geological and Geophysical, Hazards, and Archaeological Information Pursuant to 30 CFR Part 285”**
 - Provides Strategies and Techniques
 - Details of Work left to Designer
 - Site Characterization Requirements
 - High Resolution Geophysical (RG)
 - Core Sampling/Testing (Geotechnical Investigation)





Regulations and Guidelines (US)

- **American Petroleum Institute (API)**
 - API RP 2A-WSD, “Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms – Working Stress Design”
 - API RP 2GEO, “Geotechnical and Foundation Design Considerations”, April 2011



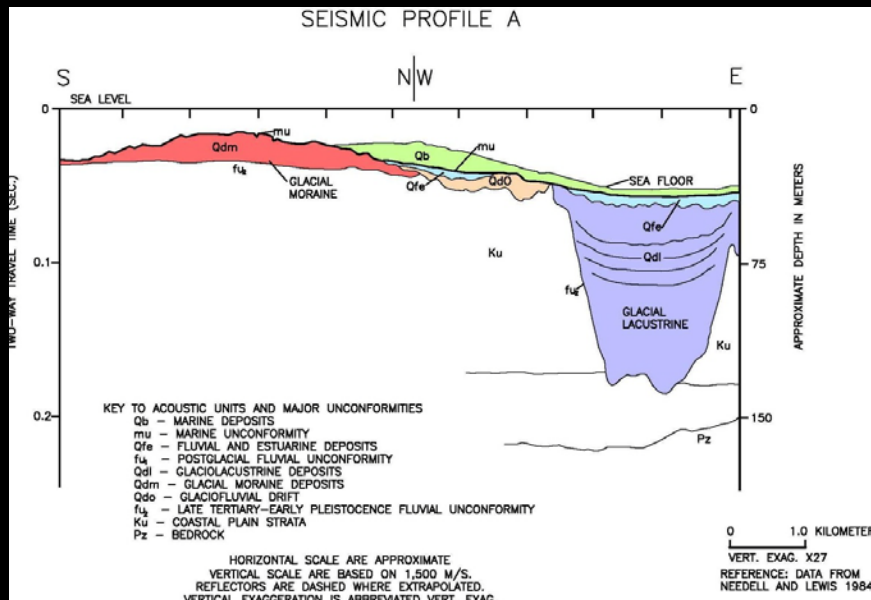
Regulations and Guidelines (European)

- International Electrotechnical Commission (IEC) 61400-3
- ISO 22475-3 “Geotechnical Investigation and Testing – Sampling Methods and Groundwater measurements”, Parts 1, 2 & 3
- ISO 14688 “Geotechnical Investigation and Testing – Identification and Classification of Soil”, Parts 1 & 2
- Det Norske Veritas DNV-OS-J101, “Design of Offshore Wind Turbine Structures”

Mid-Atlantic/Northeast Coastal Geology

- **Northeast**

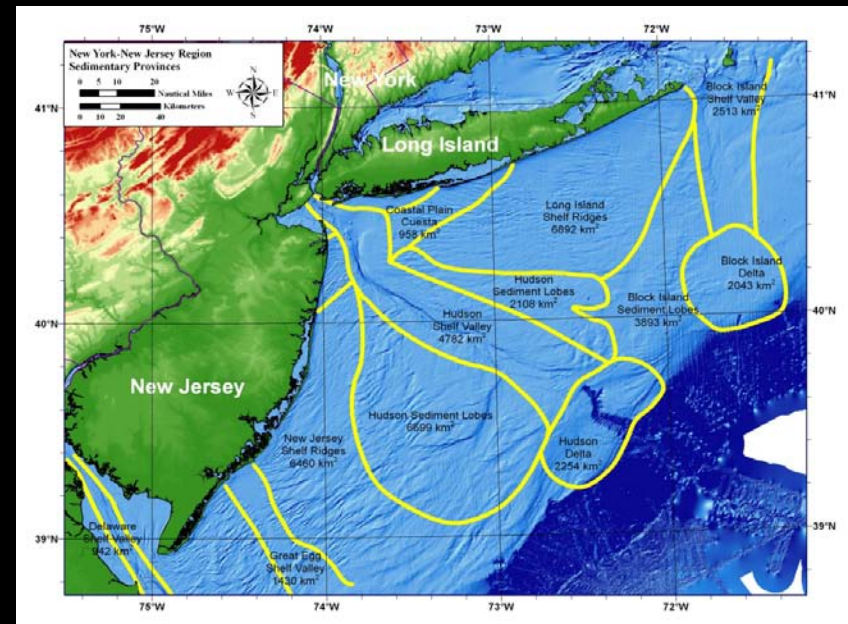
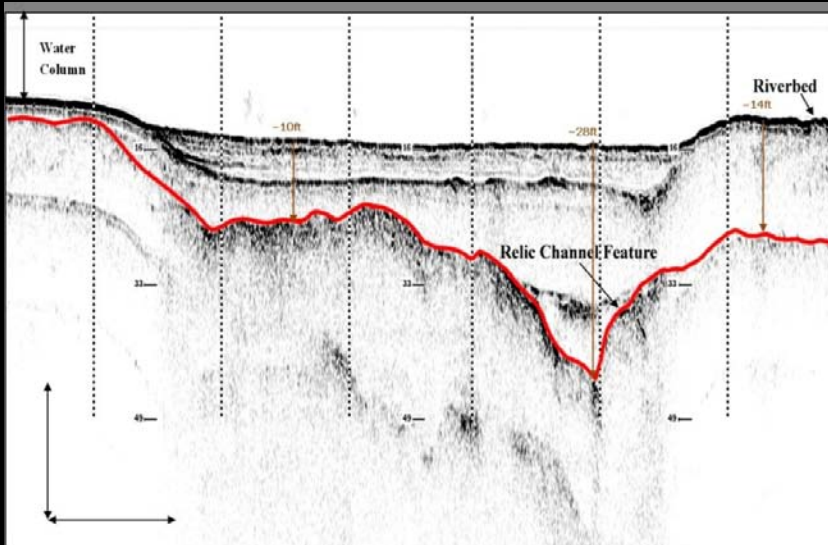
- Highly Variable Geology
- Dominated by Glacially Deposited Sediment
- Typically Dense Sand and Gravel, Stratified with Silt/Clay
- Particle Range from Boulders to Clay



Mid-Atlantic/Northeast Coastal Geology

- **Mid-Atlantic**

- Dominated by Depositional and Erosional Features
- Sands
- Variable Density
- Cut and Fill Channels





High Resolution Geophysical (HRG) & Geotechnical Investigation

- **Objectives**

- Required by BOEM to Support Review of “Plans”
- Required to Understand the Geologic and Subsurface Soil Properties to Form a Basis of Foundation Design and Installation
- Develop a Model of Soil Structure Interaction for Use by Foundation Design
- Data is also Used During the Archeological and Cultural Evaluations
- Summarized in a Geotechnical Report

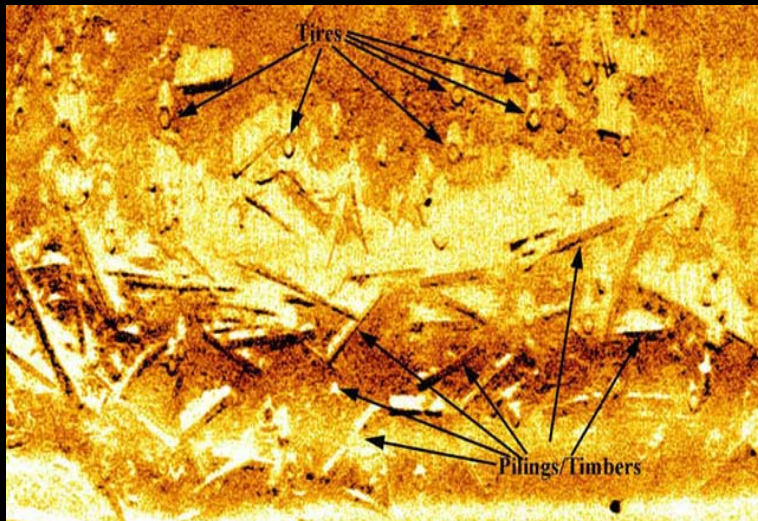




HRG Survey

- **Objectives**

- Broad Investigation Area
- Identification of Sediment Type
- Assessment of Lateral and Vertical Extent of Sediment Types
- Topographic Condition
- Identify Surface Sediment Type
- Optimize Site Selection for WTG
- General Overview of Soil Conditions





HRG Survey

- Objectives
- Methods
 - Completed in a Grid of Tracklines, Variable Spacing and Along Cable Routes of WTG Grid
 - Magnetometer (ID Objects That have a Magnetic Signature)
 - Slide Scan Sonar (Sand Waves, Surface Irregularity)
 - Shallow and Medium Sub-Bottom Profilers (Subsurface Conditions)
 - Multi Beam Bathymetry (Topography)





HRG Survey

- **Issues**

- Schedule (Production Work and Data Evaluation)
- Weather (Limitations Due to Sea State)
- Marine Mammal Shutdown
- Impacts Due to Multiple Survey Vessels





Core Sampling/Testing (Geotechnical Investigation)

- Objectives
 - Develop an understanding of the subsurface conditions (lateral/vertical extent of soil stratum)
 - Understand soil stratum consistency, soil type, and variations
 - Determine Subsurface Conditions
 - Complete Insitu Testing/Logging





Geotechnical Investigation

- **Objectives, Cont'd**
 - **Obtain Soil Samples**
 - Classification
 - Laboratory Testing
 - Strength
 - Stress-Strain Characteristics
 - Grain Size
 - **Develop Soil Properties**
 - Grain size
 - Seismic loading
 - Cyclic loading condition
 - Construction induced effects





Geotechnical Investigation

- Objectives
- Methods
 - **Shallow Conditions-Vibracoring**
 - 0 to 5 meter
 - Visual Classification
 - Disturbed Samples for Laboratory Testing





Geotechnical Investigation

- **Methods, Cont'd**

- **Shallow to Deep Conditions**

- Core Penetration Testing-CPT (Insitu Testing)
 - Direct Measurement of Soil Properties
 - Provides Data Readily Transferrable to the Design Process
 - East Coast Geologic Conditions may Limit Production

- **Test Borings**

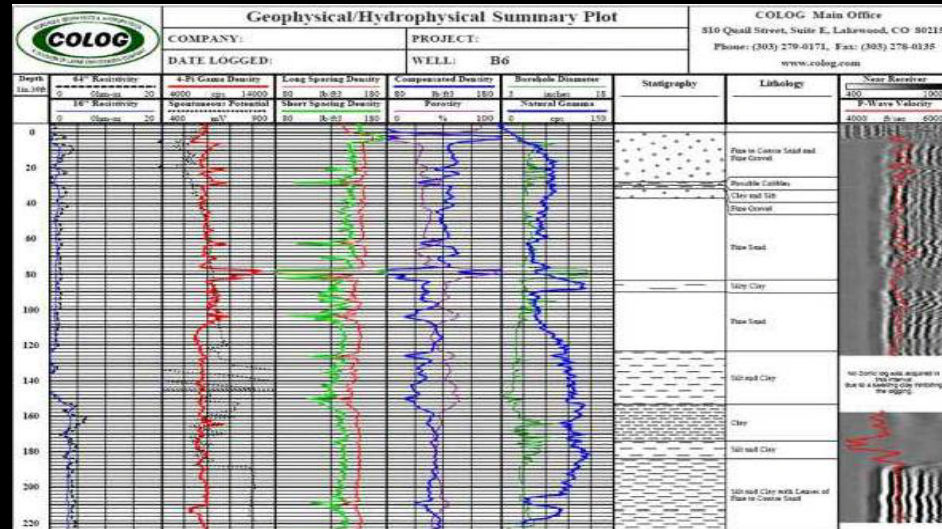
- Standard Penetration Test (SPT)
 - Undisturbed Samples
 - Insitu Testing
 - Downhole Logging





Geotechnical Investigation

- Objectives
- Methods
- Issues
 - Often Completed in Phases
 - No Single Method Provides Sufficient Data
 - Highly Weather Dependant
 - Time of Year
 - Potential Weather Delay (\$)
 - Costly





Geotechnical Investigation

- **Issues, Cont'd**
 - **Uncertain Schedule-Impacted by**
 - Weather
 - Marine Mammals
 - Cultural Evaluations
 - **Logistics**
 - Equipment Availability
 - Payment Structure
 - Long Mobilization/Fitting out time





Soil Design Parameters

Geophysical Profile

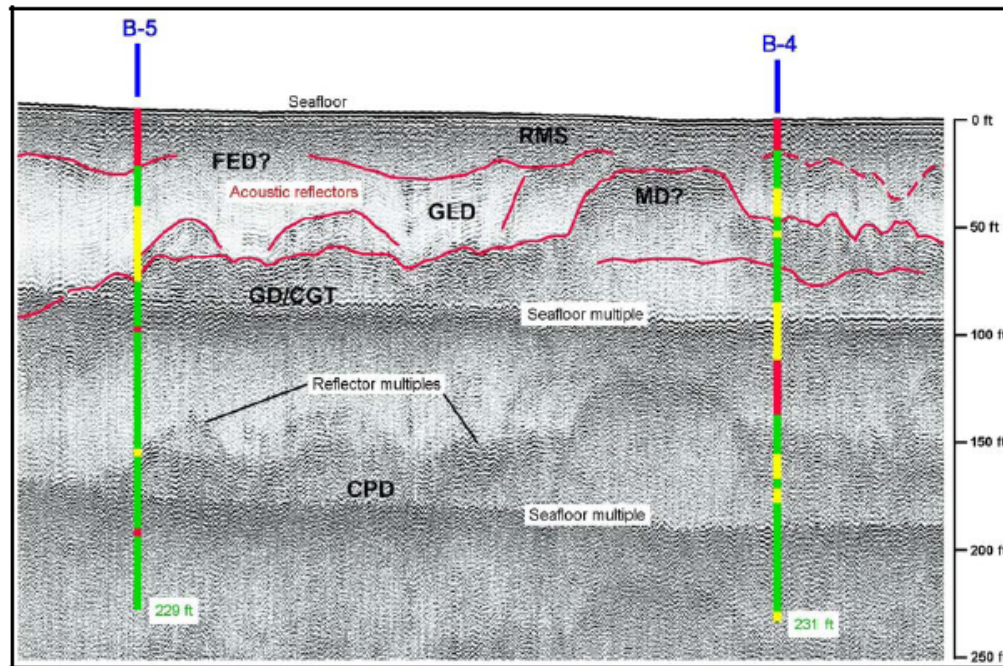


Figure 7. Section of a boomer subbottom profile showing the variable subsurface conditions in the site. Depth scale calculated using 5,000 ft/s velocity. Shading on borings: green = sand, yellow = silt/clay, red = coarse material (gravel and larger). Depth of borings below the seafloor shown at the base of each boring symbol.

Boring B-4 Profile

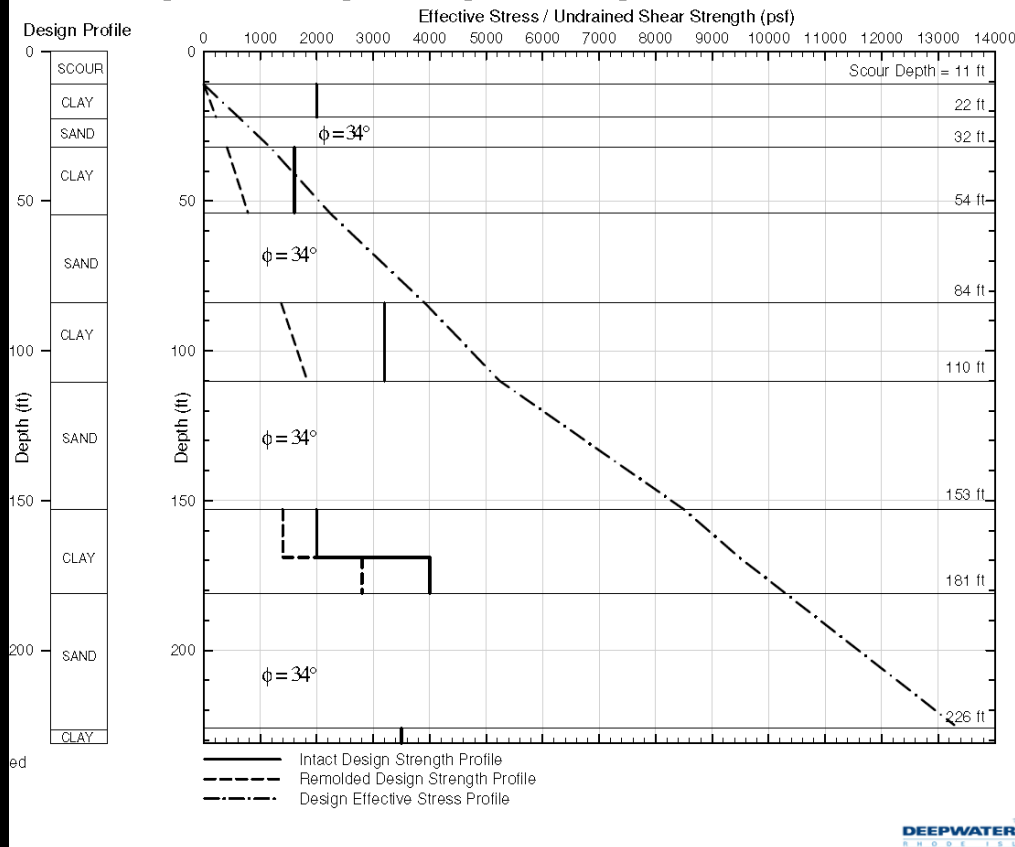
Lithology	
0	GW
	ML
	SP
	CL
50	SP
	CL
	SM
	ML
100	CL
	SC-GC
	SP
150	SM
	CH
	SP
	CH
200	SM
	CH

- Comparison of Geophysical and Geotechnical Profiles can indicate that Geophysical Layers are not Refined Enough for Geotechnical Design.



Soil Design Parameters

Figure 7-D: Boring B-4 Design Soil Strength Parameters



- Design Soil Parameters can be Highly Variable with Depth and with each Wind Turbine Location.
- Impacts to properties due to static and/or cyclic loading and/or strain
- Strength (undisturbed/disturbed)
- Stress-Strain Characteristics
- Stress History

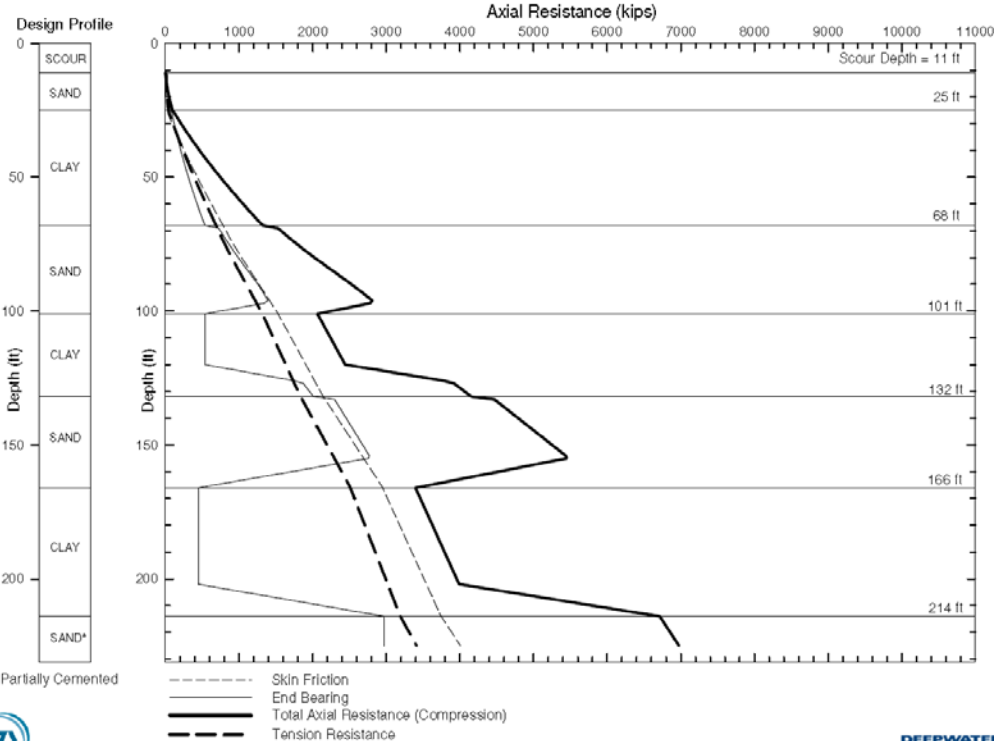


Foundation Design Parameters

- Pile Resistance with Depth can be Highly Variable Due to Varying Soil Conditions Within One Boring and Across the Site.
- Bearing Capacity
- Soil-Structure Interaction Parameters
- Liquefaction
- Summarized in a Foundation Design Report

Block Island Wind Farm 33487.01

Figure 10-G: B-7 Static Axial Capacity Resistance Loading Conditions (Resistance Factor 0.7)





Summary

- Regulations are Not specific to Turbine Foundations
- European Guidelines are Applicable
- Subsurface Conditions are Variable (Horizontally & Vertically)
- G&G Survey: Costly, Variable & Unpredictable Production, Requires Flexible Work Plan
- Data Interpretation and Evaluation: Well Established Procedures & Need for Validation