Geotechnical Mapping for Soil Physical and Mechanical Parameters and Hard Soil Depth in Badung Regency

Zefira Wisna Maulidha[1,a], Trihanyndio Rendy Satrya[b], Yudhi Lastiasih[c]

[1)] *Civil Engineering Dept, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia*

Correspondent : [a)]wmzefira@gmail.com, [b)] trendysatrya@its.ac.id &
[c)] yudhi.lastiasih@gmail.com

ABSTRACT

The infrastructure is important for the great life of a region and most of the country. Therefore, infrastructure must be always in proper condition in its functionality. Furthermore, it must follow the main principle which is infrastructure asset management. In this case, geotechnical mapping is also related to the principles of Infrastructure Asset Management in planning, designing, and feasibility studies of an infrastructure project in Badung Regency, hence the infrastructure projects are better prepared. The research methods include collecting soil investigation data, processing soil investigation data, describing the results of soil investigation data with mapping tools, and geotechnical zoning with statistical analysis. The results obtain a geotechnical map of Badung Regency in 2 and 3-dimensional forms. The 2D results in the form of a hard soil depth map can be concluded that South Kuta District has a variable depth of 0.4 – 15 meters, North Kuta District has a variable depth of 1.5 – 5 meters, Kuta District has a variable depth of 1.5 – 10 meters, Mengwi District has a variable depth of 1.5 – 10 meters, Abiansemal District has a variable depth of 5-15 meters, Petang District has a variable depth of 5-22 meters. The 3D Zone 1 lithology map can be concluded that the Zone 1 area covered with a hard soil depth of around 5 – 10 meters is dominated by sandy silt, silty sand, sand, and a little clayey silt. That area covered with a hard soil depth of about 1.5 – 5 meters is dominated by clay, clayey silt, sandy silt, silty sand, and sand with a heterogeneous distribution. The Zone 1 area is dominated by the specific volume saturated value (γsat) range of 1.5 – 2.0 t/m3. The values > 2.0 t / m3 are found in Sading area with a hard soil depth of 5-10 meters. The Zone 1 area is dominated by the range of N-SPT values = 0 - 30. The N-SPT values > 30 are found in Sading area with hard soil depths of 5-10 meters.

Keywords: geotechnical mapping, infrastructure asset management, soil type, Bandung Regency

INTRODUCTION

Infrastructure is the capital for the good life of a region and more of the country. Therefore, Infrastructure must be always in good condition of functioning (Suprayitno & Sumitro, 2020). Infrastructure needs to be well managed. Thus, it needs to be well operated, well maintained, well constructed, well designed, well planned, well registered, and well disposed of. Operation and maintenance must be based on infrastructure conditions or infrastructure performance. Infrastructure Management needs an infrastructure program based on good infrastructure evaluation (Suprayitno & Soemitro, 2018). In creating this, it must follow a principle, namely Infrastructure Asset Management. Infrastructure & Facility

Asset Management (IFAM) is a knowledge, science, and program to manage infrastructure and facilities, along their life cycle. The main objective of the IFAM is to ensure that the infrastructure and facility can sustainably well function, economically, efficiently, and effectively, while still following the green principle (Sumitro & Suprayitno, 2018). In this case, geotechnical mapping is also related to the principles of Infrastructure Asset Management in planning, designing, and feasibility studies of an infrastructure project in Badung Regency so that the infrastructure project will build well.

The development of infrastructure in Badung Regency is growing rapidly along with increasing the number of visiting tourists. In this case, several aspects need to be considered, one of them being the geotechnical aspect. This geotechnical aspect is related to the various soil conditions in Badung Regency. The diversity of soil types in Badung Regency will have an impact on the details of soil investigations if infrastructures, such as foundations, embankments, and others want to be built. This map will be used by the experts in the field as an initial reference when developing infrastructure in Badung Regency, so the initial costs, risk factors, and geotechnical analysis can be estimated before carrying out investigations in the field.

LITERATURE REVIEW

Geotechnical Mapping

Mapping is a grouping of areas related to several geographical locations including highlands, mountains, resources, and population potential affecting socio-cultural characteristics that have special characteristics of using the right scale (Munir, 2012). Geotechnical mapping is a grouping of an area based on soil investigation data. Soil investigations used in the form are sonder tests, SPT, bore logs, and laboratory data. The purpose of geotechnical mapping is to find out the distribution pattern of soil types and their characteristics in the reviewed area, to know the distribution pattern of soil consistency at a certain depth in the reviewed area, to be a guideline for initial considerations in determining the type, depth and dimension of the foundation according to the soil conditions in the reviewed area.

N-SPT Test

Standard Penetration Test is a dynamic experiment (dynamic penetrometer). The dynamic experiment is a test in which the tip is inserted into the ground by dropping loads at a certain height and the number of required strokes to push it through a certain distance. SPT is a test method that is carried out simultaneously with drilling to determine the strength of the soil.

The implementation of the test is divided into three stages. The first stage is recorded as the N1. The value of N1 is not taken as data because the soil is still dirty/drilled, while in the second and third stages N2 and N3 are added up to get the value of N stroke or SPT resistance or N-SPT = N2 + N3 (expressed in strokes/0.3 m). Then the N value can be correlated with the soil properties that have been researched.

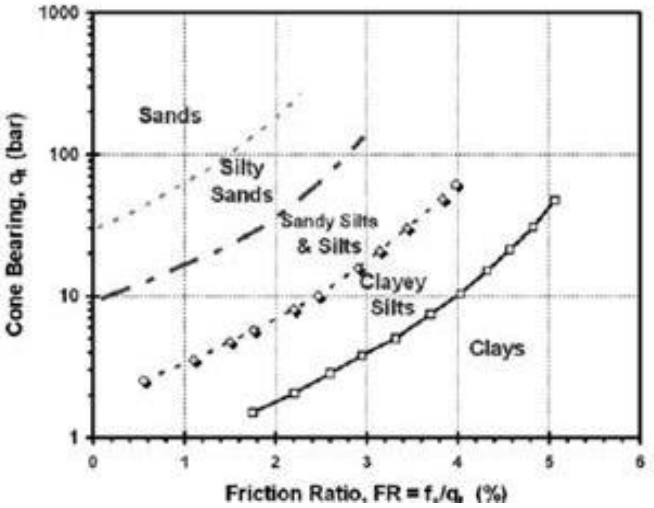
CPT Test

Cone Penetration Test is a test whose tip is conical with an angle of 60^o and with a tip area of 1.54 in^2 (10 cm^2). This tool is used by being pressed into the ground continuously at a constant speed of 20 mm/second, while the resistance of the soil to the cone of penetration (qc) is also continuously measured. CPT test is used to calculate the bearing capacity of the soil. The cone resistance (qc) obtained from the test can be directly correlated with the bearing capacity of the soil.

Correlation Between Soil Parameters

Some soil parameters correlated from the N-SPT and CPT data are as follows.

1) Robertson & Campanella (1983) proposed a simple curve to analyze soil types. This classification is based on CPT data. Picture 1, shows a graph of soil classification according to Robertson and Campanella.



source : (Robertson and Campanella, 1983)

Picture 1. Soil Classification Graph According to Robertson & Campanella

Correlation of non-cohesive soil (sand)

The correlation of qc values to several geotechnical parameters for non-cohesive soils is shown in Table 1 and Table 2.

Table 1. Correlation Between Relative Density, N-SPT, and Cone Resistance

Soil Condition	Relative Density, Dr (%)	N-SPT	Cone Resistance, qc (Mpa)
Very Loose	0 - 0.15	< 4	< 2
Loose	0.15 - 0.35	4 -- 10	2 -- 4
Medium	0.35 - 0.65	10 -- 30	4 -- 12
Dense	0.65 - 0.85	30 -- 50	12 -- 20
Very Dense	0.85 - 1.00	> 50	> 20

source: Lee et al (1983)

Table 2. Guideline for Estimating Value of N-SPT for Dominant Sand Soil

Soil Condition	Relative Density, Dr (%)	N-SPT	φ (°)	Specific Volume Saturated, γsat (ton /
Very Loose	0 - 0.15	0 - 4	0 - 28	< 1.60
Loose	0.15 - 0.35	4 -- 10	28 - 30	1.50 - 2
Medium	0.35 - 0.65	10 -- 30	30 - 36	1.75 - 2.10
Dense	0.65 - 0.85	30 -- 50	36 - 41	1.75 - 2.25
Very Dense	0.85 - 1.00	> 50	41 *	

source: Mochtar (2009)

2) Correlation of cohesive soil (clay, silt)
The correlation of qc values to several geotechnical parameters for cohesive soils is shown in Table 3 and Table 4 and equation (1).

Table 3. N-SPT Correlation with Other Soil Parameters

Cohesionless Soil					
N (blows)	0 - 3	4 -- 10	11 -- 30	31 - 50	> 50
γ (kN/m3)	-	12 -- 16	14 - 18	16 - 20	18 - 23
φ (°)	-	25 - 32	28 - 36	30 - 40	> 35
State	Very Loose	Loose	Medium	Dense	Very Dense
Dr (%)	0 - 15	15 - 35	35 - 65	65 - 85	85 - 100
Cohesive Soil					
N (blows)	< 4	4 -- 6	6 -- 15	16 - 25	> 25
γ (kN/m3)	14 - 18	16 - 18	16 - 18	16 - 20	> 20
qu (kPa)	< 25	20 - 50	30 - 60	40 - 200	> 100
Consistency	Very Soft	Soft	Medium	Stiff	Hard

source: Bowles (1984)

Table 4. Value of Soil Consistency for Dominant Silt and Clay Soil

Soil Consistency	Cohesion Undrained, Cu		N-SPT	Cone Resistance, qc	
	kPa	ton / m2		kg/cm2	kPa
Very Soft	0 - 12.5	0 - 1.25	0 - 2.5	0 - 10	0 - 1000
Soft	12.5 - 25	1.25 - 2.5	2.5 - 5	10.0 - 20.0	1000 - 2000
Medium	25 - 50	2.5 - 5.0	5.0 - 10.0	20 - 40	2000 - 4000
Stiff	50 - 100	5.0 - 10	10.0 - 20.0	40 - 75	4000 - 7500
Very Stiff	100 - 200	10.0 - 20.0	20 - 40	75 - 150	7500 - 15000
Hard	> 200	> 20	> 40	> 150	> 15000

source : Mochtar (2006), revised (2012)

According to Wahyudi and Lastiasih, to find γ_{sat} (ton/m^3) on clay soil if SPT value < 4 is as follows.

$$\gamma_{sat} = 0.08N + 1.47 \quad ...(1)$$

Where :

γ_{sat} : specific volume *saturated* (ton/m^3)
N : SPT value

3) Correlation of other soil parameters
The void ratio (e) and specific volume (γ) correlated with other soil parameters (*compression index*, Cc and *swelling index*, Cs) values are as follows.

Table 5. Correlation of Other Soil Parameters

Soil Consistency		Specific Volume Dry (γd)		e	n	Wsat (%)	γsat (t/m3)
		g / cm3	lb cb ft				
Silt, Clay	Soft ↑	0.50	31.25	4.40	0.80	163.00	1.31
		0.60	37.50	3.50	0.78	129.60	1.38
		0.70	43.75	2.86	0.74	105.80	1.44
		0.80	50.00	2.38	0.70	88.00	1.50
		0.90	56.25	2.00	0.57	74.10	1.57
		1.00	62.50	1.70	0.63	63.00	1.63
		1.10	68.75	1.45	0.59	53.90	1.69
	↓	1.20	75.00	1.25	0.56	46.30	1.76
	average	1.30	81.25	1.08	0.52	39.90	1.82
Gravel, Sand	Sand ↑	1.40	87.50	0.93	0.48	34.40	1.88
		1.50	93.75	0.80	0.44	29.60	1.94
		1.60	100.00	0.69	0.41	25.50	2.01
		1.70	106.25	0.59	0.37	21.80	2.07
		1.80	112.50	0.50	0.33	18.50	2.13
		1.90	118.75	0.42	0.30	15.60	2.20
		2.00	125.00	0.35	0.26	13.60	2.26
		2.10	131.25	0.29	0.22	10.60	2.32
	↓	2.20	137.50	0.23	0.19	8.40	2.39
		2.30	143.75	0.17	0.15	6.40	2.45
		2.40	150.00	0.13	0.11	4.63	2.51
		2.50	156.25	0.08	0.07	2.96	2.57
		2.60	162.50	0.04	0.04	1.42	2.64
	Gravel	2.70	168.75	0.00	0.00	0.00	2.70

source : Biarez dan Favre, 1976

According to Kosasih and Mochtar (2007), the values of Cc and Cs are strongly influenced by the value of the void ratio (e), liquid limit (LL), and water content (wc). The formulation can be seen in Equation (2) – Equation (3) below.

$$C_C = 0.006\,LL + 0.13{e_o}^2 - 0.13 \quad \ldots(2)$$

$$C_S = 0.002\,LL + 0.02{e_o}^2 - 0.05 \quad \ldots(3)$$

Liquefaction

Liquefaction is the reduction/disappearance of the soil shear strength due to cyclic loading when an earthquake occurs. According to Towhata (2008), liquefaction occurs in dominant sand soils with loose consistency (silty sand, sand) and saturated conditions. The analysis can be stated as follows.

Mohr-Coulomb Theory:

$$\tau = c' + (\sigma - u)\ tg\ \emptyset \quad \ldots(4)$$

For sand soil :

$$c' = 0 \quad \ldots(5)$$

Liquefaction :

$$\sigma' = (\sigma - u) = 0 \quad \ldots(6)$$

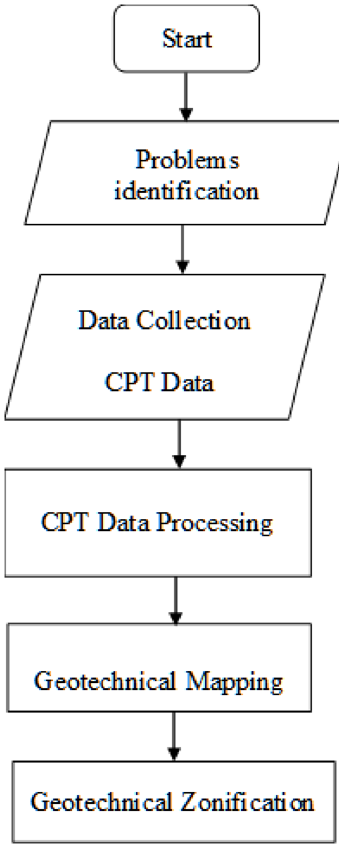
So, $\boldsymbol{\tau = 0}$

Settlement

When a low-permeability saturated soil layer is loaded, the pore water pressure in that soil immediately increases. The difference in pore water pressure in the soil layer causes water to flow into the soil layer with a lower pore water pressure, which is followed by soil subsidence. Due to the low permeability of the soil, this process takes time. Consolidation is the process of reducing volume or reducing the pore void of low-permeability saturated soil. The consolidation process can be observed with a piezometer, to record changes in pore water pressure.

RESEARCH METHODS

The flow chart related to geotechnical mapping research in Badung Regency is as follows.



Picture 2. Flowchart

Data Analysis and Processing

From the soil investigation data, the inputted parameters are N-SPT value, cone resistance value (qc), and physical and mechanical parameters (laboratory data) related to liquefaction and consolidation. In this study, the soil investigation data obtained is CPT data, so we must analyze other soil parameters from CPT data correlation.

Geotechnical Mapping

SPT, cone resistance (qc), and physical and mechanical parameters related to liquefaction and consolidation values that had been correlated, processed, and collected based on their consistency are inputted at location points in Badung Regency. The inputting process is assisted by 3D mapping tools.

Geotechnical Zonification

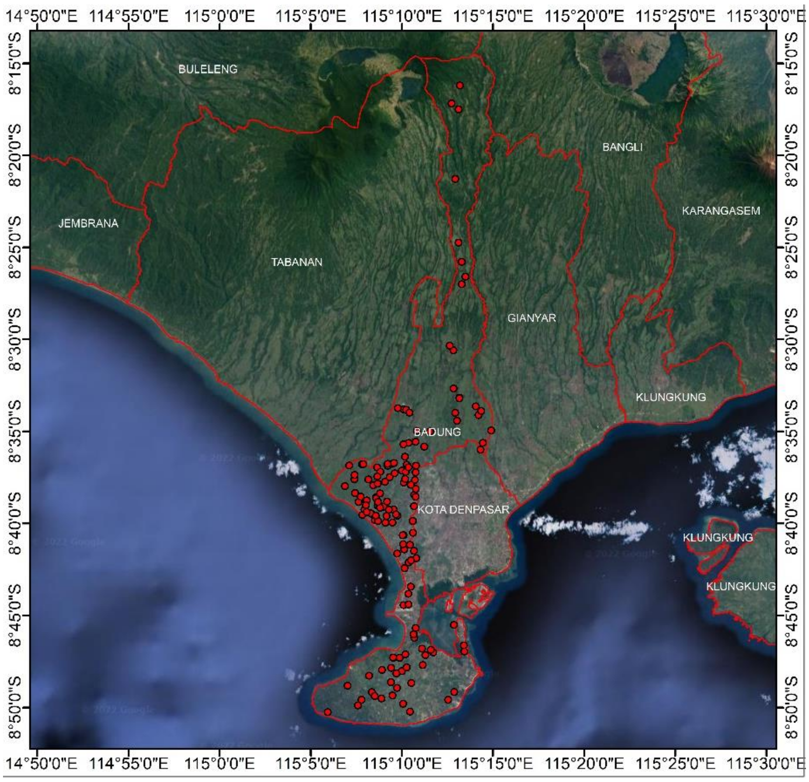
After inputting the data, zoning is carried out on the 3D mapping tool so that it is known that the area is dominated by the depth of the hard soil if it is viewed from above the map and to know the type of soil, its consistency and physical and mechanical parameters related to consolidation and liquefaction at each depth when it is viewed from the cross-section. This analysis involves numerical analysis.

RESEARCH ANALYSIS

Based on research related to geotechnical mapping in Badung Regency, the data used is CPT data. For this reason, it is necessary to correlate CPT data to obtain other geotechnical parameter values (N-SPT, sat, e, Cc, Cs, FS). From this CPT data, it can be determined the depth of the hard soil, then it will be inputted into the mapping tool, so the 2D map will be formed. For geotechnical parameters, the resulting output is 3D map. The details are as follows.

1. The cone value data qc > 250 kg/cm^2 ranges from 0.4 meters to 20 meters. CPT data has 148 points.

CPT data points can be seen in Picture 3 as follows.



(source: Google Earth, 2022)

Picture 3. CPT Data Points Distribution

CPT Data Processing

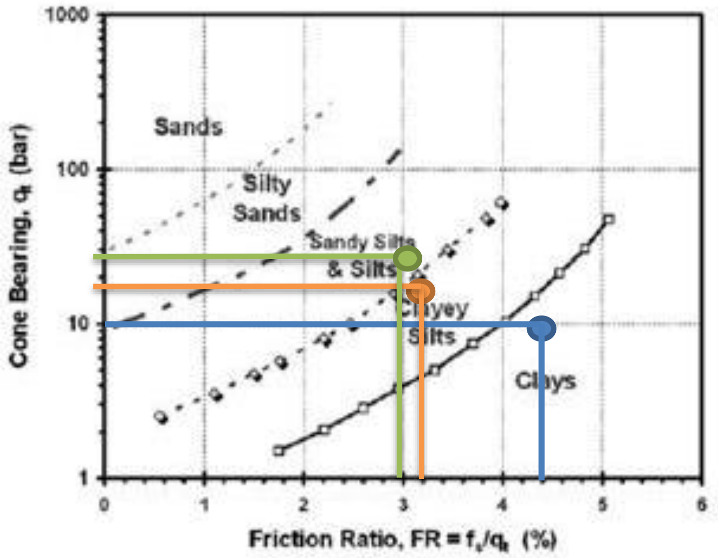
In this study, the obtained data are CPT data, so it must find soil types and other soil parameter values by correlating the CPT data. The analysis is as follows.

<u>Soil Type Analysis</u>

To determine the type of soil, the sonder data correlation is as follows.
Location : Tanah Barak – Canggu
Analysis used from the graph of Robertson & Campanella (1983) as follows.

Table 6. Sample of CPT Data Tanah Barak - Canggu

Depth (meter)	Cone Resistance Cw kPa/100	Friction Ratio Rf (%)	qc (bar)	Soil Type
0.00				
0.20	10	4.4	10	clay
0.40	12	3.9	12	clay
0.60	11	4.4	11	clay
0.80	11	4.9	11	clay
1.00	10	4.4	10	clay
1.20	12	4.2	12	clay
1.40	15	3.2	15	clayey silt
1.60	18	3.2	17	clayey silt
1.80	20	4.2	20	clayey silt
2.00	21	3.0	20	clayey silt
2.20	24	3.2	24	clayey silt
2.40	27	3.0	26	sandy silt
2.60	29	3.1	29	sandy silt
2.80	31	2.8	31	sandy silt



Picture 4. Graphical Analysis of Soil Type Determination from CPT Data

From the graphical analysis in Table 6 and Picture 4, the CPT data parameters used in the analysis are friction ratio (%) and qc (bar). From the soil data at depth 1.60 meters, the friction ratio value is 3.2% and the qc value is 17 bar. This value is connected in the graph by drawing a line to produce an orange line relationship. From this line, it can be determined that the soil type is clayey silt.

N-SPT

In correlating SPT values, the theory is adjusted to the type of soil, namely cohesive soils (dominantly silt and clay) and non-cohesive soils (dominantly sand). For cohesive soils, the theory is based on Table 3 and Table 4. The analysis is as follows.

Location : Tanah Barak – Canggu

For clay soil at depth 0 - 1.2 meter, qc = 11 kg/cm^2, consistency : *soft*,

$$\text{N- SPT} = \left(\left(\frac{11-10}{20-10}\right)x(5-2.5)\right)+2.5 = 2.8 \qquad \ldots(7)$$

So, N-SPT value of clay at depths 0 - 1.2 meters is 2.8.

Specific Volume *Saturated* (γ_{sat})

In correlating the specific volume saturated value, the theory is also adjusted to the type of soil, namely cohesive soils (dominantly silt and clay) and non-cohesive soils (dominantly sand). For cohesive soils, the theory used is based on Table 3, Table 4, and equation (1). The analysis is as follows.

Location : Tanah Barak – Canggu

For clay soil at depth 0 - 1.2 meter, N-SPT = 2.8, …(8)

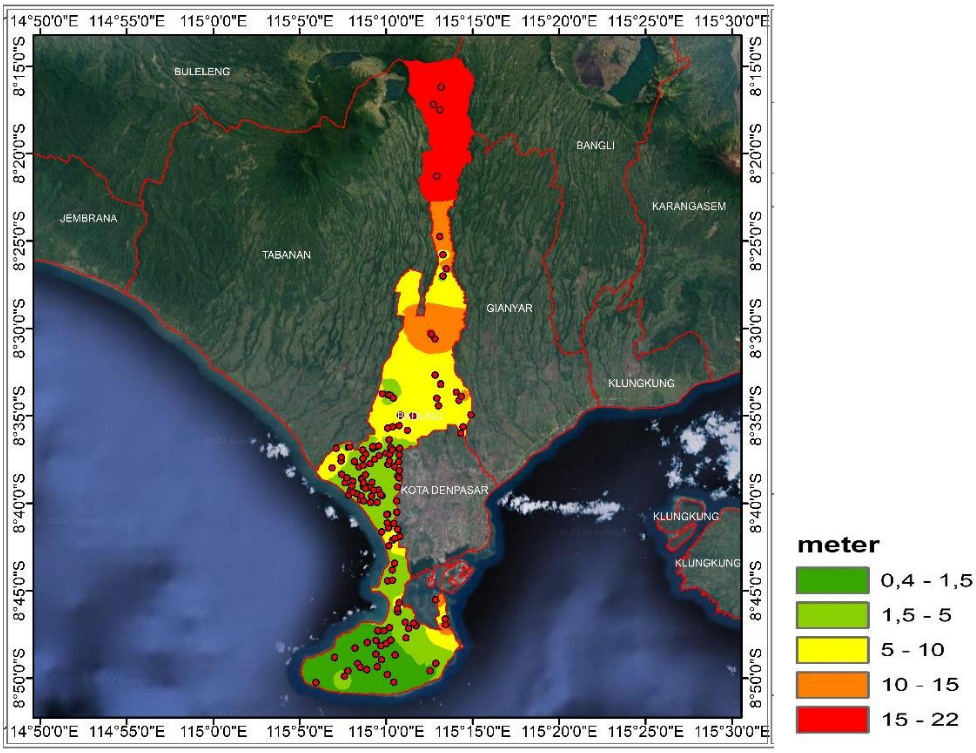
Lower limit (N = 1) → γ_{sat} = 0.08 (1) + 1.47 = 1.55 t / m^3 …(9)

Upper limit (N = 25) → γ_{sat} = 2 t / m^3 …(10)

$$\gamma_{sat} = \left(\left(\frac{2.8-1}{25-1}\right)x(2-1.55)\right)+1.55 = 1.58\ t/m^3 \qquad \ldots(11)$$

So, γ_{sat} value of cohesive soil at depths 0 - 1.2 meters is 1.58 t / m^3. …(12)

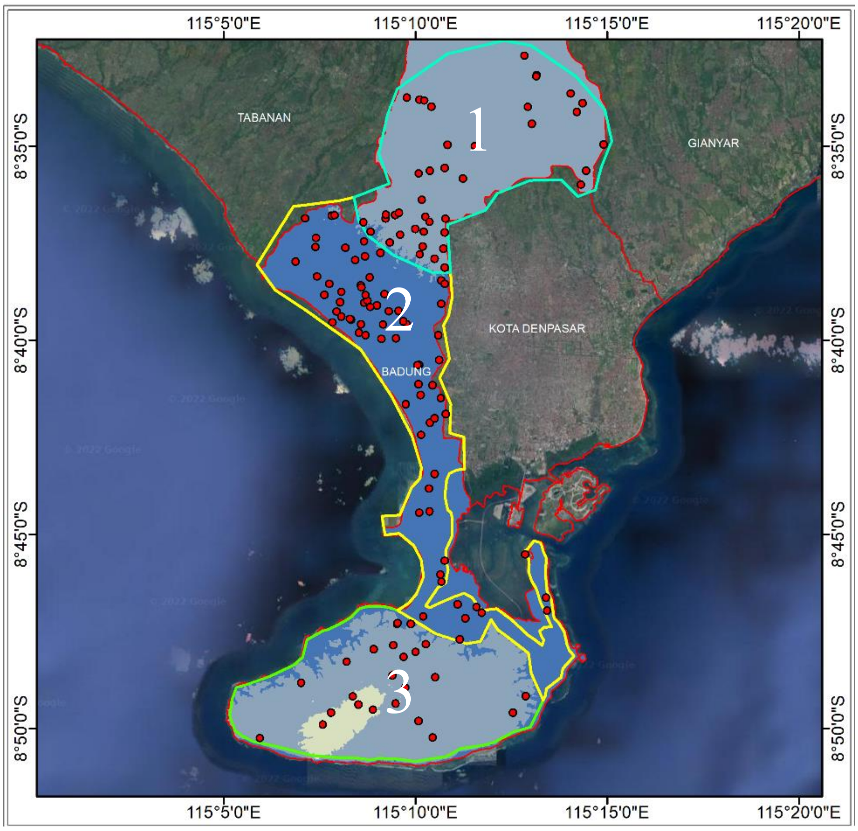
The obtained result is as follows.



Picture 5. Distribution of the Hard Soil Depth 2D Map of Badung Regency

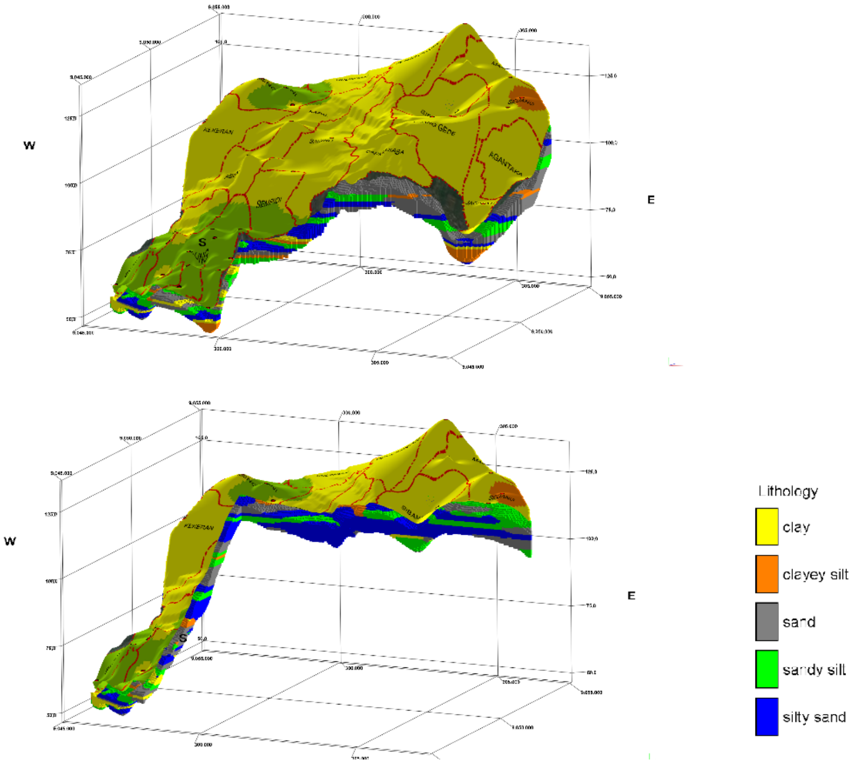
Based on Picture 5, it can be concluded that depth 0.4 – 1.5 meters dominates South Kuta District (Pecatu, Ungasan, Jimbaran). The depth of 1.5 – 5 meters dominates Kuta District (Kedonganan, Tuban, Kuta, Seminyak), South Kuta District (Taman Baruna, Teges

Gede Jimbaran, Taman Griya, Taman Jimbaran Utama), North Kuta District, Mengwi District (Mengwitani, Pererenan, Tumbak Bayuh , Buduk). The depth of 5 – 10 meters dominates South Kuta District (Benoa, Tanjung Benoa), Kuta District (Legian), Mengwi District (Munggu, Abianbase, Kapal, Sempidi), Abiansemal District (Angantaka, Sibang Gede, Sibang Kaja, Mambal, Sedang, Jagapati), Petang District (Carangsari, Getasan). The depth of 10-15 meters dominates South Kuta District (Tanjung Benoa), Abiansemal District (Blahkiuh), Petang District (Carangsari, Pangsan). The depth of 15 – 22 meters dominates Petang District (Sulangai, Pelaga).



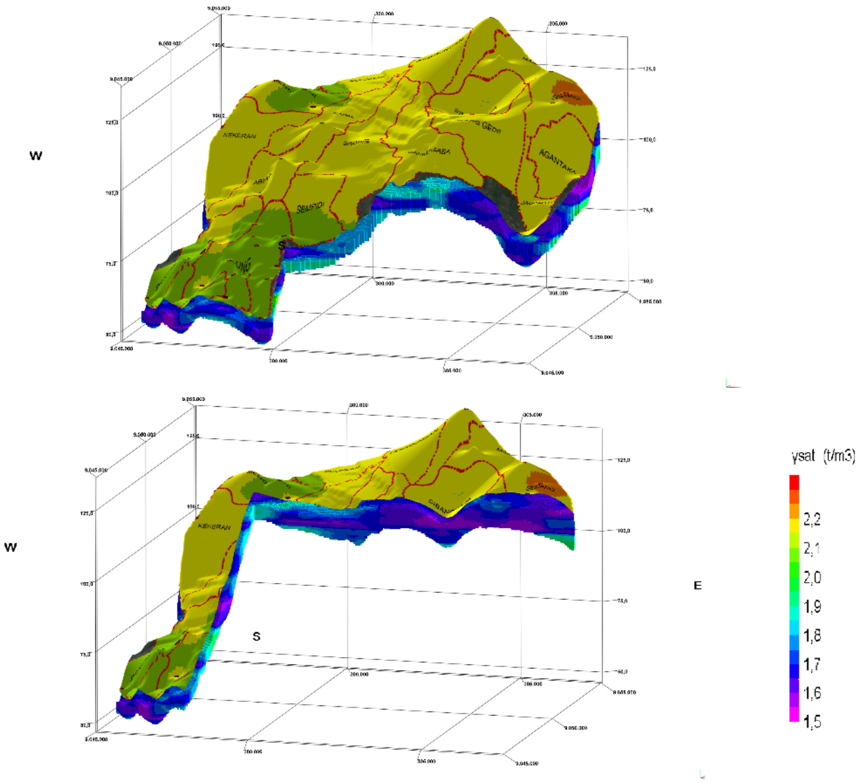
Picture 6. Zone Division of Badung Regency

From Picture 6, it can be seen that Zone 1 dominates Abiansemal District, Mengwi District (Buduk, Sempidi, Mengwitani, Kapal, Abianbase, Lukluk), and North Kuta District (Dalung). Zone 2 dominates Kuta District, North Kuta District (Kerobokan, Canggu, Tibubeneng), and Mengwi District (Munggu, Pererenan), South Kuta (Baruna Jimbaran Park, Teges Gede Jimbaran, Jimbaran Park, Griya Park, Benoa, Tanjung Benoa). Zone 3 dominates South Kuta area (Ungasan, Jimbaran, Pecatu).



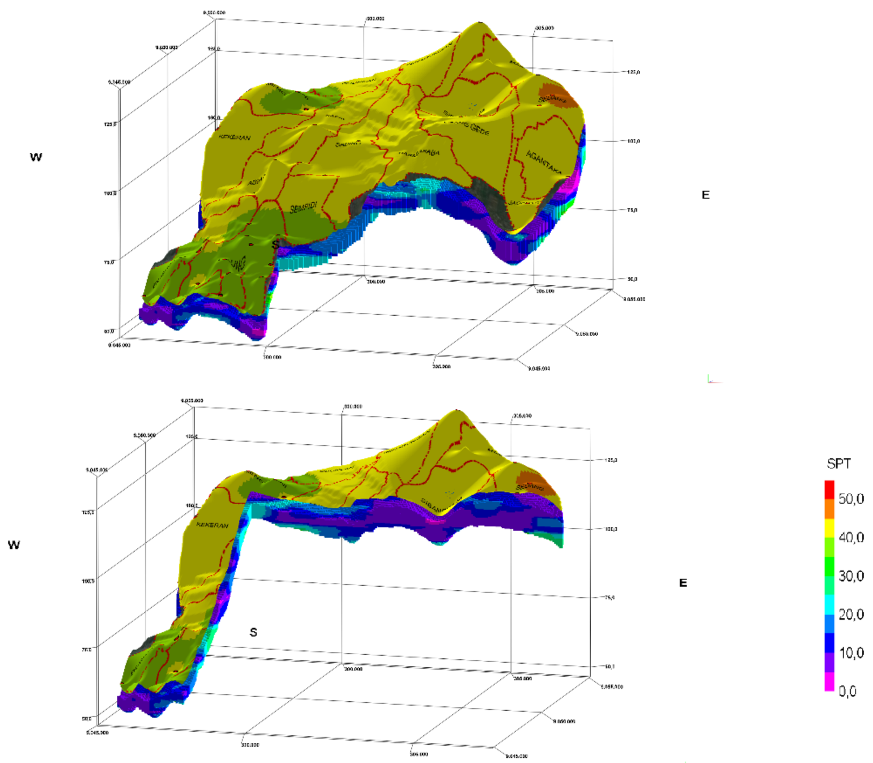
Picture 7. Lithology Mapping and Cross Section Zone 1

Based on Picture 7, the Zone 1 area covered with a hard soil depth of around 5 – 10 meters is dominated by sandy silt, silty sand, sand, and a little clayey silt. That area covered with a hard soil depth of about 1.5 – 5 meters is dominated by clay, clayey silt, sandy silt, silty sand, and sand with a heterogeneous distribution.



Picture 8. Specific Volume Mapping and Cross Section Zone 1

From Picture 8, it can be concluded that the Zone 1 area is dominated by the specific volume saturated value range of 1.5 – 2.0 t/m^3. The values > 2.0 t / m3 are found in Sading area with a hard soil depth of 5-10 meters.



Picture 9. N-SPT Mapping and Cross Section Zone

From Picture 9, it can be concluded that the Zone 1 area is dominated by the range of N-SPT values = 0 - 30. The N-SPT values > 30 are found in Sading area with hard soil depths of 5-10 meters.

CONCLUSION

The results obtained are geotechnical maps of Badung Regency in 2D and 3D forms. The 2D results in the form of a hard soil depth map can be concluded that South Kuta District has a variable depth of 0.4 – 15 meters, North Kuta District has a variable depth of 1.5 – 5 meters, Kuta District has a variable depth of 1.5 – 10 meters, Mengwi District has a variable depth of 1.5 – 10 meters, Abiansemal District has a variable depth of 5-15 meters, Petang District has a variable depth of 5-22 meters.

The 3D Zone 1 lithology map can be concluded that the Zone 1 area covered with a hard soil depth of around 5 – 10 meters is dominated by sandy silt, silty sand, sand, and a little clayey silt. That area covered with a hard soil depth of about 1.5 – 5 meters is dominated by clay, clayey silt, sandy silt, silty sand, and sand with a heterogeneous distribution. The Zone 1 area is dominated by the specific volume saturated value (γ_{sat}) range of 1.5 – 2.0 t/m^3. The values > 2.0 t / m3 are found in Sading area with a hard soil depth of 5-10 meters. The Zone 1 area is dominated by the range of N-SPT values = 0 - 30. The N-SPT values > 30 are found in Sading area with hard soil depths of 5-10 meters.

Note. This paper has been accepted and presented in ICIFAM #1 2022, Surabaya, 21-22 June 2022. ICIFAM – International Conference on Infrastructure & Facility Asset Management. This conference was organized by Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia.

REFERENCES

Ali, Fauziah dkk. (2018). **“**Kajian Geoteknik untuk Perencanaan Pembangunan Pemukiman Baru pada Kawasan Handil Berkat Makmur, Kabupaten Kapuas, Kalimantan Tengah”. *Jurnal Geosains dan Teknologi*, Vol.1, No.2, Hal 50 - 58.

Bowles, J.E., (1984). *Sifat-Sifat Fisis Dan Geoteknis Tanah*. Erlangga, Jakarta.

Das, Braja M., (translated by Mochtar N.E, and Mochtar I.B.). (1985). *Mekanika Tanah Prinsip-Prinsip Rekayasa Geoteknik.* Jilid I. Erlangga. Jakarta.

Das, Braja M., (translated by Mochtar N.E, and Mochtar I.B.). (1985). *Mekanika Tanah Prinsip-Prinsip Rekayasa Geoteknik.* Jilid II. Erlangga. Jakarta.

Hakam, Abdul. (2008). *Rekayasa Pondasi*. CV. Bintang Grafika. Padang.

Hasbi, Yudi. 2021. *Analisis Potensi Likuifaksi Berdasarkan Data SPT dan CPT.* Universitas Islam Indonesia. Yogyakarta.

Kosasih.,A., Mochtar.,I.B., (1997). ‘Pengaruh Kadar Air, Angka Pori, dan Batas Cair Tanah Lempung Terhadap Indeks Pemampatan Konsolidasi Cc dan Indeks, Pengembangan Cs”. *Master Thesis.*, Program Pasca Sarjana. Teknik Sipil ITS. Surabaya.

Lee, Ian Kenneth, dkk. (1983). *Geotechnical Engineering*. University of New South Wales, Australia.

Mochtar, Indrasurya B. (2006). “Empirical Parameters for Soft Soil in Situ”. Revised (2012). Civil Engineering Dept. Institut Teknologi Sepuluh Nopember (ITS), Surabaya.

Mochtar, Indrasurya B. (2012). “Kenyataan Lapangan sebagai dasar untuk usulan konsep baru tentang analisa kuat geser tanah dan kestabilan lereng”. *16th Annual Scientific Meeting 2012*.

Satrya, Trihanyndio Rendy, Ria Asih Aryani Soemitro, dkk. (2014). “Engineering Geological Mapping at Center of Surabaya Region by Developing Geo-Tomography Image Analysis”. *Celebes International Conference on Earth Science (CICES).*

Tazakka, Merdeka Sandi. (2021). *Modul Rockworks™*. Untuk Teknik Sipil (Geoteknik).

Tim Penyusun Esa Unggul. (2018). *Modul Pembelajaran ArcGIS*. Universitas Esa Unggul.

Suprayitno, Hitapriya, et al. (2020). "Preliminary Reflection on Performance Indicator and Performance Factor for Infrastructure Asset Management". *Journal of Infrastructure & Facility Asset Management - JIFAM. 2(1) March 2020.*

Suprayitno, Hitapriya, et al. (2020). "Preliminary Reflection on Basic Principle of Operation Management for Public Work Infrastructure Asset Management". *Journal of Infrastructure and Facility Asset Management - JIFAM 2(Sup1) December 2020.*

Suprayitno, H. & Soemitro, R.A.A (2018). "Preliminary Reflexion on Basic Principle Infrastructure Asset Management". *Jurnal Manajemen Aset Infrastructur & Facilitas – JMAIF 2(1) Maret 2018.*