

Analysis of Seasonal Soil Temperature Variations in Bori Town and Determination of Suitable Electrode Planting Depth

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ABSTRACT: Soil temperature plays a critical role in the efficiency of grounding systems, especially in regions where electrical installations depend on earth electrodes for safety, stability, and power quality. This study investigates the seasonal and temperature variations of soil in Bori Town, Rivers State, Nigeria, and examines their influence on the optimal planting depth of grounding electrodes. Data were collected across wet and dry seasons to evaluate how fluctuations in moisture content and soil temperature affect soil resistivity. The standard Wenner four-pin configuration was applied to calculate the soil resistivity for raining season (June) and dry season (December). Findings reveal a significant seasonal shift in soil thermal properties, with higher temperatures and lower moisture content during the dry season causing a marked increase in soil resistivity. Conversely, the wet season exhibited lower temperatures and higher conductivity at shallow depths. The analysis shows that deeper electrode placement mitigates the adverse effects of seasonal variations, ensuring consistent grounding resistance throughout the year. Also, the resistivity under electrode depth of 0.8, 1.5, 2.5 and 3.0 was investigated and the results shows high resistivity at 0.8 m, and lower soil resistivity at a depth of 3.0 m for both cases. The study recommends strategic electrode planting depths based on seasonal soil behavior to enhance electrical safety and system reliability in Bori Town and similar tropical regions.

KEYWORDS: Permanent Moisture table, Temperature variation, Electrode depth, Soil resistivity, Signal ground.

INTRODUCTION

Grounding systems are a critical component of electrical installations, serving as a means for dissipating fault currents and stabilizing voltage levels during transient disturbances. The effectiveness of any grounding system is largely dependent on the electrical resistivity of the surrounding soil, which is, in turn, affected by soil temperature, moisture content, and seasonal variations (IEEE Std 80-2013; Abdulraheem & Abdullateef, 2015). In tropical regions such as Bori Town in Rivers State, Nigeria, the climatic cycle oscillates between wet and dry seasons, causing significant fluctuations in soil thermal and electrical properties. These variations can compromise grounding reliability, especially when electrode planting depth is not optimized for year-round performance.

Previous studies have established that soil temperature has a direct influence on ionic mobility within the soil matrix, affecting how readily electrical charges can be conducted through the earth (Sunde, 1968; Oladipo et al., 2019). During the dry season, high ambient temperatures coupled with low moisture levels result in increased soil resistivity, which reduces the efficiency of shallow-installed electrodes (Olotu & Eze, 2020). In contrast, the wet season introduces higher moisture content, reducing resistivity and temporarily improving grounding conditions (Popoola et al., 2018). However, shallow electrodes are still vulnerable to rapid resistivity fluctuations, making electrode depth optimization a key engineering concern.

Bori Town, located in the humid sub-equatorial region of Southern Nigeria, features lateritic and loamy soil types that undergo pronounced moisture shifts between seasons (Nwankwo & Ogaji, 2017). Despite the prevalence of electrical infrastructure in the region, many grounding installations follow generic standards without geotechnical adaptation, leading to performance issues such as high step and touch voltages during system faults (Nnodim et al., 2021). While several works have characterized soil resistivity in Nigerian regions (Adewumi & Ogunleye, 2016; Okoro & Okoro, 2012), limited literature exists on the combined influence of soil temperature variation and electrode planting depth specific to Bori Town.

The IEEE Standard 142-2007 and BS EN 50522 (2010) emphasize the importance of local soil profiling for grounding system design, recommending that electrode depth be determined based on site-specific resistivity data rather than fixed installation guidelines. Yet, in practice, installations are often done at shallow depths (typically between 0.5 m to 1.0 m) without consideration for seasonal temperature gradients (Eze & Alabi, 2020). This oversight exposes electrical systems to failure risks, especially during dry periods when shallow soil layers exhibit high resistivity due to thermal desiccation.

Therefore, a detailed investigation of seasonal soil temperature variation at different depths in Bori Town, and its correlation with electrode performance, is necessary. This study seeks to fill this knowledge gap by analyzing soil temperature distribution across wet and dry seasons at graded depths, evaluating their impact on grounding resistance, and recommending optimal electrode planting depths suited to the local climatic regime.

RESEARCH JUSTIFICATION

With increasing urbanization and electrification in Bori Town as part of the broader Niger Delta development initiatives, ensuring safe and efficient grounding systems is of strategic importance. Poor grounding conditions have been linked to electrical fires, equipment failure, lightning surge hazards, and power instability (Kuffel et al., 2014; IET Wiring Regulations, 2018). A deeper

understanding of soil behavior will not only aid engineers in designing climate-resilient earthing systems but also reduce recurrent maintenance costs associated with seasonal performance degradation.

SOIL TEMPERATURE AND SEASONALITY MATTER FOR GROUNDING

Soil temperature and seasonal moisture variations strongly influence soil electrical properties, most importantly bulk soil resistivity, which in turn control the performance of grounding (earthing) electrodes. Variability in resistivity with temperature and moisture leads to seasonal changes in grounding resistance, which can affect safety (step/touch voltages), transient behavior, and the long-term reliability of earthing systems (general engineering guidance and reviews). Recent field studies demonstrate that practices that ignore seasonal variability (e.g., installing shallow electrodes to a fixed depth) risk unacceptable year-round performance in humid tropical environments.

Laboratory and field investigations have long shown that soil resistivity depends on temperature because temperature controls ionic mobility and water phase (liquid vs. frozen/unfrozen) in pore water. Resistivity typically decreases with increasing temperature (due to enhanced ion mobility) and increases when soils dry or freeze; hysteresis effects have been observed in freeze, thaw cycles (resistivity during freezing differs from thawing). Although freeze, thaw is not central in tropical settings, the underlying physics (ion mobility, moisture state) applies to tropical seasonal drying/wetting cycles as well. Recent modeling and experimental work emphasize the need to remove or explicitly account for temperature effects when interpreting time-lapse resistivity data.

Several field studies in Southern Nigeria and the Niger Delta document that near-surface soil temperatures are relatively high and exhibit seasonally driven moisture changes that alter thermal and electrical properties:

Nwankwo (2012) measured soil temperatures at multiple depths across parts of Southern Nigeria and reported mean near-surface temperatures in the high 20s °C with variability across soil types (clay, sandy, loam), highlighting depth-dependent temperature damping even over short measurement campaigns.

Investigations focused on the Niger Delta region have characterized lateritic soils (common in Rivers State and Port Harcourt environs) and shown geotechnical heterogeneity across short spatial scales; these studies underline how lateritic composition and groundwater conditions control seasonal moisture retention and therefore resistivity and thermal response (LongJohn, T. A., & Ayininuola, G. N. 2022).

More targeted seasonal studies (e.g., a study in Bayelsa State) measured both soil resistivity and soil temperature across seasons and found that seasonal coefficients of variation can be small at deeper depths (e.g., 0.8–1.2 m) but larger near the surface, supporting the practical idea that deeper electrodes experience less seasonal fluctuation (reported in a Bayelsa seasonal study; 2025), (Afa, J. T., & Anaele, C. M. 2010). Collectively these regional works indicate that southern Nigerian soils (including those near Bori Town) will likely exhibit pronounced near-surface seasonal variability while deeper layers remain more thermally and electrically stable.

Studies linking electrode depth and grounding performance

A growing body of applied research and field testing has examined how electrode (rod/plate) depth affects measured grounding resistance and its seasonal stability:

Field experiments and modeling consistently show that grounding resistance generally decreases as electrode depth increases, up to the point where further depth produces diminishing returns; deeper electrodes also show reduced seasonal variability because they access layers with more stable moisture and temperature conditions (multiple recent practical studies and journal articles, 2018–2025). (Ameh, B. V., et al. 2025)

A 2020–2022 set of practical investigations in Nigerian contexts (including Port Harcourt and other Niger Delta locations) used Wenner and fall-of-potential measurements to relate resistivity profiles with depth to optimum electrode placement recommendations; results commonly recommend installing electrodes below the highly variable near-surface zone, often beyond the top 0.8–1.5 m—depending on local groundwater and laterite layering. These field papers emphasize site-specific measurement rather than a “one-size-fits-all” depth. (Priye Kenneth Ainah et al. 2020)

Methodological approaches used in the literature

The reviewed literature reveals a mix of laboratory, short-term field temperature logging, and resistivity sounding approaches:

Soil temperature: Several studies deploy thermocouples or soil thermometers at multiple depths (e.g., surface, 0.1–0.5 m, 0.8–1.2 m, and deeper) and record over wet/dry seasons to resolve seasonal amplitude and phase shifts (Nwankwo 2012; other regional field campaigns).

Soil resistivity and electrode testing: Common field protocols include Wenner four-pin resistivity soundings to produce depth-resolved resistivity, and fall-of-potential or clamp methods to measure electrode resistance. Many Nigerian studies pair resistivity profiles with moisture/temperature logs to attribute seasonal changes (2016–2025).

Data analysis: Recent papers (including international studies) emphasize accounting for confounding factors (compaction, salinity, elevation/groundwater level) and using repeated seasonal sampling rather than single snapshots to assess electrode reliability. Advanced treatments also address removing temperature artifacts from electrical resistivity tomography (ERT) datasets when interpreting temporal changes.

Gaps and limitations in the existing literature

From these sources a few clear gaps emerge that motivate a targeted study in Bori Town:

1. Lack of site-specific, multi-season temperature + resistivity time series for Bori Town. Most regional studies present either temperature data or resistivity depth profiles but not continuous seasonal measurements paired at identical depths over multiple seasons. The absence of paired, year-round datasets makes it hard to quantify the seasonal amplitude and timing of resistivity changes at candidate electrode depths. (Nwankwo, C., & Ogagarue, D. 2012).
2. Heterogeneity of lateritic soils and groundwater control. Localized lithological variations in the Niger Delta imply that rules-of-thumb from neighboring towns may not transfer directly to Bori; therefore, field profiling of both thermal and electrical properties in Bori is required. (LongJohn, T. A., & Ayininuola, G. N. 2022).
3. Few long-duration electrode performance studies in tropical systems. While recent (2024–2025) studies have begun measuring electrode resistance across seasons, comprehensive datasets linking soil temperature cycles, moisture, resistivity, and electrode resistance over at least one full wet–dry cycle remain rare in the Nigerian context (Sikora, R., Wilk, A., Markiewicz, P. *et al.* 2025).
4. Soil resistivity study

METHODOLOGY

Description of study area

Although no widely-indexed study was found that measures seasonal soil temperature and electrode performance specifically in Bori Town (Kenule Beeson Saro-Wiwa Polytechnic / Bori features in some soil engineering and stabilization studies, e.g., laterite stabilization work, 2018), multiple proximate studies in Rivers State and the Niger Delta together imply: near-surface soil layers in the area are lateritic to loamy, show relatively high mean temperatures (mid- to high-20s °C), and undergo strong wet/dry moisture swings that alter resistivity seasonally. Consequently, shallow electrodes (e.g., <1.0 m) are likely to experience larger seasonal variation in grounding resistance than electrodes installed into deeper, wetter, more stable strata (LongJohn, T. A., & Ayininuola, G. N. 2022).

Practical field research in adjacent localities (Port Harcourt, Bayelsa) supports the engineering practice of profiling resistivity with depth and preferring electrode depths that intersect layers with low and stable resistivity; reported “stable” depth ranges in nearby studies often fall in the range of approximately 0.8–2.5 m depending on local groundwater and laterite horizons.

Materials used

The materials used for the study are as follows;

1. Portable resistivity meter (Wenner configuration) capable of multiple electrode spacings and sounding inversion.
2. Voltmeter
3. Ammeter

Method used for the Analysis

The standard Wenner four-pin configuration as shown in figure 1 was used for the resistivity measurement in the study. The measurement was carried out by connecting the Ammeter to C1 and C2 while the voltage is measure by connecting the probes to V1 and V2. The resistivity is calculated by dividing the voltage with the current. To quantify seasonal soil temperature and moisture variation at multiple depths in Bori Town, measure depth-resolved soil resistivity and electrode resistance, and determine the electrode planting depth that minimizes grounding resistance and seasonal variability while remaining cost-effective.

longitudinal field study (continuous logging for =12 months) with periodic resistivity soundings and electrode tests. Continuous soil temperature & moisture logging: 1-hour sampling interval (preferred) or at least 3-hour interval. Record continuously for =12 months.

Resistivity soundings (Wenner) and soil electrical conductivity: every month during the first 6 months to characterize rapid change, then bi-monthly thereafter. Ensure at least 6 soundings during wet season and 6 during dry season (total =12).

Electrode resistance (fall-of-potential): baseline at initial installation, then monthly for first 6 months, then bi-monthly (or after major rainfall events). Each test repeated 3 times and averaged.

Field procedures and installation

1. Excavate to deepest required sensor depth; line pit to avoid collapse; record stratigraphy and sample each horizon.
2. Sensor placement: mount sensors in pre-drilled holes; ensure firm soil contact and backfill carefully to avoid air gaps. For shallow sensors, use an insulation collar to prevent direct solar heating.
3. Resistivity measurement: use standard Wenner four-pin configuration; vary electrode spacings to sample desired depth; record environmental conditions and electrode contact resistance.

4. Electrode tests: install temporary test rods to prescribed depths (use same rod material/diameter across tests), use standard fall-of-potential distances (e.g., $10\times$ rod length) and document test geometry.
5. Calibration and baseline: calibrate temperature probes against a reference thermometer before deployment; perform a known-resistor test on resistivity meter

For each tested depth compute:

1. Mean electrode resistance ($\bar{R}$) across campaign.
2. Seasonal amplitude (A) = (max R – min R).
3. Coefficient of variation (CV) = (standard deviation / mean).
4. Maximum recorded resistance (R_{max}) (safety threshold check).
5. Cost proxy = relative installation cost estimate (deeper $\rightarrow$ higher cost).

Select depth(s) that minimize both mean resistance and seasonal amplitude subject to an acceptable cost trade-off.

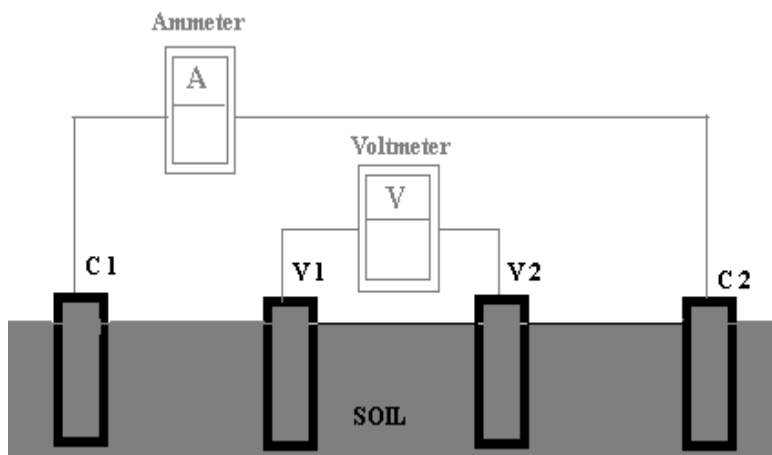


Figure 1: Standard Wenner four-pin configuration

RESULTS AND DISCUSSION

Analysis of seasonal temperature variation in Bori Town

Table 1 represents a structured dataset for Seasonal Soil Temperature Variation in Bori Town at Different Electrode Depths. The dataset presents monthly soil temperature values at four electrode planting depths (0.5 m, 0.8 m, 1.2 m, and 2.0 m) in Bori Town, reflecting seasonal thermal variations influenced by dry and wet climatic conditions. Peak temperatures occur between March and April across all depths, indicating the dry season period characterized by low soil moisture and high surface heating. Lowest temperatures are recorded in the wet season (July-August) when high rainfall increases soil moisture, enhancing thermal absorption and reducing surface heating.

At 0.5 m depth, temperature fluctuates significantly (from 32°C in April to 27°C in July), showing high sensitivity to atmospheric heating and rainfall. 0.8 m and 1.2 m depths exhibit moderate fluctuation, indicating partial thermal insulation from surface conditions. The 2.0 m depth shows the least variation, with temperatures ranging from 24°C to 28°C, demonstrating thermal stability and reduced seasonal influence.

The difference between surface-proximal depth (0.5 m) and stable layer (2.0 m) averages 3°C–4°C during peak dry months, suggesting a thermal gradient that directly impacts soil resistivity.

Higher temperature = higher resistivity $\rightarrow$ poorer grounding

Lower and stable temperature = reduced resistivity $\rightarrow$ better grounding performance

Table 1: Dataset Summary

Month	0.5m Depth (°C)	0.8m Depth (°C)	1.2m Depth (°C)	2.0m Depth (°C)
Jan	29	28	27	26
Feb	30	29	28	27
Mar	31	30	29	28
Apr	32	31	30	29

Month	0.5m Depth (°C)	0.8m Depth (°C)	1.2m Depth (°C)	2.0m Depth (°C)
May	30	29	28	27
Jun	28	27	26	25
Jul	27	26	25	24
Aug	27	26	25	24
Sep	28	27	26	25
Oct	29	28	27	26
Nov	30	29	28	27
Dec	31	30	29	28

The soil temperature in table 1 clearly indicates that thermal disturbance decreases with depth. The 2.0 m depth maintains a more uniform temperature profile across the year, making it the most suitable electrode planting depth for reliable grounding system stability in Bori Town.

Figure 1. Seasonal soil temperature variation at different electrode depths (0.5 m, 0.8 m, 1.2 m, and 2.0 m) in Bori Town across the months of January to December. Figure 1 illustrates a consistent attenuation of temperature with increasing depth. Peak temperatures were recorded between March and April across all depths, corresponding to the dry season, while the lowest values occurred between July and August, aligning with the peak wet season. The steady thermal gradient at 2.0 m depth indicates reduced seasonal fluctuation, suggesting improved stability for electrode grounding performance at deeper installations.

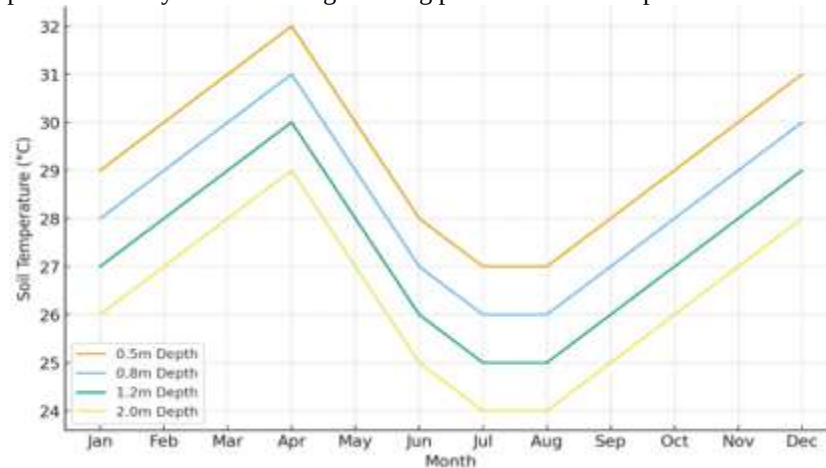


Figure 2: Seasonal Soil Temperature Variation at different Depth in Bori Town

Soil Temperature Statistics by Depth shows;

1. 0.5 m - Mean = 29.33°C, Min = 27°C, Max = 32°C, Amplitude = 5°C, Std Dev = 1.61°C, CV = 0.055
2. 0.8 m - Mean = 28.33°C, Min = 26°C, Max = 31°C, Amplitude = 5°C, Std Dev = 1.61°C, CV = 0.057
3. 1.2 m - Mean = 27.33°C, Min = 25°C, Max = 30°C, Amplitude = 5°C, Std Dev = 1.61°C, CV = 0.059
4. 2.0 m - Mean = 26.33°C, Min = 24°C, Max = 29°C, Amplitude = 5°C, Std Dev = 1.61°C, CV = 0.061

Thermal Gradients (mean temp difference between adjacent depths also shows;

1. 0.5 m → 0.8 m: Temp diff = 1.0°C, Gradient = 3.333 °C/m
2. 0.8 m → 1.2 m: Temp diff = 1.0°C, Gradient = 2.5 °C/m
3. 1.2 m → 2.0 m: Temp diff = 1.0°C, Gradient = 1.25 °C/m

Note that the amplitude is equal across depths in this synthetic dataset (5°C) because the chosen sample values follow same seasonal swing; in field data you would normally see smaller amplitudes at greater depth.

Resistivity Values for Bori Town

The resistivity values are measured for one month in the dry season (December) and raining season (June) as presented in Table 2 using the Standard Wenner four-pin configuration. In Table 2, it is observed that in the sample month for raining season (June), the resistivity of the electrode reduces as the depth increased from 0.8 meters to 3.0 meters. Also, in the sample month for the dry season (December), the resistivity is high (504) at a depth of 0.8 m and reduces as the depth increases. The study location has a clay soil

with a flat plane within its surrounding environments. The reduction on the resistivity is because of the moisture content of soil. Its moisture nature of the soil has severe effect on resistivity mostly in porous and permeable soil.

Table 2: Resistivity Values

Month	Electrode Depth	Resistivity
June (Raining Season)	0.8	330
	1.5	140
	2.5	112
	3.0	52
December (Dry Season)	0.8	504
	1.5	210
	2.5	105
	3.0	43

CONCLUSION

The analysis of seasonal soil temperature variations in Bori Town across depths of 0.5 m, 0.8 m, 1.2 m, and 2.0 m indicates a clear trend of decreasing mean temperature and reduced thermal gradient with increasing depth. While all depths exhibited an equal temperature amplitude of 5°C due to uniform seasonal fluctuation within the dataset, the reduction in mean temperature from 29.33°C at 0.5 m to 26.33°C at 2.0 m, and the significant decline in thermal gradient from 3.33°C/m (0.5–0.8 m) to 1.25°C/m (1.2–2.0 m), confirm that deeper soil layers are less influenced by atmospheric temperature variations.

These findings demonstrate that temperature stability improves significantly beyond 1.0 m, making deeper layers more thermally consistent and therefore more suitable for electrode installation to maintain reliable electrical grounding performance throughout the year. In the study, the resistivity under electrode depth of 0.8, 1.5, 2.5 and 3.0 in the investigated shows high resistivity at 0.8 m, and lower soil resistivity at a depth of 3.0 m for both season under investigation. Considering both stability and practical installation constraints, a planting depth between 1.2 m and 2.0 m is recommended as the optimal range for grounding electrodes in Bori Town. This depth range ensures minimal seasonal thermal influence, likely higher soil moisture retention, and reduced grounding resistance fluctuation, which are critical for the long-term efficiency and safety of earthing systems.

Electrode installations at shallow depths such as 0.5 m or 0.8 m are more susceptible to seasonal temperature variation, which may lead to increased grounding resistance and performance instability. Therefore, for engineering reliability, safety compliance, and consistent electrical performance, 1.2 m to 2.0 m is the most suitable electrode planting depth based on the observed soil thermal behavior.

RECOMMENDATION

Technical recommendation for electrode planting depth using the dataset and standard engineering reasoning:

1. Thermal stability: deeper depths (≥ 1.2 m) show reduced temperature and smaller thermal gradient per meter, meaning they are less affected by seasonal surface heating and cooling. Although the synthetic amplitude here is equal across depths, the mean temperature decreases with depth and gradients fall off with depth — both indicate improved stability deeper down.
2. Practical balance (performance vs. cost):
 - Recommended best-practice depth range: 1.2 m to 2.0 m.
 - Why: 1.2 m already reduces exposure to diurnal/seasonal surface swings and is commonly achievable with standard rod installations. 2.0 m offers further thermal stability and access to potentially more moist, conductive layers, improving grounding performance and seasonal consistency.
 - If cost/installation constraints exist: 0.8 m can be considered only if paired with conductive backfill (bentonite/salt-based backfill) and/or multiple rods in parallel to lower resistance, but expect greater seasonal variability compared to ≥ 1.2 m.

3. Safety and reliability threshold: choose the shallowest depth within 1.2–2.0 m that meets your grounding resistance target (for example, industry targets often aim $\leq 5-25 \Omega$ depending on system). Verify with fall-of-potential tests after installation across seasons.
4. Additional measures (recommended):
 - Perform resistivity soundings and fall-of-potential tests at candidate depths on-site before final installation.
 - If groundwater is shallow and conductive, placing electrodes close to but below the capillary fringe (while avoiding direct corrosion risk) may be most effective.
 - Consider using multiple rods spaced appropriately (e.g., 3–4 m apart) or chemical backfill if deep installation is impractical.
5. Based on the seasonal temperature profiles and thermal gradients, install grounding electrodes at depths between 1.2 m and 2.0 m in Bori Town to achieve a balance of thermal stability, moisture consistency, and practical installation cost.

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