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Original Article

Analysis of Foundations in Building Construction through the Implementation of Eurocode EC-7

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Abstract *- During the construction of buildings, shallow foundations are often encountered for economic reasons; however, this approach is flawed and may lead to dangerous consequences for both the structure and the community at large. The bearing capacity of the foundation is one of the most critical aspects of geotechnical engineering. Loads from buildings are transmitted to the foundation through columns, load-bearing walls, or other structural components. The two fundamental criteria that must be satisfied in analyzing and designing a shallow foundation are stability and deformation requirements. The stability requirement ensures that the foundation does not experience shear failure under load, while the deformation requirement guarantees that the displacement of a structure remains within the permissible limits of the superstructure. When data on soil characteristics (such as cohesion, angle of internal friction, density, etc.) are available, the allowable bearing capacity can be calculated by considering shear failure. To design the foundations of a structure, it is essential to consider the foundation's geometric shape, depth, loads, and physical and mechanical parameters according to the cited sources. In this work, four methods are employed to calculate the bearing capacity of the soil: the Terzaghi method, the Meyerhof method, the Hansen method, and the Vesic method, applying Eurocode EC7-1997:2004 to the foundation where the entire structure acts in order to achieve the permissible safety factors according to geotechnical design standards.*

Keywords *- Method, Comparative, Physicomechanical, Parameters, Bearing capacity.*

1. Introduction

Shallow foundations are frequently used in building construction due to their lower costs and ease of installation. However, this approach can be misleading and potentially hazardous, compromising not only the structural integrity of buildings but also the safety of the surrounding community. In this context, a critical aspect of geotechnical engineering is the bearing capacity of the foundation, which determines the foundation's ability to withstand applied loads without failure. Loads from buildings are transmitted to the foundation through columns, load-bearing walls, or other structural components, making the study and analysis of foundations essential for ensuring structural stability. The design and analysis of shallow foundations require the fulfillment of two primary criteria: stability and deformation. Stability ensures that the foundation does not experience failure under applied loads, while deformation guarantees that the structure remains within acceptable displacement limits [1, 2, 5]. These criteria are crucial for ensuring a safe and durable structure, preventing potential hazards to life and property. However, despite the importance of these factors, there exists a research gap regarding the accuracy and reliability of existing bearing capacity calculation methods, especially when applied under varying geological conditions and for different foundation configurations. This gap is particularly concerning in modern engineering practice, where safety and economic efficiency requirements are increasingly stringent. Previous studies have employed various methods for calculating bearing capacity when soil characteristics-such as cohesion, internal friction angle, and density-are known [3, 4, 13]. However, these methods often exhibit inaccuracies, especially when applied to complex geological terrains characterized by variability in soil parameter values. This study aims to address this gap by employing and analyzing four well-known methods for bearing capacity calculation: Terzaghi, Meyerhof, Hansen, and Vesic [8-14, 17]. The calculations are performed in accordance with Eurocode EC7-1:2004 standards, ensuring that safety factors and modern geotechnical design practices are adhered to [18-21]. The objective of this study is to analyze and compare these methods to determine their accuracy and reliability under varying soil conditions and load scenarios. Through this analysis, the study aims to improve the reliability of bearing capacity predictions, contributing to a safer and more cost-effective foundation design. Furthermore, this study seeks to provide practical recommendations for geotechnical engineers, reinforcing the connection between theory and practice in geotechnical engineering. The contribution of this study lies in improving existing methods for calculating bearing capacity and identifying the key factors affecting their accuracy. This study also aims to offer a foundation for further research in this field, paving the way for the development of new methods applicable to more complex terrains and more intricate structural configurations.

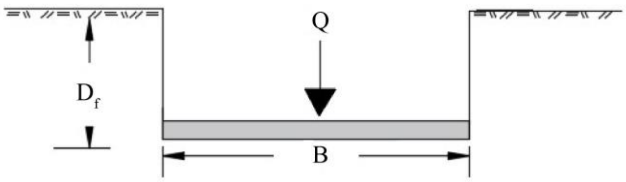

Fig. 1 The typology of foundation forms

2. Study Area

The study area designated for the facility's construction, measuring 35 m in width and 45 m in length, is located at the geographical position illustrated in Figure 2. The geological formation of this zone consists of deposits from the Nogjen formation, specifically from the Pliocene epoch. It includes clay, sands, gravelly sands, silts, and partially lignite in brown and gray colors [22]. These deposits are moderately consolidated. Physical and mechanical parameters were obtained from laboratory testing of soil samples to calculate the bearing capacity of the soil beneath the foundations. For the geomechanical investigations, seven boreholes with 146/101 mm diameters were drilled to a depth of up to 18 m. The geomechanical parameters of the soil were analyzed in the laboratory for layers at varying depths, following the ISO 9001 standard. The results of these analyses will inform the design of the foundations for the planned multi-story building.

Fig. 2 Geographical position of the object for construction

To determine the optimal parameters for the strength and deformability of soil layers, investigations were conducted using the Standard Penetration Test (SPT) method at varying depths, as presented in Table 1. During the drilling process, penetration testing was carried out according to [6, 7]. The number of blows required for penetration was recorded in the cylindrical section of the cone, which has a length of 550 mm and a diameter of 50 mm at a depth of 30.5 cm, using a weight of approximately 63.5 kg dropped from a height of about 76.3 cm. In cases where the standard penetration depth of 30.5 cm was not achieved, the number of blows was determined according to Equation (1). When the SPT is applied using a cone instead of a cylinder, the number of blows (N) is adjusted by a correction factor of 0.75, as specified in Equation (2). The correction for vertical geological weight is applied according to the following relationship in Equation (3), where Cn represents the parameter read from the diagram.

$$\mathrm{N} = 30.4 \cdot \mathrm{N}'/e \tag{1}$$

$$\mathrm{N_{cor}} = 0.75 \cdot \mathrm{N}' \tag{2}$$

$$\mathrm{N}'' = \mathrm{C_n} \cdot \mathrm{N_{cor}} \tag{3}$$

3. Materials and Methods

The research was conducted using a rotary drilling platform with a Ø 146/101 mm diameter, as shown in Figure 3. The materials utilized for geomechanical testing included soil samples, as outlined in Table 2, collected from geological-geomechanical boreholes at depths of up to 18 meters. The analysis standards were based on procedures established by the ASTM standard, which provides a framework for conducting geomechanical tests. During the study, the Standard Penetration Test (SPT) method was employed, following Equations (1), (2), and (3). The research process encompassed several phases, beginning with systematic sample collection to ensure that the obtained data were accurate and reliable. After sample collection, as illustrated in Figure 4, the samples were analyzed in the Geomechanics Laboratory [3] using standard sieving techniques. The analysis results generated grain size distribution diagrams, as shown in Figures 5 and 6. The liquid limit was determined using Casagrande's method, according to Figures 11 and 12, while strength parameters were derived from direct shear tests Figure 8 and triaxial tests Figure 9. To calculate the bearing capacity of the foundation, four methods were utilized: Terzaghi, Meyerhof, Hansen, and Vesic, according to Equations (4-7), to improve safety factors in compliance with the Eurocode EC7. The analysis of results was supported by visualizations presented in Figures (3-9), which illustrate the methods and testing processes. Settlement calculations were performed in accordance with load conditions using Settle 3D according to [11]. The results are presented in Figures 11 and 12, based on the calculation of loads at the Foundation Depth (Df), with bearing capacities detailed in (Tables 4-7). Furthermore, as shown in Figure 14, the results based on the applied methods are presented, taking into account the geomechanical parameters of the foundation structure. This systematic approach ensures a comprehensive and reliable analysis of the geomechanical characteristics of the tested materials.

3.1. Statistical Methods

To interpret and analyze the laboratory data, statistical methods were employed, including Analysis of Variance (ANOVA) and linear regression, to identify the relationships between soil characteristics and the bearing capacity of the foundation. Additionally, reliability tests, such as confidence intervals and t-tests, were conducted to ensure that the results were consistent and statistically reliable, according to [23-25]. The grain size distribution data were analyzed using grain size curves, and parameters such as cohesion and internal friction angle were analyzed through linear regression to identify their impact on bearing capacity. This structured statistical approach ensures a comprehensive and reliable analysis of the geomechanical characteristics of the tested materials, enhancing the scientific rigor and reliability of the study's findings.

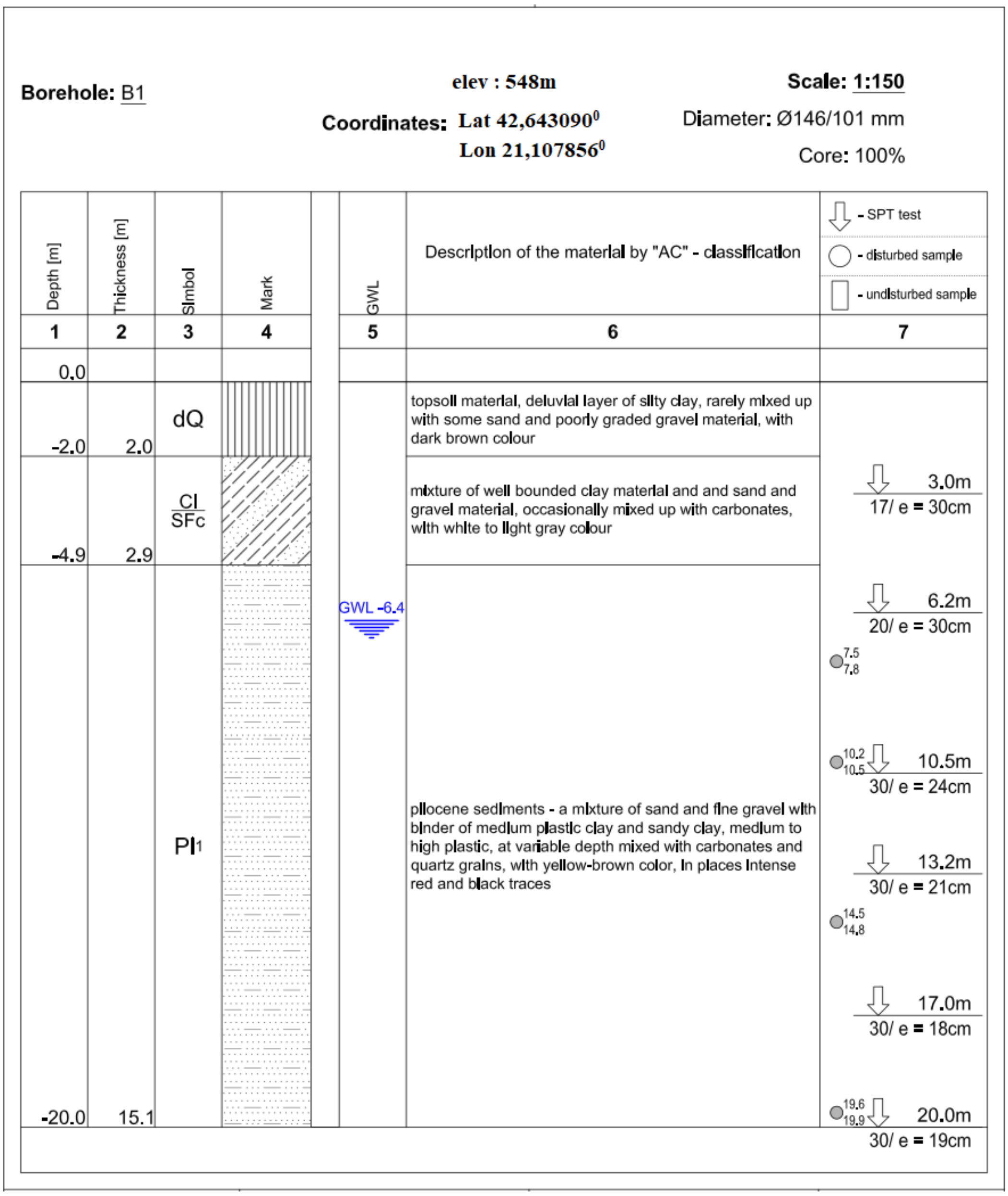

Fig. 3 Geological-geomechanical drilling

Fig. 4 Presentation of drilling samples

Table 1. Results of standard dynamic penetration test (SPT)

Shpimi	Thellësia e shpimit (m)	Numri i goditjeve (e-cm) N	Numri proporcoional i goditjeve (e=30.5cm)	Korelacioni i pjesës konike (0.75 N)	Koeficienti i korrelacionit Cn	Korelacioni i peshës vertikale N_v=C_n*(0.75) N	Korelacioni në nivel të ujit nëntokësore N_v'	E pranuar N_{SPT}
B-1	3.0	17	30	17	17	1.12	19	19
B- 1	6.2	20	30	20	20	0.93	19	19
B-1	10.5	30	24	38	29	0.75	22	22
B-1	13.2	30	21	44	33	0.68	22	22
B-1	17.0	30	18	51	51	0.60	31	31
B-1	20	30	19	48	48	0.56	27	27
B-3	3.5	17	30	17	17	1.09	19	19
B-3	6.5	30	20	46	34	0.92	31	31
B-3	9.0	30	23	40	30	0.81	24	24
B-3	15.2	30	17	54	40	0.63	26	26
B-4	5.0	22	30	22	22	1.00	22	27
B-4	8.2	30	21	44	33	0.84	27	27
B-4	11.4	30	23	40	30	0.73	22	22
B-4	14.0	30	22	42	31	0.66	21	21
B-4	17.1	30	18	51	38	0.60	23	23
B-4	20.0	30	20	46	46	0.56	25	25
B-5	4.0	19	30	19	19	1.06	20	20
B-5	8.0	30	27	34	25	0.85	22	22
B-5	12.0	30	24	38	29	0.71	20	20
B-5	16.2	30	22	42	31	0.61	19	19
B-5	18.0	30	18	51	38	0.58	22	22
B-6	4.0	20	30	20	20	1.06	22	22
B-6	7.0	25	30	25	25	0.89	23	20
B-6	10.2	30	26	35	26	0.76	20	20
B-6	13.3	30	21	44	33	0.67	22	22
B-7	3.0	18	30	18	18	1.12	21	21
B-7	6.2	30	21	44	33	0.93	30	30
B-7	17.6	30	25	37	37	0.71	26	26

$$q_u = c\,Nc\left(1 + 0.3\frac{B}{L}\right) + \gamma\, D_f\, N_q + 0.5\,\gamma'\, B\, N_\gamma\left(1 - 0.2\frac{B}{L}\right) \quad (4)$$

$$q_{ult} = c'\, N_c\; F_{cd}\, F_{ci} + q\, N_q\, F_{qd}\; F_{qi} + 0.5\,\gamma\, B' N_\gamma\, F_{\gamma d}\, F_{d\gamma}\, F_{\gamma i} \quad (5)$$

N_c, N_q, N_γ, - Bearing capacity factors
C- cohesion of the soil
γ -the unit weight of soil
D_f - foundation depth
B - width of the footing
L-length
S_c,S_q,S_γ - shape faktors
i_c,i_q,i_γ, - inclination factors
d_c,d_q ,d_γ - Depth factors
F_{cc}, F_{qc},$F_{\gamma d}$ are soil compressibility factors.
F_{qs}, F_γ scontinuous foundation
F_{qi},$F_{\gamma i}$ vertical centric loading

$$q_{ult} = c\, N_c\, F_{sc}\, F_{dc}\, F_{ic} + D_f\gamma\, N_q\, F_{sq}\, F_{dq}\, F_{iq} + 0.4\,\gamma\, BN_\gamma\, F_{s\gamma}\, F_{d\gamma}\, F_{i\gamma} \quad (6)$$

$$q_{ult} = c'\, N_c\, F_{cs}\, F_{cd}\, F_{cc} + q\, N_q\, F_{qs}\, F_{qd}\, F_{qc} + \frac{1}{2}\,\gamma\, BN_\gamma\, F_{\gamma s}\, F_{\gamma d}\, F_{\gamma c} \quad (7)$$

$$C_d = \frac{C_u}{\gamma_{c\prime}} \quad (8)$$

$$\varphi_d = \tan^{-1}\left(\frac{tg\varphi'}{\gamma_{\varphi\prime}}\right) \quad (9)$$

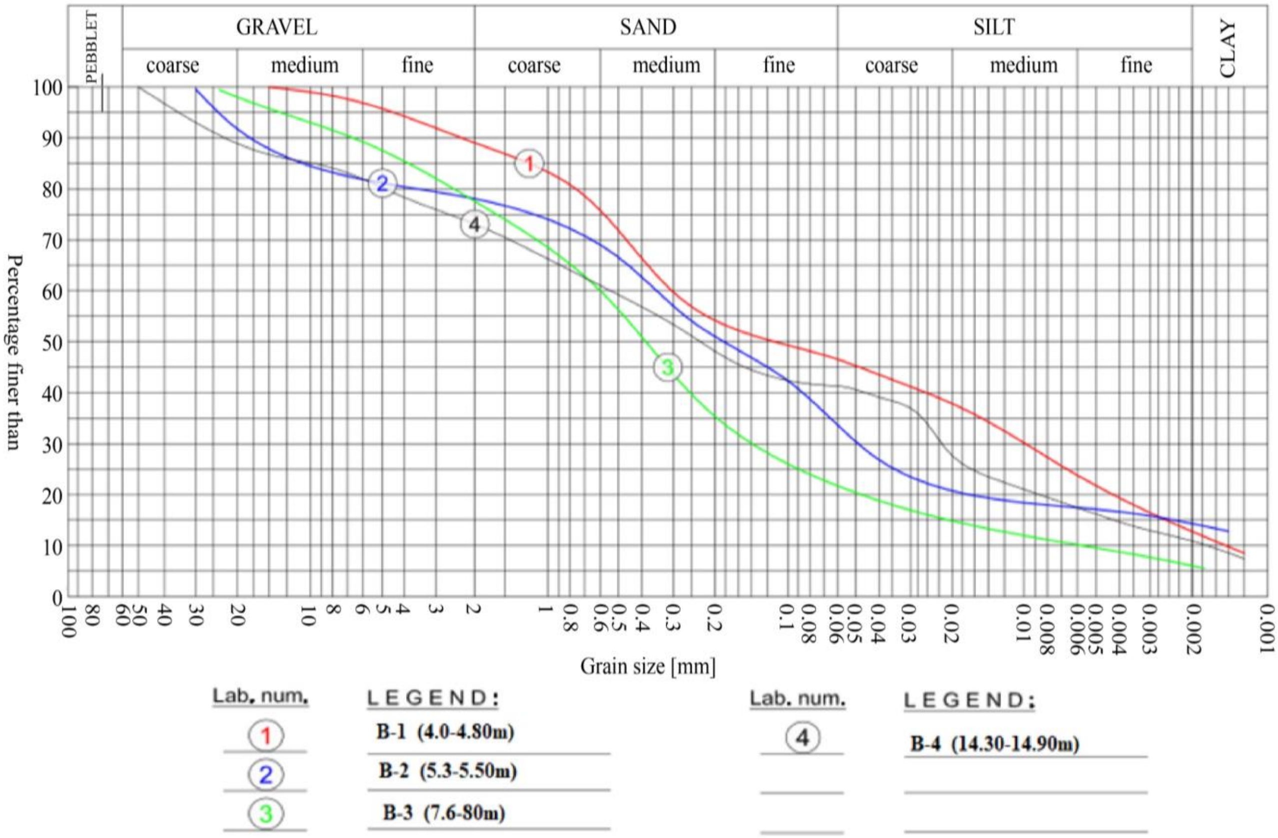

Fig. 5 Results of the grain size distribution curve for drilling B-1 to B-4

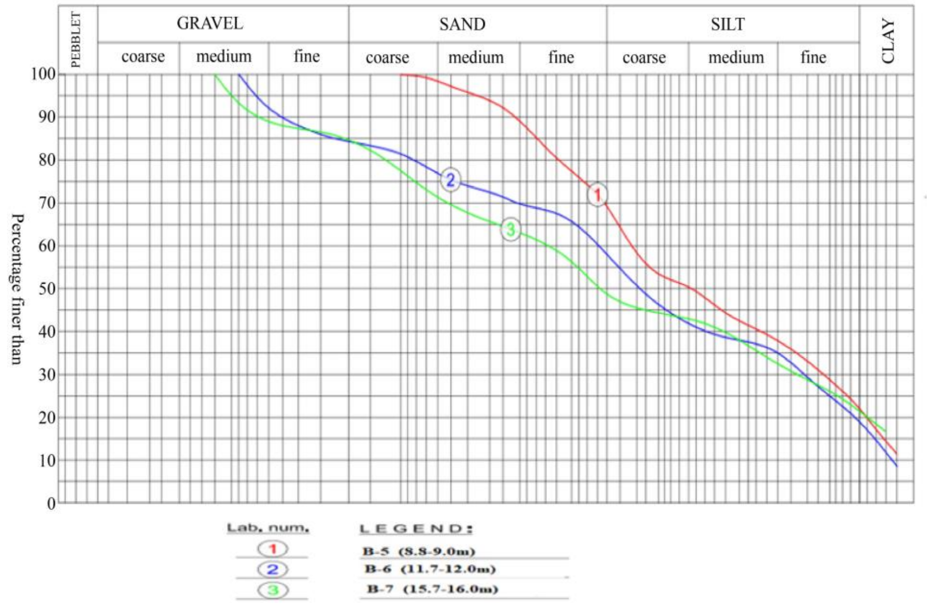

Fig. 6 Results of the grain size distribution curve for drilling B-5 to B-7

P [kPa]	Reading [mm]	$\varepsilon = \frac{\Delta h}{h}$	$h\text{-}h_0\text{-}h'$ [cm]	e	$M_{v(oed)}$ [kPa]	h=1.8[cm]
0	10.00	0	0.658	0.577	-	D=7.62 [cm]
50	9.68	0.0183	0.625	0.548	2728	γ_s=26.7 [kN/m³]
100	9.46	0.0306	0.603	0.531	4091	W_1=163.3 g
200	9.16	0.0461	0.578	0.504	6428	W_2=165.2 g
400	8.78	0.0689	0.534	0.468	8788	A=45.60 cm³
						Wd=138.9g
						V=82.09 cm³
						h_0=1.141cm
						w_1=17.57%
						w_2=18.93%
						γ=19.89 kN/m³

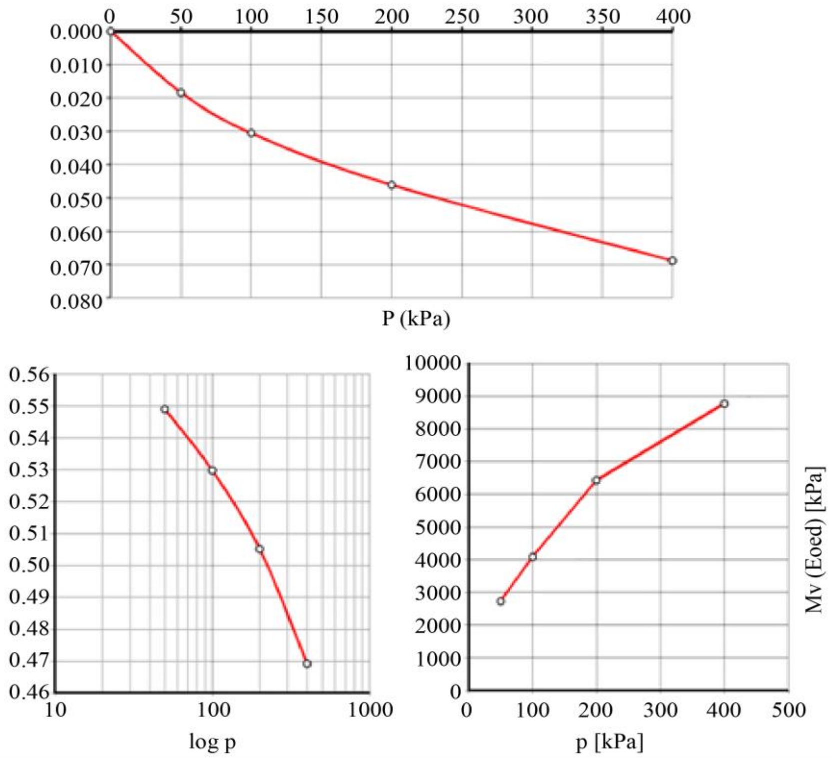

Fig. 7 Assignment of the shear modulus Mv[kPa]

moisture before examination	ω =	17.22 %
bulk density in natural condition	γ =	19.89 kN/m^3
bulk density in dry condition	γ_d =	16.97 kN/m^3

tan	φ =	0.408
angle of internal friction	φ =	22.18 °
cohesion	c =	12.45 kPa

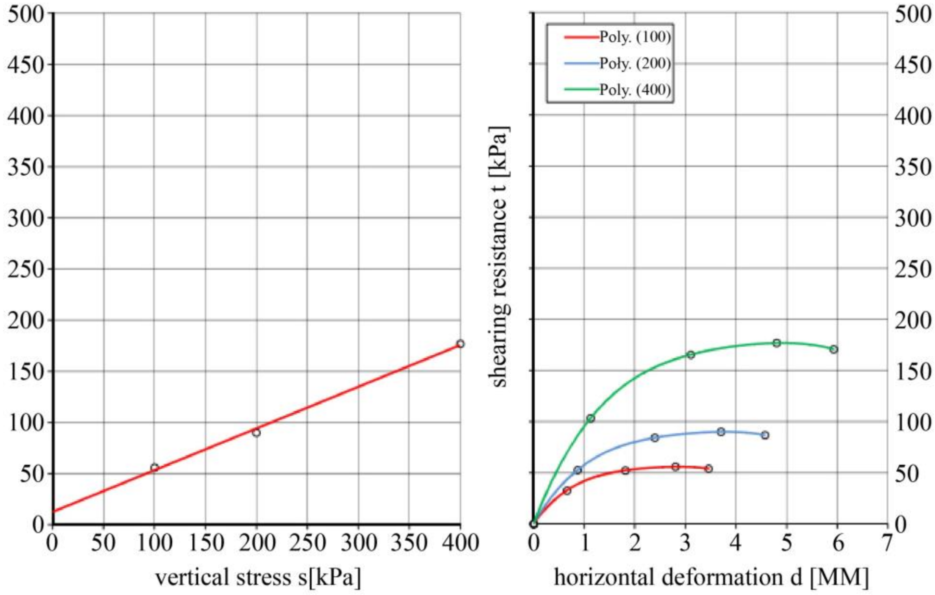

Fig. 8 Direc shear test

Test 1		Test 2		Test 3	
σ_1 kPa	225	σ_1	396	σ_1	583
σ_3 kPa	100	σ_3	196	σ_3	293

φ =	16.49	°
C =	18.00	kPa

Mohr's circle for undrained triaxial test

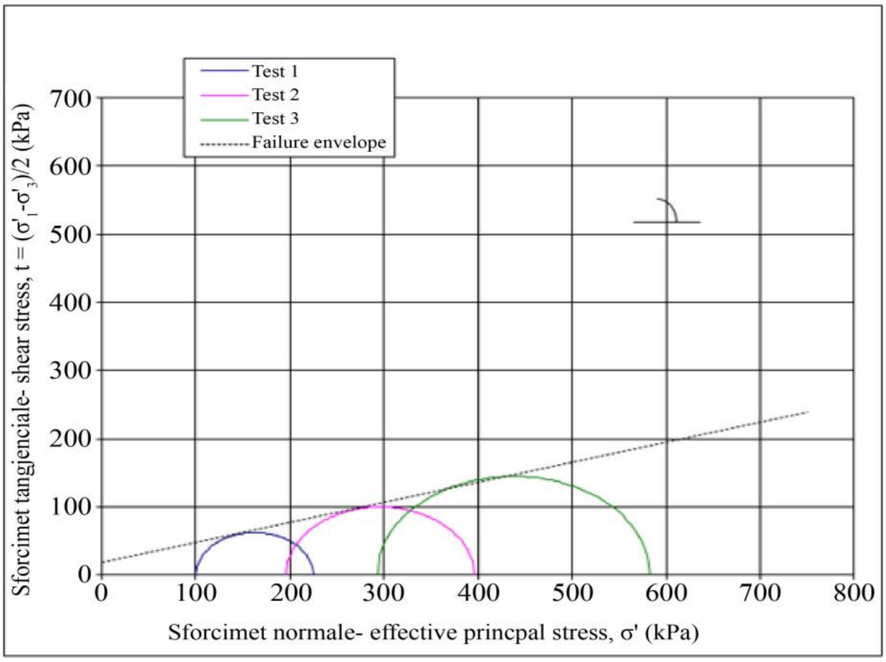

Fig. 9 Triaxial test

Table 2. Physical-mechanical parameters

γ Unit weight of soil	[18.-25] kN/m^3
φ^0 friction angle	[16^0-23^0]
C cohesion of the soil	[12-18] kN/m^2

Table 3. Atterberg limits and indexes

Point	Sounding Borehole (depth m)	LL%	PL%	PI %	W %	CI%	Sign According to AC-Classification
1	B_1(4.00-4.80)	35.79	18.20	17.56	17.22	1.06	CI
2	B2(5.3-5.50)	37.63	16.23	21.40	14.72	1.07	CI
3	B3 7.6-8.00)	36.12	17.32	18.80	16.29	1.06	CI
4	B3(9.30-9.70)	40.27	16.12	24.15	15.17	1.04	CI
5	B4(6.0-6.50)	48.58	21.24	27.34	20.22	1.04	CI
6	B4(14.30-14.90)	50.22	20.48	29.74	21.21	0.98	CH-CI
7	B5(5.60-6.0)	51.44	24.32	27.12	23.82	1.02	CH-CI
8	B5(12.30-12.60)	42.12	15.24	26.88	15.28	1.0	CI

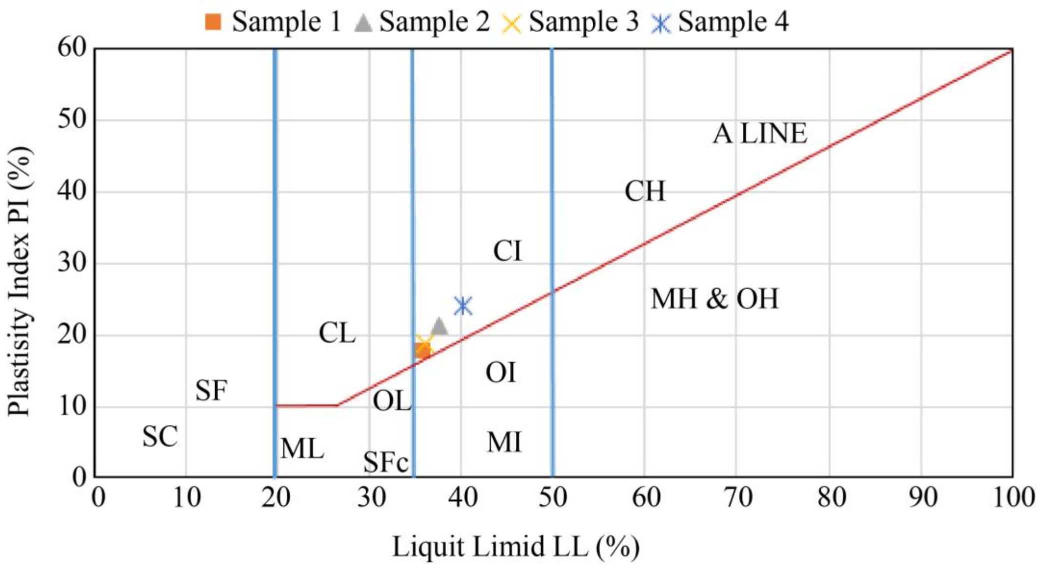

Fig. 10 Diagram of plasticity for borehole (B_1-B_3)

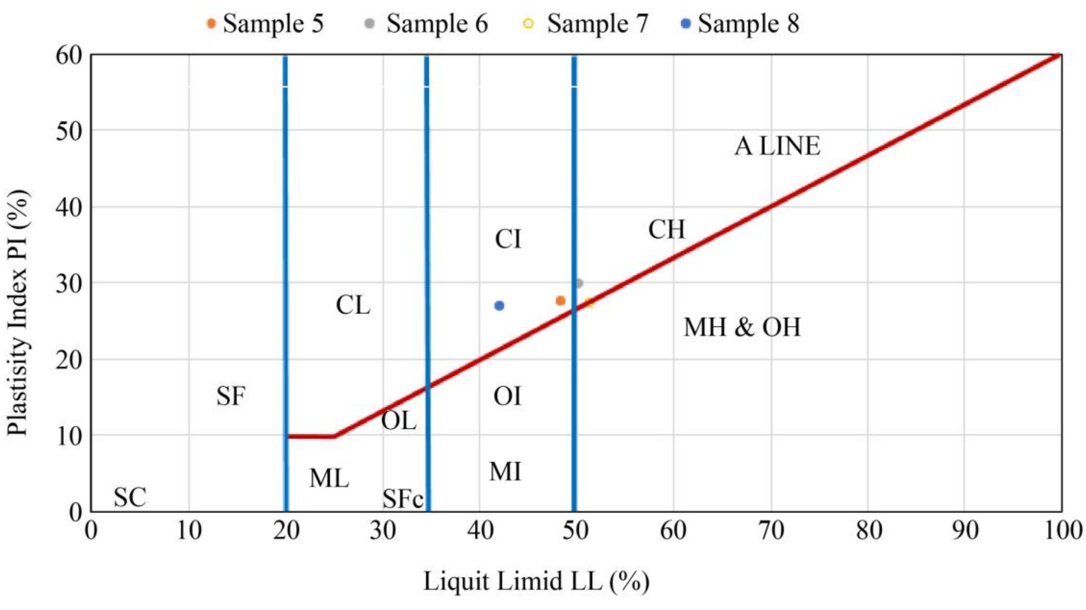

Fig. 11 Diagram of plasticity for borehole (B_4-B_5)

4. Results

The soil samples were analyzed for grain size distribution, revealing a typical particle distribution, as presented in the respective diagrams (Figures 5 and 6). This grain size analysis is a critical component in assessing the mechanical properties of the soil, as it helps identify the particles' structure and classify different soil materials into similar categories. The results from this test suggest a distribution consistent with typical soil characteristics, making it suitable for construction purposes under specific conditions. The liquidity limit, one of the key parameters for evaluating soil stability under moisture conditions, was determined using Casagrande's method, a standard and widely accepted technique for determining this value. This test is of particular significance as it helps define the potential boundaries for changes in soil consistency under wet conditions and can indicate possible signs of destabilization in the materials. The results of this analysis are shown in Figures 11 and 12, providing a clear overview of the stability characteristics of the tested materials. Classical geotechnical methods, such as those proposed by Terzaghi, Meyerhof, Hansen, and Vesic, were employed to evaluate the bearing capacity of the soil. These methods are well-established and verified through extensive applications and provide a reliable assessment of the soil's bearing capacity by taking into account its mechanical and physical properties. Bearing capacity evaluation is crucial to ensure that the designed structure can withstand the anticipated loads without compromising safety. The bearing capacity assessments are illustrated through Equations (4)-(7), which summarize the applied methodology and the impact of various parameters on the soil's bearing performance. Regarding the safety factors, these were increased in accordance with the Eurocode EC7, which serves as an internationally recognized standard for the design of safe and durable structures. An increase in safety factors is a common practice that accounts for potential uncertainties related to soil conditions or variations in applied loads. In this way, it has been ensured that the structure can bear the maximum anticipated loads without risk of failure. The definition of safety factors was carried out based on the previously discussed geomechanical analyses and methodology. Settlement calculations, which were performed using the Settle 3D software, provided reliable and valid results for assessing the possible settlement of structures. This software allows for advanced simulation of the soil's behavior under both dynamic and static load conditions, contributing to the long-term stability and safety of the structure. The results of these calculations are presented in the respective figures (Figures 11 and 12), which clearly represent the predicted settlement under the expected loads. The bearing capacity q_{all} evaluated in accordance with the geomechanical parameters of the materials under analysis. This evaluation was based on a detailed analysis of cohesion, friction angles, and loading conditions, all of which are presented comprehensively in Tables 5, 6, 7, and 8. The determination of the bearing capacity is closely related to the mechanical properties of the soil and is a critical factor in ensuring the safety of the construction project.

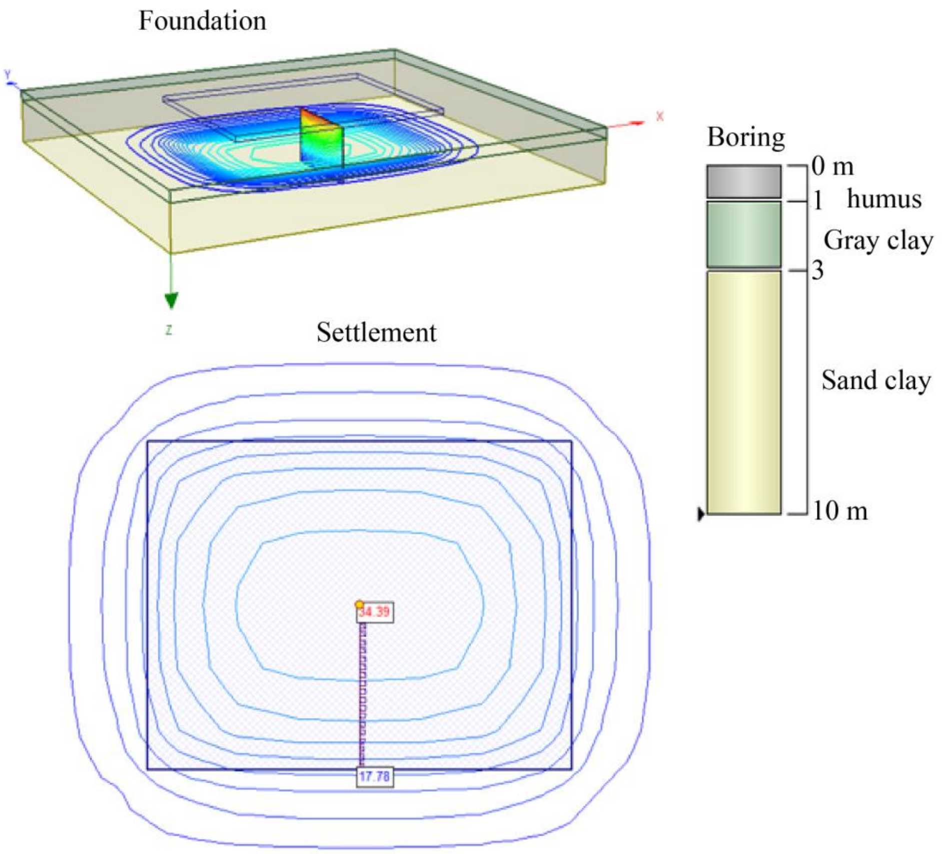

Fig. 12 Presentation of settlements according to the depth of settlement settle 3D (2022)

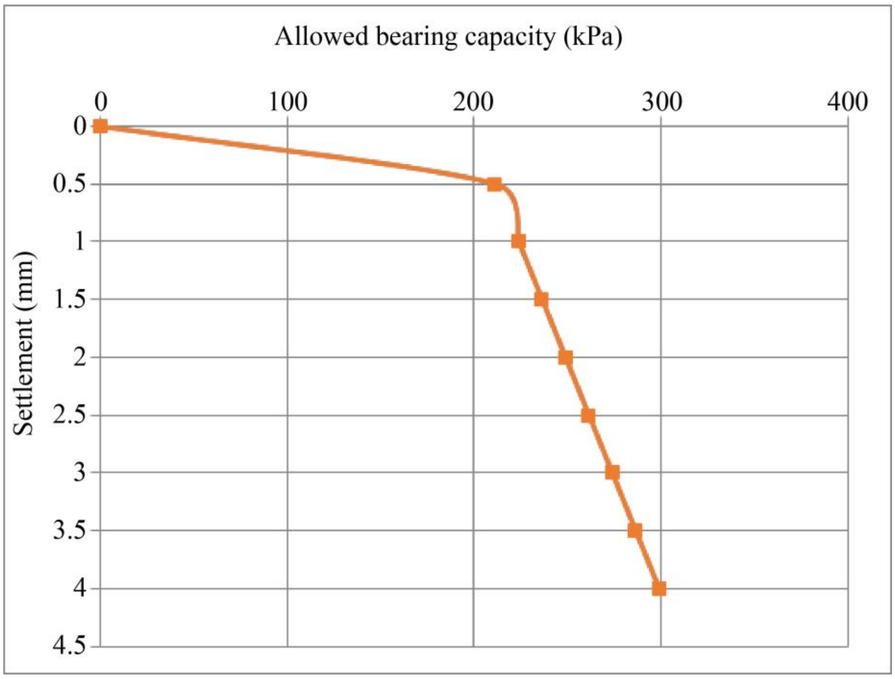

Fig. 13 Settlements according to loads

Table 4. Calculation of bearing capacity according Terzagh method

Depth	Dimension of Foundation		Bearing Capacity	The Safety Factor	Allowed Bearing Capacity
Df (m)	B(m)	L(m)	q_{ult} [kPa]	Fs	q_{all} [kPa]
1.0	24	34	525.96	3	175.32
1.5	24	34	560.49	3	186.83
2.0	24	34	595.02	3	198.34
2.5	24	34	629.54	3	209.85
3.0	24	34	664.07	3	221.36
3.5	24	34	698.60	3	232.87
4.0	24	34	733.13	3	244.38
4.5	24	34	767.66	3	255.89
5.0	24	34	802.19	3	267.40
5.5	24	34	836.72	3	278.91
6.0	24	34	871.25	3	290.42

Table 5. Calculation of bearing capacity according Meyerhof method

Depth	Dimension of Foundation		Bearing Capacity	The Safety Factor	Allowed Bearing Capacity
Df (m)	B(m)	L(m)	q_{ult} [kPa]	Fs	q_{all} [kPa]
1.0	24	34	380.17	3	126.72
1.5	24	34	416.22	3	138.74
2.0	24	34	452.44	3	150.81
2.5	24	34	488.84	3	162.94
3.0	24	34	525.43	3	175.14
3.5	24	34	562.20	3	187.4
4.0	24	34	599.14	3	199.71
4.5	24	34	636.27	3	212.09
5.0	24	34	673.58	3	224.52
5.5	24	34	711.07	3	237.02
6.0	24	34	748.73	3	249.75

Table 6. Calculation of bearing capacity according Brinch Hansen's method

Depth	Dimension of Foundation		Bearing Capacity	The Safety Factor	Allowed Bearing Capacity
Df (m)	B(m)	L(m)	q_{ult} [kPa]	Fs	q_{all} [kPa]
1.0	24	34	207.52	3	69.17
1.5	24	34	246.24	3	82.08
2.0	24	34	285.62	3	95.20
2.5	24	34	325.66	3	108.55
3.0	24	34	366.35	3	122.11
3.5	24	34	407.71	3	135.90
4.0	24	34	449.72	3	149.90
4.5	24	34	492.39	3	164.13
5.0	24	34	535.73	3	178.57
5.5	24	34	579.72	3	193.24
6.0	24	34	624.36	3	208.12

Table 7. Calculation of bearing capacity according Vesic method

Depth	Dimension of Foundation		Bearing Capacity	The Safety Factor	Allowed Bearing Capacity
Df (m)	B(m)	L(m)	q_{ult} [kPa]	Fs	q_{all} [kPa]
1.0	24	34	213.54	3	71.18
1.5	24	34	252.26	3	84.08
2.0	24	34	291.63	3	97.21
2.5	24	34	331.67	3	110.55
3.0	24	34	372.37	3	124.12
3.5	24	34	413.72	3	137.90
4.0	24	34	455.74	3	151.91
4.5	24	34	498.41	3	166.13
5.0	24	34	541.74	3	180.58
5.5	24	34	585.73	3	195.24
6.0	24	34	630.38	3	210.12

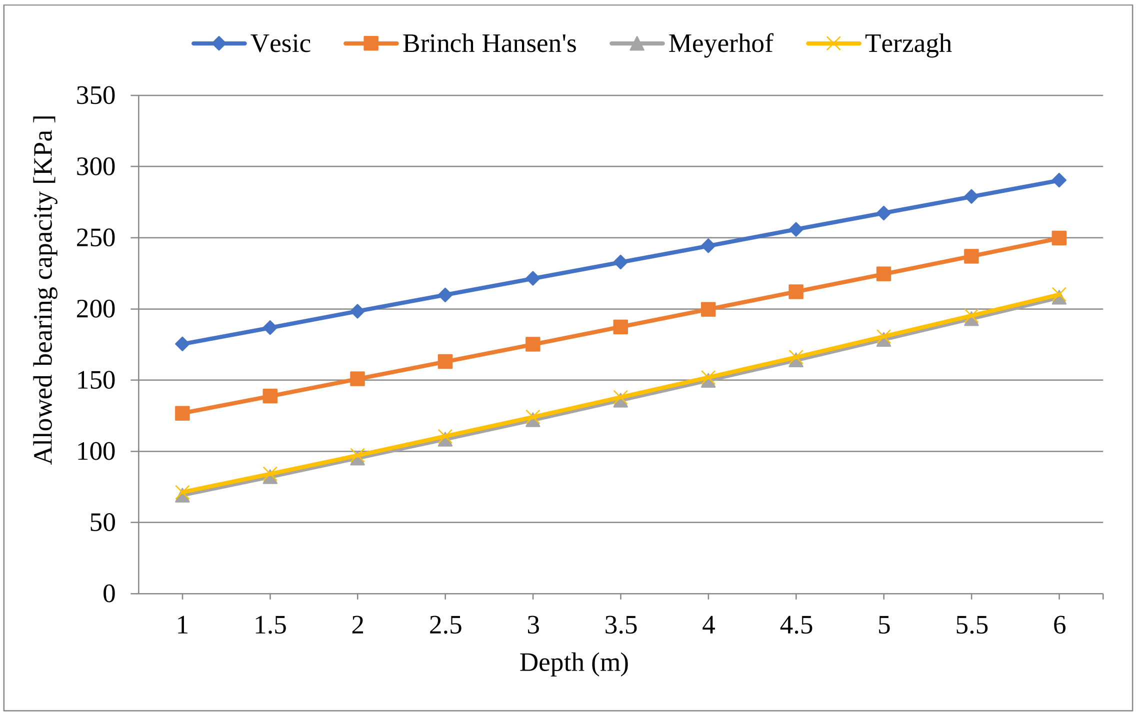

Fig. 14 Presentation of results according to method

5. Conclusion

This study provides a comprehensive and reliable analysis of the geomechanical properties of the tested materials, significantly contributing to the foundation design process. The bearing capacity of the foundation meets the safety requirements established by international standards, ensuring that the structure remains stable under the anticipated loads. The test was conducted in accordance with ASTM D1586 and EN ISO 22476-3 standards, using a metal tube and a standard weight of 63.5 kg, dropped from a height of 76 cm. The number of blows required to advance the probe by a distance of 30.5 cm was recorded and used to evaluate the soil's bearing capacity. In this study, four primary methods for calculating the bearing capacity of foundations were analyzed: Terzaghi's method, Meyerhof's method, Hansen's method, and Vesic's method. Based on the calculations and analyses performed, Terzaghi's method is the most reliable and cost-effective for assessing the bearing capacity of foundations.

This method yields higher bearing capacity values and ensures a high level of structural stability without significantly increasing construction costs. Due to these characteristics, Terzaghi's method is recommended as the primary approach for projects with standard geotechnical and structural requirements. In cases where specific soil conditions affect the calculations, Meyerhof's method presents a viable alternative, offering a high level of safety while maintaining a balance between reliability and cost. Hansen's and Vesic's methods are also valid options; however, they provide more conservative results and are recommended for projects with stricter safety requirements or when geotechnical conditions significantly deviate from standard assumptions. Given the importance of accuracy in bearing capacity calculations, a more detailed comparative analysis of these methods is recommended. Such an analysis would facilitate the selection of the most appropriate method for varying soil conditions and structural load requirements, thereby optimizing safety factors and project costs. In conclusion, based on the results of this study, continuous monitoring of geomechanical conditions during both the construction phase and post-construction is strongly recommended. This practice is essential for ensuring the structure's long-term stability and addressing potential changes in soil characteristics that may impact the safety and durability of the foundation.

Acknowledgements

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