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SUBDIVISION OF ENGINEERING GEOLOGY IN DA NANG CITY FOR DESIGNING THE CONSTRUCTIONS AND NATURAL HAZARDS

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Graphical abstract

Abstract

Da Nang city, located on the south-central coast of Vietnam, is characterized by diverse geomorphological features, including low eroded hills, karst formations, and coastal plains. In recent years, rapid urbanization and increasing construction density have intensified the challenges of building on weak and unstable ground foundations. These conditions highlight the need for geotechnical and geological assessments to support sustainable urban development. The study aims to provide a scientific basis for the planning and construction of buildings, residential areas, and transportation infrastructure in line with social-economic development. Findings reveal that the northwestern part of the city is dominated by eroded low hills (Zone I), which are further subdivided into engineering geological subzones IA, IB and IC. Covering Hoa Vang district, the western part of Da Nang, Hoa Nhon and Hoa Phu wards, Son Tra peninsula, Ngu Hanh Son Mountain, and the drainage basin of Cu De, Tuy Loan and Lo Dong rivers, these subzones are generally suitable for construction activities. In contrast, the southeastern coastal plains (Zone II)-subdivided into subzones IIA, IIB and IIC-encompasses Lien Chieu, Thanh Khe, Hai Chau, Ngu Hanh Son and Son Tra districts. These subzones are characterized by weak and unstable geotechnical foundations, which present potential risks to construction projects.

Keywords: Geological structure; Geomorphology; Engineering geology; soil characteristic; design constructions.

1.0 INTRODUCTION

The subdivision of engineering geology is the division into sub-geoengineering regions in which rocks and soils have similar physical and mechanical properties, as well as composition [1]. These basic factors are crucial for determining the ground foundation conditions, which are suitable for planning construction and development in different localities of Da Nang city [2]. This subdivision requires consideration to the geological structure, geomorphology, engineering geology, etc. With Da Nang city's development plan, constructed infrastructures and residential areas must be designed to avoid risks and withstand seismic forces according to design standards for house and building foundations. The Da Nang city area has the diversity of geomorphology consisting of low eroded hills, karst, coastal plains, along with a heterogeneous lithological structure composed of igneous and metamorphic rocks, terrigenous sedimentary rocks and multi- original sediments at the surface [3, 4]. The geoengineering foundation condition in the Da Nang city area significantly depends on the mechanical properties of soils, rocks in each region [5, 6].

Da Nang city is one of the commercial and educational centers of Vietnam and is developing as a sustainable city. In recent years, the city has faced risks from various natural hazards such as slope collapse, landsides, debris flow, etc., which have occurred in a widespread area, particularly in the rainy season [7]. The disasters have frequently occurred in prone regions characterized by unstable geological structures added with the impact of disadvantaged climatic conditions resulting in loss of life, damage to livelihoods, destruction of public transportation and negative impacts on economic development. Along with the rapid urbanization, massive infrastructure development, and increasing population pressure-with a recent population density reaching 740 people/km^2 [8], Da Nang city has experienced significant growth in high-rise buildings and transportation infrastructure. Consequently, the city's concern is to determine soil and rock properties of each geoengineering subzone and assess their susceptibility to geological hazards with its territory [9-12]. Therefore planning subdivision of the city is necessary to ensure safety for people's livelihood [7].

The purpose of this study to determine of soil and rock properties and subdivide of engineering geology in order to design and construct buildings that can withstand seismic activity and natural hazards in the Da Nang city area. These findings play an important and crucial role in selecting optimal geological conditions for construction of buildings, residential areas, roads, and other infrastructure. Factors of the above-mentioned, including the study of the engineering geology subzone in the Da Nang city area, allow us to understand the geotechnical properties and identify suitable foundation geological structures that are in accordance with National criteria 9386:2012- Design of structures for earthquake resistance [13, 14], and natural hazards. The National criteria is based on identification of ground types of Eurocode 8: Design of structures for earthquake resistance [15], which informs the city's planning.

2.0 METHODOLOGY

2.1 Materials And Study Methods

In the study, six boreholes were drilled, with depths ranging from 0 to 29 meters (1 borehole) and from 0 to 40 meters (5 boreholes). These included 02 boreholes were drilled in Ngu Hanh Son district, 02 in Hoa Vang district, and 01 borehole each in Lien Chieu and Hai Chau districts (Figure 1). The latitude and longitude of the boreholes are detailed in Table 1. Furthermore, 232 referenced boreholes from the previous studies [16, 17], with the depths ranging from 0 to10 meters and 0 to 40 meters, were also considered. These data obtained from the boreholes supported the classification of the geoengineering regions and the assessment of the ground foundation condition for construction and planning.

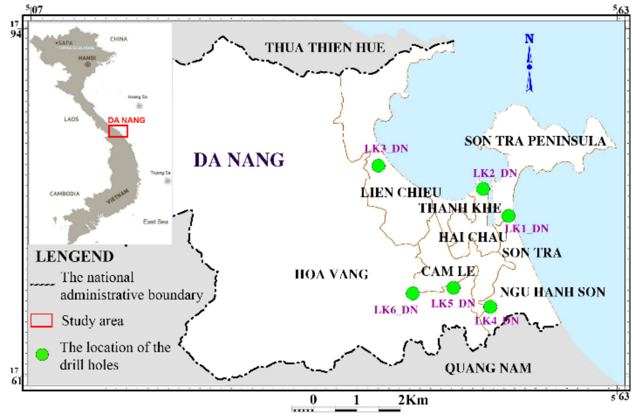

Figure 1 Boreholes location map of study area

Table 1 Latitude and longitude of 06 boreholes in the study area

Name	Latitude (N)	Longitude (E)	Location
LK1_DN	55.2504	177.6185	An Hai Dong ward, Ngu Hanh Son district
LK2_DN	55.0092	177.8770	Thuan Phuoc ward, Hai Chau district
LK3_DN	54.0110	178.0985	Hoa Hiep Nam ward, Lien Chieu district
LK4_DN	55.0781	176.7531	Hoa Quy ward, Ngu Hanh Son district
LK5_DN	54.7258	176.9363	Hoa Chau ward, Hoa Vang district
LK6_DN	54.3382	176.8817	Hoa Phong ward, Hoa Vang district

In the field, seismic wave was conducted at all 06 boreholes to determine the shear wave velocity ($V_{s,30}$) of the soil and rock layers from the topographic surface down to a depth of 30 meters (Figure 2).

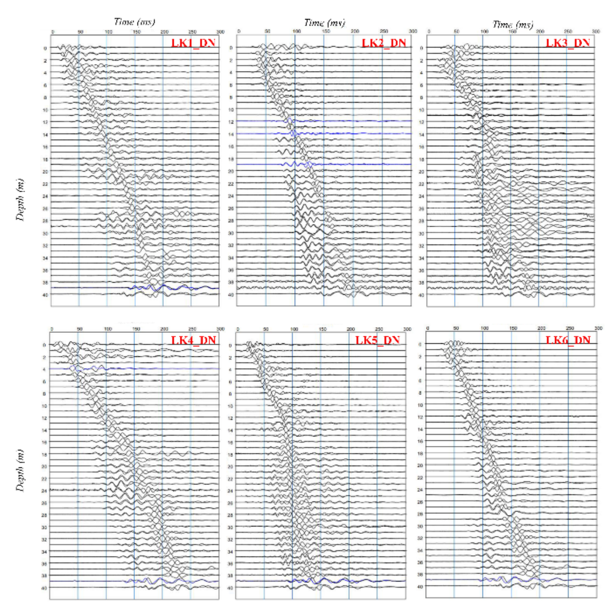

Figure 2 Shear wave velocity (Vs,30) profile obtained from seismic refraction at boreholes

Furthermore, these boreholes underwent a total of 78 times of Standard penetration testing (SPT) in accordance with the Soils - Field testing method [14, 18]. Subsequently, 73 samples were collected from these 06 boreholes and analyzed in the laboratory to determine their mechanical properties, following the Soils – Laboratory methods, which included analyses as:

- Particle - size analysis [19];
- Determination of moisture and hydroscopic water amount [14];
- Determination of density, compressibility, and unit weight [14];
- Determination of shear resistance in a shear box apparatus [13];
- Specifications for design of foundation for buildings and structures [14].

The mechanical properties and the shear wave velocity ($V_{s,30}$) obtained allowed for classification of ground types according to National criteria 9386:2012- Design of structures for earthquake resistance (Table 2). In principle, the ground types should be classified based on the value of the average shear wave velocity, Vs,30 if this value is available. Otherwise, the N_{spt} value should be used.

Table 2 Ground types [14]

Ground type	Description of stratigraphic profile	Parameters		
		$V_{s,30}$ (m/s)	N_{SPT} (blows/ 30cm)	C_u (kPa)
A	Rock or other rock-like geological formation, which may include up to 5 m of weaker material at the surface.	> 800	-	-
B	Very dense deposits: sand, gravel, or very stiff clay, at least several tens of meters thick, characterized by a gradual increase in mechanical properties with depth.	360 - 800	> 50	> 250
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay, with thicknesses ranging from several tens to hundreds of meters.	180 - 360	15 - 50	70 – 250
D	Deposits of loose- to medium-dense cohesionless soils, with or without interbedded soft cohesive layers, or deposits of predominantly soft- to firm-cohesive soils.	< 180	< 15	< 70
E	A soil profile consisting of a surface alluvium layer with V_s values corresponding to type C or D, with a thickness varying between about 5 m and 20 m, underlain by stiffer material with $V_s \approx 800$ m/s.			
S_1	Deposits consisting of, or containing, a layer at least 10 m thick of soft clays or silts with a high plasticity index (PI > 40) and high water content.	< 100	-	10 – 20
S_2	Deposits of liquefiable soils, sensitive clays, or any other soil profiles not included in types A - E or S_1			

$V_{s,30}$: The average shear-wave velocity;
N_{SPT} (blows/30cm)*: Number of blow;*
C_u(kPa): Shear strength.

2.2 General Geology And Engineering Geology

The geological structure identified within the study area, arranged in order from the oldest to the youngest, are as follows:

A Vuong Formation ($\mathcal{E}_2$-O*av*)
Long Dai Formation (O_1-S*lđ*)
Tan Lam Formation ($D_{1\text{-}2}$*tl*)
Ngu Hanh Son (C-P*nhs*)
Stratigraphic unit of Neogene age (N)
Stratigraphic units of the Quaternary (Q)

Besides, three major faults cross the study area: the Cu De river fault, which extends and trends sub-latitudinally; the Tuy Loan river fault, which extends northeastward; and the Hoa Vang – Nui Thanh fault, which is remarkably linear, trending northwest–southeast [20].

Geological characteristics of the Quaternary are formed by three stratigraphic layers: the upper layer, the middle layer, and the lower layer. Each layer is characterized by fundamental differences in term of its supplied sediment origin, lithological composition, and thickness, as well as mechanical properties [5, 6, 16, 17, 20].

The upper layer consists of Holocene sediments with multi-origins: alluvial deposits, alluvial-marine deposits, marine-wind deposits, alluvial-marine-brackish deposits and Quaternary deposits, which are mixed alluvial-diluvial-proluvial sediments. The layer has a thickness of up to 30 meters and is distributed along the rivers, streams, and coastal plains in the eastern part of the study area: Lien Chieu, Thanh Khe, Hai Chau and Ngu Hanh Son districts. The lithological composition is composed of laminated fine-grained sediments including sandy silt, clayey silt, clay and sand, which have covered on the eroded middle structural layer. The unconsolidated sediments have a weak cohesion.

The middle layer is composed of Pleistocene sediments originating from alluvial deposits, marine deposits and Quaternary deposits, which are mixed eluvial-diluvial sediments. In the western part of the study area, Pleistocene deposits are exposed at the surface and rarely found beneath the upper structural layer. The depth of this layer reaches several meters in the area adjacent to the bedrock. Almost the entire study area, the Quaternary deposits accumulate on the surface and cover the bedrock, with a depth ranging from 3 to 12 meters and reaching up to 40 meters in some locations.

The lower layer consists of igneous and metamorphic bedrocks, as well as terrigenous and biochemical sedimentary rocks. These rocks underlie the Quaternary eluvial-diluvial deposits or are found beneath the upper and middle strata. These rocks have significantly higher shear strength and compressive strength compared to the materials in the overlying layers.

3.0 RESULTS AND DISCUSSION

The study area is divided into two main engineering geology zones (I&II), characterized by fundamentally different factors: the topographic characteristic, geological structure and the geomorphology.

Engineering geology zone (I) is eroded low hills with the average height ranging from 500 to 1000 meters. Its topography is characterized by slopes of less than 30-degree, and the lithology consists of igneous, metamorphic, and terrigenous sedimentary rocks. This eroded low hill zone is distributed in the western study area and in Son Tra peninsula. The surface of these eroded low hills is covered by sediments, with a thickness ranging from few meters to 10 meters. In some locations, these surficial sediments have been eroded exposing the underlying bedrocks. The rivers and streams in this zone are narrow, short, meandering, and have steep banks. Due to its diverse engineering geology, lithological characteristics, varying arrangements of lithological complexes and mechanical properties, this zone (I) is further divided into subzones: IA, IB, and IC.

Engineering geology subzone (IA) comprises terrigenous sedimentary rocks, including coarse-grained sandstone; light grey, pink-grey sandstone containing quartz gravels; siltstone interbedded in shale, and sericitized shale. The average shear-wave velocity ($V_{s,30}$) in this subzone is > 900 (m/s). The IA subzone occupies a rather limited area in the lower part of C_u De river and in Ngu Hanh Son Mountain area, which is composed of biochemical sedimentary rocks: gray-white-limestone, dark-pinkish-limestone interbedded with sericitized quartz schist, quartzite shale and silty sandstone. The typical mechanical parameters of silty sandstone:

- o Compressive strength in dried: 414.32kG/cm^2
- o Compressive strength in saturated: 379.64kG/cm^2
- o Cohesion in dried: 80.43kG/cm^2
- o Cohesion in saturated: 72.93kG/cm^2
- o Tensile strength in dried: 65.58kG/cm^2
- o Tensile strength in saturated: 64.85kG/cm^2

Engineering geology subzone (IB) is characterized by eluvial-diluvial deposits that cover igneous, regional metamorphic and terrigenous rocks. The thickness of the sediment layer is 2 to 5 meters in Son Tra peninsula and 5 to 10 meters in Hoa Vang district, respectively. The average shear-wave velocity ($V_{s,30}$) is generally > 900 (m/s) but in some locations, it ranges from 200 to 300 (m/s). The IB subzone extends continuously from western Da Nang city to the Hoa Nhon and Hoa Phu wards. The sediments are consisted of eluvial-diluvial clay containing conglomerate, sand containing gravels and silty clay (ed^{CM}Q). Clay is stiff to stiff plastic.

Engineering geology subzone (IC) is distributed in the drainage basin of the rivers: Cu De, Tuy Loan, Lo Dong and in some coastal areas of Son Tra peninsula. From the top to the bottom, the lithological types of the IC subzone are alluvial sandy-silty clay containing conglomerates (a^{CM}Q), alluvial-diluvial-proluvial gravels containing pebbles (adp^{G}Q), and alluvial-diluvial-proluvial sandy-silty clay (adp^{CM}Q). The sediments cover the bedrock. Locally, eluvial-proluvial sediments have eroded. The thickness of the sediment layer varies from few meters to 20 meters. The average shear-wave velocity ($V_{s,30}$) ranges from 200 – 300 up to 700 – 800 (m/s).

The typical mechanical parameters representing the lithological complex of IB and IC subdivisions are presented in Table 3.

Table 3 The typical mechanical parameters represent the lithological complex in IB and IC subzones

		IB subzone (ed^{CM}Q)			IC subzone		
		clay containing gravels	sand containing gravels	silty clay	sandy-silty clay containing conglomerates (a^{CM}Q)	Gravels containing pebbles (adp^{G}Q)	sandy-silty clay (adp^{CM}Q)
Thickness (m)	Maximum		35.00		50.10	16.50	13.50
	Minimum		0.50		0.50	5.40	2.70
	Medium		8.23		14.53	9.78	9.79
Parameters	Cohesion (kG/cm^2)	0.297	0.241	0.334	0.197	0.318	0.139
	Internal Friction angle (degree)	24°57′	25°42′	27°48′	15°29′	27°23′	10°28′
	Modulus of total deformation (kG/cm^2)	311.92	390	336.10	148.73	411.90	83.80
	N_{spt} (number of blow/30cm)	45.39	57.50	101	22	102	9.33
	Shear strength C_u (KPa)	208.20	-	195	103.41	-	179.14

Engineering geology zone (II) is the coastal plains, which have gentle slopes or are relatively flat, with sand dunes spreading along the coast. These coastal plains extend in the eastern part of the study area, encompassing the districts: Lien Chieu, Hai Chau, Thanh Khe, Ngu Hanh Son, as well as the southeastern part of Hoa Vang district. The coastal plains are formed by mudflats and sediments originating from the deposition of alluvium, marine sources, wind action and swamps. In some areas, the sediments have been eroded by wind. The elevation of the coastal plains varies from a few meters up to 15 meters, with the topography generally decreasing towards the sea. The zone is further divided into subdivisions, including IIA, IIB, and IIC.

Engineering geology subzone (IIA) extends along the coastal area from Hoa Hiep ward to Thanh Khe district, the Han river banks at the estuary part and from the southern Son Tra peninsula to Ngu Hanh Son district. The lithological profile of the IIA subzone, from the surface downwards, is composed of sediments: marine-wind sand, sandy-silty clay (mv^{S}Q), alluvial-marine silty clay containing shell fragments (am^{CM}Q), and marine clay (m^{CM}Q). This sediment layer is approximately 30 to 50 meters thick and covers eluvial-proluvial deposits (ed^{CM}Q). The average shear-wave velocity ($V_{s,30}$) is ranging from 200 to 300 (m/s).

The Engineering geology subzone (IIB) is distributed in the northwest – southeast direction of the study area, and extends from Cu De river to Cau Do river. The majority of marine sediments are composed of silty sand (m^{S}CQ), clayey sand (m^{S}CQ), silty clay and sandy clay (m^{CM}Q), which were deposited on eluvial-diluvial silty clay containing gravels and sand containing gravels (ed^{CM}Q). The total thickness of the sediments is 20 to 40 meters. The average shear-wave velocity ($V_{s,30}$) varies from 200 to 300 (m/s).

Engineering geology subzone (IIC) occurs along the Han river and extends from the seashore to Cam Le confluence. This subzone widens towards the western part of Cau Do river and Yen river, the eastern Co Co river, and the southern Quang Nam province. The lithological sequence in the IIC subzone, from top to bottom is composed of sediments from multiple origins: alluvial muddy clay (a^{CO}Q) is at the surface, underlain by alluvial-marine-brackish clay (amb^{CO}Q), and at the deepest level, alluvial-marine sandy clay (am^{CM}Q) and marine silty clay (m^{CM}Q). The sediment series accumulates on eluvial-proluvial sediments (ed^{CM}Q) and has a total thickness of 20 – 40 meters. The average shear-wave velocity ($V_{s,30}$) ranges from less than 100 (m/s) to 200 (m/s).

Beneath the sediment series of the IIA and IIB subzones are regional metamorphic, igneous and terrigenous rocks. However, underneath the sediments of the IIC subzone there is an appearance of the regional metamorphic rock.

The typical mechanical parameters that represent the lithological complex of the IIA, IIB and IIC subzones are shown in Table 4.

Table 4 The typically physical and mechanical parameters of the lithological types in IIA, IIB and IIC subzones

		IIA subzone			**IIB subzone**			**IIC subzone**			
		Sand (mv^{S}Q)	Silty clay (am^{CM}Q)	Clay (m^{CM}Q)	Silty sand (m^{SC}Q)	Clayey sand (m^{SC}Q)	Silty clay (m^{CM}Q)	Muddy clay (a^{CO}Q)	Clay (amb^{CO}Q)	Sandy clay (am^{CM}Q)	Silty clay (m^{CM}Q)
Thickness (m)	Maximum	30.10	16.30	50.10	41.50	41.50	50.10	22.90	21.30	16.30	50.10
	Minimum	13.60	1.00	0.50	7.90	7.90	0.50	16.70	8.00	1.00	0.50
	Medium	24.30	6.94	14.53	19.41	19.41	14.53	19.74	13.43	6.94	14.53
Parameters	Cohesion (kG/cm^2)	0.013	0.143	0.184	0.012	0.218	0.172	0.062	0.200	0.047	0.172
	Internal Friction angle (degree)	33°26’	8°37’	12°13’	36°35’	17°37’	14°33’	3°25’	8°14’	4°04’	14°33’
	Modulus of total deformation (kG/cm^2)	176.88	87.63	105.49	187.47	111.12	140.35	11.40	106.73	107.48	140.35
	N_{spt} (number of blow/30cm)	24.89	7.2	10.24	43.08	23.50	17.80	3.0	6.83	3.40	17.80
	Shear strength C_u (KPa)	104.22	15.29	110.42	109.91	62.32	108.52	12.20	12.32	12.06	108.52

Based on the determined mechanical properties and National criteria 9386:2012- Design of structures for earthquake resistance, the IA subzone with the average shear-wave velocity ($V_{s,30}$) > 900 (m/s) is classified as ground type A. The IB subzone which generally has ($V_{s,30}$) greater than 900 but some locations with ($V_{s,30}$): 200 – 300 (m/s) and the IC subzones with ($V_{s,30}$) ranging from 200 – 300 up to 700 – 900 (m/s) are classified as ground type E or A (Table. 2). Ground type A or E is characterized by a maximum 5 meters of weaker material at the surface and underlain by stiffer material. These subzones are well-suited for the construction projects. Groundwater in these subzones is mostly contained in fissures and is non-pressurized. The static water level depth in the IA subzone is changing from 3.5 to 7.5 meters, whereas the static water level in the IB & IC subzones varies seasonally throughout the year, at approximately depths of 3.0 meters and 0.3 to 1.0 meters, respectively. The dynamic geological processes in the IA subzone can include karst formation and surface washout while weathering, erosion and the formation of ditches can occur in the IB & IC subzones.

In contrast, the IIA and IIB subzones with ($V_{s,30}$): 200 - 300 (m/s) are categorized as ground type C, D while the IIC subzone with ($V_{s,30}$) ranging from < 100 to 200 (m/s) is identified as ground type S_1, C or D (Table. 2). These ground types are characterized by thick sediments and loose-to-medium cohesion. The engineering geological foundation in these areas is weak and unstable, requiring careful design consideration for constructions. Groundwater within these subzones is primarily contained in fissures and is non - pressurized. The depth of static water level in the IIA subzone is unstable and variable depending on the other regions, ranging from 0.45 to 2.0 meters in Hoa Khanh and from 1.8 to 11.2 meters in Hai Chau. The water level in the IIB and IIC subzones fluctuates from 1.9 to 4.73 meters, (with an average of 2.71 meters) and from 1.0 to 3.1 meters, (with an average of 2.67 meters), respectively. All the static water levels are seasonably variable due to influence of surface water and rainfall. The dynamic geological processes observed can include sand flows into the foundation pits and ditches, as well as erosion. Additionally, the Ngu Hanh Son mountain area in the IIA subzone occurs karst processes.

In general, the study area has 02 mainly engineering geology zones (I&II) which are divided into 06 subzones: IA, IB and IC; IIA, IIB and IIC. The IB subzone (green color) occupies the largest area and widely distributed in the northwest part and in Son Tra peninsula. The subzones IC (turquoise color), IIC (orange color) and IIB (pink color) have smaller areas, and appear in the southeast part, while IIA (yellow color) is a narrow region, extending along the coastal of the western study area and the IA subzone (blue color) is the smallest region, located in the northeast. The distribution and properties of the subzones are shown in Figure 3 and Table 5.

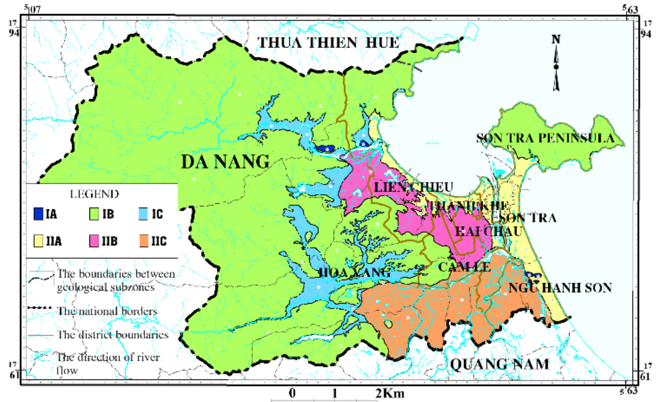

Figure 3 Spatial distribution of engineering geology subzones

Table 5 Properties of the engineering geology subzone and ground type

Geotechnical zones	Subzones	Description	Ground type
Eroded low hills	IA	Series of terrigenous sedimentary deposits and biochemical sedimentary rock are exposed on the surface.	A
	IB	The subsurface is composed of eluvial-diluvial deposits ($ed^{CM}Q$) with a thickness ranging from 2 to 10 meters, underlain by bedrocks consisting of regional metamorphic, igneous and terrigenous rock.	E or A
	IC	The order lithology from the top downwards consists of alluvial deposits ($a^{CM}Q$), alluvial- diluvial-proluvial deposits ($adp^{G}Q$ and $adp^{CM}Q$), with a thickness ranging few meters to 20 meters. Bedrocks lies beneath these sediments.	E or A
Coastal plains	IIA	From the top downwards, the lithological sequence comprises marine-wind sand ($mv^{S}Q$), alluvial-marine silty clay ($am^{CM}Q$) and then marine clay ($m^{CM}Q$). This thick sediment series is ranging from 30 to over 50 meters and overlies eluvial-proluvial deposits ($ed^{CM}Q$). Below these deposits are regional metamorphic, igneous and terrigeneous rocks.	C, D
	IIB	The lithology consists of a series of marine sediments: silty sand ($m^{SC}Q$,), clayey sand ($m^{SC}Q$) and silty clay and sandy clay ($m^{CM}Q$). The sediment layer ovelies eluvial-diluvial deposits ($ed^{CM}Q$). The total thickness ranging from 20 to over 40 meters and is underlain by bedrocks: regional metamorphic, igneous and terrigenous rock.	C, D
	IIC	The lithology is composed of series of deposits: alluvial muddy clay ($a^{CO}Q$) is at the top, alluvial-marine-brackish clay ($amb^{CO}Q$) in the lower part, and alluvial-marine sandy clay ($am^{CM}Q$) and marine silty clay originated ($m^{CM}Q$) at the lowest part. This sediment series is ranging from 20 to 40 meters in thickness and covers on eluvial-proluvial sediments ($ed^{CM}Q$). Underlying the deposit there is the regional metamorphic rock.	S_1, C or D

4.0 CONCLUSION

The morphology of the Da Nang city area is composed of eroded low hills (I) and coastal plains (II). The eroded low hill zone (I) comprises IA, IB and IC engineering geological subzones, which are classified as ground type A or E in the design of structures for earthquake resistance. The thickness of deposits in this zone is from 2 to 5 meters and 5 to 10 meters, and underlain by the bedrocks or eluvial-proluvial deposits. The eroded low hills are commonly in the northwest part of the study area, such as in Hoa Vang district, the western Da Nang city, Hoa Nhon, Hoa Phu wards, Son Tra peninsula, Ngu Hanh Son mountain and within drainage basin of the Cu De, Tuy Loan, Lo Dong rivers. The IB subzone covers the largest area, while the IA and IC subzones are smaller. These subzones are highly suitable for the construction works.

On the other hand, the coastal plains (II) consists of IIA, IIB and IIC engineering geological subzones, which correspond to ground types C, D, S1 or E. The subzones have formed from the sediment materials with a thickness ranging approximately from 20 to 40 meters and tend to decrease in elevation towards the sea. The coastal plains are widely located in the southeastern study area, including Lien Chieu, Thanh Khe, Hai Chau, Ngu Hanh Son and Son Tra districts. The engineering geological foundation in these areas is unstable and weak. Therefore, it is essential to incorporate suitable geotechnical solutions into designs to ensure structural safety and reduce vulnerability to natural hazards.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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