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Hydrodynamic characteristics of a wind turbine monopile foundation integrated with an oscillating water column wave energy device

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An OWC-integrated monopile foundation

■Offshore monopile foundations are commonly used but are subject to large wave forces in deep-sea environments. Integration of oscillating water column (OWC) devices aims to reduce wave loads and capture additional energy.

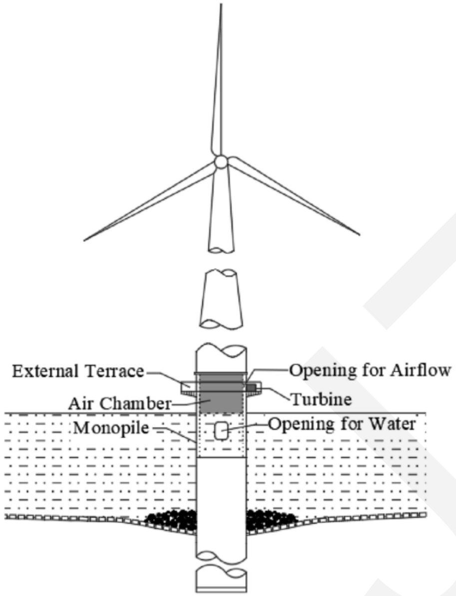

Fig. 1. Concept of An OWC-integrated monopile foundation. Reprinted from (Yanni Li, 2022), Copyright 2022, with permission from Elsevier

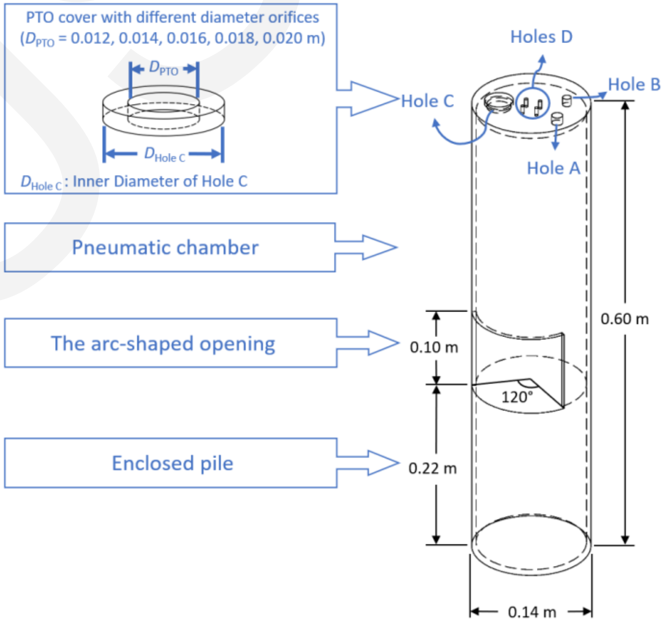

Fig. 2. Geometric details of the laboratory-scale OWC integrated monopile foundation model

Objectives

■To assess and understand load-reduction characteristics on OWC monopiles.

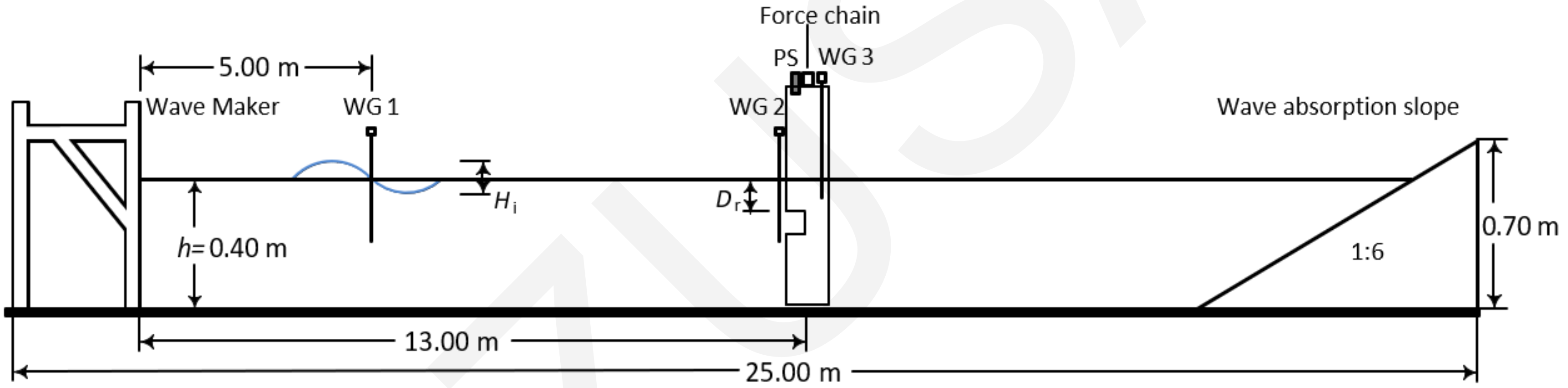

Fig. 3. Schematic diagram of the experimental setup

In this study, the water depth h was kept at 0.40 m for all test conditions, and so the draft of the OWC chamber D_r was fixed at 0.06 m. The wave period T was varied from 0.70 s to 1.60 s at an interval of 0.10 s, and the target incident wave height H_i was varied from 0.03 m to 0.06 m at an interval of 0.01 m.

Hydrodynamic characteristics

■Water Surface Oscillation and Air Pressure Fluctuation

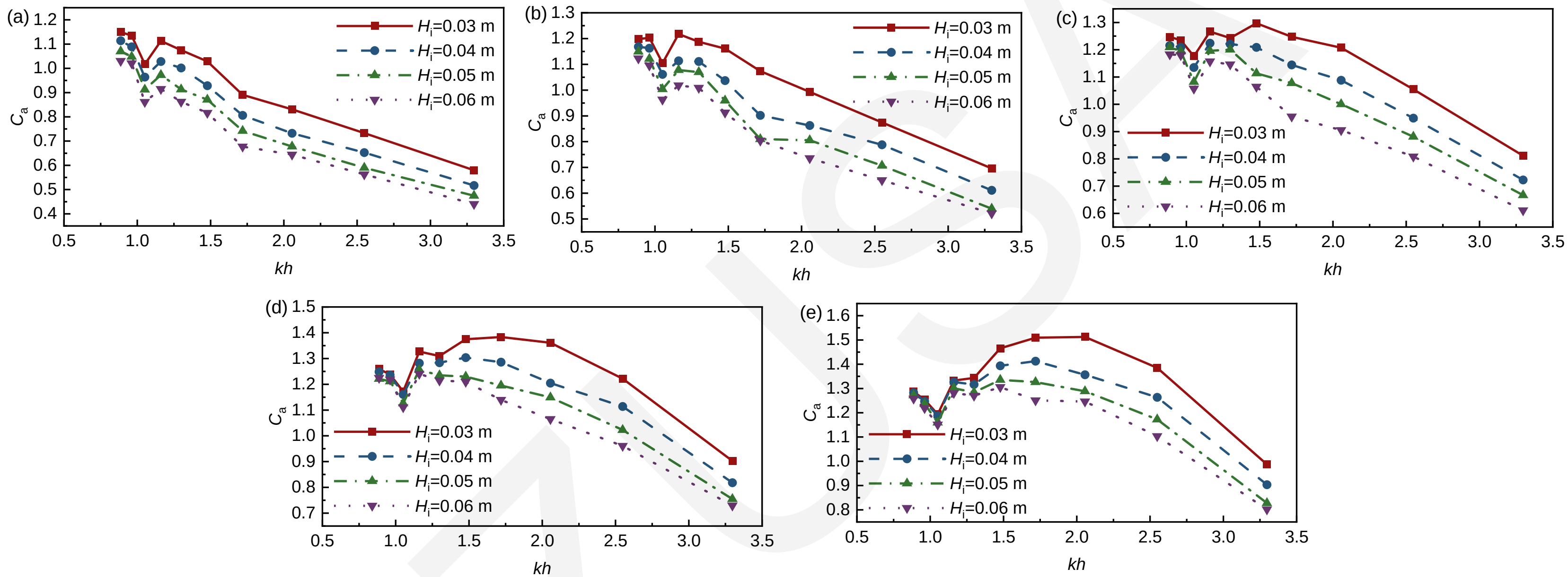

Fig. 4. Variation of in-chamber water surface oscillation coefficient C_a versus *kh* for different values of H_i with: (a) *e*=0.85%; (b) *e*=1.16%; (c) *e*=1.51%; (d) *e*=1.92%; (e) *e*=2.37%

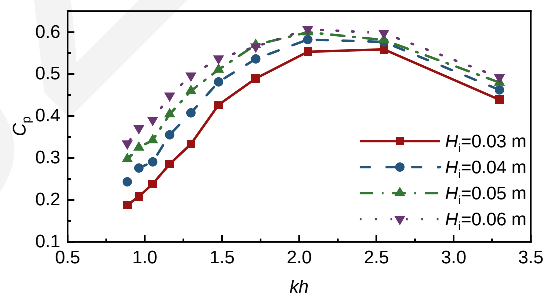

Fig. 5. Variation of the air pressure coefficient C_p versus *kh* for different values of H_i with *e*=1.51%

Hydrodynamic characteristics

■Wave Energy Extraction Power and Efficiency

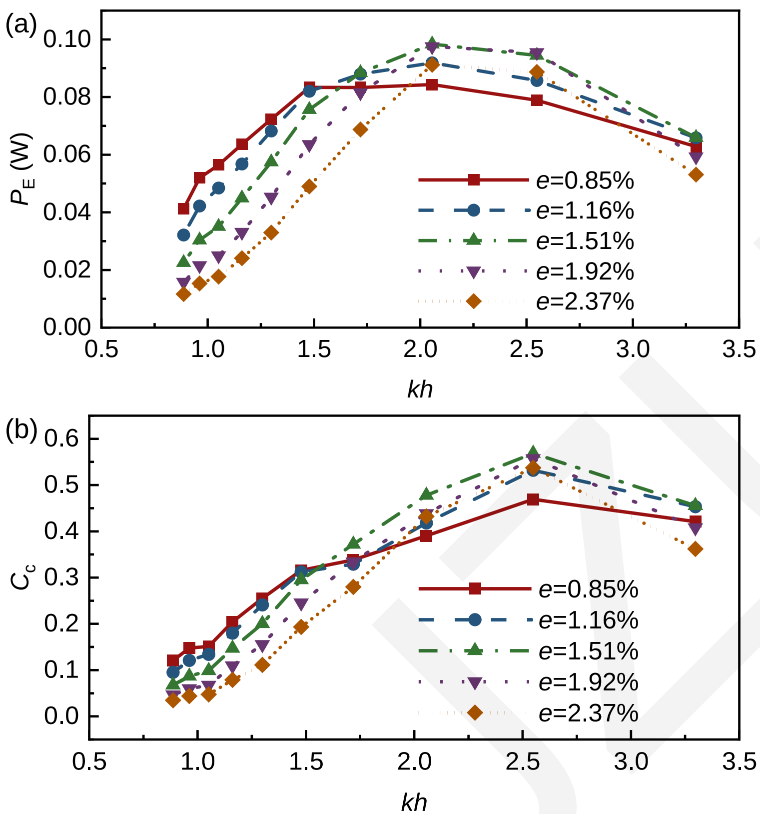

Fig. 6. Variation of (a) the pneumatic power P_E and (b) the capture width ratio C_c versus *kh* for different values of *e* with H_i=0.04 m

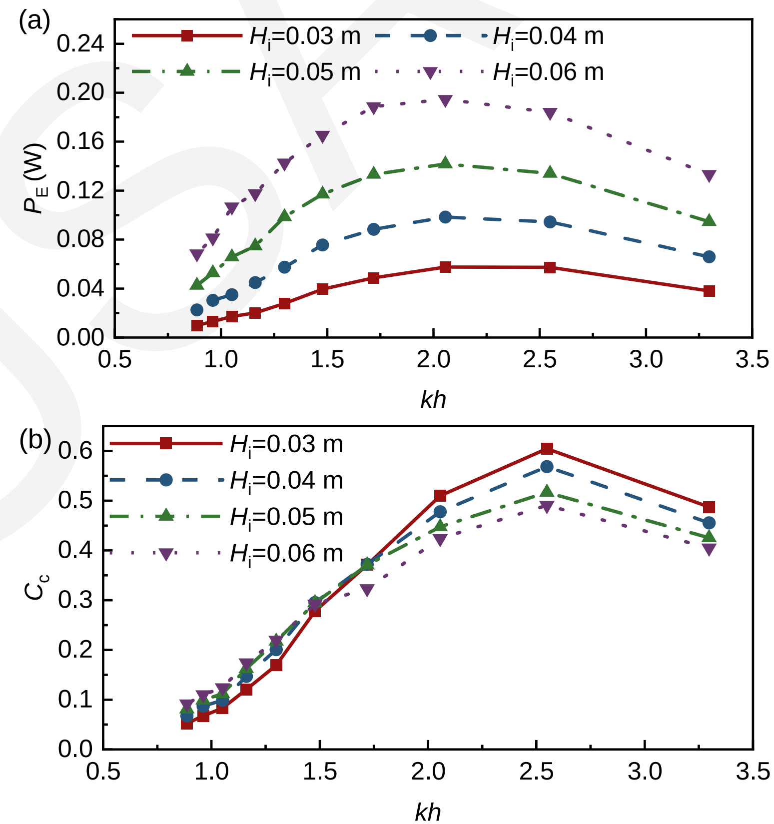

Fig. 7. Variation of (a) the pneumatic power P_E and (b) the capture width ratio C_c versus *kh* for different values of H_i with *e*=1.51%

Hydrodynamic characteristics

■Wave Load Reduction Results

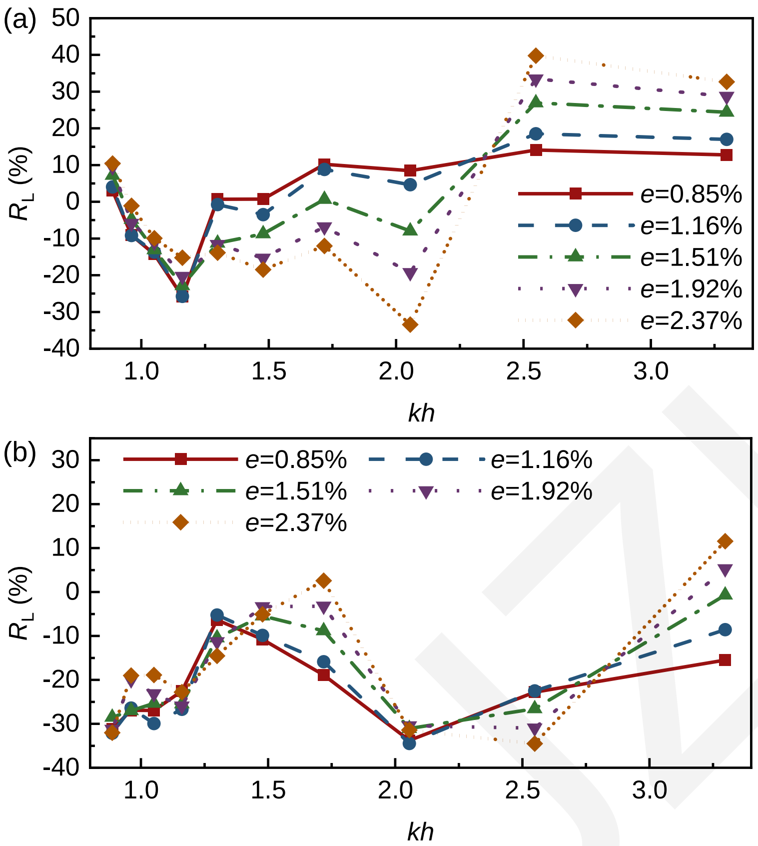

Fig. 8. Variation of the ratio of load reduction R_L versus *kh* for different values of e with H_i=0.04 m in (a) the positive direction and (b) the negative direction

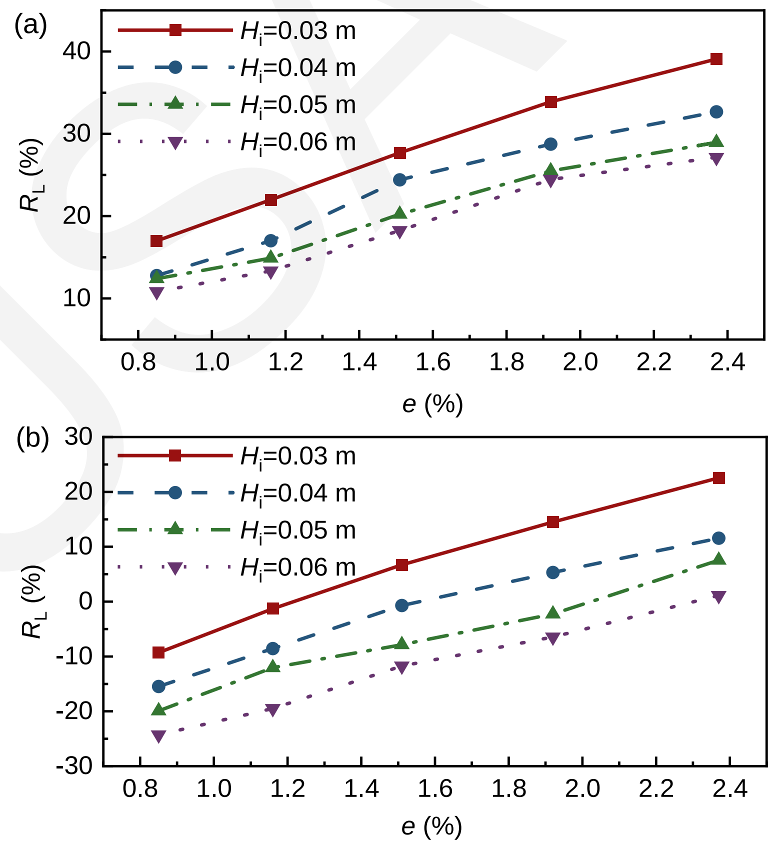

Fig. 9. Variation of the ratio of load reduction R_L versus *e* for different values of H_i with *kh*=3.30 in (a) the positive di-rection and (b) the negative direction

Conclusions

- **Hydrodynamic characteristics and wave energy efficiency:** The in-chamber water surface oscillation coefficient (C_a) and pneumatic power (P_E) are influenced by incident wave height and frequency, with higher opening ratios shifting peak frequencies to higher wave frequencies due to quadratic damping effects.
- **Load reduction in the positive direction:** OWC monopiles reduce positive wave loads at high wave frequencies, with smaller C_a and larger P_E providing better load reduction.
- **Effect of opening ratio on load reduction:** Large opening ratios cause load surges at medium wave frequencies, so medium ratios (e.g., 1.16% or 1.51%) are optimal for load reduction.
- **Optimal opening ratio:** An opening ratio of approximately 1.51% maximizes both wave energy capture and load reduction, offering strong performance across low- to high-frequency sea states.
- **Future research:** Further studies on structural strength using finite element methods and wave angle effects could deepen the understanding of OWC monopiles' performance.