Geotechnical Investigation of Caraga State University-Main Campus for Structural Development

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Abstract: *Geotechnical investigations are essential for ensuring structural safety, especially in developing institutions like Caraga State University. While the university continues infrastructure expansion, a research gap exists in site-specific soil profiling and foundation recommendations. This study aimed to provide a comprehensive geotechnical evaluation for the university's main campus, focusing on subsurface profiling, soil classification, liquefaction assessment, and bearing capacity estimation. Field activities included Standard Penetration Testing (SPT) and wash boring, followed by laboratory testing to determine Atterberg limits, grain size, specific gravity, and plasticity. The soil was identified as clayey silt (ML and MH), with high plasticity and low susceptibility to liquefaction. Bearing capacity was calculated using both Terzaghi's and general methods, recommending isolated and mat foundations with allowable capacities ranging from 39 to 98 kPa. The results offer reliable data for structural design and serve as a benchmark for future developments, ensuring cost-effective and resilient infrastructure in the university campus.*

Keywords: geotechnical investigation, bearing capacity, plasticity, liquefaction, foundation

1. INTRODUCTION

Caraga State University's growth as an academic institution is depicted on its increasing number of enrollees, the revision and strengthening of programs offered, the consistency of linkage established, the development of teaching force through the faculty development program, and most importantly is the rise of new facilities to provide and meet the needs of its students and its region. Its main campus is located at KM7, Amayo, Butuan City, Caraga Region, Philippines, with an auxiliary campus at T. Curato Street, Cabadbaran City, Agusan Del Norte, a state university that offers and serves the Caraga Region with its accredited programs and relevant diploma, associate, undergraduate, and graduate courses. As the world continues to evolve, Caraga State University Main Campus is adapting to meet the changing needs of the students and the region. Caraga State University invests in building modern facilities and infrastructure like H.E.R.O. Learning Commons (Library). It was featured on July 23, 2021, in local media outlet "Philippine Information Agency" that it was recognized as the largest state university library in Mindanao, expected to cater over 2,000 learners from various part of Mindanao, and across the country, making it also the first library to include locator maps, an automated book drop system, and nap pads. This building is designed to enhance the learning experience, research capabilities, and overall campus environment.

Geotechnical investigation is required for foundations and ground engineering work, which usually includes infrastructure developments. To obtain the ground profile, groundwater conditions, and geotechnical parameters, ground investigation must be carried out at the proposed infrastructure development. As Caraga State University-Main Campus is adapting to support its students and its region, it is vital to ensure that the proposed structural development will provide safety, durability, and cost-effectiveness of construction projects. Identifying potential risks such as foundation failure, slope instability, and soil contamination helps mitigate hazards and ensures successful project outcomes [1]. It is imperative to ensure that the university's infrastructure is built on a solid foundation. Several potential findings can be major problems if not identified prior to design. Physical borings, while discrete in nature, can help identify buried obstacles or voids, uncontrolled fill, unusually soft soils, and subsurface conditions that require special handling. Not only does this help us understand how the earth will affect man-made structures, but geotechnical investigations also expose the impacts developments could impose on the ground [2]. This will be helpful in assessing its suitability, identifying potential risks, and informing design decisions on the proposed structural development in Caraga State University-Main Campus; this proactive approach ensures the safety, durability, and cost-effectiveness of the building, safeguarding lives and investments. This will also be helpful for future geotechnical investigations of the institution. It will serve as a baseline for future assessments, allowing for informed decision-making, risk mitigation, and sustainable development.

2. METHODOLOGY

2.1 Locale of Study

The site that will be considered is located at Caraga State University - Main Campus, KM7, Amayo, Butuan City, the undeveloped land at the front of the Food Innovation Center and behind the Food Technology Building. The geotechnical investigation aims to assess the subsurface conditions and evaluate the suitability of the site for future construction.

2.2 Methodological Framework

The methodological framework, as shown in Figure 1, shows the structured plan that outlines the approaches, processes, and techniques used in the research study. The framework starts with the first step, which is the preparation, which includes the different preliminary site investigations. Next, the data collection is followed by soil exploration or the in-situ investigation and the laboratory testing methods. Lastly, the geotechnical reports which include the foundation recommendations and conclusion of the study.

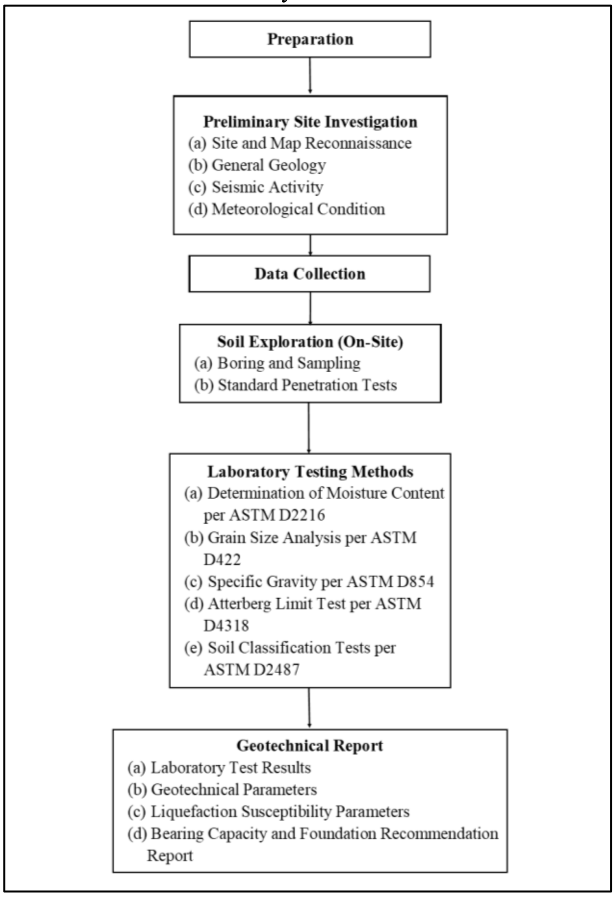

Fig. 1. Framework of the Study

2.3 Preliminary Site Investigation

The preliminary site investigation consists of different processes, including describing the topography, determining general geology, and understanding the seismic and meteorological conditions of the site as the initial step, which helped the researchers identify visible geological features such as rock outcrops, water bodies, and signs of soil erosion. Additionally, historical data about the site's previous land use or any geotechnical challenges (such as landslides or flooding) was determined and confirmed by CSU's Engineering and Construction Office, helping to identify potential issues early in the process for future development.

In this study, a site visit was conducted to describe the study area and identify the final location of the boreholes. Understanding the terrain is essential for designing structures that account for slope, water flow, and other factors that could affect stability and drainage.

The general geology of the whole region could also possibly provide some insights into the geological situation of the site. Past stratigraphic studies help identify different layers of soil and rock, providing insight into potential challenges like unstable soils or geological structures such as faults or folds. These factors directly influence foundation design and the overall stability of buildings.

Seismic activity must also be evaluated, especially in earthquake-prone regions like the Philippines. This involves a seismic hazard analysis, reviewing historical earthquake data, and understanding the proximity of fault lines. It also requires an assessment of how the site's geology will respond to seismic waves.

Finally, meteorological conditions are analyzed to understand the long-term impact of weather on the site and its structures. This includes studying rainfall patterns, which can cause flooding or erosion, and evaluating wind and storm data to design buildings that can withstand high wind loads from frequent storms or typhoons. Each of these methods provides critical data that informs safe, sustainable, and resilient structural development for the university campus.

2.4 Data Collection

2.4.1 In-situ Soil Exploration

Wash Boring, or a Rotary Drilling Machine, is used. Attached to the Wash Boring is a Double Tube Core 34 Barrel (47.6mm) sampler type for soil sampling. This method enables a detailed examination of soil stratification at greater depths, providing critical data for designing deep foundations. The drilling method was Wash Boring/Rotary Drilling, the test conducted has three (3) successive segments of 15 cm (6 inches), consisting of a standard split spoon sampler that is 5.08 cm (2 inches) in outer diameter. The depth intervals of each segment are 1.5m.

2.4.2 Standard Penetration Test (SPT)

A donut Hammer Manual type of SPT Hammer was used with a free fall height of 70.0 cm. These in-situ exploration methods will form the backbone for the site investigation. SPT offered essential data on soil strength and density, which helped in the design of foundations that can withstand the stresses of construction and environmental factors. A free-falling hammer, weighing 63.6 kg. (140 lbs.), was dropped from a height of 76.2 cm (30 inches). A split barrel sampler (SPT) with a diameter of 5.08 cm (2 inches) and a length of 3.0m (9.8 feet) was used to obtain disturbed soil samples. Meanwhile, core barrel samplers (coring) with a diameter of 47.6 mm (18.7 inches) and a length of 3.0 m (9.8 feet) were used to obtain undisturbed rock cores. The number of blows required to penetrate the three (3) 15-cm layers was recorded. The blow counts of the last two layers are added to give the N-value of a particular 45 cm stretch, which is considered as the measure of density or consistency of the soil. When hard materials are encountered, including gravel and rock formations, coring is employed, and the Rock Quality Designation (RQD) and Total Core Recovery (TCR) are applied. The standard penetration number corrected for field conditions can be computed using the equation below:

$$\boldsymbol{N_{60}} = \frac{N\eta_H\eta_B\eta_S\eta_R}{60} \tag{1}$$

Where:
N_{60} = standard penetration number corrected for field conditions
N = measured penetration number
η_H = hammer efficiency
η_B = correction for borehole diameter 37
η_s = sampler correction
η_R = correction for rod length

2.4.3 Laboratory Tests

The sieve analyses were performed to determine the particle sizes of the soil sample in accordance with ASTM D422. The test was done to classify the particles into a range of sizes, which is translated by obtaining the weights of particles into a range of sizes, which is translated by obtaining the relative weights of particles per size. This procedure classifies particles with sizes larger than 75 micrometers through sieving, while those smaller than 75 micrometers are classified through a sedimentation process.

The Liquid Limit (LL) and the Plastic Limit (PL) were determined by applying ASTM D4318. The liquid limit of soil is described as the moisture content, represented as a percentage, at which, under specific conditions, standardized soil paste changes from a plastic to a liquid state. This transition is measured by employing a standardized laboratory method called the Casagrande liquid limit test. The point where the state of soil changes from a semi-solid to a plastic stage, measured in terms of moisture content, is called the plastic limit, and the method for specifying that point is simple and easy [7]. The measured values for the liquid and plastic limits of soils are widely used as index parameters. They are used to compute the plasticity index, which can be empirically correlated against many soil properties in geotechnical design [8].

Soil classification was determined based on ASTM D2487 using the Unified Soil Classification System (USCS). For Specific Gravity (G_s) values, it was based on ASTM D854 and must be determined for any geotechnical characterization to define the relative proportions of solids, liquids, and air in a soil, and hence to both compute weight-volume parameters and determine the particle size distribution curve of fine-grained soils by hydrometer analysis [9].

2.5 Geotechnical Parameters

2.5.1 Bulk Unit Weight and Submerged Unit Weight

The bulk unit weight, also known as moist unit weight, is defined as the total weight of a soil sample (including both solids and water) divided by its total volume. The submerged unit weight, or buoyant unit weight, represents the effective weight of soil when submerged in water. It accounts for the upward buoyant force exerted by the water, reducing the soil's apparent weight [10].

2.5.2 Elastic Modulus

In geotechnical engineering, the elastic modulus is a fundamental parameter used to characterize the stiffness of soil, particularly its ability to deform elastically under applied loads. According to Bowles, for fine-grained soils such as silts, sandy silts, or clayey silts, a practical empirical relationship can be used to estimate the modulus of elasticity based on Standard Penetration Test (SPT) values. The formula recommended is shown in the equation below, where N is the corrected SPT blow count [11].

$$E_s = 0.3N + 1.8 \tag{2}$$

2.5.3 Undrained Cohesion

Undrained cohesion is a key shear strength parameter for soils, particularly under short-term or rapid loading conditions where drainage does not occur. One widely accepted method of estimating undrained cohesion involves determining the Undrained Shear Strength using empirical relations of corrected N-values to the undrained shear strength as shown in Equation 3. The unconfined shear strength is then used to compute unconfined compressive strength, along with the bearing capacity factor, as shown in Equation 4. The undrained cohesion is then acquired using the relationship between unconfined compressive strength, as shown in Equation 5.

$$S_U = \frac{N_{60}}{10} \text{ (for clayey soils)} \tag{3}$$

$$q_u = S_u N_u + \gamma D_f N_q \tag{4}$$

$$c_u = \frac{1}{2} q_u \tag{5}$$

Where:
S_u = Unconfined Shear strength
N_{60} = Corrected N-Values
q_u = Undrained Compressive Strength.
N_u and N_q = Bearing Capacity factors
D_f = Depth
γ = Soil Unit Weight
c_u = Undrained condition

2.4.4 Internal Angle Friction.

The internal angle of friction (ϕ) is essential for evaluating the shear strength of granular soils, which directly influences slope stability, bearing capacity, and earth pressure calculations. One practical and widely accepted method for approximating this parameter is through empirical correlations with corrected Standard Penetration Test (SPT) N-values. As shown from the equation below, the internal angle of friction for clean sands can be estimated using the correlation [12].

$$\phi = 27.1 + 0.3(N_1)_{60} - 0.00054[(N_1)_{60}]^2 \tag{6}$$

Where:
$(N_1)_{60}$ = value of N_{60} corrected to a standard value
ϕ = soil friction angle

2.4.5 Coefficient of Active and Passive Earth Pressure

Determining the coefficient of earth pressure is critical in designing retaining walls, sheet piles, and other soil-structure systems. These coefficients quantify the lateral pressure exerted by soil on a structure under different conditions. Specifically, the coefficient of active earth pressure (K_a) and the coefficient of passive earth pressure (K_p) are used to evaluate the minimum and maximum lateral pressures, respectively. When the soil mass tends to move away from a retaining structure, the soil reaches an active state, and the pressure it exerts is calculated using Equation 7, which defines the coefficient of active earth pressure. Conversely, when the soil mass is compressed against a structure, it reaches a passive state, and the resistance is determined using Equation 8, which defines the coefficient of passive earth pressure.

$$K_a = \frac{\cos(\alpha-\theta)\sqrt{1+\sin^2\theta\prime - 2\sin\theta\prime\cos\phi}}{\cos^2\theta(\cos\alpha + \sqrt{\sin^2\theta\prime - \sin^{2\alpha}}} \tag{7}$$

$$K_p = \frac{1+\sin\phi}{1-\sin\phi} \tag{8}$$

Where:
θ = Inclination of backfill too horizontal

ϕ = Angle of internal friction (effective)
α = Inclination of wall face to vertical
θ' = relative angle between Backfill and Wall Face
D_f = Depth
γ = Soil Unit Weight

2.4.6 Porosity

Porosity is a fundamental soil property that quantifies the ratio of void spaces to the total volume of soil, providing critical insight into the soil's ability to retain water, air, and other fluids. In geotechnical engineering, porosity is closely related to other properties such as permeability, compressibility, and strength. One way to determine porosity indirectly is by using the unit weight of the soil and its specific gravity.

2.4.7 Liquefaction Susceptibility Parameters

Soil liquefaction is the rapid reduction of shear strength in soil, which can lead to significant structural damage during earthquakes. It typically affects loose, water-saturated, fine-to-medium-grained sands with particle sizes ranging from 0.075 to 0.20 mm and an SPT-N value below 10. The phenomenon is most critical at depths of about 6 meters, especially when the water table is within 0 to 3 meters of the surface, making such soils highly susceptible to liquefaction. Through these parameters, it is easy to evaluate areas that are at high risk of liquefaction, enabling proactive design and safety measures for structures.

2.5 Engineering Implications

The bearing capacity of soil is essential for designing foundations that can safely support structural loads. Under undrained conditions, common in saturated clays and during rapid loading scenarios, the shear strength of the soil is primarily governed by its cohesion, and the internal friction angle is considered negligible. For this condition, Terzaghi's bearing capacity theory simplifies the general equation by using specific bearing capacity factors [13]. Equation 9 is used for strip footing in undrained conditions and for Square and Circular footing, equation 10 will be used.

$$q_u = 5.7c_u + q \tag{9}$$

$$q_u = 7.41c_u + q \tag{10}$$

The bearing capacity is calculated using the General Bearing Capacity. The general bearing capacity equation is used to estimate the ultimate bearing capacity of soil beneath a foundation, accounting for various factors such as soil strength, foundation shape, depth, and loading conditions. Unlike Terzaghi's simplified assumptions, the general bearing capacity equation incorporates a more comprehensive set of parameters that provide a realistic and adaptable estimation, especially for foundations with inclined loads, different shapes, and at various depths. Below is the equation for general bearing capacity.

$$q_u = c'\lambda_{cs}\lambda_{cd}\lambda_{ci} + q\lambda_{qs}\lambda_{qd}\lambda_{qi}N_q + \frac{1}{2}\lambda_{ys}\lambda_{yd}\lambda_{yi}\gamma BN_\gamma \tag{11}$$

Where:
λ_{cs}, λ_{qs}, and λ_{ys} = shape factors
λ_{cd}, λ_{qd}, and λ_{yd} = depth factors
λ_{ci}, λ_{qi}, and λ_{yi} = inclination factors

3. RESULTS AND DISCUSSION

3.1 Subsurface Soil Profile and Conditions

The characterization of the subsurface conditions at the project site was established through an in-situ soil exploration at the strategic borehole locations, primarily consisting of Standard Penetration Test (SPT), and various laboratory tests. Figures 2 to 4 show the soil profile of each borehole. The groundwater table was also measured from the three boreholes with a length of 1.5 meters from the ground level. The corrected N-values from the Standard Penetration Test differ from every layer, which ranges from 2 to 8 values. Based on the classification of the twelve (12) samples, the soil is categorized to be Clayey Silt (MH). Clayey Silt is described as brown (0-3 meters in depth) and grayish blue (3-5 meters). Clayey silt with medium plasticity was found in soft to medium stiff states at varying layers.

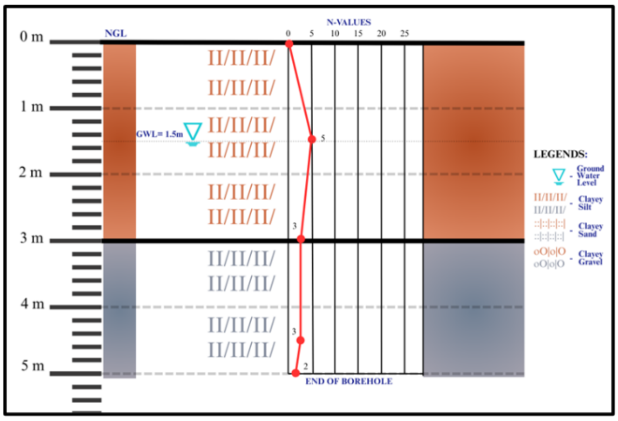

Fig. 2. Soil Profile of Borehole 1

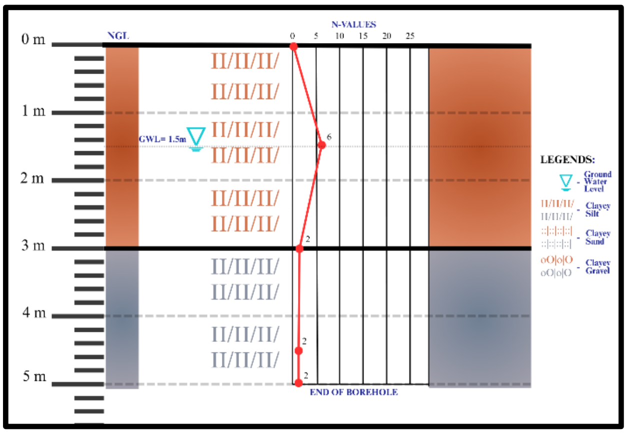

Fig. 3. Soil Profile of Borehole 2

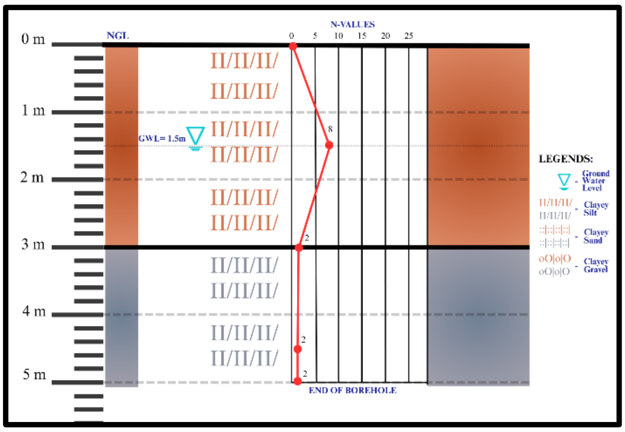

Fig. 4. Soil Profile of Borehole 3

3.2 Standard Penetration Test Data Results

The sample depth ranging from 1 meter to 5 meters, soil description, consistency of the soil, number of blows per 15 cm interval, raw N-values, and the corrected N_{60}-values accounting for the hammer efficiency and correction for sampler, rod length, and borehole diameter is based on the recommendations of Seed et al.,1985 and Skemton, 1986 [14]. Additionally, the percent recovery indicates the quality and continuity of the recovered samples during drilling.

3.3 Laboratory Test Results

3.3.1 Grain Size Analysis, Moisture Content, and Atterberg Limits Test Results

Table 1. Atterberg Limit Test Results from Borehole 1 to Borehole 3 Soil Samples

Borehole / Sample Number	Sample Depth (m)	No. 40	No. 200	Liquid Limit (LL%)	Plastic Limit (PL%)	Plasticity Index (PI%)
BH-1 SS-1	1.05 - 1.50	87.5	63.8	53.7	27	27
BH-1 SS-2	2.55 - 3.00	87.9	65.0	54.7	30	25
BH-1 SS-3	4.05 - 4.50	86.3	61.0	58.3	31	27
BH-1 SS-4	4.55 - 5.00	88.6	67.8	53.7	31	23
BH-2 SS-1	1.05 - 1.50	89.2	69.5	54.8	31	24
BH-2 SS-2	2.55 - 3.00	87.8	66.3	53.7	31	23
BH-2 SS-3	4.05 - 4.50	87.9	65.4	51.6	30	22
BH-2 SS-4	4.55 - 5.00	87.9	66.4	53.9	30	24
BH-3 SS-1	1.05 - 1.50	85.9	61.6	54.6	30	24
BH-3 SS-2	2.55 - 3.00	85.3	65.5	54.7	31	24
BH-3 SS-3	4.05 - 4.50	86.1	64.2	52.1	30	22
BH-3 SS-4	4.55 - 5.00	85.4	61.3	54.4	30	24

Using the classification system defined in ASTM D2487-17, and plotting it on the plasticity chart, the soil falls below the A-line and has a liquid limit greater than 50%, indicating that the material is of high plasticity. Therefore, the soil consists of inorganic silts of high plasticity or elastic silts. Given the notable plasticity and silt content, the sample may also be identified descriptively as silty clay, aligning with typical MH soil behavior under geotechnical evaluation.

3.3.2 Soil Classification

Table 2. Soil Classification based on USCS

Borehole No.	USCS Classification		Depth (m)		Thickness
	Abbreviation	Description	Start	End	
BH-1	ML	Clayey Silt	0.0	5.0	5.0
BH-2	ML	Clayey Silt	0.0	5.0	5.0
BH-3	ML	Clayey Silt	0.0	5.0	5.0

The table shows the soil classification for three boreholes BH-1 to BH-3 which indicates clayey slit designated by the abbreviation "ML". The classification is consistent across all boreholes with a soil layer starting from 0.0 meters up to 5 meters, resulting in a uniform thickness of 5 meters for each borehole. The soil type has low to medium compressibility and is characterized as fine particles.

3.3.3 Specific Gravity

The soil sample taken from Borehole BH-1, Sample SS-1, at a depth of 1.05–1.5 meters, classified as MH (inorganic silt of high plasticity), yielded a specific gravity of 2.675 at 27°C. When corrected to the standard reference temperature of 20°C using the appropriate temperature coefficient (0.99831), the adjusted specific gravity is 2.671. This value falls within the typical range for silt and clay soils, which is generally between 2.65 and 2.90 [15]. The result indicates that the soil contains a normal composition of mineral particles, most likely dominated by silty materials with fine-grained constituents. This specific gravity value supports the earlier classification of the soil as MH under the Unified Soil Classification System (USCS), reinforcing its inorganic nature and high plasticity behavior. The soil sample obtained from Borehole BH-2, Sample SS-1, at a depth of 1.05–1.5 meters, classified as MH (inorganic silt of high plasticity), shows a specific gravity of 2.686 at 27°C. After applying the temperature correction factor of 0.99831, the specific gravity at the standard reference temperature of 20°C is 2.681. This value is well within the typical range for silty and clayey soils, which is between 2.65–2.80 [16], suggesting a normal mineral composition, likely dominated by fine-grained silts with relatively low organic content. The consistency of this result with that from BH-1 reinforces the soil classification as MH under ASTM D2487-17, indicating a predominantly silty soil with high plasticity and confirming its expected geotechnical behavior. The soil sample taken from Borehole BH-3, Sample SS-1, at a depth of 1.05–1.5 meters, classified as MH (inorganic silt of high plasticity), yielded a specific gravity of 2.677 at 27°C. After applying the temperature correction factor of 0.99831, the adjusted specific gravity at 20°C is 2.672. This value falls within the typical range for silty and clayey soils, which is approximately 2.65 to 2.90, indicating a standard mineralogical composition commonly associated with fine-grained, inorganic silt. The result supports the classification of the soil as MH according to ASTM D2487-17, affirming the presence of a highly plastic silty material with relatively low organic content, suitable for interpretation in geotechnical design and soil behavior analysis.

3.3.4 Liquefaction Susceptibility Parameters

This section outlines the criteria used to assess the potential for soil liquefaction at the project site. Liquefaction is a seismic hazard that primarily affects loose, saturated, fine-grained soils under cyclic loading conditions. The evaluation considers soils under cyclic loading conditions. The evaluation considers soil classification, groundwater conditions, and field test data such as SPT (Standard Penetration Test) results.

There are few various ground condition criteria aside from the loose-state, water-submerged, and cohesionless soil to assess the susceptibility to liquefaction of a certain area under dynamic loads caused by seismic activity and ground shaking. These include soil composition, plasticity characteristics, and standard Penetration Test (SPT) N-values.

Table 3. Parameters and their threshold for Liquefaction Susceptibility

Parameter	Threshold for Higher Liquefaction Susceptibility	Acquired Data from the Soil Samples (Average)
Clay Fraction (less than 0.005 mm)	less than 15%	64.93%
Plasticity Index (PI)	less than 12	24
Liquid Limit (LI)	less than 35%	54.28%
Corrected N-values	less than 10	4

Based on the tabulated parameters in Table 3. The soil is not susceptible to liquefaction. The average clay fraction of the samples is 64.93%, which is significantly higher than the commonly accepted threshold of 15% for liquefiable soils. This high clay content suggests a predominance of fine-grained, cohesive particles that are typically resistant to the pore pressure buildup necessary for liquefaction. Additionally, the Plasticity Index (PI) of the soil averages 24, well above the 12% limit associated with higher liquefaction susceptibility. This further confirms that the soil exhibits moderate to high plasticity.

3.3.5 Engineering Implications

3.3.5.1 Isolated Footing

The tables presented below are the bearing capacity of isolated footings based on different interpretations. Table 4, which follows Terzaghi's bearing capacity formula, provides conservative estimates with values ranging from 39 kPa to 98 kPa. These values consider the classic bearing capacity equation, assuming simplified conditions. The results tend to decrease with increasing depth and width, possibly due to soil variability or diminishing overburden contribution. This also indicates that the depth and the width of a foundation can affect the allowable bearing capacity of the soil.

Table 4. Bearing Capacity using Terzaghi's Formula for Isolated Footing

Bearing Capacity - Terzaghi's Formula (kPa)			
	Width (m)		
Depth (m)	**1**	**2**	**3**
1	98	97	94
2	45	56	62
3	58	42	58
4	60	39	39

Table 5. General Bearing Capacity for Isolated Footing

General Bearing Capacity (kPa)			
	Width (m)		
Depth (m)	**1**	**2**	**3**
1	147	104	114
2	343	284	275
3	433	373	405
4	538	427	357

Table 6. Recommended Bearing Capacity for Isolated Footing

Recommended Bearing Capacity (kPa)			
	Width (m)		
Depth (m)	**1**	**2**	**3**
1	98	97	94
2	45	56	62
3	58	42	58
4	60	39	39

Table 5 presents the general bearing capacity, which is notably higher across all depths and widths, reaching up to 538 kPa. This method incorporates additional adjustment factors that lead to generally increasing depth capacity, suggesting improved confinement and resistance from surrounding soil.

Table 6 is identical to Table 4, indicating that the conservative estimates from Terzaghi's method were adopted as the allowable recommended values. This suggests a cautious design approach where theoretical lower-bound values were chosen to prioritize structural safety in design.

3.3.5.2 Mat Foundation

The results in Tables 7 to 9 present the computed bearing capacities for Mat foundations at varying depths and widths. Table 7 shows the values derived using Terzaghi's bearing capacity formula, which provides fundamental estimates without the inclusion of modification factors. The results here remain constant across widths, especially at greater depths, with values ranging from 57 kPa to 97 kPa.

Table 7. Bearing Capacity using Terzaghi's Formula for Mat Footing

Bearing Capacity - Terzaghi's Formula (kPa)				
	Width (m)			
Depth (m)	**5**	**10**	**15**	**20**
1	97	97	96	96
2	57	57	62	62
3	58	58	58	58
4	60	60	60	60

Table 8. General Bearing Capacity for Mat Footing

General Bearing Capacity (kPa)				
	Width (m)			
Depth (m)	**5**	**10**	**15**	**20**
1	161	292	432	572
2	256	341	464	597
3	329	365	466	584
4	211	422	478	612

Table 9. Recommended Bearing Capacity for Mat Footing

Recommended Bearing Capacity (kPa)				
	Width (m)			
Depth (m)	**5**	**10**	**15**	**20**
1	97	97	96	96
2	57	57	62	62
3	58	58	58	58
4	60	60	60	60

In contrast, Table 8 presents the general bearing capacity values, where significantly higher values are observed, reaching up to 612 kPa. These values account for shape, depth, and load inclination factors, thus representing a more realistic depiction of field behavior under complex conditions. As the width of the Mat Foundation increases, the bearing capacity also shows a substantial increase, which aligns with the benefit of larger footing areas distributing loads more effectively.

Table 9 provides the allowable recommended bearing capacities identical to those in Table 6, suggesting that the allowable capacities were conservatively adopted from Terzaghi's basic estimates. This approach implies that a factor of safety of 3 was applied to generalized bearing capacities when deriving the allowable values, ensuring structural stability and minimizing the risk of failure. Overall, the comparison highlights a design strategy that prioritizes safety, using the lower-bound capacities even when favorable computed values are available.

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

This study conducted a detailed geotechnical investigation of the Caraga State University–Main Campus to assess the subsurface soil conditions and support structural development initiatives. The results provide crucial insights into the site's geotechnical behavior, aiding in the design of safe, durable, and cost-effective infrastructure.

Field exploration, including Standard Penetration Testing (SPT) and wash boring, revealed that the subsurface soil is predominantly clayey silt (ML and MH) with varying degrees of plasticity, ranging from medium to high. Laboratory tests such as Atterberg limits, grain size analysis, specific gravity determination, and moisture content analysis further supported these classifications. Notably, the soils exhibited plasticity index values averaging 24 and liquid limits exceeding 50%, confirming their classification as inorganic silts with high plasticity.

The assessment of liquefaction susceptibility showed that the site poses minimal risk, primarily due to high clay content, moderate to high plasticity, and SPT N-values averaging above the critical threshold for liquefaction. This finding is vital for structural safety, particularly in a region exposed to seismic hazards.

Engineering evaluation using both Terzaghi's method and the general bearing capacity approach revealed allowable bearing capacities for isolated and mat footings, ranging from 39 to 98 kPa. While the general bearing capacity method yielded higher theoretical values, conservative estimates from Terzaghi's method were adopted as recommended values to ensure structural safety under varying load conditions.

The implications of this study are significant. First, it offers a site-specific geotechnical dataset that is invaluable for foundation design, minimizing the risks of differential settlement, bearing failure, and soil-structure interaction problems. Second, it contributes to the development of standardized geotechnical practices within the university, establishing a benchmark for future infrastructure planning and risk mitigation strategies. Lastly, it highlights the importance of integrating empirical field data with analytical models to develop safe and economically viable foundation solutions.

In conclusion, this investigation provides a foundational framework for ongoing and future construction projects at Caraga State University. It ensures that structural designs are grounded in reliable soil behavior predictions and aligns with engineering best practices for sustainable campus development. Continued geotechnical research and periodic reassessment of site conditions are recommended as the university grows and its infrastructure footprint expands.

4.2 Recommendations

The following recommendations are proposed to further improve the study and support better design decisions. In construction, it is recommended that all active subsurface utilities within the project location and its immediate surrounding areas be located, marked, protected, or relocated. Excavation activities during the rainy season and other unforeseen situations may require dewatering. Dewatering activities and proper drainage of surface runoff water should be ensured. Proper damp-proofing for the foundations of structures located near/along a water source should be provided, such as the use of waterproofing admixtures, use of rich concrete mix, and a low cement ratio. If Reinforced Concrete (RC) Piles are considered for the proposed structure, the selected length of the RC pile foundation must be verified by performing at least one 1 full-scale pile load test. The Pile Load Test should be performed three (3) times the design load and must be in accordance with ASTM D1143. For soil improvement, it is recommended to be applied to the entire building footprint rather than isolated locations within the area. If it chooses to improve the ground, one must consider backfilling material; the exposed surfaces should be proof-rolled or improved in compaction. For shallow foundations to be placed on overburdened soils, materials that are soft, weak, and/or loose at the excavation base level should be completely removed and backfilled with select fill material. The selected fill should be at least A-3 material in accordance to the AASHTO soil classification and should be placed and compacted in layers to at least 90% of modified proctor density. Backfilling activities require proper monitoring and adherence to procedures and standards to achieve uniform thickness, density, and water content. Field density tests may be conducted to ensure quality backfilling. For sustainable applications for foundation systems, it can be improved if manufacturing concrete is associated with high environmental and social costs due to the high energy consumption requirement that contributes to Greenhouse Gas (GHG) emissions. Additionally, the extraction of raw materials, such as aggregates, may contribute to the air and water pollution of surrounding areas. It is a highly optimized foundation design to reduce overall consumption; it is recommended to design and improve systems by reducing highly excessive regulatory specifications when applicable and optimizing element designs. Lastly, the study could be improved if the depth of each borehole were deeper; it could significantly contribute to what type of design of the foundation would fit the location. By implementing these recommendations, the reliability and performance of the proposed structure and future development of the structure can be significantly improved.

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