

RESEARCH SOLUTIONS FOR PRECAST CONCRETE REVETMENTS USING ALB-REBAR TO RETAIN CORAL SAND FOR OFFSHORE ISLANDS IN VIETNAM

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Abstract

Gravity revetment solutions are a popular choice for shore protection at atolls under the harsh conditions of ocean waves. The precast revetment option is preferred to reduce shipping costs for materials and ensure quick construction. This article studied precast concrete revetments with ALB composite material reinforcement and conducted experimental research to determine the shear resistance characteristics of coral sand and the friction characteristics of concrete materials with coral sand. Based on the experimental parameters, the authors calculated the stability of the ALB embankment structure against the effects of wave loads during storms. With experimental data obtained from coral sand samples prepared with equivalent density in the field, the results showed that the stability coefficient of the revetment is significantly higher than the one obtained from the traditional calculation concept.

Keywords: Coral sand; internal friction angle; external friction angle; void ratio; relative density.

1. Introduction

To protect the banks on atolls, people in the past often used gravity revetment structures made of concrete materials, often poured in place. Under the impact of regular wave loads and erosion by the marine environment, after more than 30 years of exploitation, this traditional embankment structure has clearly deteriorated. Figure 1 shows that the surface of the wave deflectors, slope, and toe protection has all experienced erosion, leaving only crushed stone aggregates.



Fig. 1. Gravity revetment made of concrete poured in place on an offshore island in Vietnam after more than 30 years of exploitation.

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Faced with the inadequacies of traditional revetment and embankment solutions, researchers and businesses are required to look towards new technological solutions and new materials. One of these solutions is "Precast structures to protect river banks, lakes, and sea dikes" from Busadco. This solution has achieved successful implementation across various provinces and cities, earning a commendable reputation (Figures 2-5). It utilizes hollow-wall thin-walled concrete structures, non-metal reinforcements, assembly-type connections, cubic layouts, diverse designs, and multiple sizes. Designed to be open and easily constructed even in muddy conditions, the costs are reduced by approximately 20 - 30% compared to site-cast structures and other methods [1].

Precast non-metal reinforcement concrete revetments are designed using polypropylene fiber-reinforced (PP) and glass fiber-reinforced polymer (GFRP). These fibers are resistant to alkali, do not absorb water, and do not corrode; they have a much higher tensile strength than steel reinforcement; Helps concrete reduce shrinkage, reduce the formation of cracks, increase waterproofing, tensile and compression resistance; increase the durability of concrete. Therefore, using non-metal reinforcement in concrete to replace steel reinforcement will ensure corrosion resistance and increase the sustainability of the structure and is very suitable for the climatic conditions in Vietnam.



Fig. 2. Fishing Village - Xuyen Moc revetment using non-metallic reinforced concrete.



Fig. 3. Precast structures were built to prevent coastal erosion in Thai Binh.

At present, coral research has garnered significant attention from numerous scientists [2-8]. However, there is a limited number of publications addressing the friction between concrete and coral sand [5, 9, 10]. Feng Ze-kang and colleagues [5] employed a surface shear test model to investigate the mechanical behavior of the interface between coral sand and structures (steel, concrete), considering changes in surface roughness. According to Robinson [11], friction characteristics between coral and concrete hinge on various factors such as structural surface roughness, relative density of coral sand,

compressive stress, shear strain rate, size of experimental equipment, particle size, shape characteristics of the sand particles, and the type of experimental model. Remarkably, very few studies have comprehensively considered all of these factors.

In Vietnam, the design of revetment for offshore islands on coral platforms often applies the standard TCVN 9901:2014 "Hydraulic structures - Requirements for seadike design" [12]. When auditing the sliding surface of embankment structures, the skin friction coefficient is taken according to Table 1 as follows:

Table 1. Friction coefficient according to TCVN 9901:2014 [12]

No.	Interface materials between wall - foundation	Friction coefficient
1	Concrete and concrete	0.55
2	Grouted stone and grouted stone	0.65
3	Quarry stone and quarry stone	0.70
4	Concrete and quarry stone (surface flattened by gravel)	0.60
5	Grouted stone and quarry stone (surface flattened by gravel)	0.65
6	Riprap and coarse, fine sand foundation	0.50 - 0.60
7	Riprap and dust sand foundation	0.40
8	Riprap and clay sand foundation	0.35 - 0.50
9	Riprap and clay, loam foundation	0.30 - 0.45

Table 1 shows that the standard does not mention the friction parameters of concrete structures with natural ground and especially coral sand ground. In this study, we analyzed the parts of precast concrete revetments with ALB composite material reinforcement and conducted experimental research to determine the shear resistance characteristics of coral sand and the friction characteristics of concrete materials with coral sand. From the experimental parameters received, we calculated the stability of the ALB embankment structure against the effects of wave loads during storms.

2. Precast concrete revetments with ALB composite material reinforcement

Offshore islands in Vietnam frequently experience seasonal sand movement. To augment the available land area, an embankment is essential for retaining this shifting

sand. Gravity revetment solutions have emerged as a favored method for shore protection, particularly for atolls facing the challenges posed by harsh ocean waves. This article delves into the research of embankment structural solution, as outlined below:

The structure consists of hollow-wall thin-walled concrete tanks arranged side by side. These tanks are filled with coral sand up to a height 0.5 m below the top of the tank. On the surface, there is a 50 cm thick layer of reinforced coarse sand with 7% cement, compacted tightly to create an erosion-resistant surface. Each thin-walled concrete tank features a hexagonal cross-section with sides measuring 1.32 m in length and a height of 2.8 m. The tank is buried at a depth ranging from 0.3 m to 0.5 m into the coral ground, ensuring that the top of the tank aligns with a crest elevation of +2.30 m.

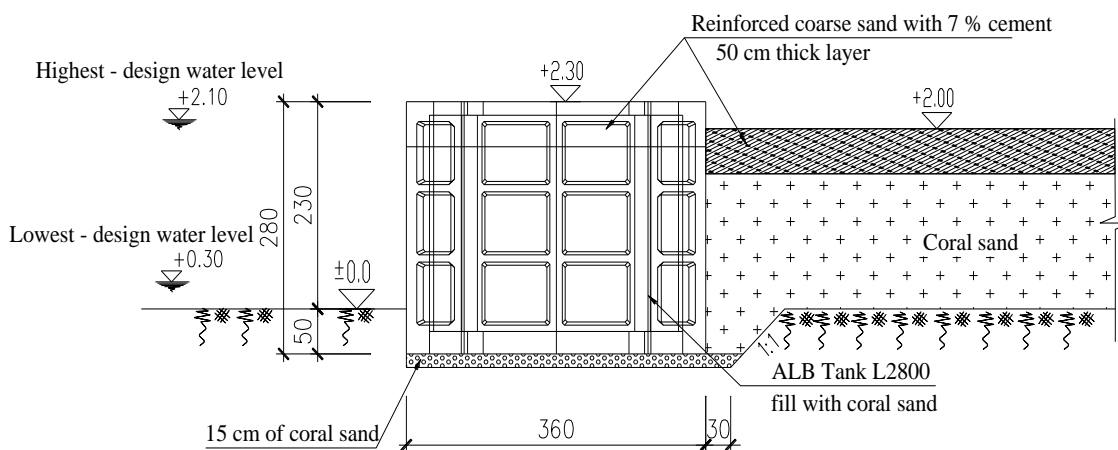


Fig. 4. Vertical cross-section - Alternative1.

The ALB D2500-L2800 tank is a precast thin-walled concrete structure featuring concrete grades of M800 and GFRP bars, rendering it impervious to the corrosive effects of the marine environment. Each tank adopts the shape of a hexagonal prism box, standing at a height of 280 cm, inclusive of the bottom. The tank's base is hexagonal, inscribed within a circle with a diameter of 264 cm. Each ALB tank comprises two wall panels, each weight of 33 kN, and one bottom panel weight of 24 kN. These components are designed to optimize the transportation process from the onshore factory to the construction site. Figures 5 through 6 depict the process of installing the ALB tank at the site.



Fig. 5. Compacted coarse sand with 7% cement.



Fig. 6. The tank is moved to the construction location by crane after completion of installation.

3. Experimental research to determine the shear resistance characteristics of coral sand

Coral sand was collected from an island in the East Sea of Vietnam (Fig. 7). The physical properties of coral sand are shown in Table 3.



Fig. 7. Coral sand was collected from an island in the East Sea of Vietnam.

Table 3. Physical parameters of the coral sand

Parameters	Value
Unit weight of solid matter, γ_s (kN/m ³)	26.71
Maximum void ratio, e_{max}	0.93
Minimum void ratio, e_{min}	0.60

Figure 8 displays the grain-size distribution curves. From this, the uniformity coefficient is determined as $C_u = 6.31$, and the coefficient of curvature as $C_c = 1.11$. According to the standard TCVN 5747:1993 [13], this coral sand is classified as belonging to the SW type.

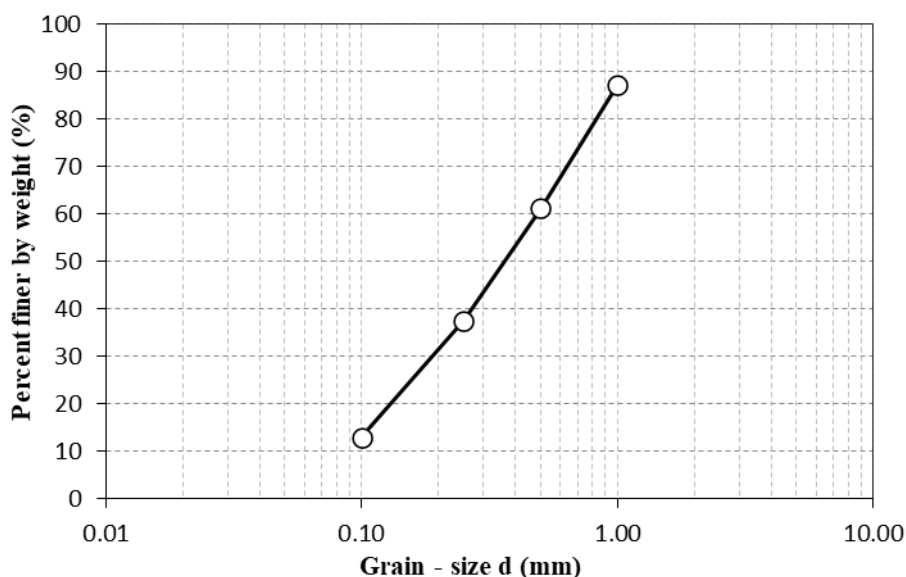


Fig. 8. Grain-size distribution curves.

To assess the stability of the embankment, it is essential to determine the shear strength parameters of coral sand and the external friction angle between the bottom concrete of the revetment and the coral sand (for evaluating resistance against sliding). Due to sea level fluctuations ranging from +0.3 m to +2.2 m, compacting the coral sand behind the revetment presents a challenge. Initially, construction design consulting units assumed the internal friction angle of the sand behind the embankment to be equivalent to the internal friction angle in the saturated state, indicating a very loose state ($\varphi = 30^\circ$). However, post-construction field surveys revealed that the coral sand achieved a certain density with varying water levels, the rolling compactor and trucking processes. Excavation methods post-construction indicated an uneven density in the coral sand layer behind the embankment, ranging from medium to dense. Therefore, in this study, two experiments were conducted with coral sand at different densities, i.e. $D_r = 50\%$ (medium) and $D_r = 75\%$ (dense), as follows:

- Experiment 1: Determine the shear resistance parameters of coral sand with a shear speed of $SR = 1$ mm/min. This experiment involves three samples with one type of density, corresponding to different vertical stress levels: $\sigma = 50$ kPa; $\sigma = 100$ kPa; $\sigma = 200$ kPa.

- Experiment 2: Determine the external friction angle between the bottom concrete of the revetment and the coral sand. The test samples of this experimental model have a vertical stress of $\sigma = 50$ kPa and an $SR = 1.0$ mm/min shear rate.

To investigate the interaction between coral sand and concrete surfaces, we employed the experimental setup illustrated in Figures 9 and 10. Utilizing the Shearmatic direct shear test apparatus, we customized an additional cutting board beneath the cutting

box. The lower cutting board was meticulously designed and manufactured to ensure compatibility with the upper cutting board and to encase the box-shaped concrete sample for testing.

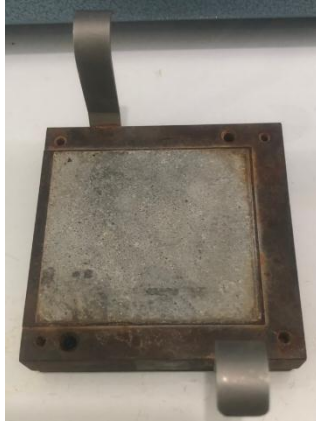


Fig. 9. The lower steel cutting board is made to accommodate the concrete sample.

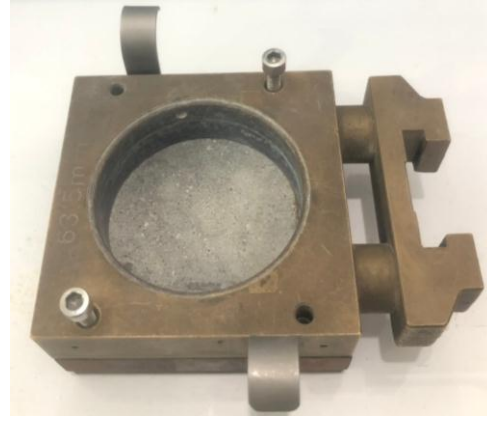


Fig. 10. Insert the concrete sample into the Shearmatic direct shear test apparatus.

When increasing the density of coral sand from medium to dense, the friction angle did not increase much (from 41.77° to 42.21°), but the unit cohesion increased about 2.7 times (from 8.61 kPa to 23.441 kPa).

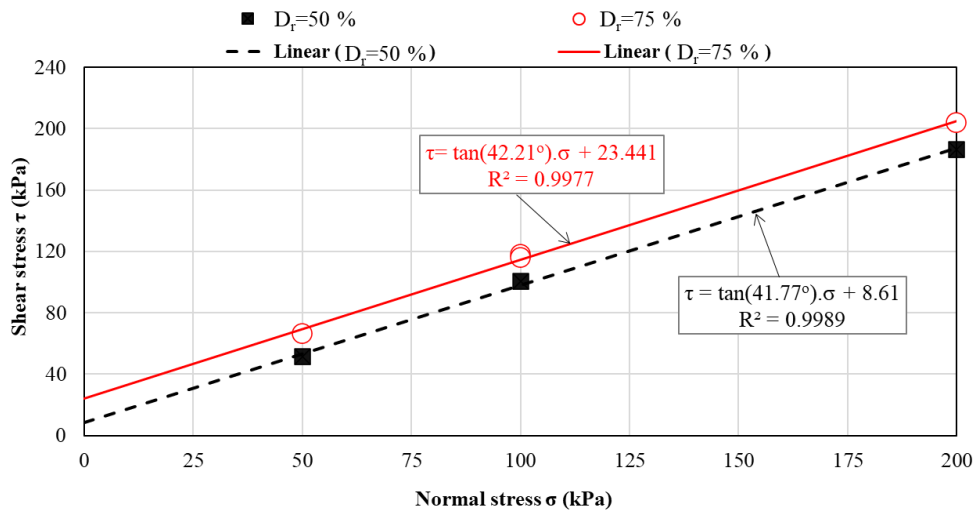


Fig. 11. Envelopes of shear strength-normal stress with two relative densities.

The external friction angle according to the results of experiment 2 is determined as follows:

$$\tan \delta = \frac{P_f^{\max}}{N} \quad (1)$$

where δ is external friction angle; P_f^{\max} is maximum friction force; N is vertical force, $N = \sigma \cdot F$ (F is area of soil sample, σ is vertical stress).

Figure 12 illustrates that for medium or dense relative densities, the relationship curve between friction force and horizontal displacement lacks a distinct peak value. The friction force gradually increases until reaching a ultimate strength, after which it tends to stabilize. With an increase in relative density from medium to dense, the external friction angle (δ) also increases, shifting from 36.40° to 38.24° .

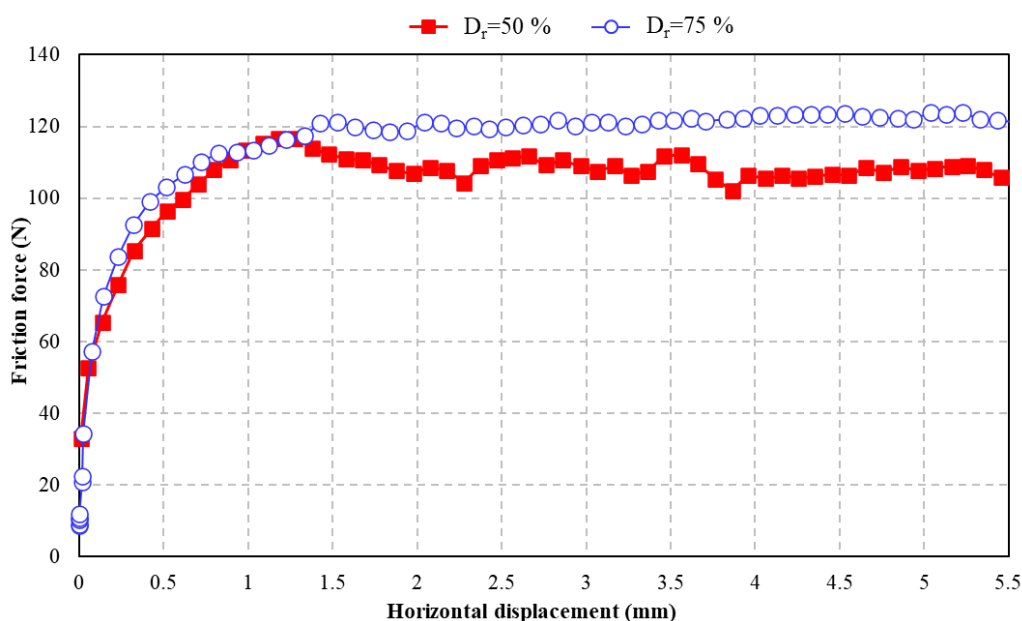


Fig. 12. The relationship between friction force and horizontal displacement with two relative densities.

4. Calculation of ALB revetment stability

The revetment structure is subject to the pressure of incoming or outflow waves in various scenarios, such as storms and monsoons. In this study, we specifically examined the stability of the revetment under wave parameters simulated for Typhoon Tembin and the condition where the structure experienced outflow wave pressure. Utilizing the experimental results outlined above, we conducted an assessment of the stability of the ALB revetment, considering the following three options:

- Option 1: Considering the coral sand behind the revetment was in a very loose-density state, the internal friction angle was taken corresponding to the saturated state, $\varphi = 30^\circ$ and when there was no actual measured data, the external friction angle is taken $\delta = \varphi = 30^\circ$ (according to Article 9.2.2.4 of TCVN 9901:2014).

- Option 2: Based on experimental results with coral sand samples prepared in a medium-density state.

- Option 3: Based on experimental results with coral sand samples prepared in a dense-density state.

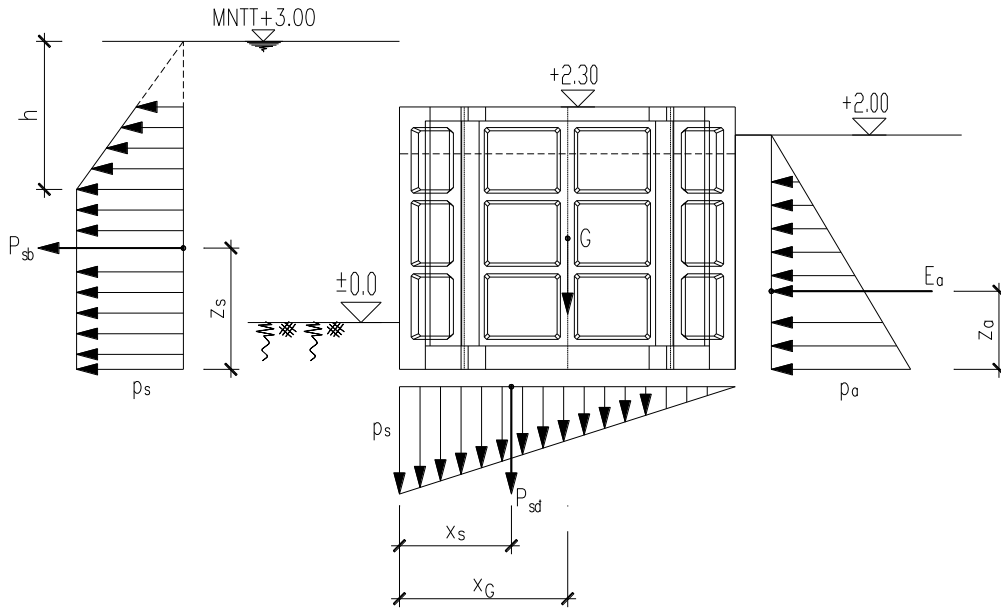


Fig. 13. Forces acting on ALB revetment.

The forces acting on the revetment include: weight of the embankment body; active earth pressure; outflow wave pressure (calculated according to OCDI-2002 standards [14]).

Stability factor against sliding (K_{trp}) and overturning (K_l) is determined as follows:

$$\begin{cases} K_{trp} = \frac{T_{ms}}{E_a + P_{sb}} = \frac{(G + P_{sd}) \cdot \tan \delta}{E_a + P_{sb}} \\ K_l = \frac{G \cdot x_G + P_{sd} \cdot x_s}{E_a \cdot z_a + P_{sb} \cdot z_s} \end{cases} \quad (2)$$

where T_{ms} is friction force between the revetment's bottom surface and the coral sand; E_a is total active force acting on surface; P_{sb} is the force of run-down wave acts on the wall of revetment; G is weight of revetment in water; P_{sd} is the force of run-down wave acts on the bottom of revetment; x_G , x_s , z_a , z_s are lever arm of forces G , P_{sd} , E_a , P_{sb} , respectively.

The calculation results for the sliding surface and overturning stability of the revetment are presented in Table 4. The ALB revetment demonstrated stability assurance under the Tembin storm scenario across all three options. However, when calculated

according to option 1 (assuming the soil behind the revetment was only in a very loose density), the safety factor coefficients were significantly lower than those for the two options based on laboratory experimental results with samples having a density suitable for field conditions.

Table 4. The stability of ALB revetment according to 3 options

Content	Unit	Option 1	Option 2	Option 3
Sand relative density	-	Very loose	Medium dense	Dense
Sand internal friction angle, φ	Degrees	30	41.80	42.20
External friction angle between the concrete and the coral sand, δ	Degrees	30	36.40	38.24
Weight of revetment in water, G	kN/m	80.00	80.00	80.00
Active lateral earth pressure coefficient, K_a	-	0.333	0.200	0.196
Total active force acting on surface, E_a	kN/m	9.11	5.48	5.37
Maximum run-down wave pressure, p_s	kPa	15.8	15.8	15.8
The force of run-down wave acts on the wall of revetment, P_{sb}	kN/m	40.4	40.4	40.4
The force of run-down wave acts on the bottom of revetment, P_{sd}	kN/m	28.5	28.5	28.5
Friction force between the revetment's bottom surface and the coral sand, T_{ms}	kN/m	62.6	80.0	85.5
Sliding force	kN/m	49.5	45.9	45.8
Resisting forces	kN/m	62.6	80.0	85.5
Stability factor against sliding, K_{ap}	-	1.26	1.74	1.87
Stability factor against overturning, K_l	-	2.95	3.14	3.15
Safety coefficient of stability against sliding (Structure grade IV – TCVN 9901:2014)		1.20	1.20	1.20
Safety factor against overturning (Structure grade IV – TCVN 9901:2014)		1.45	1.45	1.45
Conclusion		Acceptable		

5. Conclusion

In this article, we compared two structural alternatives for revetments on coral islands in the East Sea. The results revealed that the alternative employing a non-metallic reinforced ALB precast revetment offered numerous advantages over the traditional revetment approach. These included faster construction progress, facilitated by assembling boxes in the factory and transporting them to the construction site, thereby reducing dependency on unusual weather conditions. Additionally, the structure boasted a longer lifespan due to the utilization of high-strength concrete grades (M800) and non-metallic reinforcement, making it resilient to aggressive environments.

Due to the fluctuating water levels within the revetment height, achieving optimal compaction and density control of coral sand presents challenges. Nevertheless, the filled coral sand managed to attain a density ranging from medium to dense levels. This study experimentally determined the shear resistance parameters of coral sand and the friction characteristics of concrete-coral with medium to dense density. A summary of the experimental results indicates that, owing to its rough and angular grain structure, coral sand exhibits a substantial internal friction angle and appears to possess an apparent adhesive force. As the density of coral sand increases from medium to dense, the friction angle sees a marginal increase, while the intensity of the adhesive force escalates approximately 2.7 times. The ratio of the angle of external friction (δ) to internal friction (φ) for the medium-dense sample is $\delta/\varphi = 0.87$; for the dense sample, $\delta/\varphi = 0.90$.

If we consider the filled coral sand to be in a very loose density state only, the stability factor against sliding of the ALB revetment closely aligns with the requirements of the TCVN 9901:2014 standard. The experimental data, obtained from samples made with coral sand having the same density as the field, demonstrates a significantly high stability factor against sliding. This reinforces the conclusion that the precast concrete revetment with ALB composite material reinforcement is a viable and rational alternative to traditional revetment solutions.

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NGHIÊN CỨU GIẢI PHÁP KÈ LẮP GHÉP ALB GIỮ CÁT SAN HỒ CHO CÁC ĐẢO XA BỜ Ở VIỆT NAM

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Tóm tắt: Kè trọng lực là giải pháp phổ biến để bảo vệ bờ cho các đảo san hô dưới điều kiện khắc nghiệt của sóng đại dương. Để giảm bớt chi phí vận chuyển biển cho vật liệu và đảm bảo thi công nhanh thì giải pháp kè lắp ghép là giải pháp ưu tiên được lựa chọn. Bài báo nghiên cứu giải pháp kè lắp ghép bằng cốt phi kim ALB và nghiên cứu thực nghiệm xác định đặc trưng kháng cắt của cát san hô và đặc trưng ma sát của của vật liệu bê tông với cát san hô. Từ các tham số thực nghiệm nhận được, các tác giả tính toán kiểm định mức độ ổn định của kết cấu kè ALB trước tác dụng của tải trọng sóng trong bão. Sử dụng dữ liệu thực nghiệm thu được từ các mẫu cát san hô được chế bị có độ chặt tương đương ở hiện trường, cho thấy hệ số ổn định của kè cao hơn đáng kể so với quan niệm tính toán truyền thống.

Từ khóa: Cát san hô; góc ma sát trong; góc ma sát ngoài; hệ số rỗng; độ chặt tương đối.

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