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AVALIAÇÃO DO PLANO SISTEMATIZADO E ATRIBUTOS FÍSICOS DO SOLO DO GRAMADO DA ARENA CASTELÃO EM FORTALEZA-CE

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RESUMO: O estudo foi realizado no gramado da Arena Castelão (Fortaleza-CE), com o objetivo geral de diagnosticar o plano sistematizado (topografia) e atributos físicos do solo quanto à drenagem superficial, transmissão de água no solo e resistência mecânica à penetração. Os objetivos específicos foram mapear a topografia para avaliar a eficiência do escoamento superficial; quantificar a velocidade de infiltração básica do solo (VIB) e condutividade hidráulica do solo saturado (Ko) e identificar camadas compactadas via resistência à penetração. A topografia foi analisada com estação total (83 pontos) e os softwares *DataGeosis e Surfer*; a infiltração pelo método do cilindro-infiltrômetro; a Ko com permeâmetro de carga constante e a resistência do solo à penetração com um penetrômetro de impacto. Os resultados indicam que há ocorrência de declividades irregulares no lado oeste (contrariando o padrão FIFA de 0,5%); VIB de 154,9 mm h^{-1} ("muito alta"); Ko entre 114,3–236,0 mm h^{-1} ("alta a muito alta"); resistência à penetração crítica (>4,53 MPa) abaixo de 0,12m próximo aos gols. Conclui-se que ajustes topográficos e manejo da compactação são essenciais para manter padrões internacionais de segurança e desempenho.

Palavras-chave: Drenagem, Infiltração, Compactação.

EVALUATION OF THE SYSTEMATIZED PLAN AND PHYSICAL ATTRIBUTES OF THE SOIL OF THE ARENA CASTELÃO TURF IN FORTALEZA-CE

ABSTRACT: The study was conducted on the turf of Arena Castelão (Fortaleza-CE, Brazil), with the general objective of developing a systematized plan (topography) and evaluating physical soil attributes such as surface drainage, water transmission, and mechanical resistance. The specific objectives were to map topography to evaluate surface drainage efficiency, quantify basic infiltration velocity (VIB) and saturated hydraulic conductivity (Ko); and identify compacted layers via penetration resistance. Topography was analyzed using a total station (83 points) and *DataGeosis/Surfer* software; infiltration via double-ring infiltration method; Ko was analyzed with a constant head permeameter; and resistance was analyzed with an impact penetrameter. The results indicate irregular slopes on the west side (in contrast to the 0.5% standard of the FIFA); VIB of 154.9 mm h^{-1} ("very high"); a Ko between 114.3–236.0 mm h^{-1} ("high to very high"); and critical penetration resistance (>4.53 MPa) below 0.12 m near the goal areas. It is concluded that topographic adjustments and compaction management are essential for maintaining international safety and performance standards.

Keywords: Drainage, infiltration, Compaction.
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1 INTRODUCTION

Arena Castelão, located in Fortaleza, Ceará, is among the most important stadiums in Brazil. Built in 1973 and renovated in 2012 for the 2014 FIFA World Cup, the internationally recognized stadium hosted events such as the Copa Libertadores, Copa Sudamericana, and Campeonato Brasileiro. Furthermore, it is a contender to host the 2027 FIFA Women's World Cup in Brazil (SESPORTE 2024), highlighting its global importance.

Owing to its importance in the national and international football scene, Arena Castelão has been hosting an increasing number of events. In 2024, the stadium hosted 63 official matches and one concert, posing considerable challenges to the maintenance of the pitch. Intensive use results in excessive wear and tear, such as soil compaction and damage to the grass, which are factors that compromise the quality of the field and can impact both the performance of the athletes and safety during matches.

The quality of the pitch is essential for playability, athlete safety, and the fan experience. Stadiums with well-maintained pitches are better suited to host international events, which increases the visibility of national football. Well-maintained pitches provide better dynamics in matches and reduce the risk of injuries. However, efficient maintenance requires not only manual labor but also the use of appropriate technologies and management practices.

Regular turf testing is essential for monitoring its condition. Uniformity, compaction, and drainage analysis tests allow for early identification of problems, enabling more effective preventative and corrective maintenance. These data also help optimize resource use and ensure the safety and performance of the field for high-level matches. Therefore, conducting technical tests on Arena Castelão turf is fundamental for assessing its current condition and guiding future maintenance decisions. These tests are crucial for ensuring the longevity and quality of the field, providing a safe environment for athletes and a positive experience for fans, as well as contributing to the excellence of football in Brazil.

The overall objective of this research was to perform a diagnostic analysis of the systematized plan considering surface runoff conditions (surface drainage), water transmission in the soil, and soil resistance to penetration. To this end, the following specific objectives were established: to carry out a georeferenced planimetric survey to map the topography of the area and evaluate the efficiency of the current surface drainage system; to determine the characteristics of water infiltration into the soil using the concentric cylinder infiltrometer method; to determine the saturated hydraulic conductivity of the soil (Ko) using a constant head permeameter; and to evaluate the soil resistance to penetration with an impact penetrometer.

The integration of these objectives allowed for a multidisciplinary approach, linking topographic, hydrophysical, and mechanical data to propose improvements to the systematized plan. This includes adjustments to the slope of the terrain to optimize surface runoff, management practices to reduce soil compaction (selective subsoiling), and improvements to the surface drainage infrastructure, ensuring greater efficiency and sustainability in the proper growth and development of the lawn.

2 MATERIALS AND METHODS

The study was conducted on the grass field of Arena Castelão, in Fortaleza-CE, through a technical-scientific agreement between the Federal University of Ceará (UFC), the Secretariat of Sports of the State of Ceará (Sesporte) and the company Campanelli Gramados Esportivos e Áreas Verdes, responsible for the phytotechnical maintenance of the grass field.

The locations of the tests and soil sample collection are shown in Figure 1. The soil water infiltration test was performed at point 1, with the purpose of conducting a comparative analysis with a test performed on December 12, 2012, during the stadium's renovation for the Confederations Cup and World Cup.

Figure 1. Location of field tests and soil sample collection.

Source: Author (2024)

For the topographic analysis of the field relief, 83 altimetric points were collected and strategically distributed to ensure accuracy and representativeness. Of these, four points were positioned at the vertices of the corner areas, delimiting the boundaries of the terrain, whereas 79 points were uniformly distributed along the field, covering flat areas, slopes, and critical zones of interest. Data collection was performed using a Ruide RTS-820 total station, a high-precision instrument that combines angular and distance measurements, following the radiation survey method. This method consists of positioning the equipment at a fixed point (station) and measuring the coordinates (X, Y, Z) of multiple points from this reference, ensuring speed and consistency in the measurements.

The raw data collected by the Total Station were imported into the DataGeosis software, where they were processed to calculate the UTM (Universal Transverse Mercator) coordinates of each of the 83 topographic points. The georeferenced information was subsequently transferred to the Surfer 8.0 program (Golden Software), which was subsequently used to create contour lines through spatial interpolation. The process included the application of the ordinary kriging interpolation method (or inverse distance weighting, depending on the project configuration), ensuring accuracy in representing the altimetric variations in the terrain. The vertical equidistance defined for the contour lines was 0.03 m, allowing the identification of critical microlevel differences for the analysis of surface runoff and drainage.

In the infiltration test, two sheet metal cylinders with diameters of 0.30 m and 0.20 m were used, and both were 0.20 m high. The following auxiliary instruments were also used: a graduated ruler to measure the water level in the cylinder, thin black plastic used at the beginning of the test to prevent infiltration when water was introduced into the cylinder, and a stopwatch and a spirit level.

In the field, the two cylinders were installed in the soil to a depth of 0.05 m, ensuring perfect contact between the soil and the cylinder walls. Afterward, the bottom of the central cylinder was covered with plastic, and water was introduced into the inner and outer cylinders until near the upper edge. The plastic was removed, and the first reading of the infiltrated water depth was taken immediately using a graduated ruler.

Water level readings and the times at which these measurements were taken were recorded in an auxiliary spreadsheet. The measurement intervals were shorter at the beginning because of the faster initial infiltration process. The water levels in both cylinders were kept approximately equal, and they were refilled during the tests.

The values of accumulated infiltrated layers as a function of accumulated time were analyzed using regression, according to a potential statistical model that best fits the physical behavior of the infiltration process, in the form:

$$Z = KTa \quad (1)$$

in which
Z: accumulated infiltration layer, mm;
T: Cumulative infiltration time, min;
K and a: empirical parameters of the model obtained by regression.

The instantaneous infiltration rate equation (q) was obtained by differentiating the cumulative infiltration rate equation (Z) with respect to time; that is,
q = dZ/dT and therefore,

$$q = K'.T^{n} \quad (2)$$

in which,
q: instantaneous infiltration rate, mm h^{-1};
T: Accumulation time, min;
K'en: empirical parameters of the model.

Undisturbed soil samples were collected at four georeferenced points on the soccer field to preserve the natural structure of the material for analysis of the saturated hydraulic conductivity of the soil. The sampling locations included Point 1 (near the infiltration test area), Point 2 (north goal area), Point 3 (geometric center of the field), and Point 4 (south goal area).

In the laboratory, the samples were initially placed to saturate in a tray with water raised to one-third of the cylinder's height, allowing the water to rise in the sample profile for 24 hours. Afterward, a cylinder of the same dimensions was attached to the top of each sample to introduce a hydraulic head during the tests. The saturated soil hydraulic conductivity (Ko) tests were subsequently performed using a constant-head permeameter equipped with a Mariotte bottle to ensure the maintenance of the hydraulic head during the test. The following equation was used to measure the saturated soil hydraulic conductivity (Ko):

$$Ko = \frac{Va.L}{A.t(h+L)} \quad (3)$$

in which
Va: Volume of water percolated during time t;
A: Cross-sectional area of the sample;
L: Sample length;
h: Potential pressure (hydraulic head) at the top of the sample.

The soil penetration resistance test was performed using a Stolf model impact penetrometer (1991). Four georeferenced points were evaluated at the sample collection sites for the Ko analysis, ensuring spatial consistency in the correlation between the mechanical resistance and hydraulic parameters. In accordance with investigations conducted by Stolf in the 1990s, a protocol was established to interpret impact penetrometer measurements as soil penetration resistance values.

This work integrated theoretical foundations and practical experiments and examined three equations commonly applied in civil engineering to translate the number of blows per decimeter (blows/dm) into dynamic soil resistance (kgf/cm^2).

The mathematical model adopted for the equipment developed by Stolf, widely used in

Brazil, is defined by the following relationship: R (kgf/cm^2) = 5.6 + 6.89 N (blows/dm).

In agriculture, this technique is relevant for reliably quantifying the mechanical resistance of the soil, supporting strategic decisions. Its application allows mapping compacted areas, evaluating ideal conditions for root development, and guiding management practices that preserve soil health. The characteristics of the penetrometer used in the field are as follows: a weight of 1.64 kg with a free-fall impact of 0.36 m, a cone base area of 2.27 cm^2 and a mass of the other components of 1.53 kg.

The chosen points were based on the locations where undisturbed samples were collected for the saturated soil hydraulic conductivity tests. Impact and depth data were recorded in a spreadsheet for later calculation of penetration resistance, which was performed using an Excel spreadsheet.

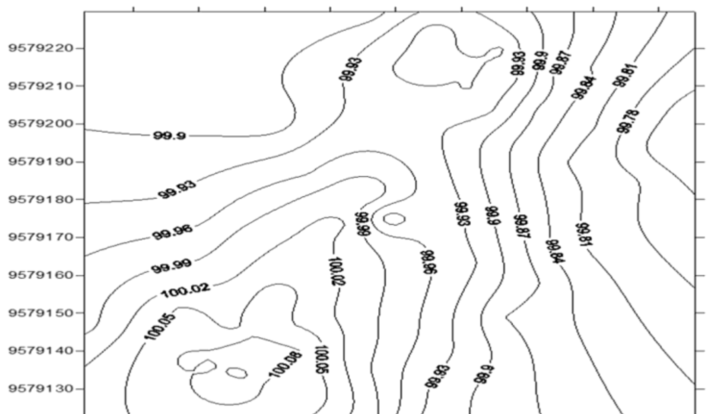
On the basis of the collected data, the mechanical resistance of the soil was calculated using an Excel spreadsheet following a standardized methodological sequence: initially, the number of impacts applied was divided by the corresponding penetration value (in cm), yielding an index that relates the energy expended to the depth reached.

Next, the result was converted to decimeters (dm), adjusting the scale to make the units compatible and allow the application of the force formula. On the basis of this relationship, the penetration resistance was determined in kilograms of force per square centimeter (kgf/cm^2), considering the cross-sectional area of the penetrometer. For standardization, the values in kgf/cm^2 were converted to megaPascals (MPa) using the conversion factor (Stolf, 1991).

3 RESULTS AND DISCUSSION

The contour lines of the systematized field plan according to data collected on 05/11/2024, which demonstrate average regular slope gradients of 0.5% toward the east, taking the center of the field as a reference, are shown in Figure 2. Notably, this slope occurs regularly throughout the entire field, from the center eastward. From the middle of the field northward, average slopes of 0.2% are observed, although not regularly; however, from the middle of the field southward, a systematized plan contrary to what was expected is observed, as an average inclination of 0.2% is observed.

Figure 2. Contour lines of the Arena Castelão lawn on November 5, 2024.

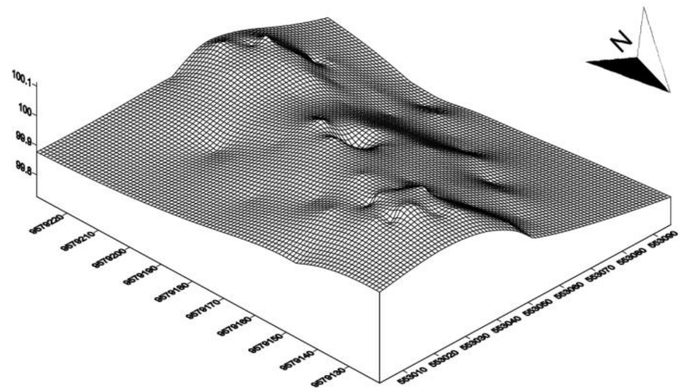


Source: Author (2024)

A three-dimensional model of the pitch's relief is shown in Figure 3. Notably, during the renovation of the Castelão stadium for the Confederations Cup and the 2014 World Cup, which was completed at the end of 2012, the slopes of the base soil or ground surface were created with “four-sided slopes,” that is, gradients of 0.5% toward the sides and 0.5% toward the goals, starting from the center of the field, ensuring the removal of excess water from the surface during very heavy rainfall.

Considering that most of the water occurs in the midfield and that rainfall exceeding the soil infiltration capacity would cause excess water on the surface, slope gradients are needed toward the goals and sidelines. This is a standard recommendation for all high-level stadium construction (CONMEBOL, 2019). Therefore, taking as a reference the conditions of the systematized plan for the 2014 World Cup, minor alterations to the systematized plan are observed, although of a magnitude that would not compromise aspects related to surface drainage of the playing field.

Figure 3. Ground response surface.



Source: Author (2024)

Table 1 presents the data collected in the field for the study of water infiltration characteristics in the soil, which are represented by Figure 4, which expresses the behavior of the accumulated infiltrated water layer (Z) as a function of the accumulated time (T). A high coefficient of determination (r^2) is observed for the physical behavior of the water infiltration characteristic in the soil.

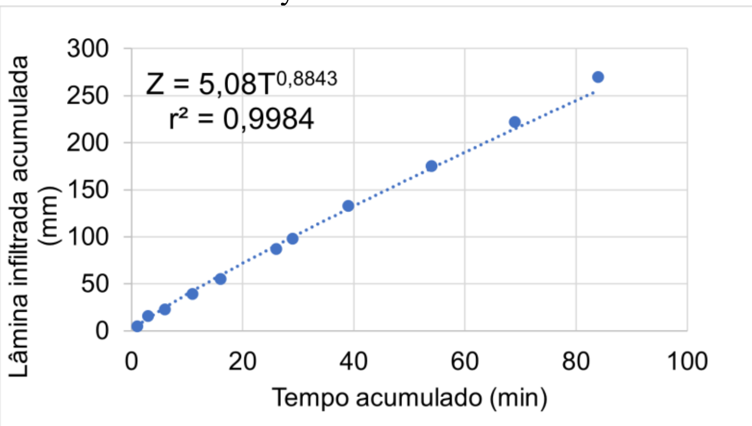
In the field test, after 84 minutes of testing, an infiltrated water layer 270 mm in size formed. A similar study carried out on 12/12/2012 near the location where this test was performed, on the occasion of the end of the field renovation for the 2013 Confederations Cup and the 2014 World Cup, showed a similar value, with an infiltrated water layer of 256 mm after 76 minutes of testing (Table 2), thus demonstrating a preservation of the soil's water infiltration characteristics, even after 12 years.

Table 1. Field data from the soil water infiltration test on January 14, 2025.

Time Inst. (min)	Accumulated time . (min)	Reading (cm)	Instrument Blade (cm)	Accumulated blade thickness (mm)
0	-	2.9	0	-
1	1	3.4	0.5	5
2	3	4.5	1.1	16
3	6	5.2	0.7	23
5	11	6.8/1.7	1.6	39
5	16	3.3	1.6	55
10	26	6.5	3.2	87
3	29	7.6/2.2	1.1	98
10	39	5.7/2.4	3.5	133
15	54	6.6/1.6	4.2	175
15	69	6.3/1.7	4.7	222
15	84	6.5	4.8	270

Source: Author

Figure 4. Accumulated infiltrated water layer as a function of accumulation time.



Source: Author

Table 2. Data from the test conducted in 2012 in preparation for the 2014 World Cup (04/12/12).

Time Inst. (min)	Accumulated time . (min)	Reading (cm)	Instrument Blade (cm)	Accumulated blade thickness (mm)
0	0	2.4	0.0	0.0
1	1	3.4	10.0	10.0
2	3	4.3/2.0	9.0	19.0
3	6	3.3	13.0	32.0
55	11	5.8/2.9	25.0	57.0
10	16	3.9	10.0	67.0
10	26	5.9/0.5	20.0	87.0
10	36	6.5/2.5	60.0	147.0
10	46	7.1/1.8	46.0	193.0
10	56	3.8/1.7	20.0	213.0
10	66	3.7/1.7	20.0	233.0
10	76	3.7	23.0	256.0

Source: Nascimento Filho (2012).

During the saturated soil hydraulic conductivity test using the constant head permeameter technique, under steady-state flow conditions, the volume of water percolated over a period of ten minutes was collected because of the observed high water transmission, and the saturated soil hydraulic conductivity was calculated. Table 3 presents the data for calculating the saturated soil hydraulic conductivity (Ko) for the four soil samples from the football field at the Plácido Aderaldo Castelo Stadium.

In accordance with Pizarro (1985), the values of saturated soil hydraulic conductivity (Ko) can be classified according to the methods in the references presented in Table 4. Therefore, the values obtained in the tests are classified in the range of high to very high saturated soil hydraulic conductivity, conferring a high capacity for water transmission in the soil profile.

Table 3. Data for calculating the hydraulic conductivity of saturated soil.

Variables	North Goal	South Goal	Next to the infiltration test .	Center
Va (mL)	119	108	224	102
L(cm)	7,216	7,211	7.11	7,344
A (cm^2)	39.15	38.4	38.2	39.5
h (cm)	3,489	3,437	3,489	2,045
t (min)	10	10	10	10
Ko ($mm\ h^{-1}$)	122.9	114.3	236.0	121.0

Source: Author

Table 4. Hydraulic conductivity classes of saturated soil.

Ko Classes	Values (mm h-1)
Very low	<2.1
Low	2.1 – 12.5
Average	12.5 – 41.7
High	41.7 – 208.3
Very high	>208.3

Source: Pizarro (1985).

The results of the soil penetration resistance tests are shown in Figure 5. The soil penetration resistance data, obtained at the four distinct points, revealed significant variations, all of which were compared with the penetration resistance classification values presented in Table 5.

Figure 5. Soil resistance to penetration at other points.

Source: Author

Table 5. Classification of soil penetration resistance

Classes	Limits (MPa)	Limitation to root growth
Very low	< 1.0	Without limitation
Low	1.1 to 2.50	Few limitations
Average	2.6 to 5.00	Some limitations
High	5.1 to 10.00	Serious limitations
Very high	10.10 to 15.00	Roots barely grow.
Extremely high	15.00	Roots do not grow.

Source: Canarache (1990).

The area near the infiltration test showed low to medium resistance values in the 0 to 0.20 m depth layer, increasing to the high class after this depth. This finding indicates that the root growth zone (0–0.20 m) offers favorable conditions for its development, becoming more restrictive from 0.20 m onward.

The points located at the south and north goals exhibited the highest resistance indices along the profile, reaching values that classify the 0.10–0.20 m soil layer as having high resistance to penetration. These results are likely associated with intense trampling in these regions during sporting activities, which are common in areas near the goals where there is a higher concentration of players. Excessive compaction in these locations can compromise the root development of grasses and water efficiency, as observed by Carrow and Duncan (2011). in professional soccer fields.

The point located in the center of the field, in turn, had lower and more homoeneous resistance values, indicating average compaction in the 0.10–0.20 m layer. This condition may be favorable for water infiltration and lawn health, but it is on the borderline to present values that could restrict root growth.

The analyses demonstrated that the highest penetration resistance indices were identified in the regions near the two target areas. This pattern corroborates the findings of Alfonsi et al. (2015), who, when studying the spatial distribution of compaction in soccer fields, recorded peaks of penetration resistance precisely in the vicinity of one of the goals. According to the author, these areas are among the most susceptible to compaction because of intense movement and recurrent trampling by players during matches, which are factors that reduce soil porosity and increase soil density.

4 CONCLUSION

There is a need for adjustments to the systematized plan, especially on the west side, taking the central axis of the field as a reference, to restore the slopes of the base soil or terrain surface to gradients of 0.5% for the sides and 0.5% for the goals, as established for the 2014 World Cup. The use of the *top dressing technique* is recommended for this restoration;

The water infiltration rate in the soil, with a value of 154.9 mm $h^{-1,}$ is classified as "very high," preserving the soil's water infiltration characteristics even 12 years after the renovation of the field's structural conditions.

The values of saturated soil hydraulic conductivity (Ko) are classified in the range of "high to very high" water transmission capacity in the soil profile, constituting a favorable attribute for effective drainage in the soil profile;

In general, limitations to root growth arise from a depth of 0.12 m, especially in regions close to the two target areas. Most of the points analyzed vary between the classifications of "good quality" and "low quality" along the profile, according to the criteria established by FIFA (2022).

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