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Assessment of Geotechnical Properties of Settlement Area Soil: A Case Study of Burdur Province, Türkiye

İ. İskender SOYASLAN[1*], Servet CEVNİ[2]

[1]Burdur Mehmet Akif Ersoy University, Faculty of Engineering and Architecture, Department of Civil Engineering, Burdur, Türkiye, ORCID: 0000-0001-5282-8094.

[2]Burdur Mehmet Akif Ersoy University, Faculty of Science Depertment of Materials Engineering, Burdur, Türkiye

ABSTRACT: The Türkiye Earthquake Zones Map shows that Burdur's core, in a first-degree earthquake zone, has suffered catastrophic earthquakes that killed and damaged people. To reduce earthquake damage, soil geotechnical attributes must be accurately assessed and structures built in accordance with ground dynamics. This study will determine the physical and mechanical properties of the soils in Burdur city center's urban settlement region and estimate structural concerns using geotechnical data. The research region was uniformly characterised by soil borings at 28 places to a depth of 300 metres, along with Standard Penetration Tests. Following Turkish Standards Institute guidelines, disturbed (D) and undisturbed (UD) drilling samples were tested for unit weight, water content, sieve analysis, Atterberg limits, and shear box tests. USCS-based soil classifications and Terzaghi-based bearing capacity calculations were used. The research findings indicate that the prevailing soil profile in the study region is predominantly categorised as inorganic clay, clayey gravel, and silty clay, with a majority of low- to medium-plasticity clay (CL). The flexible nature of this dominant soil may increase ground amplification during an earthquake. Conversely, it has been noted that the sand content in the soil of specific areas within the Bağlar, Karasenir, and Bahçelievler neighbourhoods is considerably elevated; it has been established that these regions possess a substantial liquefaction potential due to water absorption and the increase in groundwater levels. The research underscores the imperative of site-specific ground enhancement measures and foundation drainage systems for secure building.

KEYWORDS: Burdur, soil classification, bearing capacity, geotechnical properties

1. INTRODUCTION

Türkiye, positioned atop active tectonic bands, has historically experienced catastrophic earthquakes. The core district of Burdur, one of the districts most impacted by seismic activity, is designated as a first-degree earthquake zone according to the Türkiye Earthquake Zones Map [1]. The earthquakes that transpired in the region in 1914 and 1971 inflicted extensive damage and considerable loss of life. Given the swiftly growing population and the demand for development, it is essential to precisely ascertain the ground parameters in areas impacted by earthquake-generating fault lines to guarantee secure and cost-effective urbanisation.

The seismic activity of Burdur and its vicinity is predominantly influenced by the Isparta Angle and the Fethiye-Burdur Fault Zone, which delineate the convergence area of the Aegean Arc and the Cyprus Arc. The left-lateral oblique-slip fault zone, approximately 300 km in length, extends from the Gulf of Fethiye to Lake Burdur and is the primary source of seismic activity in the region [2] [3]. Western Anatolia is clearly diverging from Central Anatolia along the Fethiye-Burdur fault zone and the Eskişehir fault zone. The velocity of the westward displacement of the Western Anatolia block escalates from north to south [4]. The detrimental effects of earthquakes are strongly correlated not only with the fault's size or the focus's depth but also with the geotechnical characteristics of the soil strata traversed by the seismic waves.

The geological structure of the region reveals that the Burdur basin is predominantly composed of Neogene-aged freshwater sediments and Quaternary-aged alluvial deposits [2]. Recent engineering geology studies indicate that the wide regions designated as "alluvium" in Burdur's city centre consist of lake-derived soils characterised by elevated clay and silt content, exemplifying the Burdur Formation [3, 4]. These fine-grained soils, characterised by freshwater sediments, display soft and malleable characteristics; they exhibit a low to moderate propensity for swelling in response to variations in water content [4].

The pliable and malleable characteristics of the soil can markedly augment the "earthquake amplification" effect by elevating the amplitude of seismic waves during a probable earthquake [1]. Furthermore, the elevated shallow groundwater level and significant sand composition in certain regions present a risk of soil liquefaction during earthquake events. The adverse characteristics of soil behaviour may result in settlement issues and shear failures in building foundations [5, 6].

This study aims to ascertain the lithological, physical, and mechanical qualities of the soils in the Burdur city centre settlement region, considering the geological and tectonic dangers, by comprehensive field and laboratory investigations [10]. Soil-bearing capacity analyses were performed utilising data from representative points of the city, and geotechnical evaluations for safe construction were provided.

2. MATERIALS AND METHODS

This study involved comprehensive field and laboratory investigations, as well as theoretical analyses, to ascertain the geotechnical characteristics and structural bearing capacities of the primary soil units in the urban settlement area of Burdur city centre.

2.1. Field Investigations and SPT

SPT was initially established in 1927 and has been extensively utilised, particularly in North America, South America, and Japan [7]. It is a straightforward and cost-effective test commonly employed to ascertain the characteristics of soils in situ. Subsequent years saw the standardisation of SPT by the American Society for Testing and Materials (ASTM) in 1958, prompted by its increased utilisation. Initially issued by ASTM under the standard number ASTM D1586, it has undergone several revisions to date [12] [13] [14][8].

The Standard Penetration Test (SPT) is the most often employed field test in soil investigation research. The rationale for favouring SPT includes acquiring data on the soil's mechanical properties, extracting soil samples, calculating bearing capacity, and its cost-effectiveness and simplicity of use. One of the primary advantages of SPT is its applicability in contexts where undisturbed samples are challenging to get, particularly in rotary drilling and sandy and silty conditions and when soil properties are compromised owing to disturbance. The limitation of SPT is that it yields inaccurate findings in clays and silts, and it fails to accurately represent the subtle variations in the soil profile [7].

SPT is the predominant and acknowledged technique in penetration testing for assessing subsurface conditions and evaluating the bearing capability of cohesionless soils. During the drilling of a borehole using the Standard Penetration Test (SPT), data regarding the soil's resistance to penetration is acquired, and concurrently, a soil sample can be collected [9]. SPT is a widely employed technique in soil research within our nation for acquiring soil samples and determining bearing capacity based on test outcomes.

Equations have been established based on SPT test outcomes utilising soil parameters specified as undrained shear strength (qc), internal friction angle (ϕ), relative density (Dr), and unit weight (γ). These equations are employed to determine bearing capacity and stress unit deformation. The formulation and efficacy of these equations have been determined using the number of blows (N) derived from the SPT test. The N impact number is transformed into the N60 corrected impact number as specified in Equation 1.

$$N_{60} = \frac{E_m x\, C_B x\, C_R x C_S x N}{0.60} \quad (1)$$

N60 represents the modified N value for field research, Em denotes the hammer efficiency, CB indicates the modification for borehole diameter, CR signifies the correction for drill rod length, and N refers to the recorded SPT value.

To perform a comprehensive analysis of the soil profile in the research area, soil foundation drilling wells have been established at 28 distinct places, achieving a total depth of 300 metres, which uniformly represents the region (Figure 1). During the field drilling, a Standard Penetration Test (SPT) was conducted on-site to ascertain the density or consistency of the soil strata, delineate layer borders, and identify the shallow groundwater level [10].

Figure 1. Drilling of a borehole for soil investigation.

In SPT applications, it is acknowledged that in instances of hard ground, when no advancement occurs after 50 blows during the 15 cm driving procedure, the test is concluded, resulting in the attainment of the refusal (red) value. During the drilling operations, disturbed (D) soil samples were collected using a Shelby tube, along with undisturbed (UD) soil samples from suitable depths for laboratory tests (Figure 2).

Figure 2. Shelby tube used to collect disturbed soil sample from borehole.

The SPT applications performed in the study adhered to TS-5744 criteria. As per TS-5744, the procedure involves driving a standard penetrometer, weighing 63.5 kg, into the ground by releasing it from a height of 76.2 cm. The SPT must be advanced to the designated depth for execution. The portion of the equipment above the ground is delineated into three segments at 15 cm intervals. A 63.5 kg hammer is dropped from a height of 76.2 cm onto the pipe, and the number of blows required for the point to penetrate 15 cm is measured and documented. The frequency of strikes escalates on rigid surfaces. As the terrain becomes more pliable, the frequency of blows diminishes. The procedure of pushing the tube into the earth is finalised with three 15 cm strokes, amounting to a total of 45 cm. The initial 15 cm of blows are disregarded. The initial 15 cm of penetration is designated as the settling phase. The total number of strikes for the second and third 15 cm penetrations is calculated. The standard penetration number is the cumulative amount of these 30 cm strokes (Figure 3).

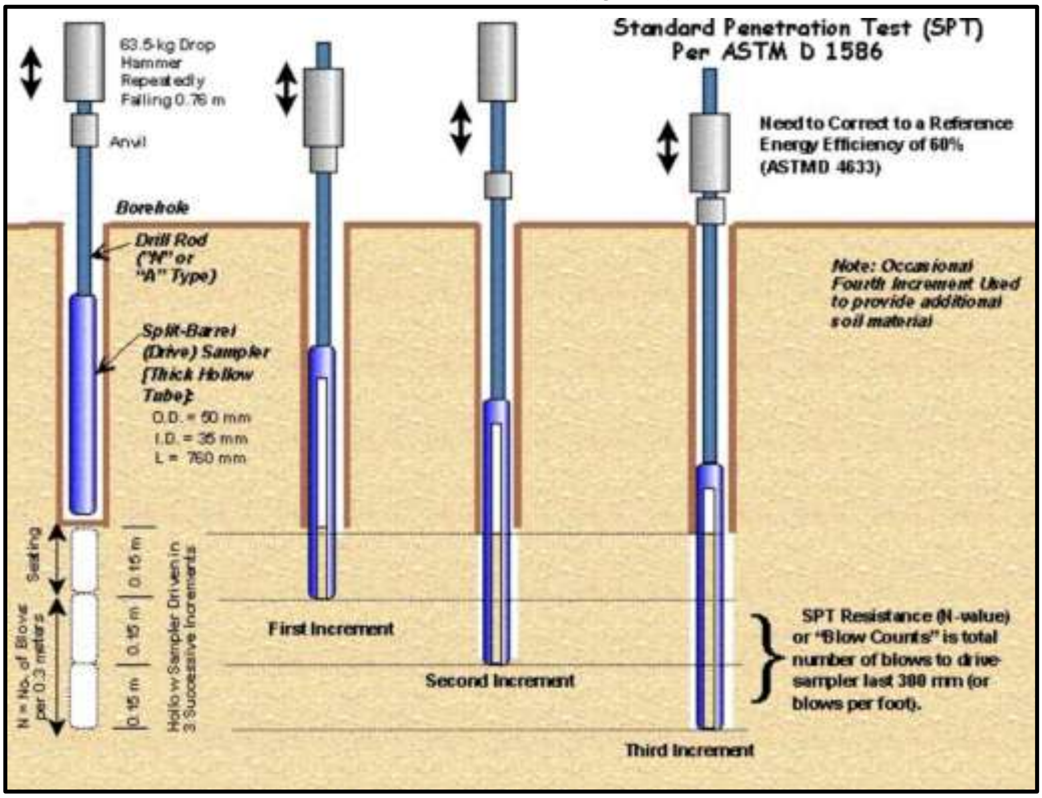

Figure 3. Standard Penetration Test Steps [11]

2.2. Laboratory Investigations

Laboratory tests adhering to the Turkish Standards Institute (TS 1900-1) and ASTM (American Society for Testing and Materials) criteria were performed to ascertain the physical, index, and mechanical properties of soil samples collected from the field [12]. Sieve analysis was performed to determine the grain size distribution of the soils, utilising a conventional sieve series in compliance with ASTM D 422 standards [12]. The behaviour of fine-grained soils in relation to variations in water content has been characterised by determining the consistency (Atterberg) limits, namely the liquid limit, plastic limit, and shrinkage limit. Furthermore, shear box tests were performed to ascertain the soil's shear strength parameters (cohesion and internal friction angle), while the soil's natural water content and unit weight were quantified.

2.3. Soil Classification and Bearing Capacity Assessments

The soil units in the study area have been classified according to the Unified Soil Classification System (USCS) based on the physical index qualities derived from laboratory studies. The Unified Soil Classification System (USCS) is a standardised methodology employed in engineering and geotechnical contexts to categorise soil according to grain size distribution, plasticity, and organic matter concentration [13].

The bearing capacity analysis of the soils in the Burdur settlement area, defined as the force applied per unit area necessary for the onset of failure and sliding, was performed utilising the established Terzaghi (1943) methodology as referenced in the literature [14]. The approach established by Terzaghi indicates that the soil's behaviour upon attaining ultimate bearing capacity is represented in Figure 4. These assumptions also take into account the initial region beneath the foundation, specifically the wedge component that ascends vertically with the foundation. The other II region comprises a logarithmic curve that delineates the radial slip zone. The final region, III, denotes the segment of the terrain characterised as a linear shear field operating on a planar surface.

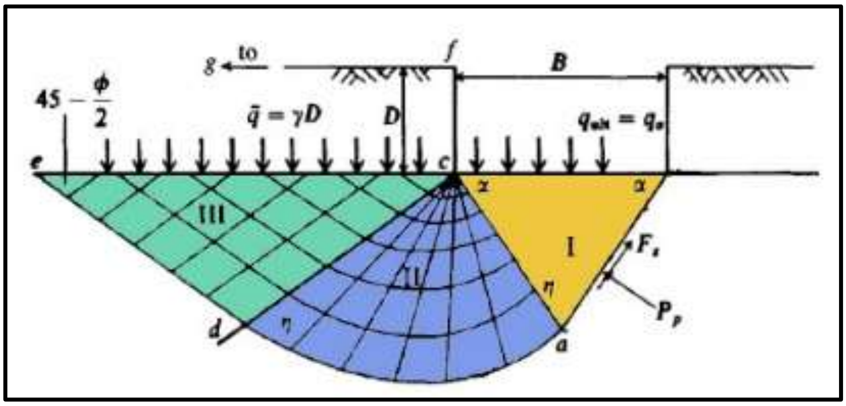

Figure 4. Terzaghi carrying capacity limit state representation [5]

Terzaghi initially made his calculations for strip foundations and later developed methods for other square and rectangular foundations using the data he obtained experimentally. The Terzaghi formula for determining bearing capacity is presented in Equation 2. The foundation lengths have been established as 1 m.

$$q_d = \mathrm{c.Nc.}\left(1 + 0{,}2.\frac{B}{L}\right) + \gamma_1 1.\mathrm{Df.Nq} + \gamma_2.\mathrm{N\gamma}.\left(0{,}5 - 0{,}1\frac{B}{L}\right) \quad (2)$$

The Nc, Nq, Nγ used in the equation are dimensionless bearing capacity factors, and the Terzaghi bearing capacity equation 2, definition, and coefficient are calculated using tables [15]. The calculated soil bearing capacity is divided by the safety factor to determine the soil safety stress.

In the calculations, it was assumed that the foundation interacts with the ground in a rough manner, there is no eccentric loading, and general shear failure occurs in the ground, and the bearing capacity values according to the limit states of the strip foundation were obtained. The ultimate bearing capacity (qd) values of the soil, calculated using the Terzaghi formula, were divided by safety factors ranging from 3 to 5, chosen based on the soil type and the current engineering conditions, thus determining the Soil Safety Stress (qem) values to be used in structural design.

The safety factors (Gs) in soil bearing capacity calculations are the coefficients by which the computed ultimate bearing capacity is divided to guarantee its safe application in structural design. In classical soil mechanics, this coefficient is often selected between 3 and 5, contingent upon the soil's current condition and the engineer's judgement during the computation. In numerous conventional applications and traditional methodologies, this value is typically regarded as 3.

In this work, the safety factor (Gs) was uniformly set at 3 in the Terzaghi bearing capacity calculations utilising data from 28 boreholes in the city centre of Burdur. The calculations, by standardising the foundation's depth, width, and length at 1 metre while maintaining a constant safety factor, have allowed for a clearer and more objective comparison of the load-bearing capacity variations across the 28 distinct drilling locations.

3. RESEARCH RESULTS

This part presents the field and laboratory data acquired from 28 foundation drilling wells (DW) to ascertain the soil properties and geotechnical parameters of the Burdur provincial settlement area. The drilling wells were drilled to depths ranging from 7 meters to 15.45 meters to depict the overall geological profile of the research area, with a cumulative drilling length of 300 meters.

3.1. Laboratory Test Resulst and Soil Classification

The findings of physical index and mechanical (shear box) tests performed on disturbed and undisturbed soil samples collected from the field indicate that the soil profile of the research region is primarily made of fine-grained soils. The soils were classed according to the Unified Soil Classification System (USCS), utilising the acquired sieve analysis and Atterberg limits data. Table 1 presents the physical and mechanical laboratory test results from various reference boreholes across different sites in the study region.

Upon examination of the laboratory findings, it was shown that the predominant soil types in the research area were inorganic clay, clayey sand, and silty clay (CL) exhibiting low to medium flexibility. In certain areas of the research represented by BH10 and BH11, the liquid limit (LL) values surpassed 50%, categorising the soil as high plasticity inorganic clay (CH).

Table 1. Summary of laboratory test findings and soil classifications for selected boreholes in the research region.

No	Sample type	Index properties		Consistency limits			Grain size distribution			Cohesion (kN/m^2)	Angle of internal friction (ϕ)	Soil class. (USCS)
		W_n	γ_n	LL	PL	PI	Gravel	Sand	Fine			
BH1	UD	15.42	15.20	NP	NP	NP	0.36	71.21	28.43	11.8	18.87°	SM
BH2	SPT			NP	NP	NP	0.13	81.7	18.17			SM
BH3	UD	21.93	16.43	41.37	20.69	20.68	0.04	11.05	88.91	19.7	13.30°	CL
BH4	SPT			42.99	22.06	20.93	0.13	11.07	88.8			CL
BH5	UD	14.09	20.3	48.1	24.08	24.02	50.16	27.3	22.54	11.6	21.0°	GC
BH6	SPT	NP	NP	48.43	24.14	24.29	50.07	23.77	26.16			GC
BH7	UD	4.6	18.0	NP	NP	NP	0.02	83.51	16.47	4.5	21.73°	SM
BH8	SPT	NP	NP	NP	NP	NP	0.04	82.55	17.41			SM
BH9	SPT	NP	NP	49.38	25.65	23.73	0.21	10.23	89.56			CL
BH10	UD	21.83	17.8	53.17	25.71	27.46	3.2	12.71	84.09	18.1	13.71°	CH
BH11	SPT	NP	NP	53.98	26.51	27.47	2.83	13.27	83.9			CH
BH12	UD	20.51	18.87	39.7	21.35	18.35	0.44	2.34	97.22	67	5.00°	CL
BH13	SPT	NP	NP	39.06	22.54	16.52	0.74	6.55	92.71			CL
BH14	UD	22.98	18.78	41.02	19.19	21.83	0.35	9.72	89.93	60	5.00°	CL
BH15	SPT	NP	NP	28.31	17.16	11.15	9.03	38.08	52.89			CL
BH16	UD	19.56	18.07	41.02	19.19	21.83	1.18	9.04	89.78	63	5.00°	CL
BH17	SPT	NP	NP	NP	NP	NP	1.89	93.87	4.24			SP
BH18	SPT	NP	NP	NP	NP	NP	3.09	87.6	9.31			SW-SM
BH19	SPT	NP	NP	22.77	12.5	10.27	0	39.81	60.19			CL
BH20	SPT	NP	NP	51.64	20.89	30.75	0.27	5.03	94.7			CH
BH21	UD	11.18	17.2	44.13	22.36	21.77	0.04	14.94	85.02	20.1	13.12°	CL

BH22	SPT	NP	NP	49.33	24.24	25.09	0	9.68	90.32			CL
BH23	UD	28.03	17.9	48.08	24.13	23.95	0	17.78	82.22	22.0	12.12°	CL
BH24	SPT	NP	NP	48.39	24.97	23.42	0	4.14	95.86			CL
BH25	UD	20.35	17.5	49.57	25.34	24.23	9.06	1.76	89.18	19.9	13.00°	CL
BH26	SPT	NP	NP	49.57	24.92	24.65	6.6	2.99	90.41			CL
BH27	UD	7.35	18.71	NP	NP	NP	0.14	40.66	59.2	4	23.00°	ML
BH28	SPT	NP	NP	NP	NP	NP	5.27	60.99	33.74			SM

In the regions of boreholes BH7, BH8, BH9, BH27, and BH28, particularly where the alluvial fan exerts influence, it has been established that the fine-grained ratio diminishes, with the soil composition comprising non-plastic (NP) silty sands and poorly graded sand-silt mixtures (SM).

3.2. SPT and Bearing Capacity Results

SPT was performed at intervals of 1.5 meters during foundation drilling to assess the soil's density and consistency, with the results documented. To distinctly analyse the variations in bearing capacity both laterally and vertically, the Terzaghi (1943) strip foundation formula was employed to compute the soil bearing capacities.
To ensure standardisation in the computations, the foundation breadth (B) is set at 1 metre, the foundation length (L) at 1 metre, and the foundation depth (D_f) at 1 metre. To guarantee structural integrity under dynamic and static loads, a safety factor (G_s) of 3 was used, and the ground bearing pressure (q_{em}) values were ascertained individually for each drilling site.
The acquired bearing capacity results have demonstrated notable variations contingent upon the soil material constituting the building's substructure (CL, CH, or SM). Calculations reveal that CH and CL type clay soils, characterised by high cohesion (c) values and plasticity, pose a risk of settlement, whereas SM type soils with elevated sand content necessitate alternative engineering methods.
The identification of soft and highly plastic clay layers by laboratory tests suggests that, given the behaviour of seismic waves in the ground, the earthquake amplification factor will be significantly elevated, resulting in increased surface shaking intensity. Moreover, in areas with loose alluvial deposits, this condition exacerbates the seismic hazard.

4. RESULTS AND DİSCUSSİON

The city of Burdur, positioned in a first-degree earthquake zone, has sustained significant damage during the earthquakes of 1914 and 1971 and is located on active tectonic faults, particularly the Fethiye-Burdur Fault Zone. This study meticulously analysed the geotechnical features of the soils underneath the existing structures in the city centre, revealing that the local soil conditions substantially elevate seismic hazard potential.
The predominant lithology in the study area primarily comprises soft and flexible freshwater sediments (clay-rich formations). The primary engineering hazard associated with these fine-grained and pliable soils is their capacity to amplify seismic waves and convey them to the surface during an earthquake. The soil's significant flexibility indicates that the earthquake amplification factor will attain elevated levels. Recent research in the literature confirms that loose alluvial soils demonstrate adverse behaviours after an earthquake, mainly ground amplification and liquefaction. In this context, it is imperative to exercise extreme caution in the foundation designs of structures in areas characterised by high-plasticity clay (CH) and low-medium-plasticity clay (CL) in the city centre of Burdur to alleviate the hazards of resonance and excessive settlement.
Recent geophysical ground studies in the literature are providing a more dynamic perspective on the safety factor. In conventional approaches, the safety factor is considered a constant, often 3 or 4, however in bearing capacity estimates derived from seismic velocities, the ratio of P-wave to S-wave velocities (Vp/Vs) may serve as the safety factor. This methodology is significant from an engineering standpoint; in weak, water-saturated soils, the Vp/Vs ratio assumes elevated values (e.g., 3.5, 4, 5), whereas as the soil consolidates and moisture content diminishes, this ratio declines (e.g., 1.5, 2, 2.5). In the seismic (dynamic) method, the safety factor is not a constant value but rather a site-specific parameter that fluctuates in accordance with the ground's physical and mechanical properties (such as water saturation, density, etc.).
In certain drilling sites where the alluvial fan is prominent and the soil profile exhibits a high sand content (silty sand - SM units), the danger of soil liquefaction, characterised by a distinct risk profile, becomes significant. In areas with shallow groundwater levels, there exists a possibility of total loss of bearing capability under seismic loads.

Engineering recommendations are provided following a thorough geotechnical assessment of the study area:

- The zoning plan for Burdur city centre must be restructured based on soil lithology and established bearing capability profiles. Geotechnical risk maps should be updated on a neighbourhood basis if local authorities find them necessary.
- Risk-prone and secure zones must be distinctly delineated, and attributes such as building elevation and foundation type, pertinent to each neighbourhood or region, should be ascertained.
- Ground improvement methods prior to construction should be unequivocally mandated, particularly in regions characterised by elevated sand content and susceptibility to liquefaction.
- Comprehensive microzoning studies must be conducted in the city centre, where the seismic amplification factor is significantly elevated, and current fault and risk maps at a scale of 1/1000 should be promptly developed.

Contribution Statement

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5. CONCLUSION

To ascertain the geotechnical features and seismic risk characteristics of the soil in the Burdur city settlement region, drilling and laboratory analyses were performed to a total depth of 300 metres over 28 distinct locations. Consequently, the soil in the areas of Emek, Konak, Zafer, Akın, Üçdibek, Çeşmedamı, and Burç, while predominantly clay-rich and compact, demonstrates significantly elevated plasticity properties. The largest potential for ground settlement in the city centre has been identified in these places; hence, building foundations in these locations should be planned with broader bases, and settlement concerns must be considered.

In the Mehmet Akif Ersoy, Tepe, and Değirmen neighbourhoods, together with the Yeni, Cemil, Yenice, and Dere neighbourhoods situated southeast of the Köprübaşı area, it has been ascertained that the terrain possesses a notably hard and regular profile. Regions with low groundwater levels are optimal for building due to their less risk of soil liquefaction or erratic ground movement. In specific areas of the Bağlar, Karasenir, and Bahçelievler neighbourhoods, a significant sand content in the soil profile has been noted. Prior to building in these regions, ground enhancement must be executed to alleviate the risk of liquefaction, potentially instigated by shallow groundwater after an earthquake.

The groundwater level in the Hızır İlyas and Menderes neighbourhoods has been assessed as relatively shallow (high). Given the present circumstances, despite the predominance of modular or lightweight structures (such as greenhouses and farmhouses) in these regions, it is imperative to undertake comprehensive geotechnical investigations on a parcel basis prior to any prospective multi-storey developments.

It is an inescapable reality that the predominant soil composition in Burdur Province (freshwater sediments) will demonstrate plastic behaviour during a hypothetical seismic event and increase earthquake waves. The data acquired represent the city's macro-scale risk profile, given the research area's size. To generate comprehensive microzoning maps of the city, it is essential to substantially augment the number of drillings and reiterate the ground dynamic studies.

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