



Rock Physics Diagnostic (RPD) as a Value-Added Tool in Site Investigation of the Subsea Characteristics for an Offshore Wind Farm Site in Ca Mau, Vietnam

Pham Huy Giao^{1,3}(✉), Nguyen Duc Thanh², Doan Huy Hien¹, Pham Hong Trang¹,
Pham Quy Ngoc¹, Bui Viet Dung¹, Ly Van Chien², and Le Cao Minh²

¹ Vietnam Petroleum Institute (VPI), Hanoi, Vietnam
giaoph@vpi.pvn.vn

² Technical World (TW), Ho Chi Minh City, Vietnam

³ PetroVietnam University (PVU), Ba Ria, Vietnam

Abstract. The study wind farm site is located near-shore in the Ca Mau province, about 35 km far away from Ca Mau city to the East, about 3 km from Ganh Hao town - Bac Lieu province to the South, with a shallow water depth from 2.5 to 3.5 m. An integrated geotechnical-geophysical survey was conducted at the site. In addition to common geotechnical testing, an emphasis in this study was given on PS seismic logging data analysis by Rock Physics Diagnostic (RPD), a method that is more commonly used in analysis of oil and gas well data. As results the subsea soil profile of five layers up to 80 m deep was well characterized by both geotechnical and elastic parameters. In addition, based on the RPD charts one can have a better idea of sedimentological conditions of the young soils at the study site.

Keywords: Near-shore investigation · Offshore wind farm · Rock Physics Diagnostic (RPD) · Seismic logging

1 Introduction

For many countries “*there is currently limited detailed understanding and data on the national offshore seabed characteristics*” [1], thus greater efforts are needed to improve understanding of the subsoil profile underlying the planned offshore wind energy areas to support development decision-making. While PetroVietnam as the leading national company for oil and gas exploration and production still wonders about its suitable position in the supply chain of renewable energy industry, the private sector has been proactively involved in developing wind farms from small to large scale in offshore area, which used to be the traditional operation space of the former. The question is whether or not a win-win cooperation can be made between a state-based organization like Vietnam Petroleum Institute (VPI) and a private company like Technical World (TW) with their own advantages and disadvantages in the period of energy transition. The objective of

this joint research is to perform a near-shore site investigation and its data analysis with an emphasis on seismic logging data acquired at a shallow water depth at the Ca Mau offshore wind farm site with the help of the rock physics diagnostic (RPD) approach, which is more common for oil well log data analysis.

2 Rock Physics Diagnostic (RPD) Method

“Rock physics is defined as science exploring quantitative relations between various properties (attributes) of the natural rock” [2]. It has started as a “velocity-porosity” science with applications mainly in oil and gas exploration, in particular for well log data analysis and static reservoir modeling. It has developed to “velocity-porosity-mineralogy” and then “velocity-porosity-mineralogy-fluid” science. Rock physics studies rocks “as a holistic object whose various properties (attributes) are extracted from experiments simulating processes such as elastic wave propagation, fluid and electrical transport etc.” [2]. Below are given a number of fundamental equations used in rock physics modeling (RPM):

$$V_p = \sqrt{\frac{K + \frac{4}{3}G}{\rho_b}} \quad (1)$$

$$V_s = \sqrt{\frac{G}{\rho_b}} \quad (2)$$

$$M = \rho_b V_p^2 \quad (3)$$

$$G = \rho_s V_s^2 \quad (4)$$

$$K = M - \frac{4}{3}G \quad (5)$$

$$AIP = \rho_b V_p \quad (6)$$

$$\vartheta = \frac{1}{2} \frac{(V_p/V_s)^2 - 2}{(V_p/V_s)^2 - 1} \quad (7)$$

$$\lambda = K - \frac{2}{3}G \quad (8)$$

Where: V_p , V_s are the compressional and shear velocity (m/s); K , M , G are the bulk modulus, compressional modulus and shear modulus (GPa), respectively; AIP is the acoustic impedance (m/s*g/cc); ϑ is Poisson ratio; λ is Lamé's constant (GPa).

When building out a rock physics model (RPM) one has to detect various velocity-porosity trends and assign each of them to appropriate depth intervals and depositional sequences. This process is called rock physics diagnostic (RPD). For newly deposited sediments a chart of VP versus porosity (F) with the Reuss elastic bound is very useful in

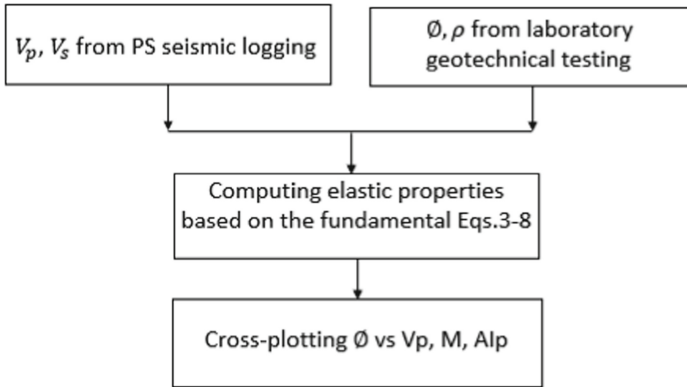


Fig. 1. Flow chart of rock physics diagnostic (RPD).

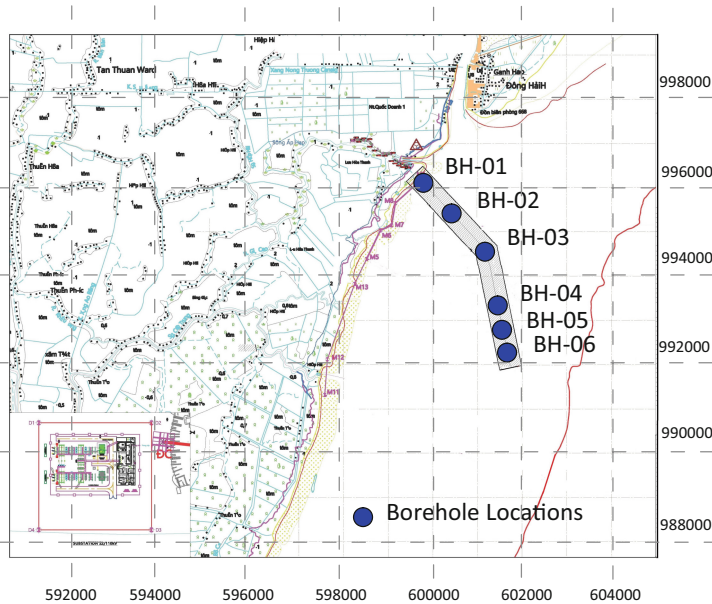


Fig. 2. Study site and seismic borehole locations [4].

deciphering rock texture [3]. For this study the methodology follows the chart as shown in Fig. 1.

The study wind farm site belongs to Dam Doi district, Ca Mau province, with a shallow water depth from 2.5 to 3.5 m. It is about 35 km far away from Ca Mau city to the East, about 3 km from Ganh Hao town - Bac Lieu province to the South as seen in Fig. 2 with the locations of six PS seismic boreholes [4] that were conducted as a part of an integrated geotechnical-geophysical near-shore investigation, which included the

drilling and sampling works, laboratory geotechnical testing (grain size analysis, Atterberg limits, water content, bulk density, direct shear test, triaxial test, and consolidation test), in-situ geotechnical testing including CPTU, field vane shear.

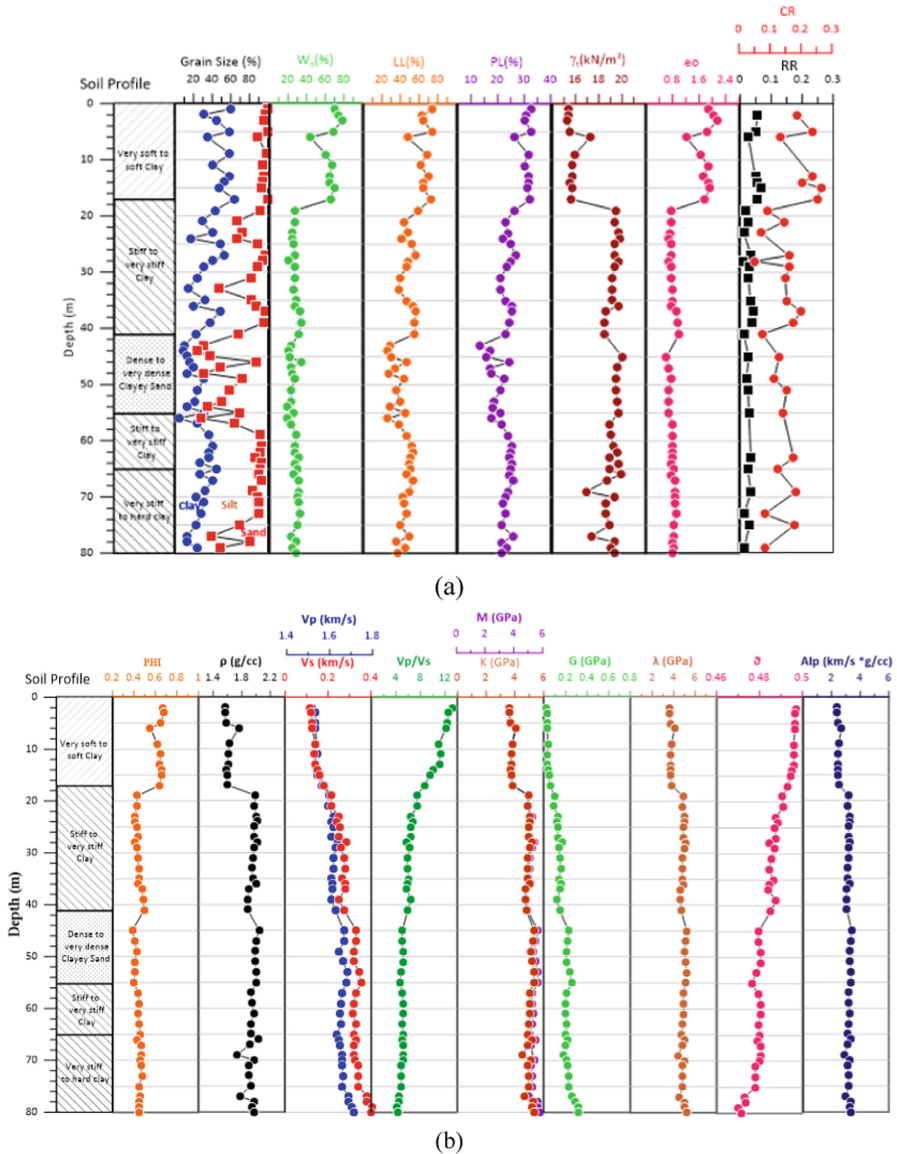


Fig. 3. (a) The near-shore subsoil profile at the Ca Mau wind farm site and (b) Elastic characteristics of the seabed at the Ca Mau wind farm site.

3 Results and Discussion

Table 1. (a) Geotechnical characteristics of the study site seabed and (b) Elastic characteristics of the study site seabed.

(a)

Layer No	Name	Depth (m)	Geotechnical characteristic analysis									
			Grainsize			LL	PL	W	Bulk density	Void Ratio e ₀	CR	RR
			sand (%)	silt (%)	clay (%)	%	%	%	kN/m ³			
1	Very soft to soft clay	0-17	3.79	46.24	49.97	65.71	31.02	65.91	15.74	1.81	0.22	0.05
2	Stiff to very stiff clay	17 -41	18.23	48.32	33.45	49.32	23.89	27.46	19.25	0.79	0.13	0.03
3	Dense to very dense clayey sand	41 - 55	50.30	31.50	18.20	34.91	18.81	24.07	19.64	0.69	0.13	0.03
4	Stiff to very stiff clay	55- 64	21.85	48.95	29.19	45.09	23.28	26.23	19.23	0.80	0.18	0.03
5	Very stiff to hard clay	64-80	21.29	51.67	27.03	44.96	23.40	28.94	18.75	0.84	0.13	0.02

(b)

Layer no	Name	Depth (m)	Geophysical characteristics analysis										
			∅	ρ (g/cc)	V _p (m/s)	V _s (m/s)	V _p /V _s	M (GPa)	G (GPa)	K (GPa)	A _{Ip} (km/s *g/cc)	∅	λ (GPa)
1	Very soft to soft clay	0-17	0.64	1.61	1538.09	139.81	11.19	3.80	0.03	3.76	2.47	0.50	3.74
2	Stiff to very stiff clay	17 -41	0.44	1.96	1614.03	257.67	6.31	5.11	0.13	4.94	3.17	0.49	4.85
3	Dense to very dense clayey sand	41 - 55	0.42	1.98	1668.10	335.85	4.97	5.51	0.22	5.22	3.31	0.48	5.07
4	Stiff to very stiff clay	55- 64	0.44	1.94	1652.81	323.52	5.11	5.31	0.21	5.03	3.21	0.48	4.90
5	Very stiff to hard clay	64-80	0.46	1.91	1667.68	350.04	4.79	5.32	0.24	5.00	3.19	0.48	4.85

As the results the geotechnical characteristics of the study site seabed are presented in Fig. 3a and Table 1a, while those of elastic characteristics are presented in Fig. 3b and Table 1b, respectively. In this study the whole range of elastic properties such as the ratio between P and S-wave velocities (V_p/V_s), Acoustic impedance (A_{Ip}), Poisson's

ratio (ν), Lamé’s constant (λ), bulk modulus (K), compressional modulus (M) and shear modulus (G) could be determined using Eqs. 1 to 8.

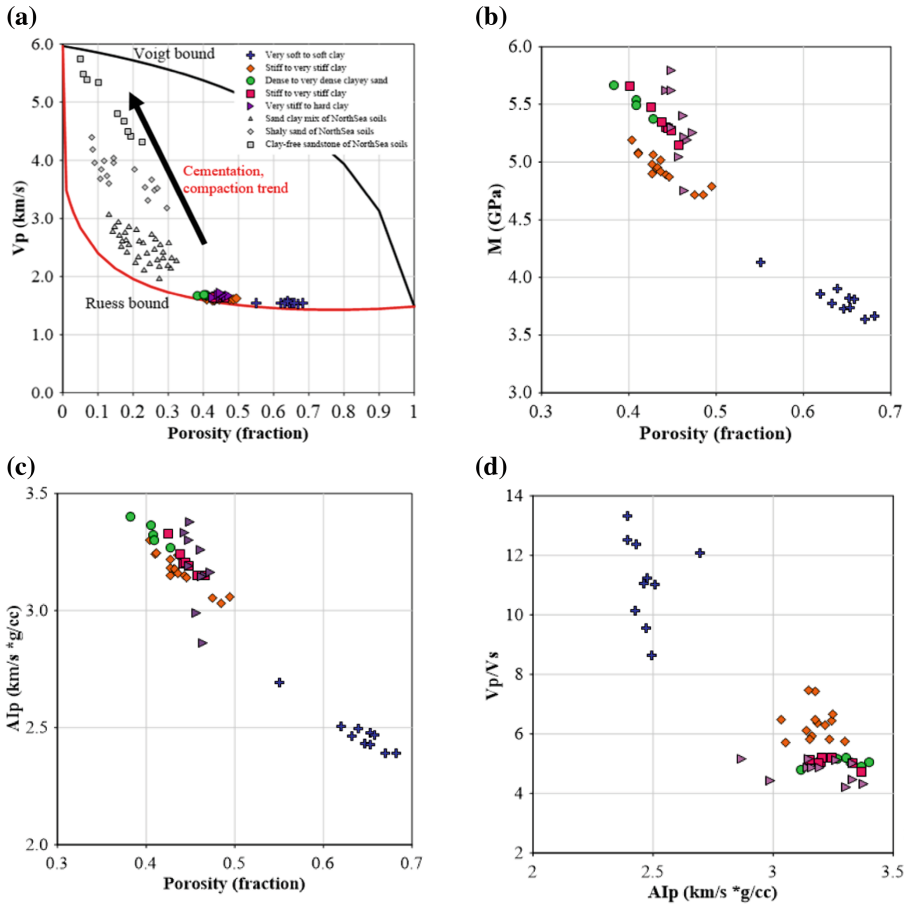


Fig. 4. RPD charts constructed for the study site: (a) V_p vs F in comparison with the North Sea soil data, updated from [4]; (b) M vs. F , (c) A_{Ip} vs F ; (d) V_p/V_s vs A_{Ip} .

Based on the results of an integrated geotechnical and geophysical analysis the subsoil profile up to 80 m deep was completely characterized, consisting of five soil layers, i.e., very soft to soft clay (0–17 m), stiff to very stiff clay (17–41 m), medium dense to very dense clayey sand (41–55 m) having a medium sand of about 2 to 3 m thick in the upper part, stiff to very stiff with two sublayers from 55 to 65 m (stiff fat to lean clay) and 65 to 55–80 m (hard lean clay). Some rock physics diagnostic (RPD) charts were constructed for the study site as shown in Fig. 4a–d. In Fig. 4a the data points of the Ca Mau soils are located close to the curve of Ruess’s bound, which indicates of very young sediments, in particular the very soft clay on top. It is interesting to see that

the five soil layers identified by geotechnical characteristics could be well defined by elastic characteristics as seen in Fig. 4b–d and Table 1a and b.

4 Concluding Remarks

The seabed characteristics of an offshore wind farm site in Ca Mau, Vietnam, were completely characterized by an integrated geotechnical-geophysical investigation and data analysis. The subsoil profile up to 80 m deep under the sea bottom consists of five well defined layers. Layer 1 of very soft to soft clay on top has highest porosity (0.55–0.7) and V_p/V_s (8.3–14), lowest M (3.5–4 GPa) and AI_p (2.3–2.5 km/s²*g/cc). In contrast, Layer 5 of very stiff to hard clay is characterized by the highest M (5–6 GPa), AI_p (3–3.3 km/s²*g/cc), and lowest V_p/V_s (4–5); Layer 4 has a M (5.2–5.7 GPa) higher than that of the layer 2 (4.7–5.2 GPa), whereas V_p/V_s of layer 4 (4.7–5) is smaller than that of the layer 2 (5.8–7.8); The layer 3 has smallest porosity and highest velocity compared to those of the other layers as seen in Table 1b, indicating a mixture of clay-sand. It is first time the RPD method was applied for a shallow seismic logging survey, whose results agree well with the results from geotechnical testing, thus it can be a value-added tool for further nearshore site investigations for offshore wind farms' construction along the coast of Vietnam.

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