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Multiline Ring Anchor system for floating offshore wind turbines

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Background

- The trend in the offshore wind industry:
  - Stronger, more consistent wind resources
  - Mitigation of aesthetic issues

  ⇨ ✓ FOWTs*
  ✓ Installation in deeper & farther water
- Nevertheless, the high capital cost of the support system remains a primary obstacle → A need for cost-effective FOWT system

* floating offshore wind turbines

Introduction

- Considerations for the development of anchors for mooring FOWTs:

Cost

- Fewer & lighter anchors
- Maximizing geotechnical efficiency

⇨ ✓ Material cost ↓
✓ Transport cost ↓
✓ Installation cost ↓

Soil condition

- Deployable in the wide range of soil conditions → many potential sites

Reliability

- Precise positioning
- Deep embedment depth

⇨ ✓ Robust performance under unintended loading conditions

- Thus, multiline ring anchor (MRA) developed to address the above considerations [1, 2]

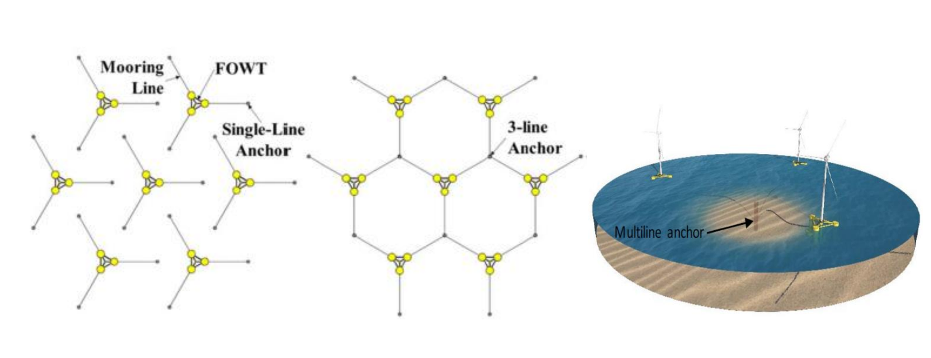


Figure 1. Comparison between single line anchor and multiline anchor [2]: (a) layout of single line, (b) layout of 3-line anchor, (c) multiline anchor concept

The Multiline Ring Anchor (MRA)

A. The concept of the MRA

- An embedded ring with up to 6 mooring lines
- Optional wing plates or keying flaps (Fig. 2) → enhancing horizontal & vertical load capacity
- The pile is penetrated to a certain embedment depth using driving or suction installation. Then the pile is extracted, leaving the ring anchor adequate depth (Fig. 3)

B. Potential advantages of the MRA

- Install in the wide range of soil → wide potential resources sites
- Multiline potential → reduced costs for geotechnical investigation, transport, material, fabrication, and installation
- Geotechnical efficiency: less than most plates, but still well above piles and caissons
- Precise positioning & deep embedment → high reliability

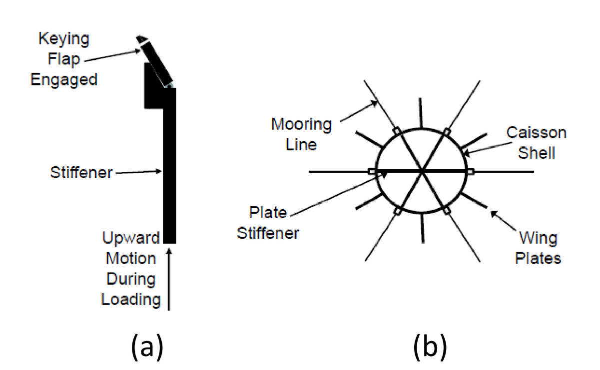


Figure 2. Strategies for enhancing load capacity: (a) keying flaps, (b) wing plates

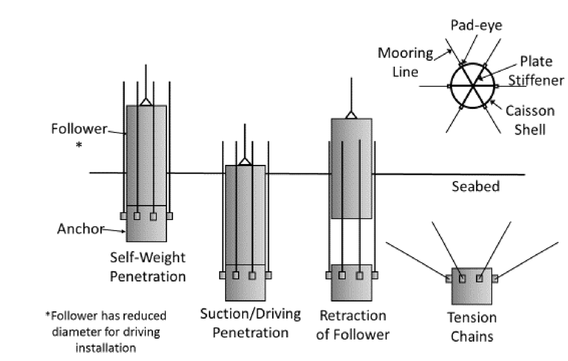


Figure 3. The installation procedure of the MRA

Example Comparative Study

- Comparison to conventional suction caisson (SC) anchors can be instructive (Fig.4).
- A typical soft clay (e.g Gulf of Mexico, [3]): $s_u(z)$=5+2kPa/m*z

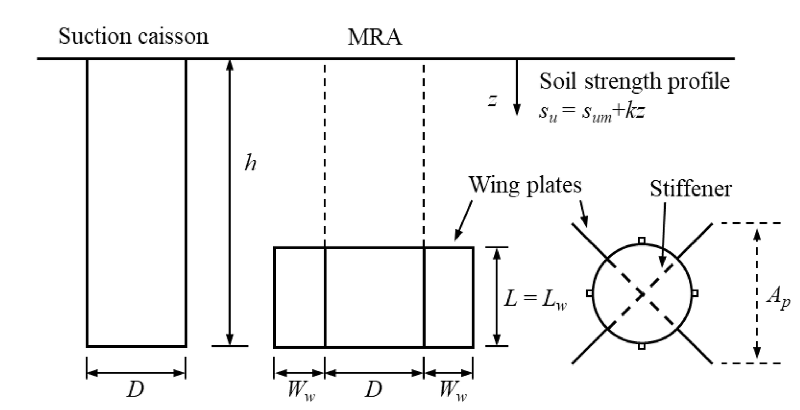
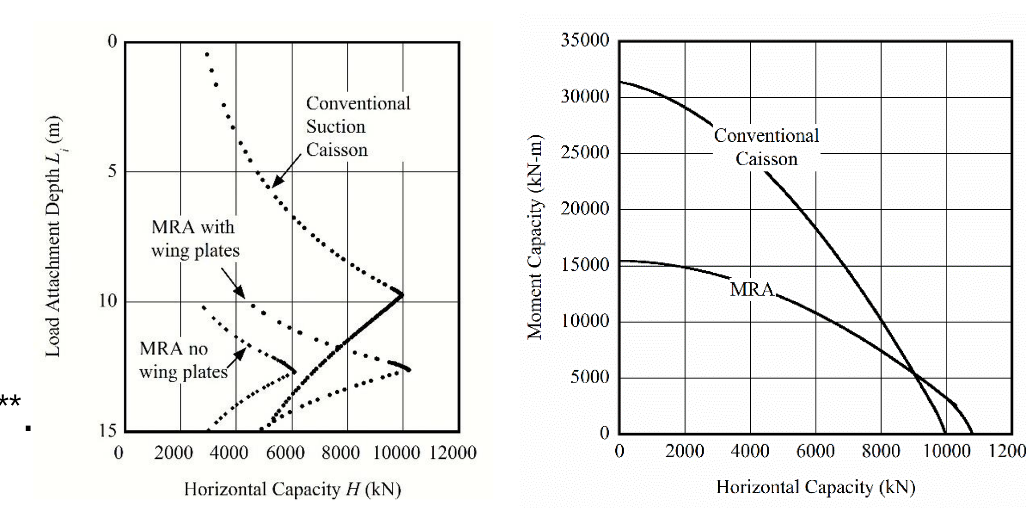


Figure 4. Suction caisson and MRA in clay

A. Load capacity comparisons

- Consider SC and the MRA designed to provide load capacity equal to that of SC (Appendix)
- Horizontal load capacity, H (Fig. 5)
  - H_{max}: Parity can achievable without increasing D.
  - The MRA has less moment resistance than SC due to shorter length (Moment, $M = H \mid L_i - L_{iopt} \mid$)**.
- Vertical load capacity, V (Table 1)
  - V_{max}: The MRA diameter needed to be increased to 4m to achieve parity in V_{max} with the SC.



(a) Load attachment depth vs. capacity

(b) Load-moment capacity interaction

Figure 5. Horizontal load capacity of MRA in clay

([1] floating offshore wind turbines)

Table 1. Comparative evaluation of suction caisson and MRA load capacity

Anchor	Features	Capacity enhancement	Weight (kN)	H_{max} (kN)	V_{max} (kN)
Suction caisson	D = 3 m L = 15 m t = 0.04 m	--	557	9,960	5,130
MRA matching horizontal capacity	D = 3.3 m L = 5.5 m z_{tip} = 15 m t = 0.04 m	6 wing plates: W_w = 1.65 m L_w = 5.5 m t_w = 0.04 m	350	10,800	--
MRA matching vertical capacity	D = 4 m L = 6.67 m z_{tip} = 15 m t = 0.04 m	6 wing plates 3 stiffeners: L_s = 6.67 m t_w = 0.04 m	538	--	5,250

B. Comparative efficiency

- Geotechnical efficiency ($\eta_H = H_{max}/W$)
  - Horizontal loading: MRA η_H = 29, SC η_H = 17.9
  - Vertical loading: MRA η_V = 9.8, SC η_V = 9.2

  → motivate to further research about keying flap
- Weight efficiency: ex) AHV transport operation
  - 1 SC = 3 or 4 MRA → fewer trips or smaller AHVs

** L_i: load attachment depth, L_{iopt}: Optimum L_i

Concluding Comments

- The MRA provide a means for significantly reducing the number of foundation footprints, with associated cost reductions.
- Installation cost for the MRA are medium (suction) to high (driving). However, the multiline potential may tend to offset its greater installation costs.
- Deep embedment & precise positioning can ensure robust performance under unintended loading and reliable prediction.
- Compared to SC, the MRA has a clear advantage under horizontal loading, future research is needed to improve the vertical load capacity by introducing keying flaps.

Appendix

- The MRA load capacity parity can be achieved by increasing D or W_w of wings.
- The design procedure is to (1) evaluate the MRA capacity using the same D as the suction caisson, (2) add wing plates to a maximum dimension $W_w = D/2$, and (3) if the previous step does not produce the target load capacity, incrementally increase D.
- Estimated using a plastic limit analysis [4]

References

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[3] Quiros G, Young A, Pelletier J and Chan J 1983 Shear strength interpretation for Gulf of Mexico clays. In: *Geotechnical practice in offshore engineering,* (Austin, Texas: ASCE) pp 144-65

[4] Aubeny C 2017 *Geomechanics of Marine Anchors* (Boca Raton: CRC Press, Taylor & Francis Group)