Comparing Benthic Impact of Anchor Systems for Marine Renewable Energy Systems off the Coast of Southeast Florida

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Resource Assessment

Approx. 48 km (30 nm) transect of FAU data collection.

Current ***Thermal*** ***Surface Current (On shore CODAR Stations)***

26° 05' N

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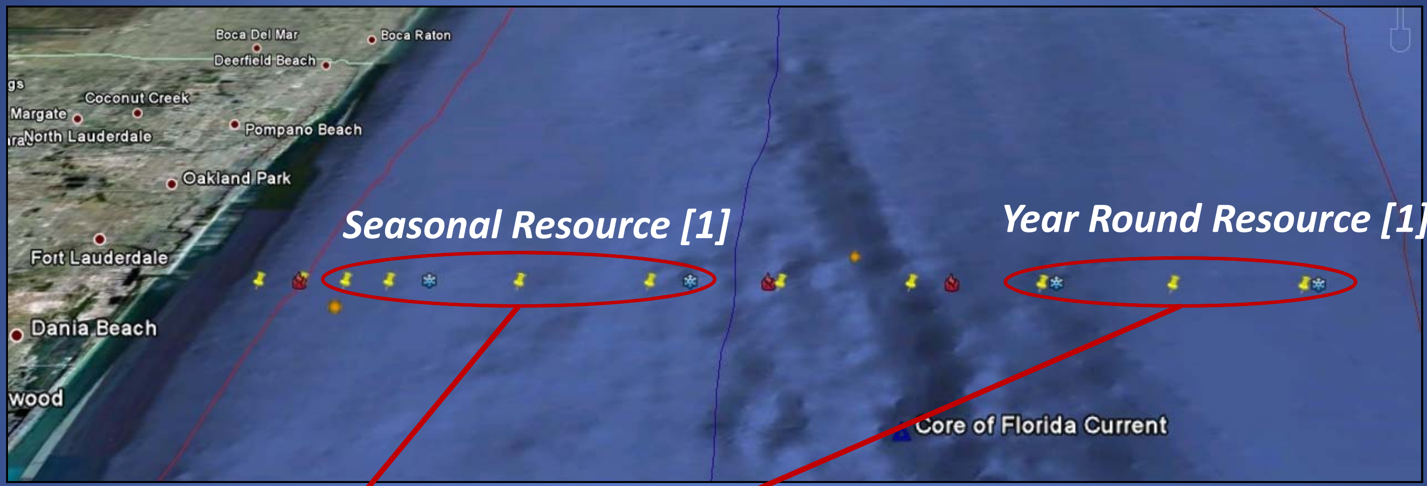

26° 05’ N

[1] (Leland, 2009)

NIOT of India’s 1 MW Floating OTEC Plant
(Source: http://www.eurocean.org/np4/124.html**)**

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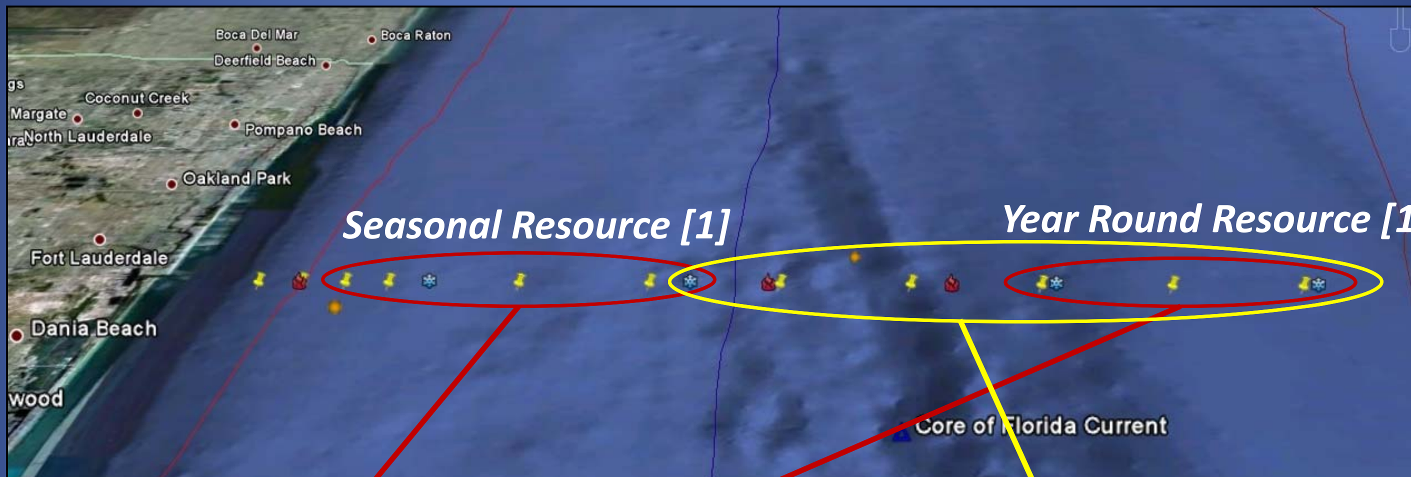

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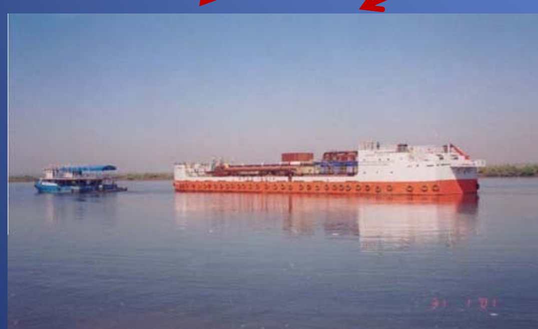

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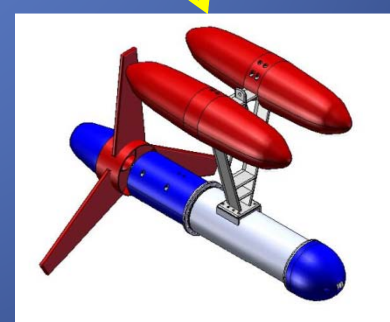


Drawing of FAU's First Generation Ocean Current Turbine Prototype.

Project Objectives

Purpose: Define and quantify the range of anchor requirements of marine renewable energy systems within this region.

•Regional study of bottom types.

•Identify applicable anchor types.

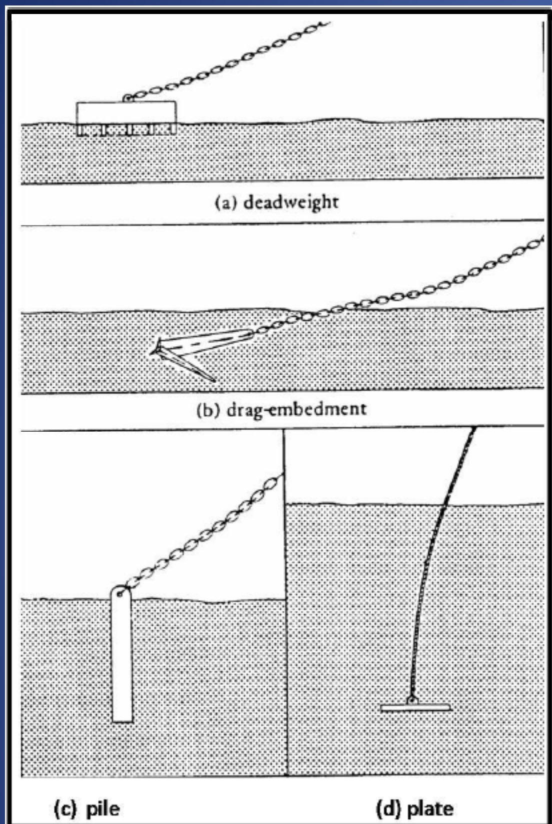
•Develop a basis for metocean conditions for the region.

•Create simulations of single point moored marine renewable energy (MRE) devices with environmental characteristics of the test area to extract anchor loading.

•Perform preliminary anchor sizing for a range of devices and locations.

•**Compare benthic impact as well as identify gaps in current knowledge of this region.**

Anchor Types



Source: (Sound and Sea Technology, 2009)

Seafloor Material	Deadweight	Pile	Plate	Drag
Soft clay, mud	++	+	++	++
Soft clay layer (0-20 ft) over hard layer	++	++	o	+
Stiff clay	++	++	++	++
Sand	++	++	++	++
Hard glacial till	++	++	++	+
Boulders	++	o	o	o
Soft rock or coral	++	++	++	+
Hard, massive rock	++	+	+	o
Seafloor Topography				
Slope < 10 deg	++	++	++	++
Slope > 10 deg	o	++	++	o
Loading Direction				
Omnidirectional	++	++	++	o
Unidirectional	++	++	++	++
Large uplift	++	++	++	o
Lateral Load Range				
To 100,000 lb	++	+	++	++
100,000 to 1,000,000 lb	+	++	+	++
Over 1,000,000 lb	o	++	o	o

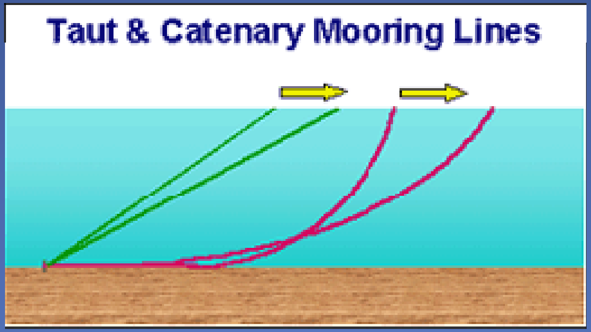
++ Functions well
\+ Functions, but not normally the best choice
o Does not function well

Source: (Sound and Sea Technology, 2009)

•All types shown function in sand (cohesionless) and clay or mud (cohesive soils) where adequate sediment depths exist.

•Only deadweight functions well in hard rock bottoms and hard bottoms with little sediment overlay. A drilled and grouted pile will work but has increased costs with difficulty in deployment.

Single Point Mooring Configuration

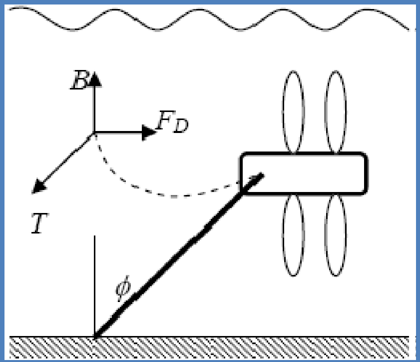


Source: http://www.tensiontech.com/services/mooring.html

Taut (30° to 45° to horizontal)

•Raises anchor connection point off seafloor.

•Applicable Anchors:
  Deadweight
  Pile
  Plate (direct embedment)



Source: (Clarke et al., 2008)

Catenary (Near 0 ° to seabed)

•Creates larger footprint with chain on seafloor but transfers anchor loading to lateral loading, requiring anchors with lower uplift capacities.

•Applicable Anchors:
  Deadweight
  Pile
  Plate
  Drag embedment (unidirectional loading)

Marine Hydrokinetic Turbine Anchor Loading

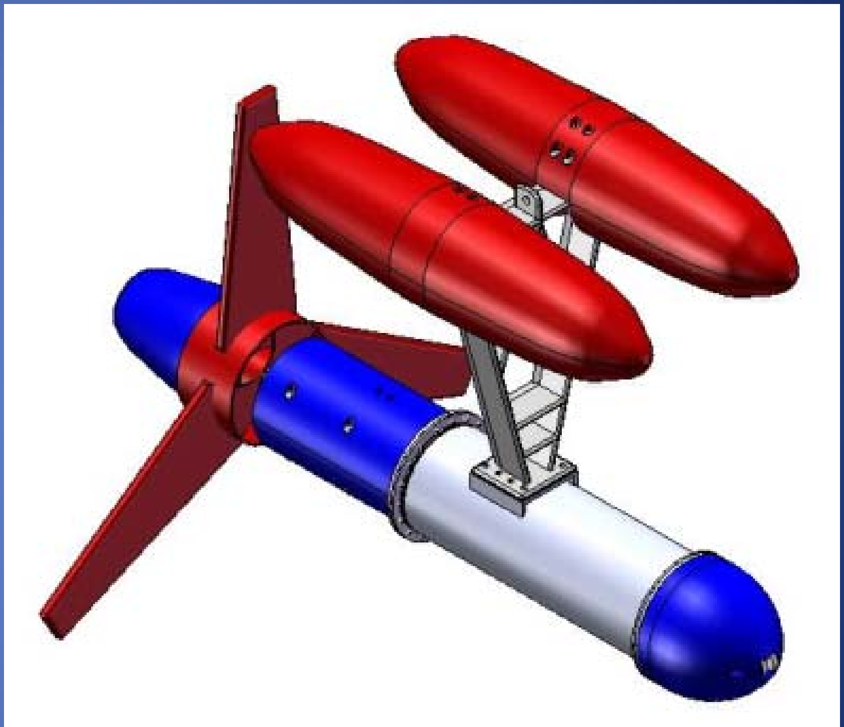
- Single point moored hydrokinetic turbines were modeled in Orcaflex as subsurface 3-d buoys with drag characteristics of FAU's 1st generation ocean current turbine.

- A drag coefficient was found using results of a numerical simulation created for predicting the performance of FAU's turbine [Varientvelde, 2009].

At a tip speed ratio of 3.9 where maximum power output was created:

$$C_d = \frac{D}{\frac{1}{2}\rho U^2 A},$$

D = 20.25 kN
U = 2.5 m/s
ρ = 1,026 kg/m^3
A = πr^2 =7.07 m^2
(3 m diameter)



Drawing of FAU's 1st Generation Ocean Current Turbine Prototype.

C_d=0.89

Offshore Standards

- Metocean Conditions within the region?

  American Petroleum Institute (API) for the Gulf of Mexico

  Det Norske Veritas (DNV) for the Gulf of Mexico

  Local NOAA weather buoys for past hurricane data

- Mooring System Standards for MRE devices?

  API

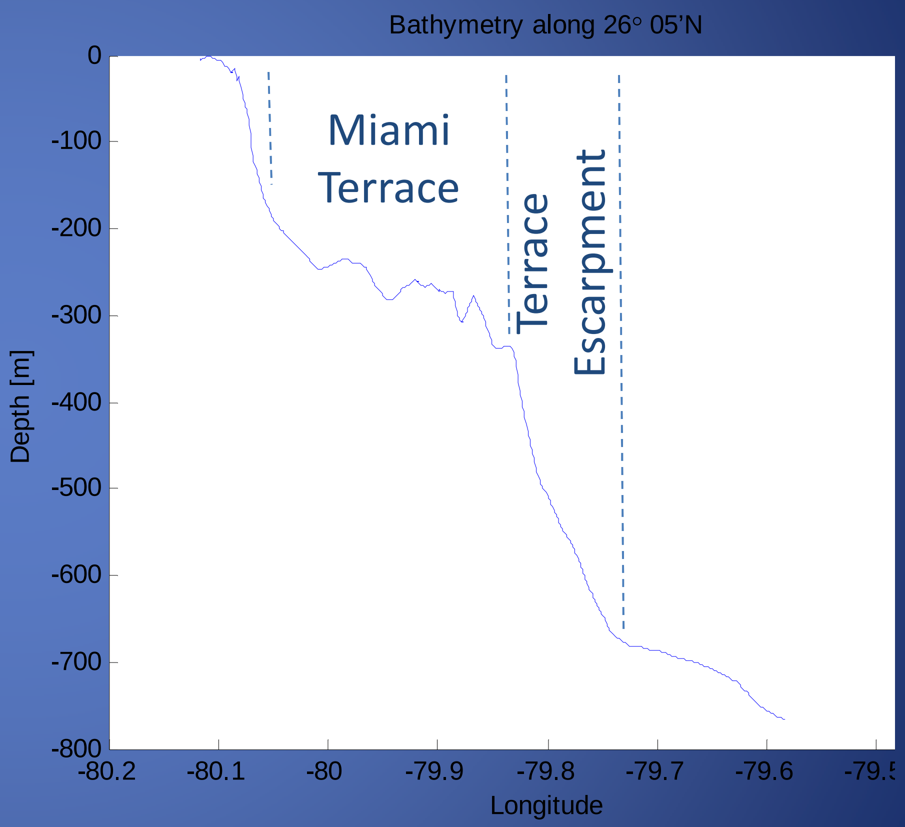
  DNV

  Navy Design Guides and Manuals

Simulation Parameters

Mooring Scenarios

- **Atop Miami Terrace: 325 m depth**
  - 1.25 mooring scope
    - 8 rotor diameters
  - 1.5 mooring scope
    - 8 rotor diameters
  - 2 mooring scope
    - 8 rotor diameters
- **Beyond Terrace Escarpment: 700 m depth**
  - 1.25 mooring scope
    - 8 rotor diameters
  - 1.5 mooring scope
    - 8 rotor diameters

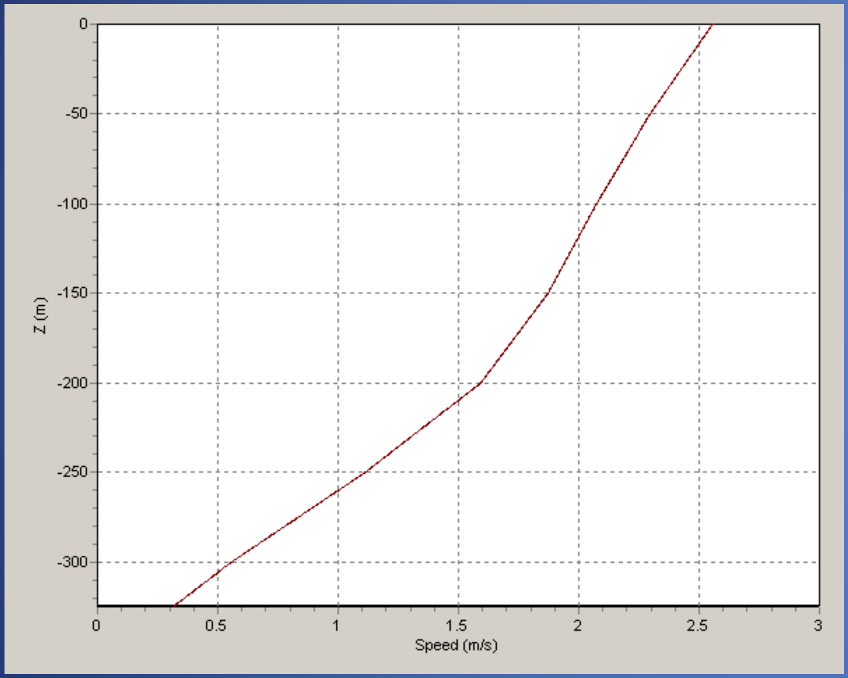


Total of 40 simulations with turbine at 50 m operating depth

Simulation Parameters

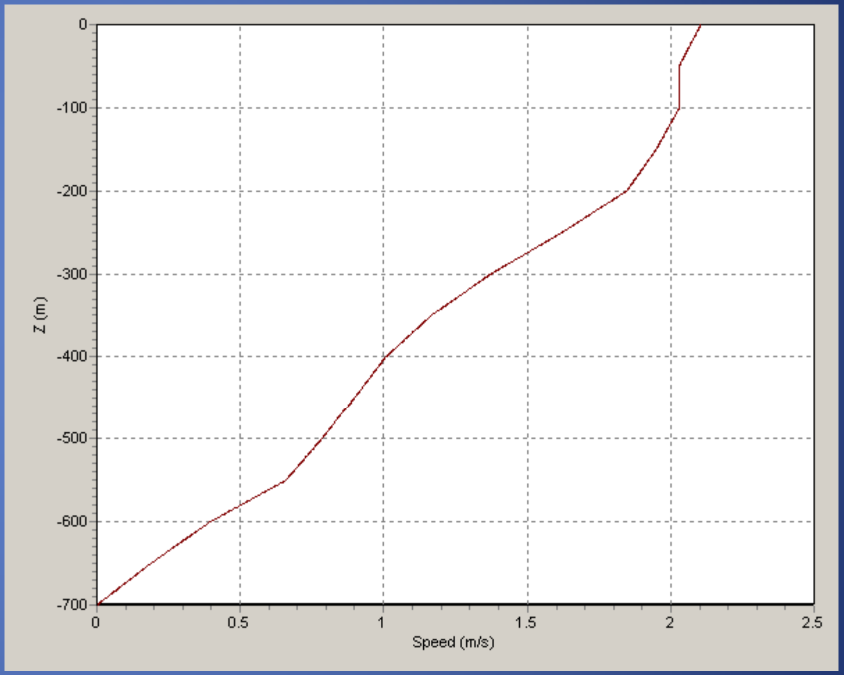
Current Profiles

Max. Current Profile at 325 m depth



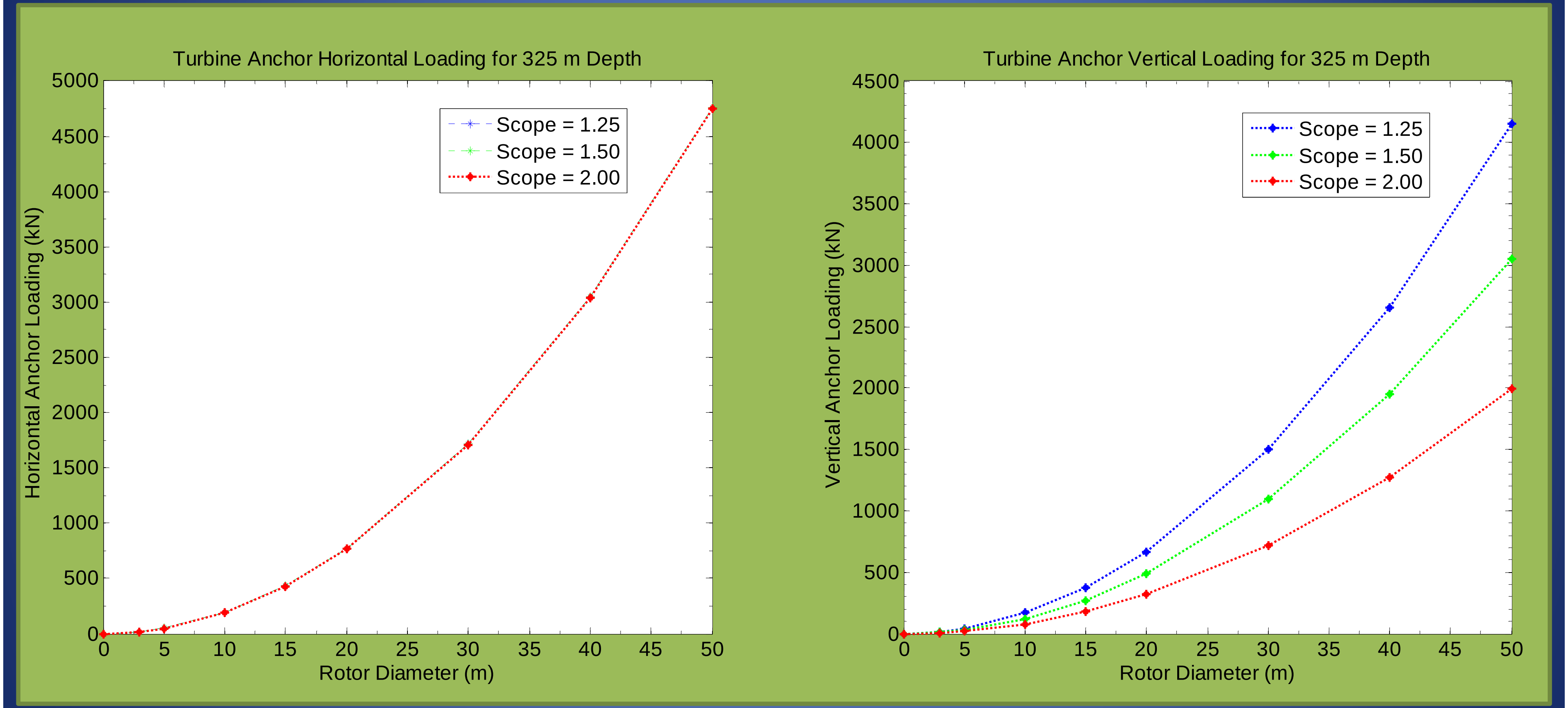
Source: Subsurface ADCP buoy deployed for 18 months, 3 miles west of the core of the Florida Current (Raye,2002).

Max. Current Profile at 700 m depth



Source: HYCOM data for 700 m depth at 27.0 N.

Anchor Loading Results
325 m depth



- Overall tension increases with decreasing scopes because of added buoyancy needed to remain at 50 m depth.
- Vertical loading increases with higher uplift angles and increased buoyancy.

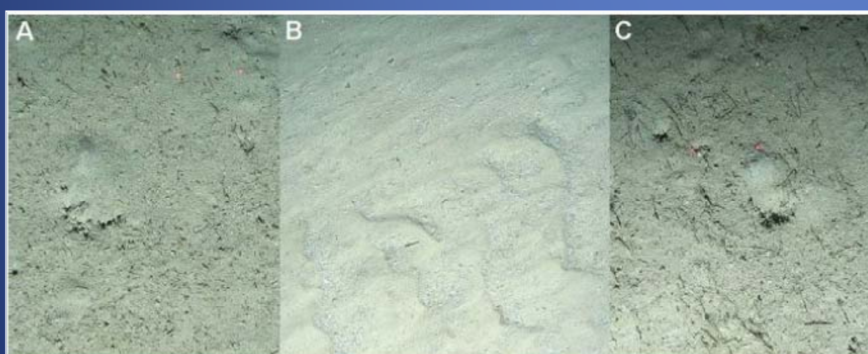
Preliminary Anchor Sizing

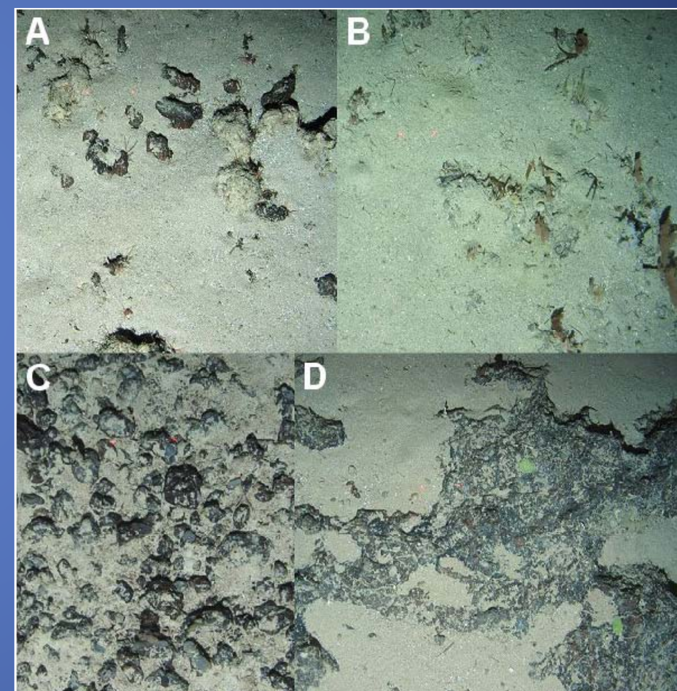
- Limited knowledge of sediment depths leads to uncertainties of deploying seafloor penetrating type anchors.

Regional Bottom Types

Source: Calypso Pipeline Survey

(Messing et al., 2006)



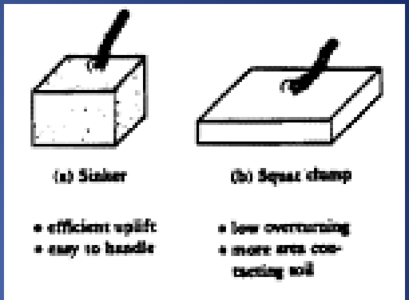


•Traditional drag embedment not applicable for the presented results because of high uplift angles.

•Applicable anchors: Deadweight, pile, plate.

Preliminary Anchor Sizing

- Preliminary anchor sizing was first performed for concrete deadweight anchors with simulation results and general anchor sizing formulas supplied by NCEL (Taylor, 1982).



1) Weight (in water) required to resist sliding:

$$W = \frac{F_h}{\tan(\phi - 5°)} + F_v$$

2) Minimum anchor width without shear keys:

$$B = \left[\frac{6WF_h}{\gamma_s (W - F_v)} \right]^{\frac{1}{3}}$$

3) Max. height of mooring line connection point above base of anchor with or without shear keys:

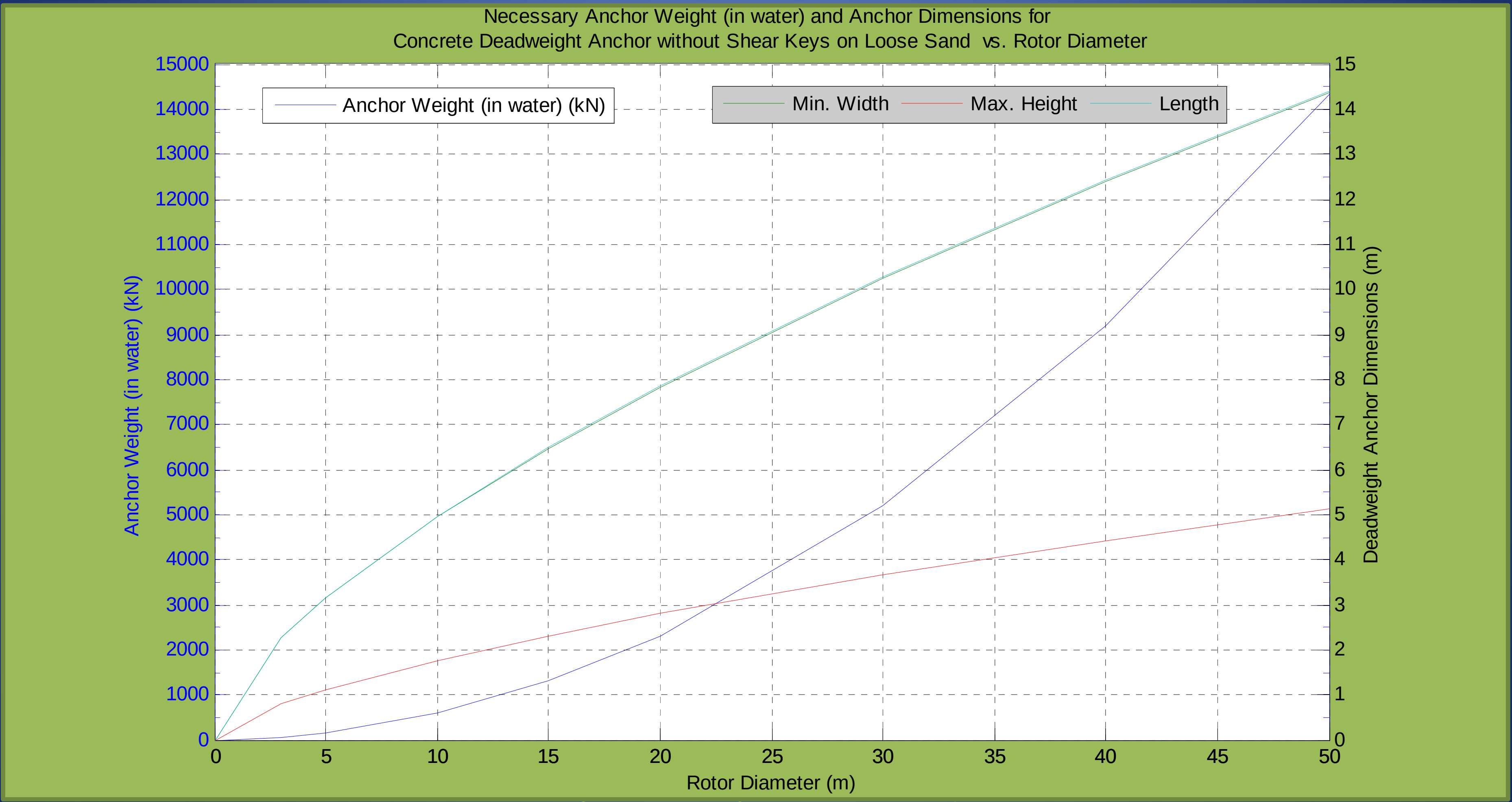
$$H = \frac{B(W - F_v)}{6F_h}$$

4) Length of anchor to achieve necessary volume:

$$L = \frac{W}{gHB(\rho_c - \rho_{sw})}$$

Example Anchor Sizing Results

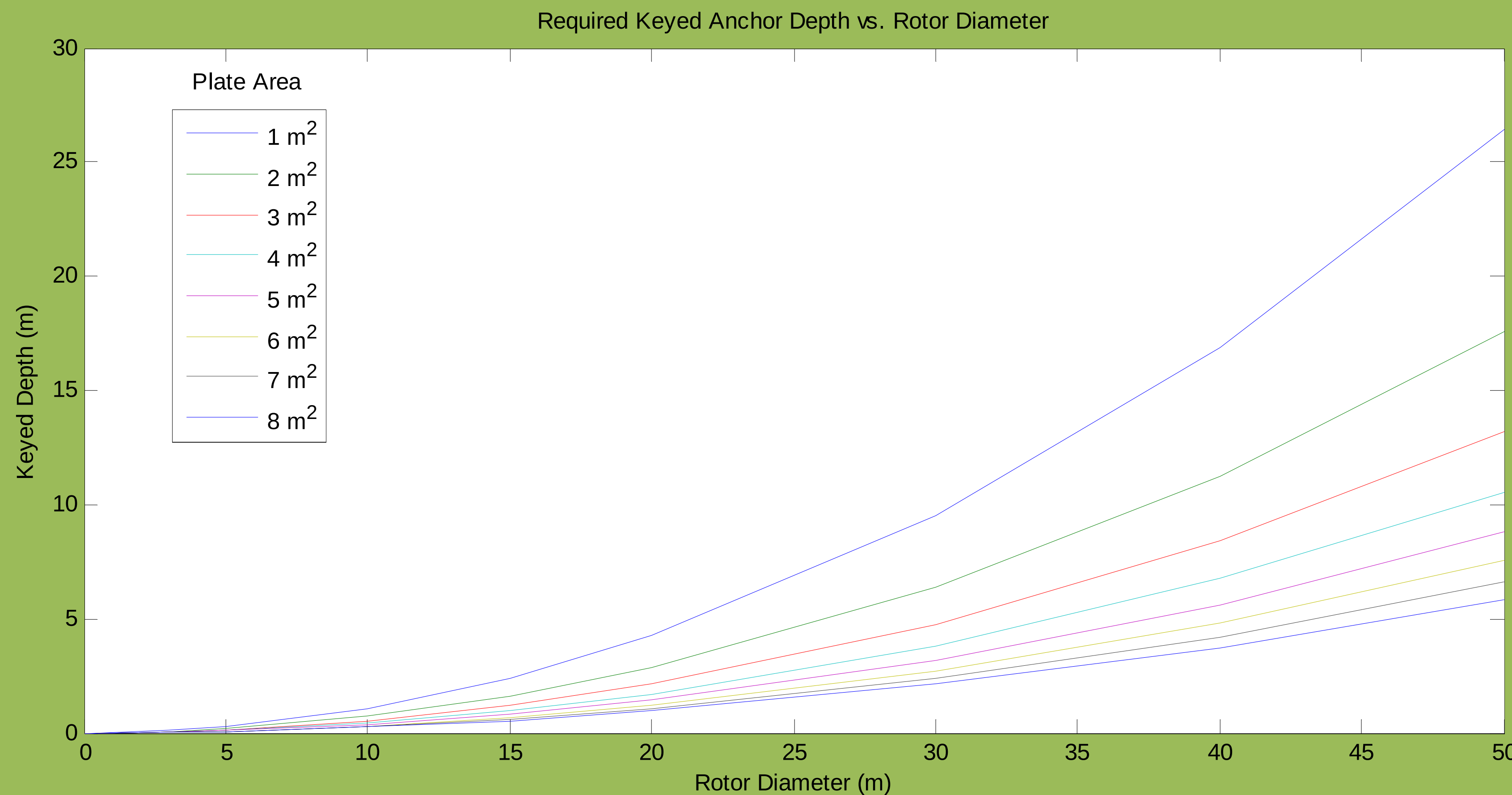
Location: 325 m depth atop Miami Terrace **Mooring Scope:** 1.25 **Bottom Type:** Loose Sand with Angle of Internal Friction = 30° **Anchor Type:** Sinker or Squat Lump Style Concrete Anchor with no shear keys



- **Compare footprint of necessary anchor size.**
- **Deadweight anchor size limited by anchor handling equipment.**
- **Cost of mooring system vs. potential power output.**

Example Anchor Sizing Results

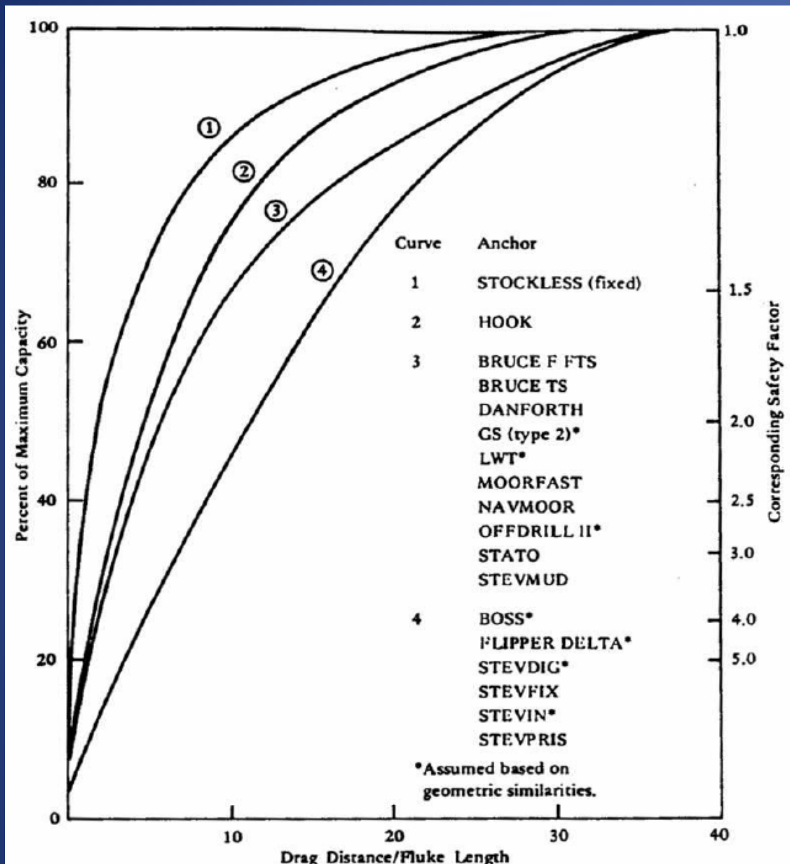
Location: 325 m depth atop Miami Terrace **Mooring Scope:** 1.25 **Bottom Type:** Loose Sand with Angle of Internal Friction = 30° **Anchor Type:** Driven Plate Anchor



- **Necessary depth of sediment and required plate area for increasing rotor diameters.**
- **Cost of mooring system vs. potential power output.**

Drag Embedment

Drag Distance in Clay



Source: (Sound and Sea Technology, 2009)

"In sand, the maximum capacity is achieved in less than about 10 fluke lengths of drag" (NCEL, 1987).

Fluke Tip Penetration

Estimated Maximum Fluke Tip Penetration of Some Drag-Embedment Anchors

Anchor Type	Normalized Fluke Tip Penetration (in fluke lengths) Sands & Stiff Clays	Muds (i.e., soft silts & clays)
Stockless*	1	1½ to 2 (3)**
Moorfast	1	4
Offdrill II		
Boss Danforth Flipper Delta GS (TYPE 2) Lwt* Stato Stevfix* Stevpris	1	4½
Bruce FFTS Bruce TS Hook Stevmud	1	5

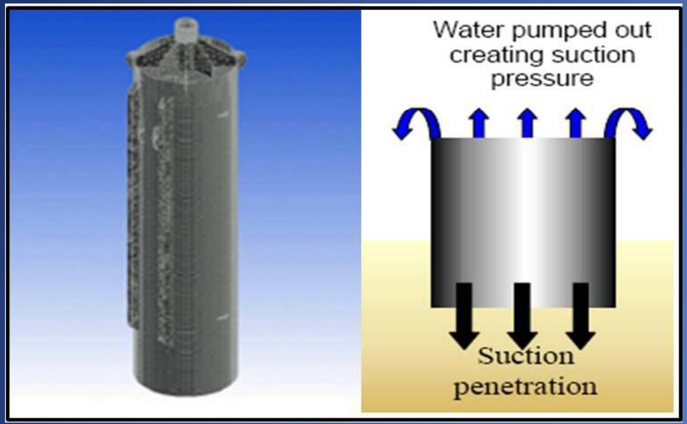
*Requires special handling to ensure fluke tripping in mud.
**Fixed fluke Stockless.

Source: (Sound and Sea Technology, 2009)

- Impact assessed by necessary drag distance for embedment and movement and length of chain segment on seafloor to achieve near 0° uplift angle.

Piles

Suction | Driven | Drilled and Grouted



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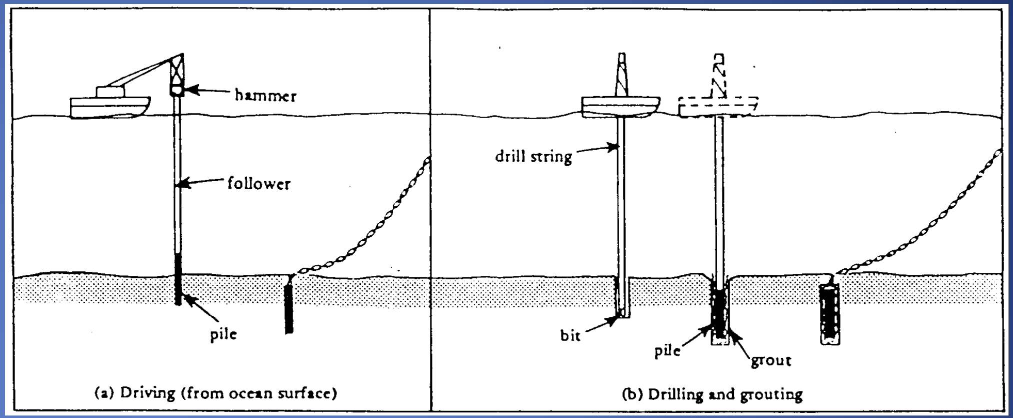


Source: (NCEL, 1985)

Impact

- Foot print equal or greater (drilled and grouted) than the area of pile end in addition to chain connection
- Movement of displaced sediment in deployment and retrieval

Advantages (NCEL, 1985)

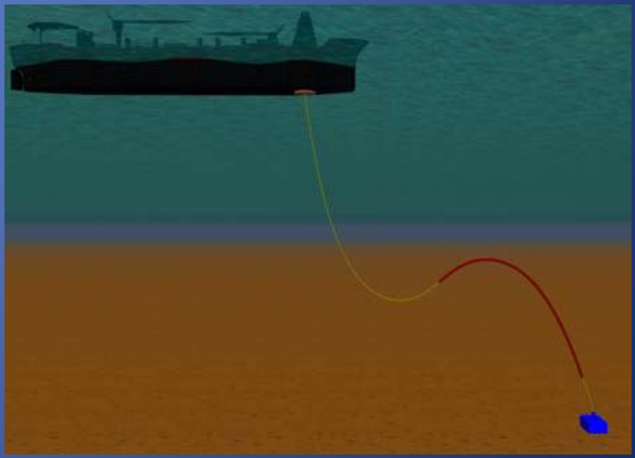
- No setting distance
- Anchor dragging eliminated

- Used only if other anchoring options are inadequate because of high deployment costs

Methods to Reducing Benthic Impact

- Reduce Gravity Anchor Footprint
  - Increase anchor bottom roughness.
  - Addition of skirts or shear keys for increased loading capacity causing anchor failure to occur in the soil and not at the soil anchor interface.
- Addition of sinker to drag embedment anchors to reduce mooring scope if device allows.
- Raise anchor connection point or portion of chain off seafloor with use of line floats.
- Properly sizing selected anchors with data from detailed site surveys.

Source: (Sound and Sea Technology, 2009)



Source: Orcaflex 9.3 B

Gaps in Current Knowledge of the Test Site

In a location where resource assessment is undergoing, the two biggest gaps in current knowledge for mooring system design and deployment are:

- Site specific metocean conditions for use in simulation
- Site specific benthic surveys with sub bottom profiling and soil sampling for detailed anchor design.