CHALLENGES IN ENGINEERING GEOLOGICAL MAPPING AT LARGE SCALES 1:2000 FOR SUBMERGED CORAL ISLANDS

Quy Dat Nguyen[1,*], Quang Trung Dinh[1]

[1]*Institute of Techniques for Special Engineering, Le Quy Don Technical University*

Abstract

This article presents a methodology for creating large-scale engineering geological maps (1:2000) for submerged coral islands in Vietnam's maritime zones, in accordance with the national standard TCVN 9156:2012. The primary objective is to provide a comprehensive representation of key geological and environmental factors, particularly coral sediments that influence land use planning, construction design, and implementation. As there are currently no specific national standards for engineering geological mapping in coral-based island areas, this study references various related standards and documents. It also highlights significant issues that need to be addressed when conducting large-scale engineering geological mapping in submerged coral environments.

The results demonstrate that large-scale engineering geological mapping is of considerable scientific and practical value for construction planning, resource management, and natural disaster mitigation. The article also recommends further research to enhance mapping accuracy and the development of appropriate technical standards. Future directions emphasize the integration of modern technologies, such as GIS-based digital mapping, 3D geological modeling, and virtual reality (VR) applications, to simulate geological conditions and assess geohazards in marine island environments. These advancements aim to address challenges posed by climate change and promote sustainable development.

***Keywords**: Large-scale engineering geological maps; coral rock; submerged island; coral sedimentary rock.*

1. Introduction

The Engineering Geological Map (EGM) is a thematic map that illustrates the engineering geological conditions of a specific territory or study area. It is used to support territorial economic planning, infrastructure design, and the implementation of engineering solutions. According to current regulations, large-scale EGMs are defined at scales ranging from 1:5000 to 1:1000 [1].

In Vietnam, no large-scale EGM has yet been developed for coral island regions, and there are no specific national standards for engineering geological surveying and mapping under the unique conditions of coral-based foundations. To address this gap, this study adopts the national standard TCVN 9156:2012 – Hydraulic Structures:

[*] Corresponding author, email: quydatnguyen@mta.edu.vn
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Method for Large-Scale Engineering Geological Mapping (1:5000 to 1:1000) as a reference framework to develop an EGM at a scale of 1:2000 for a submerged coral island area. The study also discusses several technical and practical challenges encountered during the implementation.

The initial development of an EGM for submerged coral islands is of significant practical importance. It helps identify the geotechnical characteristics of the coral-based substrate and supplements existing datasets on the geological conditions of coral environments. This information is essential for planning and designing specialized hydraulic structures. Furthermore, the EGM contributes to geological risk assessment and management, evaluation of groundwater and hydrogeological resources, and provides a scientific basis for the rational exploitation and environmental protection of coastal and island zones.

2. Technical requirements and mapping procedures for engineering geological maps according to TCVN 9156:2012

The EGM is compiled based on the correction and systematization of empirical data collected through field mapping, investigation, laboratory testing, and long-term monitoring. It is also integrated with various base maps such as geological, geomorphological, and hydrogeological maps. Together with its accompanying explanatory report, the EGM serves as a comprehensive document that synthesizes the results of engineering geological surveys. The EGM must be accompanied by a summary table of the standard values of physical and mechanical properties of different soil and rock types, engineering geological cross-sections, a map legend, and a system of conventional symbols [2].

2.1. Technical requirements

The engineering geological mapping was carried out before the implementation of drilling investigations and laboratory and in-situ testing within the study area [1]. However, since no medium-scale maps had been previously created for the project site, a larger scope of work was necessary. In addition to field surveys and direct observations, the research team gathered supplementary data from past construction and scientific projects, including records from borehole and field testing.

The large-scale engineering geological mapping relied on field observations of stratigraphy, topography, geomorphology, and hydrogeological conditions [1]. Given the unique characteristics of the study area, which is a submerged coral island, the mapping activities were primarily conducted during low tide to allow access to exposed reef flats. In deeper water areas, direct observation was more challenging; therefore, the extent of mapping was defined based on the influence of sea level variations, which are directly relevant to construction and exploitation activities on the submerged island. This presents one of the distinctive technical challenges in carrying out engineering geological mapping in such environments.

The permeability of coral soil and rock is closely related to tidal fluctuations and the porosity characteristics of the coral foundation. In submerged island areas, it is also necessary to consider oceanographic factors such as tidal levels, tidal range, nearshore currents, and barometric variations in the geotechnical analysis. The determination and calibration of permeability parameters should be performed in coordination with hydrographic survey data to ensure the accuracy and consistency of the results.

The topographic base map used for this study had a scale of 1:2000. The mapped area covered approximately 100 hectares, which is larger than the direct footprint of the planned hydraulic structures. This extensive mapping was done to clarify general geological conditions, anticipate potential alignment adjustments, and assess engineering geological dynamics in the broader area, including weathering, karstification, and erosion phenomena.

The standards for large-scale engineering geological mapping depend on the mapping scale, the complexity of engineering geological conditions, and the quality of outcrops at observation points, as detailed in Tabs. A.1 and A.2 of Appendix A in TCVN 9156:2012 [1]. In this case, the engineering geological conditions were classified as ranging from simple to moderately complex (levels 05-06), and the quality of the outcrops was considered moderate. Therefore, for a mapping scale of 1:2000 in the submerged island area, the required density of observation points ranges from 200 to 350 points per square kilometer, with a borehole density of 37 to 64 holes per square kilometer.

The required investigation depth is determined based on the zone of engineering geological influence corresponding to the type of planned hydraulic structures, such as breakwaters, docking basins, or dredged reservoirs. Accordingly, boreholes were designed with depths ranging from 10 to 60 meters. Observation points were geodetically positioned using a Garmin GPSMAP 78s device (Fig. 1). Given that the minimum borehole depth was 10 meters, and according to the standards, each 10-meter segment of the borehole is considered equivalent to one observation point [1].

The scope and methodological approach of large-scale engineering geological mapping are determined by the chosen mapping scale. At a scale of 1:2000, the primary classification unit is the engineering geological type, which is defined based on the lithological homogeneity and consistent physical characteristics of each rock or soil type. This classification is established through systematic investigations of the physical and mechanical properties of soil and rock materials. The mapping process is typically divided into two seasons: fieldwork is conducted during the dry season, while data processing, map drafting, and interpretation occur during the rainy season [1]. However, due to the coastal and insular nature of the study area, specific hydro-meteorological conditions must be considered. These include tidal fluctuations, marine currents, wave dynamics, and weather variability.

Fig. 1. Handheld GPS positioning device.

To ensure data reliability and survey safety, fieldwork should be scheduled during periods of favorable marine conditions. Furthermore, it is essential to maximize low-tide periods to enhance access to exposed geological outcrops, which are otherwise submerged. This strategy not only improves observational accuracy but also supports more comprehensive and reliable engineering geological interpretations in submerged coral island environments.

2.2. Implementation of engineering geological mapping

After completing the project outline and cost estimation, the preparatory phase began with a field survey. Coral rock is a unique type of sedimentary formation that results from the lithification of coral remains due to changing environmental conditions. This rock type has distinct physical, mechanical, and lithological characteristics compared to common continental rocks, and it is not currently addressed by existing construction standards.

The fieldwork started with a review and synthesis of geological survey data previously collected from scientific and infrastructure development projects in the region [3]. The objective was to clarify the stratigraphy, lithological structure, mineral composition, and textural features of coral rocks within the study area. Based on these findings, the orientation of coral formations was analyzed, and coral rocks were classified into major groups by depth: coral sand layer, branching coral layer, coral rubble layer, and massive coral rock layer.

In terms of topographic characteristics, the mapping area is situated in a submerged island environment, classified as semi-submerged. During high tide, the entire area is inundated, while portions of the reef emerge above water during low tide. The topography is directly influenced by oceanographic conditions, such as tides, wave action, and erosional processes, leading to seasonal surface variations. However, the overall morphology is primarily shaped by erosional dynamics - mixed sediment deposition.

The geomorphological features of the coral island in this mapping area resemble isolated reef islands with atoll-like structures that barely rise above sea level (Fig. 2). This area is part of a larger coral reef system extending in a northeast-southwest direction, characterized by considerable length. In the central portion of the reef, a total of 201 coral species have been identified [4].

Fig. 2. Engineering geological mapping area.

Due to the unique topographic conditions, field surveys were conducted using specialized boats. The survey schedules were carefully coordinated with weather and tidal conditions to ensure both efficiency and safety. Key observation points were chosen during low tide, when the terrain's surface features were more clearly visible. The large-scale engineering geological mapping in the study area was carried out along nine survey transects, with a total of 256 observation points documented. Additionally, lithological samples were collected in the field for laboratory testing (Fig. 3).

Fig. 3. Engineering geological mapping conducted during low tide.

In the study of the geological characteristics and physical-mechanical properties of coral rock, methodologies typically used for limestone and dolomite terrains were employed. In the area under investigation, the coral materials are primarily composed of aragonite crystals. Throughout the diagenetic process, these aragonite crystals are transformed into calcite, which results in the formation of massive coral limestone with porosity ranging from 10% to 40% [4].

During the mapping process, it is crucial to take into account the sedimentary layers of coral origin. This involves focusing on bedding characteristics, lithological composition, degree of weathering, and specific physical-mechanical properties. From a structural geology perspective, factors such as jointing, fracturing, and dynamic geotechnical phenomena were analyzed using previous scientific reports, dissertations, and related research projects, in conjunction with field observations and descriptions. Sampling was conducted both at the surface and within boreholes for subsequent laboratory testing, along with in-situ field experiments (Figs. 4, 5). In terms of hydrogeology, the groundwater in the submerged island area comprises two aquifer systems: a porous aquifer within unconsolidated sediments, including sand, gravel, branches, cobbles, and coral fragments, and a fracture-cavity (karst) aquifer within limestone-coral rock.

These two aquifers are hydraulically interconnected with each other and with seawater, exhibiting tidal fluctuations. Consequently, they share a common water level and do not require separate representation. Nevertheless, it is necessary to provide hydrogeological parameters such as hydraulic conductivity (K), specific discharge (q), or pumping rate (Q) corresponding to drawdown (S). Additionally, information on chemical composition and an assessment of groundwater corrosivity should be included. Due to technical, weather, and temporal constraints, these measurements have not yet been conducted. This limitation is also highlighted as a recommendation for future studies to improve the completeness of hydrogeological data for engineering geological investigations in the study area.

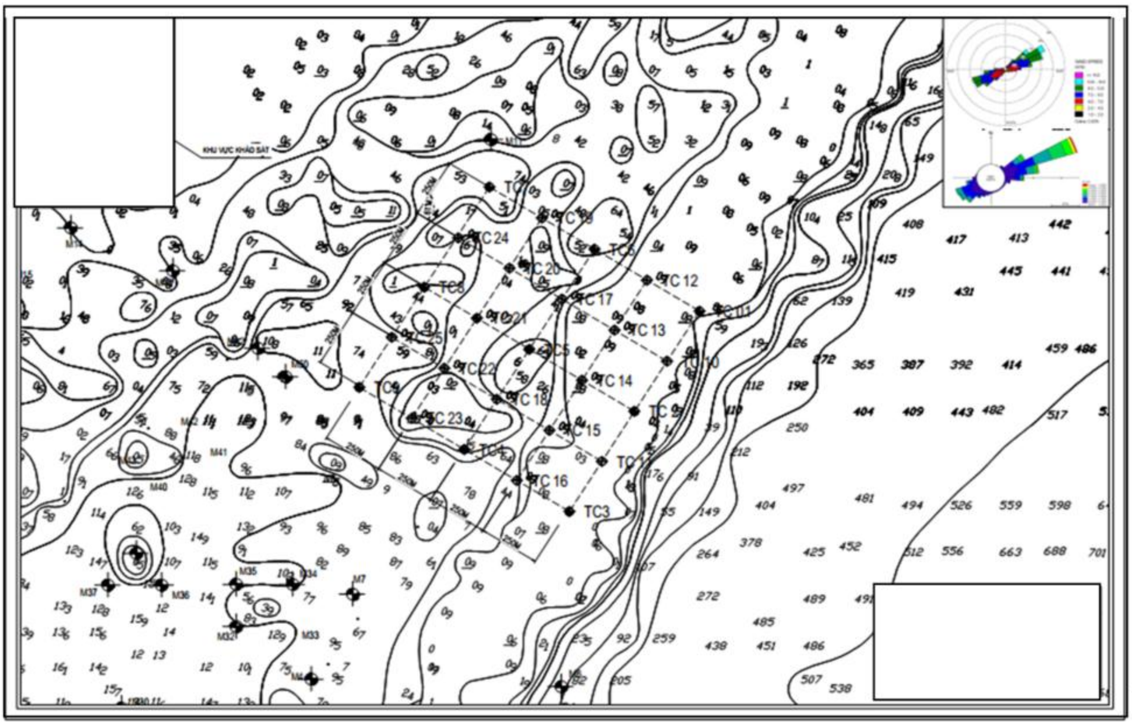


Fig. 4. The layout of the borehole survey conducted within the submerged island study area.

The results of large-scale engineering geological mapping, following data revision, include the creation of two types of maps: the engineering geological data map and the engineering geological map.

Fig. 5. In-situ drilling for engineering geological investigation.

The engineering geological data map provides a comprehensive and accurate depiction of all fieldwork conducted within the mapped area. This map serves as the primary source of data. The engineering geological map must include geological cross-sections, which can be presented separately from the map itself.

The large-scale (1:2000) engineering geological map is developed based on field survey results, including traverses, boreholes, laboratory tests, in-situ tests of physical and mechanical properties, petrographic analyses, marine water sample testing, and other specialized investigations related to geology, geomorphology, hydrogeology, and natural construction material resources. It also incorporates previously collected regional data [1]. The details of these findings are presented in Section 5.

3. Content and methodology for the compilation of the 1:2000 engineering geological map

The compilation of large-scale (1:2000) engineering geological maps adheres to the guiding principle of lithological origin, as rocks and soils are critical factors in engineering geological investigations. The classification levels presented on the 1:2000 scale maps include lithological complexes, lithological types, and engineering geological types, all of which are mapped onto a topographic base map of the same scale [1].

In terms of thematic classification, the engineering geological map created for the submerged island area falls under the category of specialized engineering geological maps. These maps are specifically designed to support construction design for various types of hydraulic structures and contribute to territorial economic development planning as well as geological environmental protection. As a result, elements related to engineering geological conditions that are not directly associated with construction, such as hydrogeology and tectonics, are either omitted or simplified. Conversely, key elements that directly pertain to the design and construction of hydraulic structures such as buildings, revetments, locks, and dredging works are presented in great detail. These crucial elements include: stratigraphy, physical and mechanical properties of coral rocks and soils, topography and geomorphology of the surveyed area, natural mineral construction materials, and certain geodynamic phenomena [2].

According to the level of detail and intended use, I. V. Popov proposed a classification system for engineering geological maps that is considered more suitable for Vietnam's territorial conditions than those suggested by other authors. Based on this system, the 1:2000 scale engineering geological map is categorized as a detailed engineering geological map, typically compiled for small areas and founded on data obtained from site investigations, laboratory testing, and field monitoring, all of which support technical design and construction drawings [2].

The engineering geological map must present elements such as coral reef geological structures, geomorphology, hydrology, geodynamic processes and phenomena, and natural mineral construction materials. Additionally, the map includes symbols indicating the positions of boreholes, sampling locations, and field tests [1].

The methodology for representing engineering geological conditions involves the use of symbols for lithological complexes, lithological types, and engineering geological types. Each lithological complex is assigned a representative color based on its origin, in accordance with geological mapping conventions. For marine-origin soils and rocks in the surveyed area, blue tones are used in combination with the letter "m". Since standard lithological symbols for coral rocks are not specified in existing regulations, they are represented by particle size symbols (e.g., sand, gravel, coral fragments) based on the composition of core samples. The symbols for engineering geological types indicate the physical and mechanical properties and conditions of coral rocks and soils, following Appendix C of the national standard TCVN 9156:2012 [1].

4. Results of the 1:2000 scale engineering geological mapping on a submerged coral island

4.1. Scope of work performed

The engineering geological map was created through a thorough analysis of data on engineering geological conditions obtained from surveys conducted on the submerged coral island. These surveys included engineering geological mapping, geological and topographic drilling investigations, field and laboratory testing, as well as data collected from previous projects and research studies. The results of this mapping consist of actual data drawings, a 1:2000 scale engineering geological map covering an area of 100 hectares, and an explanatory report accompanying the engineering geological map.

The collected data includes a total of 16 boreholes with a combined depth of 110 meters, 45 soil and rock samples, and 5 water samples. Standard Penetration Tests (SPT) were conducted 23 times. For the mapping, direct drilling data consisted of 25 boreholes, including 2 boreholes with depths of 60 meters, totaling 440 meters in depth; 219 soil and rock samples for laboratory testing; 10 water samples; and 150 field SPT tests.

The survey routes included 9 traverses with 256 measurement points, all represented on the actual data map, covering the mapped area of 100 hectares. Additionally, samples for petrographic composition and age dating were collected (Fig. 6).

4.2. Evaluation of engineering geological conditions in the submerged coral island region

4.2.1. Topography and geomorphology

The submerged island chosen for this study extends approximately 31.5 kilometers in length and 5.6 kilometers in width (Fig. 7), following a northeast-southwest axis. The surrounding coral reef rim is relatively high, continuous, and enclosed, with the average elevation of the coral platform ranging from +0.3 to +0.6 meters above the tidal datum (Nautical chart). During low tide, the coral platform emerges, exposing an area that is about 600 to 800 meters wide. The central part of the reef features a natural lagoon that is approximately 2.6 kilometers wide and 8 kilometers long, with the lagoon floor elevation varying between -4 meters and -16 meters relative to the tidal datum.

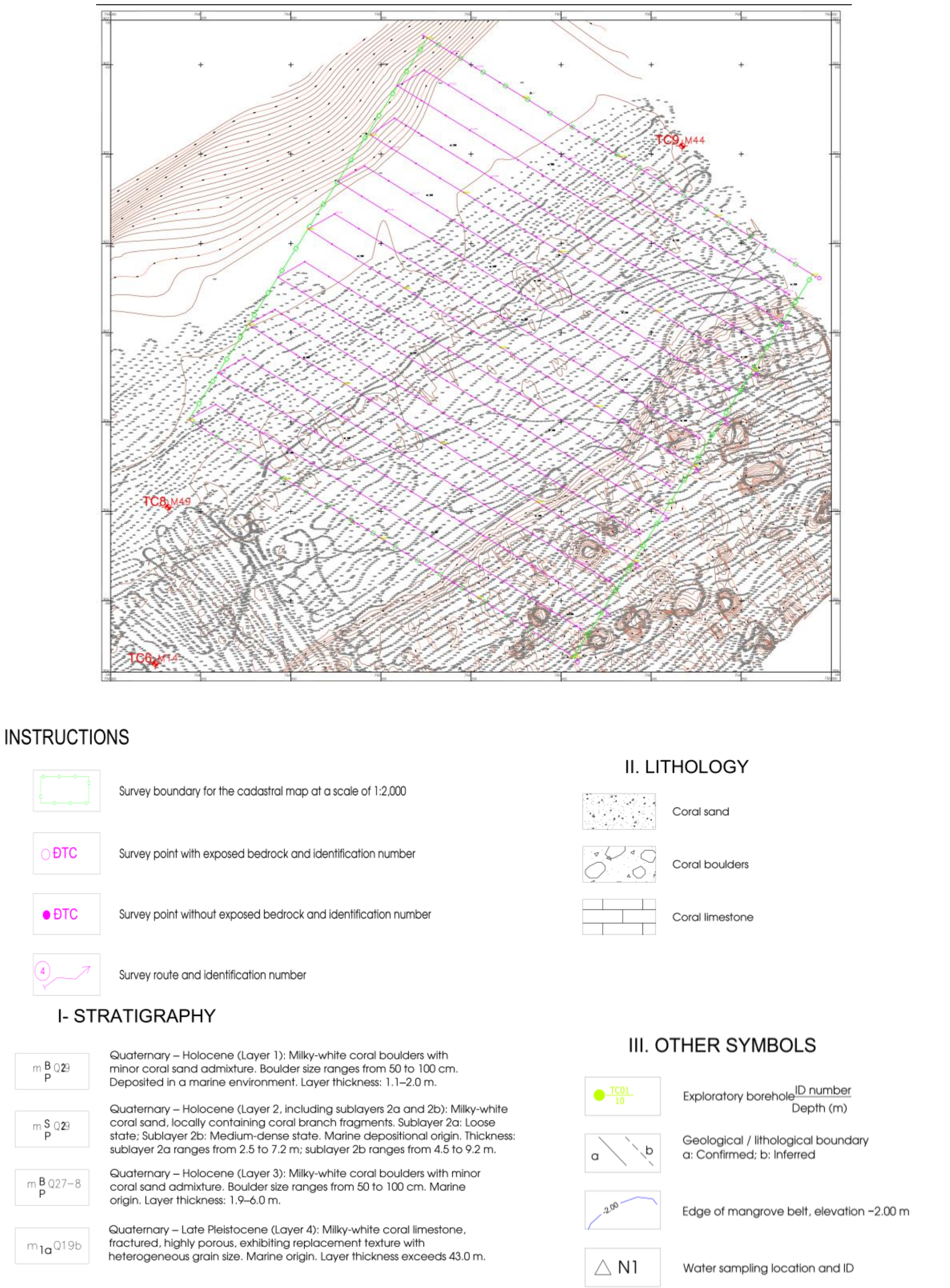


Fig. 6. Actual field data map at a scale of 1:2000.

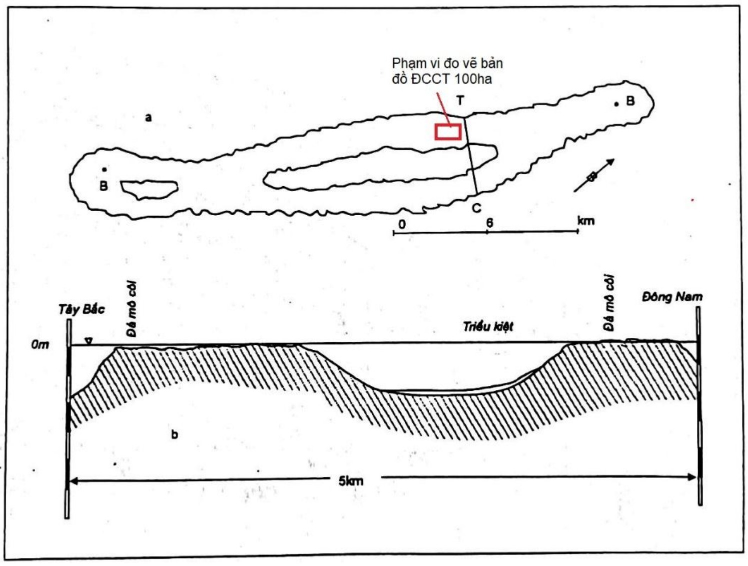


Fig. 7. Diagram of the coral reef in the study area and the scope of the geological engineering mapping (This figure is adapted from the doctoral dissertation by T. D. Hoa, 2003 [4]*).*

According to data collected by T. D. Hoa and presented in his doctoral dissertation, the morphological structure of the reef consists of several components: bays, reef flat, reef crest, and reef slope. There are two sequential bays along the length of the reef. The main bay, located on the eastern side, is approximately 8 kilometers long, 2.5 kilometers wide, and has a depth of 20 meters. In contrast, the smaller bay on the western side measures about 2 kilometers in length, 700 meters in width, and has a depth ranging from 5 to 7 meters. The floors of both bays are relatively flat and covered with a sediment layer composed of white biogenic sand mixed with coral rubble and calcareous mud. The reef flat is gently sloping and shallow; during low tide, the reef surface becomes exposed, forming a rim that encloses the two bays. The area covered by engineering geological mapping includes this reef flat, which spans 100 hectares. It is primarily composed of strongly cemented coral rock that withstands the effects of waves and currents. The part of the reef facing the bays is mainly covered with reef detrital sediment, such as sand and coral gravel. Additionally, the reef crest is segmented by channels and features many caves and cavities. The reef slopes are quite steep, extending down to depths of up to 20 meters, with gradients ranging between 40° and 60° [4].

4.2.2. Stratigraphy and physical-mechanical properties

a) Lithological composition

Coral primarily consists of the mineral aragonite. The aragonite crystals in coral skeletons typically have a fibrous, radiating, feather-like structure, forming fibrous bundles and plate-like shapes (Tab. 1).

The lithological characteristics and diagenetic processes mentioned above determine the geotechnical properties of the coral rock foundation. The composition, texture, structure, and physical-mechanical parameters change in a way that enhances rock durability with depth in each sequence while exhibiting complex variations laterally.

b) Stratigraphy and physical-mechanical properties

Based on the analysis of 41 borehole cores (Fig. 8) and the results of the Standard Penetration Test (SPT) conducted in the field, the stratigraphy within the surveyed reef platform area is divided into four layers.

The characteristics of these soil layers are described in order from top to bottom as follows:

Layer 1 - Loose coral gravelly sand with small coral branches

This layer appears at the surface but is unevenly distributed. It consists of medium to coarse-grained coral gravelly sand, milky white, with a loose structure. The thickness ranges from 5.0 to 7.0 meters; SPT blow count (N): 7 to 9.

Average physical-mechanical properties: Density γ = 2.65 g/cm³; dry angle of repose α_k = 33°55'; wet angle of repose α_w = 25°32'; maximum void ratio e_{max} = 1.068; minimum void ratio e_{min} = 0.683; maximum dry density γ_{max} = 1.575 g/cm³; minimum dry density γ_{min} = 1.283 g/cm³; conventional design pressure R_o = 1.0 kG/cm²; total deformation modulus E_o = 50.0 kG/cm².

Fig. 8. Drilling survey method using a jack-up rig.

Layer 2 - Moderately dense coral gravelly sand with small coral branches

The boundary between Layer 1 and Layer 2 is not well-defined. This layer has a similar composition of medium to coarse-grained coral gravelly sand, milky white, but in a moderately dense state. The thickness ranges from 4.5 to 8.0 meters; SPT blow count (N30**)**: 17 to 24.

Tab. 1. Results of lithological analysis of coral rock samples

Sample ID	M02
Sample location	Sunken coral island
Rock name	Coral limestone
Macroscopic description	The rock is ivory white, fine-grained, and reacts strongly with 5% HCl. It contains numerous pores ranging in size from **0.3 mm to 3.5 mm**, with an uneven pore distribution. The structure of the rock is relatively solid, and the average pore volume throughout the sample is approximately 25%.
Texture	Replacement, uneven grain size
Structure	Porous
Mineral composition	Calcite: ~99%; Clay: 1%
Detailed description under microscope	The coral limestone sample shows that the entire coral skeleton has undergone pseudomorphic replacement by a calcite aggregate with irregular grain sizes, leading to the obliteration of its original structure. Scattered remnants of coral colonies' walls and bases are still observable but in indistinct forms. The carbonate mineral aggregate replacing the coral structure has grain sizes ranging from microcrystalline (< 0.01 mm) to fine-grained, small grains (< 0.2 mm). The composition includes calcite and dolomite, which are interspersed. **Calcite** is predominant over dolomite. It has irregular grain shapes, and fine-grained calcite clusters often have clay-dust coatings that give them a faint brownish hue. **Dolomite** typically ranges from **0.03 mm to 0.2 mm** in size, mostly occurring as incomplete rhombohedral grains, some of which are distorted or equant, with relatively clean surfaces. In fine-grained to small-grained carbonate clusters, distinguishing between calcite and dolomite can be difficult. Therefore, additional analytical methods are required for precise quantification. Under one Nicol prism, both **calcite and dolomite** appear colorless with false adsorption effects. Under two Nicol prisms, they exhibit high-order white interference colors.

Average physical-mechanical properties: Density γ = 2.65 g/cm³; dry angle of repose α_k = 33°12'; wet angle of repose α_w = 25°38'; maximum void ratio e_{max} = 1.062; minimum void ratio e_{min} = 0.688; maximum dry density γ_{max} = 1.572 g/cm³; minimum dry density γ_{min} = 1.283 g/cm³; conventional design pressure R_o = 1.5 kG/cm²; total deformation modulus E_o = 114.0 kG/cm².

Layer 3 - Coral blocks and fragments with coral gravelly sand and branches

This layer is encountered in most boreholes. Within the investigated depth range, its thickness varies from 4.0 to 11.0 meters. Core samples retrieved consist of cylindrical or crushed rock fragments (Fig. 9). The layer is primarily composed of coral blocks (50-100 cm in size), mixed with coral gravelly sand, milky white in color, and unevenly distributed across the boreholes. SPT blow count (N30): Minimum: 10, maximum: 17, average: 13.

Fig. 9. Coral blocks and fragments in core samples and on the reef flat.

Summary of average physical-mechanical properties: Natural bulk density γ = 2.45 g/cm³; specific gravity γ_s = 2.74 g/cm³; dry compressive strength R_d = 91.15 kG/cm²; saturated compressive strength R_s = 71.99 kG/cm²; softening coefficient f = 0.79.

Layer 3a - Mixed coral gravel-sand with occasional coral branches

This layer consists of medium to fine-grained coral gravel-sand, milky white in color, with a loose to moderately dense structure. It is unevenly distributed, sometimes appearing as lenses within Layer 3. The layer thickness within the surveyed depth range varies from 2.0 to 7.0 meters (Fig. 10).

Fig. 10. Mixed layer.

Summary of average physical-mechanical properties: Density γ = 2.65 g/cm³; dry angle of repose α_k = 34°07’; wet angle of repose α_w = 21°28’; maximum void ratio e_{max} = 1.113; minimum void ratio e_{min} = 0.688; maximum dry density γ_{max} = 1.570 g/cm³; minimum dry density γ_{min} = 1.260 g/cm³.

Layer 4 - Moderately to slightly weathered coral limestone

This layer is relatively stable in distribution and is only encountered in boreholes deeper than 15.0 m. The top of the layer is found at a depth of approximately 12 m. The thickness within the surveyed borehole depth range is 45 m. However, the degree of rock fracturing varies with depth, with an RQD (Rock quality designation) of 11% to 43%, indicating highly fractured rock with uneven distribution. TCR (Total core recovery): 27-43%. The layer is mainly composed of hard coral limestone, appearing in shades of grayish-white to yellowish-gray, with numerous fractures.

Although the rock structure is relatively solid, it has a high porosity (10-20%), which is filled with coral gravel, sand, and rock fragments. These components are cemented together by a pisolitic (oolitic) cement, forming a massive and dense structure (Fig. 11).

Summary of average physical-mechanical properties: Rock porosity = 0.09%; void ratio n_h = 0.1%; void ratio n_t = 8.89; natural bulk density γ = 2.54 g/cm³; specific gravity γ_s = 2.78 g/cm³; dry compressive strength R_d = 165.47 kG/cm²; saturated compressive strength R_s = 135.42 kG/cm²; softening coefficient f = 0.82.

Fig. 11. Coral rock mass in the layer 4.

4.2.3. Geodynamic phenomena in engineering

The primary engineering dynamic geological processes occurring in the marine area of the Spratly Islands include: marine geological activity, weathering processes, and coastal erosion.

The weathering processes in the Spratly Islands region are primarily influenced by several factors, including temperature, water, air, chemical activity, and microbial action. The islands are made up of coral detrital sediments with high porosity (30-50%), resulting in considerable vertical permeability. The surrounding reef platforms are constantly exposed to seawater, which intensifies the weathering processes throughout the region. Oxidation and hydrolysis significantly alter the coral sediments in terms of color, shape, size, and composition, ultimately leading to a reduction in material strength. The weathering crust reaches a thickness of approximately 5 to 6 meters from the island surface and serves as a medium for the absorption and storage of rainwater on the islands [4].

Coastal erosion occurs as wave action erodes the island margins, gradually pushing the shoreline inland. This process causes landslides, the destruction of materials, and the transportation of detrital sediments away from the islands. The wave activity along the reef platform results in strong surface erosion and breaks down coral frameworks, creating materials that are transported and deposited elsewhere on the islands by currents. Additionally, underwater currents may induce subsurface erosion and sand liquefaction. These dynamic geological phenomena significantly impact the bearing capacity of foundation soils and the structural stability of engineering works [4].

4.2.4. Natural mineral construction materials

The use of natural mineral construction materials in coastal and island areas is crucial, especially for reducing construction costs by utilizing locally available resources. In this context, coral-based materials, which are abundantly found in reef environments, have been studied as potential substitutes for conventional concrete aggregates.

Recent research has explored the feasibility of using seawater instead of freshwater, replacing natural river sand with coral sand, and using coral stone as a partial substitute for conventional coarse aggregates in cement concrete. Experimental mix designs incorporating these materials have been developed, yielding slump values between 40 mm and 60 mm and compressive strengths reaching up to 35 MPa. The concrete mixtures made with seawater and coral aggregates have been assessed against conventional concrete in terms of workability and strength performance.

Although these results are promising, further investigations are necessary to evaluate the long-term mechanical behavior of coral-based concrete, particularly beyond 180 days of curing. It is essential to carefully assess the durability, strength development, and microstructural stability of coral aggregate concrete to ensure its reliability for structural applications. Additionally, research should extend to explore the full replacement potential of conventional aggregates and freshwater with coral-based aggregates and seawater in concrete mixtures designed for a target compressive strength of 25 MPa or higher [5].

4.3. Engineering geological map

Based on the collected data, which includes borehole results for stratigraphic profiling, laboratory test results of coral soil and rock samples, water sample analyses, and outputs from field mapping compiled in the factual documentation map, an engineering geological map has been created. This map synthesizes and visualizes the subsurface conditions and engineering geological characteristics of the surveyed area. The resulting interpretations of the engineering geology are presented in Figs. 12-14.

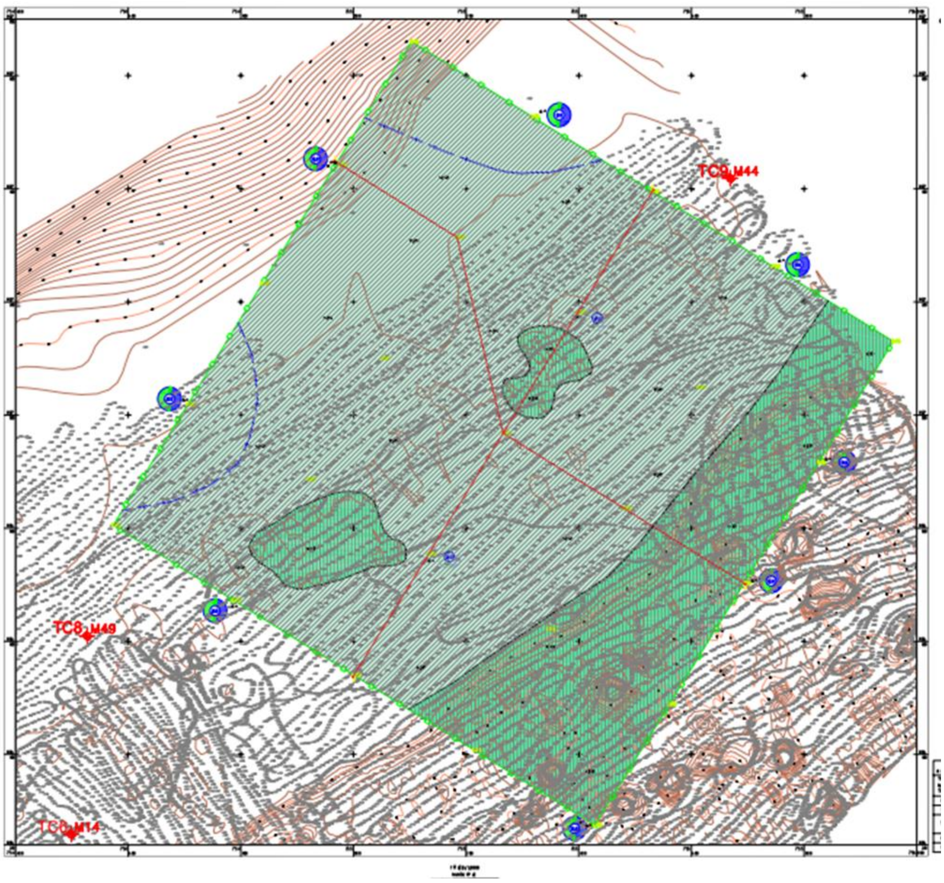


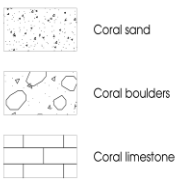
Fig. 12. Engineering geological map of the submerged coral island area.

LEGEND

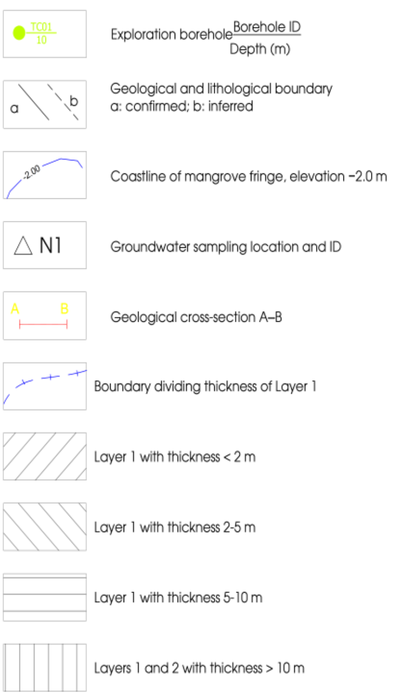
I. ENGINEERING GEOLOGICAL CLASSIFICATION

Lithological assemblage	Lithological type	Engineering geological type	Geological age	Symbol	Description
Marine	Weathered rock - soil	Poorly graded material	mQ29	m^{B}_{P}Q29	Quaternary - Holocene (Layer 1): Milky-white coral boulders with minor coral sand admixture.Boulder size ranges from 50 to 100 cm. Deposited in a marine environment. Layer thickness: 1.1 - 2.0 m
	Sandy soil	Poorly graded material		m^{S}_{P}Q29	Quaternary - Holocene (Layer 2, sublayers 2a: Milky-white coral sand, locally containing coral branch fragments. Sublayer 2a: Loose state Marine depositional origin, Layer thickness: 2.5m-7.2m.
					Quaternary - Holocene (Layer 2, sublayers 2b: Milky-white coral sand, locally containing coral branch fragments, Medium-dense state; Marine depositional origin, Layer thickness: 4.5m-9.2m.
	Weathered rock - soil	Poorly graded material	mQ27−8	m^{B}_{P}Q27−8	Quaternary - Holocene (Layer 3): Milky-white coral boulders with minor coral sand admixture. Boulder size ranges from 50 to 100 cm. Marine origin. Layer thickness: 1.9 6.0 m.
	Coral limestone	Weak rock, poorly fractured	mQ19b	m_{1a}Q19b	Quaternary - Late Pleistocene (Layer 4): Milky-white coral limestone, fractured, highly porous, exhibiting replacement texture with heterogeneous grain size. Marine origin. Layer thickness exceeds 43.0 m

II. LITHOLOGY



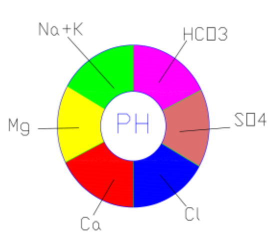
III. OTHER SYMBOLS



STRATIGRAPHIC CHARACTERISTICS AND AVERAGE PHYSICO-MECHANICAL PROPERTIES OF SOIL AND ROCK LAYERS

Zone	Lithological complex	Stratigraphic characteristics	Thickness (m)	Physical–mechanical properties	Hydrogeological and marine geological conditions	Engineering geological processes	Construction feasibility
1	Marine	Layer 1: Milky-white coral boulders, containing a minor amount of sand and gravel; boulder size ranges from 50 to 100 cm.	1.1-2.0m	Δ=2.74g/cm³; γ_{tn}=2.45g/cm³; Compressive strength (Natural / Saturated): (91.15/71.99)kG/cm²; Softening coefficient K=0.79.	- **Tides:** Diurnal tidal regime, with a maximum tidal range of 2.2 m; - **Salinity regime:** Chloride–sodium type; salinity approximately 23.14–26.26 g/L; pH ≈ 8.5; - **Seawater temperature:** Surface layer temperature ranges from 26.5 to 29.0 °C; - **Waves:** Controlled by the monsoon wind regime; - **Currents:** Tidal currents play the dominant role.	Sedimentation and erosion processes are well developed, with sedimentation being dominant. Karst phenomena are weakly developed. The area lies within the regional seismic zone, with an expected earthquake magnitude of M = 6.1–6.6.	Submerged in water at depths greater than 14 m. Subject to the effects of waves, wind, and currents, particularly the portion above the water level, which experiences horizontal wave forces causing vibration and oscillation of the structure. Submerged coral has a lower load-bearing capacity. Construction is difficult.
		Layer 2 – Sub-layer 2a: Milky-white coral sand and gravel, locally containing coral branches and fragments; loose to porous in condition.	2.5-7.2m	Δ=2.65g/cm³; e_{min}=0.688, e_{max}=1.068; γ_{min}=1.283g/cm³, γ_{max}=1.575g/cm³; Conventional design pressure: R_0=1.00kG/cm²; Total deformation modulus: E_0=49.0kG/cm².			
		Layer 2 – Sub-layer 2b: Milky-white coral sand and gravel, locally containing coral branches/fragments; medium dense condition.	4.5-9.2m	Δ=2.65g/cm³; e_{min}=0.688, e_{max}=1.062; γ_{min}=1.283g/cm³, γ_{max}=1.552g/cm³; Conventional design pressure: R_0=1.50kG/cm²; Total deformation modulus: E_0=114kG/cm²		Sedimentation and erosion processes are well developed, with erosion being dominant. Weathering processes are well developed, predominantly physical weathering. The area lies within the regional seismic zone, with an expected earthquake magnitude of M = 6.1–6.6.	Tidal action causes the coral environment to undergo alternating wetting and drying. The coral foundation is also affected by waves, wind, and weathering processes, leading to erosion and abrasion of the island. Structures constructed on this type of foundation must take into account the range of wave action and surface current activity. Corrosion effects: Seawater is much more corrosive than groundwater, with sulfate corrosion being the dominant and severe form.
		Layer 3: Milky-white coral boulders, containing a small amount of sand and gravel; boulder size ranges from 50 to 100 cm.	1.9-6.0m	Δ=2.74g/cm³; γ_{tn}=2.45g/cm³; Compressive strength (Natural / Saturated) (91.15/71.99)kG/cm²; Softening coefficient K=0.79.			
		Layer 4: Milky-white coral limestone, fine-grained, porous structure, replacement texture, with non-uniform grains.	>43.0m	Δ=2.78g/cm³; γ_{tn}=2.54g/cm³; Compressive strength (Natural / Saturated): (165.47/135.42)kG/cm²; Softening coefficient K=0.82.			

CHEMICAL COMPOSITION OF WATER



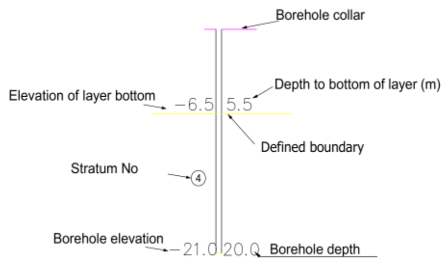


Fig. 13. Legend of the engineering geological map.

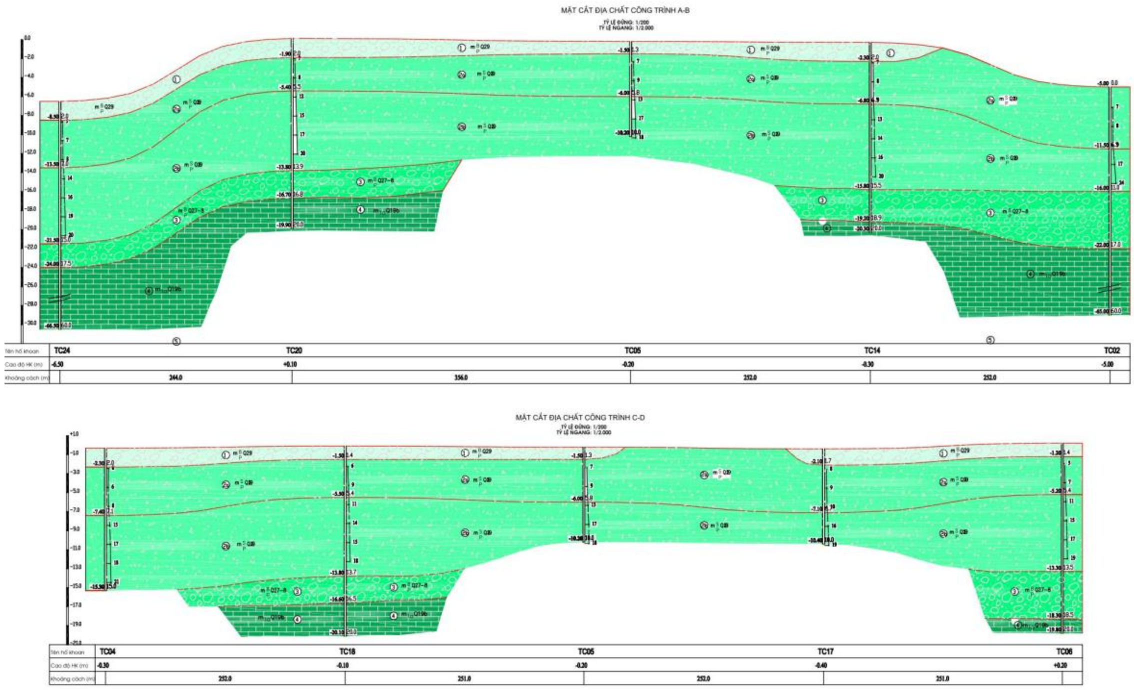


Fig. 14. Engineering geological cross-section.

5. Conclusions, recommendations, and future research directions

5.1. Conclusion

The 1:2000 scale engineering geological map was created in strict accordance with established regulations, ensuring it is based on sufficient data and possesses both scientific and practical significance. This map effectively supports the design and construction of projects in coral limestone soil-rock environments located on submerged islands. Several key considerations must be taken into account when producing large-scale engineering geological maps in marine island areas:

Technical standards: Currently, there is no dedicated standard specifically applicable to the surveying and mapping of engineering geological maps in submerged coral island regions. As a result, the surveying process follows TCVN 9156:2012 – Hydraulic works – Methods for surveying and mapping large-scale engineering geological maps (scale of 1:5000 to 1:1000).

Regarding preparatory work: the survey and mapping activities require thorough preparation of equipment. For drilling, a self-elevating jack-up rig should be employed to ensure stability and feasibility under offshore survey conditions. Materials needed include bentonite suitable for use in seawater, waterproof sample containers, and corrosion-resistant materials to maintain sample quality and equipment durability.

Fieldwork execution: In addition to strictly adhering to technical survey procedures, special attention must be paid to marine environmental factors such as waves, tides, currents, rig towing, and potential karst phenomena during drilling. These conditions may lead to issues such as stuck drill pipes and excessive drilling fluid consumption. Furthermore, logistics must be managed effectively to ensure progress and safety during field operations.

Key issues in large-scale engineering geological mapping:

1) Limited research materials: Research materials on submerged islands are very limited. To create a large-scale map, medium- or small-scale base maps are needed; however, these are often unavailable in study areas, necessitating a significantly greater volume of survey work.

2) Mapping scope challenges: Determining the scope of mapping is complicated due to the submerged nature of the islands, with only partial exposure during low tides. The mapping scope should integrate depth-related sea level data relevant to the exploitation of submerged islands.

3) Underwater observation limitations: As the islands are submerged, observation points are underwater, resulting in fewer visible outcrops compared to terrestrial environments, with only portions exposed during low tide. Consequently, surveying methods must differ from those used on land.

By addressing these considerations, the process of creating large-scale engineering geological maps in submerged island environments can be significantly improved.

5.2. Recommendations and research directions

Continuing the execution of deep boreholes is crucial for gathering comprehensive stratigraphic data with depth, enabling a thorough assessment of engineering geological conditions. Additional laboratory tests using modern, specialized equipment, as well as field tests, should be conducted to ensure the accuracy and reliability of geotechnical parameters of coral limestone soils and rocks.

A detailed study of hydrogeological factors is required. Although the two groundwater layers, the porous aquifer and the fracture–cavity (karst) aquifer, are hydraulically connected with each other and with seawater, exhibiting tidal fluctuations, they share a common water level and do not need to be represented separately. Nevertheless, it is necessary to provide hydrogeological parameters such as hydraulic conductivity (K), specific discharge (q), or pumping rate (Q) corresponding to drawdown (S), as well as information on chemical composition and an assessment of groundwater corrosivity.

Engineering geological maps are vital for construction planning, natural resource management, and disaster risk reduction. In light of the challenges posed by climate change and the need for sustainable development, current research efforts focus on improving the accuracy and digital updating of geological data through advanced surveying and analytical technologies. These advancements include the development of digital mapping, the integration of Geographic Information Systems (GIS) with spatial databases to create interactive maps, and the exploration of automated analysis for updating geological data. Moreover, the construction of 3D engineering geological maps aims to enhance subsurface structural visualization, and the development of seabed engineering geological maps will support marine infrastructure design and construction.

These advancements are expected to improve project design and construction efficiency, promote rational resource exploitation, and contribute to environmental protection, especially in specialized areas such as submerged coral islands and coastal regions with complex geological conditions.

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MỘT SỐ VẤN ĐỀ VỀ XÂY DỰNG BẢN ĐỒ ĐỊA CHẤT CÔNG TRÌNH TỈ LỆ LỚN 1:2000 KHU VỰC ĐẢO SAN HÔ CHÌM

Nguyễn Quý Đạt[1], Đinh Quang Trung[1]

[1]*Viện Kỹ thuật công trình đặc biệt, Trường Đại học Kỹ thuật Lê Quý Đôn*

Tóm tắt: Bài báo trình bày phương pháp xây dựng bản đồ địa chất công trình tỉ lệ lớn (1:2000) cho các đảo san hô chìm tại vùng biển Việt Nam dựa trên tiêu chuẩn TCVN 9156:2012. Mục tiêu nhằm phản ánh đầy đủ các yếu tố môi trường địa chất đặc thù (trầm tích san hô) có ảnh hưởng đến quy hoạch sử dụng đất, thiết kế và thi công công trình. Trong bối cảnh chưa có tiêu chuẩn quốc gia riêng cho khu vực biển đảo có nền san hô, nghiên cứu đã lựa chọn, áp dụng một số tiêu chuẩn và tài liệu có liên quan để tham khảo, đồng thời chỉ ra các vấn đề chính cần lưu ý trong quá trình đo vẽ bản đồ địa chất công trình tỉ lệ lớn tại khu vực này.

Kết quả nghiên cứu cho thấy, việc xây dựng bản đồ địa chất công trình tỉ lệ lớn có giá trị khoa học và thực tiễn trong quy hoạch xây dựng, quản lý tài nguyên và giảm thiểu rủi ro thiên tai. Bài báo đề xuất tiếp tục nâng cao độ chính xác của công tác khảo sát và hoàn thiện hệ thống tiêu chuẩn kỹ thuật phù hợp. Định hướng nghiên cứu trong tương lai tập trung vào ứng dụng công nghệ hiện đại như bản đồ số tích hợp GIS, bản đồ địa chất 3D kết hợp thực tế ảo (VR) để mô phỏng điều kiện địa chất và hỗ trợ đánh giá rủi ro, nhằm đáp ứng các thách thức do biến đổi khí hậu và yêu cầu phát triển bền vững.

Từ khóa: *Bản đồ địa chất công trình tỉ lệ lớn; đá san hô; đảo chìm; trầm tích san hô.*

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