Available online at JDR Website: http://journal.unublitar.ac.id/jdr
Journal of Development Research, 9 (2), November 2025, Pages 215-220
DOI: https://doi.org/10.28926/jdr.v9i2.470

Analysis of the Impact of Soil Quality on the Effectiveness of Lightning Rod Grounding Systems at the JoMA Boutique Villas and Resort Project

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Received: 11 September 2025 | Revised: 26 November 2025 | Accepted: 28 November 2025

Abstract

The grounding system is a critical component of lightning protection, as it directs lightning currents safely into the earth to protect buildings, equipment, and human life. This study evaluated the grounding resistance of the JoMA Boutique Villa & Resort project and assessed its effectiveness based on SNI 03-7015-2004, IEEE Std 80-2013, and NFPA 780, all of which specify a maximum allowable resistance of 5 Ω. Measurements taken at four grounding electrode points using an earth tester produced values of 2.41 Ω, 0.23 Ω, 0.11 Ω, and 0.22 Ω. All results were significantly below the required threshold, with calculated effectiveness levels ranging from 207.47% to 4545.45%. The variations in resistance values were influenced by soil characteristics, where embankment soil exhibited higher resistance compared to wet clay soil. Overall, the grounding system installed at the project site demonstrates high effectiveness and reliability in protecting structures and electronic equipment, while also minimizing the risks of step and touch voltages that can endanger human safety.

Keywords: *Electrical safety; Grounding effectiveness; Grounding system; Lightning protection, Soil resistance*

Introduction

Lightning protection systems are a crucial component in modern infrastructure design, particularly in commercial buildings and accommodations such as JoMA Boutique Villas & Resort. With tropical climates characterized by high rainfall and significant lightning intensity, the presence of a reliable protection system is crucial for maintaining human safety, protecting electronic equipment, and ensuring smooth operations. One of the main elements of this system is grounding, which functions to channel lightning currents safely to the ground (Ariana & Riana, 2019). However, the effectiveness of grounding is not only determined by technical design, but is also influenced by soil characteristics. Soils with high resistivity, such as rocky or dry sandy soils, have the potential to increase grounding resistance and reduce system performance (Akhir et al., 2024).

In the context of the JoMA Boutique Villas & Resort project, variations in contours and soil types at the construction site make geotechnical analysis and soil resistivity measurements crucial. Without proper evaluation, the installed grounding system risks not meeting safety standards according to national and international regulations (SNI, IEEE Std 80-2013, NFPA 780) (Akhir et al., 2024). Therefore, this study was conducted to examine the effect of soil quality on the effectiveness of lightning rod grounding, as well as to determine the most appropriate installation method, such as electrode deepening, expanding the grounding system, or using materials that increase soil conductivity (Androvitsaneas et al., 2020).

The results of this study are expected to support the planning of an optimal lightning protection system, adaptive to local soil conditions, cost-efficient, and meeting safety standards in the premium hospitality industry.

Methods

This research methodology uses a quantitative approach, with the research location being the lightning rod installation project at JoMA Boutique Villas & Resort Sebatu, Tegallalang. The research area covers 1,100 m² with a terraced contour, and the installation is planned to be installed on the roof frame shows on Figure 1.

Figure 1. Reasearch Location

Data collection was conducted using primary and secondary data. Primary data was obtained through direct on-site observation and interviews with relevant parties, while secondary data was obtained through documentation of lightning rod resistance test results and literature review from books, journals, and other reliable sources. The three methods used include: observation to determine real field conditions, documentation to obtain supporting data from test documents, and literature studies to study theories, formulas, and components relevant to the research.

This research was conducted through several systematic stages, as outlined in a flowchart. The first stage was a literature review, examining theories, standards, and previous research relevant to lightning rod installations and grounding systems. Next, field data was collected to determine the conditions of the research location, including land contours and other supporting parameters. Based on this data, soil resistivity testing was conducted to determine the soil's ability to conduct electrical current.

The test results then proceed to the data analysis stage. This stage determines whether the obtained soil resistivity values meet the feasibility standards. If the results are acceptable, the research proceeds to the conclusion-drawing stage. However, if the results are not acceptable, improvements are made using one or a combination of three methods:

1) Addition of ground rod points,
2) Increasing the depth of the ground rod, or
3) Adding chemicals to the soil.

After the repairs were made, the soil resistivity test was repeated until the results were obtained according to standards, then the study was closed with a conclusion.

To assess how effectively a grounding system works under certain soil quality conditions, the following Equation (1) is used:

$$Effectiveness \frac{R_{standard}}{R_{current}} \times 100\% \quad (1)$$

The grounding effectiveness equation is used to assess the extent to which the grounding system (grounding) is capable of operating optimally under certain soil conditions. This calculation aims to determine the success rate of the grounding installation compared to the established standard values.

Results and Discussions

A. Grounding Resistance Measurement Result

System grounding a well designed grounding system is characterized by low resistance values, allowing surge currents, electromagnetic induction, and system imbalances to be immediately diverted to the ground. This prevents potential damage to equipment while reducing the risk to human safety. Based on the IEC 60364 and PUIL standards, the recommended grounding resistance value is in the range of 1–5 ohms, or can be lower for certain installations (Johan et al., 2025). Grounding resistance measurements were conducted using the Kyoritsu Digital Earth Tester KEW 4105A at several grounding electrode points installed in the JoMA Boutique Villa & Resort project. The results of grounding resistance measurements at the project location were obtained at four test points which can be seen in Table 1.

Table 1. Grounding Resistance Measurement Result

No	Location	Maximum Standard	Measurement results	Status
1	Point 1	5 Oh	0.11 Ohm	Meet the standards
2	Point 2	5 Oh	0.22 Ω	Meet the standards
3	Point 3	5 Oh	0.23 Ω	Meet the standards
4	Point 4	5 Oh	2.41 Ohms	Meet the standards

The measurement results show variations in grounding resistance values at each electrode point. A relatively high value was found at point 4 (2.41 Ω), which is likely influenced by drier soil conditions or less homogeneous soil density. Conversely, a very low value at point 1 (0.11 Ω) indicates the soil in that area has a high water content, resulting in low resistivity, making the electrode more optimal in conducting current to the ground.

Meanwhile, points 2 (0.22 Ω) and 3 (0.23 Ω) showed nearly identical results, reflecting the consistency of soil characteristics at both locations. This is advantageous because the grounding system is not based on a single point but is reinforced by multiple electrodes with equivalent performance.

Overall, despite differences in values between points, all measurements at the JoMA Boutique Villa & Resort project were well below the maximum standard of 5 Ω. This confirms that the grounding system installation meets and even exceeds safety standards and provides reliable protection for buildings, electronic equipment, and human safety from the risk of lightning strikes.

B. Analysis of Measurement Results

Detention value grounding the results obtained show that the soil system at the research location is in the very good category. According to the literature, soil with high moisture and clay content (clay) tends to have low resistivity, so it is more effective in conducting lightning currents to the ground (Arifin, 2021). This is in line with the geographical conditions of the research location in Tegallalang, Gianyar, which is an area with a moist soil contour due to high rainfall and a dominant clay soil structure.

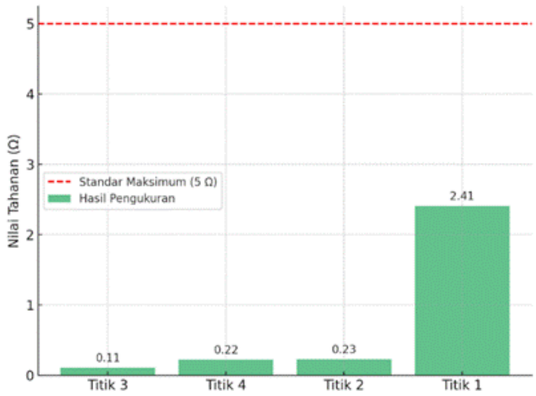

Figure 2. Comparison of Grounding Resistance Measurement Results with Standard Values

As seen in Figure 2, the measurement results show that all points have grounding resistance values far below the maximum limit of 5 Ω according to the SNI 03-7015-2004, IEEE Std 80-2013, and NFPA 780 standards. The graph makes it clear that despite the variations between points, the overall grounding system remains effective and meets safety standards.

The difference in values is influenced by several main factors. First, the type and characteristics of the soil: points 1, 2, and 3 are in a clay area with high humidity so that the resistivity is low and the grounding resistance is very small (<0.3 Ω). In contrast, point 4 is in an area of fill soil which tends to be less homogeneous, large pores, and has a higher resistivity (Putra et al., 2022). Second, soil moisture: high water content increases electrical conductivity (Hendrik et al., 2023), as seen in point 1, while the uneven distribution of moisture in the fill soil at point 4 causes a higher value. Third, the depth and quality of the electrode contact: the deeper the electrode is embedded, the more stable the soil moisture it reaches, so the resistance is lower. If the electrode is in a shallow fill layer, contact with the soil is less optimal (Hardi et al., 2023). Fourth, the homogeneity of the soil material: consistent clay soil is better at conducting current than fill soil mixed with sand or gravel.

From these results, it can be concluded that the variation in grounding resistance values reflects local soil conditions at the JoMA Boutique Villa & Resort project. Although there are differences between points, all results remain well below the standard. This ensures that the grounding system is able to accelerate the discharge of lightning currents to the ground, reduce the risk of step and touch voltages, and increase the reliability of protection for buildings, electrical installations, and electronic equipment in the resort area (Wijayanto et al., 2023).

C. Evaluation of Grounding System Effectiveness

Evaluation of the effectiveness of the grounding system was carried out by comparing the resistance measurements at each point to the maximum standard value of 5 Ω. The effectiveness of the grounding system at the four measured points can be seen in Table 2.

Table 2. Effectiveness of Grounding System

No	Location	Mark	Information

1	Point 1	4545,45%	Being the best point, it reflects the soil with very high conductivity.
2	Point 2	2271,73%	Being the best point, it reflects the soil with
3	Point 3	2173,91%	very high conductivity.
4	Point 4	207,47%	The lowest effectiveness value is due to the presence of fill soil, but it is still well above 100%, so the system is still very reliable.

Based on the calculations, all points had effectiveness rates above 200%, with most exceeding 2000%. This demonstrates that the installed grounding system not only meets standards but also performs significantly better than the minimum limits, providing maximum protection for buildings, electronic equipment, and human safety from lightning strikes.

D. Implications for System Security

Resistance measurement resultsgroundingThe grounding values at four points show very low values. This ensures that lightning current can be channeled to the ground quickly and safely, protecting the resort building from the risk of structural damage due to overvoltage. Furthermore, the grounding values below 1 Ω at most points (points 1, 2, and 3) also ensure the safety of electronic equipment sensitive to voltage surges, while reducing long-term maintenance costs.

From a human safety perspective, the extremely low resistance reduces the potential for both step and touch voltages, thus minimizing the risk of fatal electric shocks. This highly effective grounding system strengthens the overall reliability of the lightning protection system, ensuring optimal functioning of the lightning protection devices. However, variations in soil conditions, such as those at point 4 in the embankment area, still require attention, as they could potentially experience changes in resistivity in the future. Therefore, periodic re-measurements are recommended to maintain the system's effectiveness (Triyanto et al., 2022).

The results of this study not only meet the standards, but also show much better performance compared to the findings of several previous studies on clay and wet sand soils which are generally in the range of 1–3 Ω. With values achieved below 1 Ω at most points, it can be concluded that the grounding system at the JoMA Boutique Villa & Resort project is very reliable, capable of protecting buildings, equipment, and occupants with a high level of safety, as well as ensuring the continuity of resort operations.

Conclusions

Based on the results of measurements and analysis conducted on the JoMA Boutique Villa & Resort project, several key points were obtained. The grounding resistance values at the four test points ranged from 0.11 Ω to 2.41 Ω, all well below the maximum limit of 5 Ω according to the SNI 03-7015-2004, IEEE Std 80-2013, and NFPA 780 standards. The lowest value was achieved at Point 1 (0.11 Ω) and the highest at Point 4 (2.41 Ω), both of which still met the criteria for very good and safe.

The soil characteristics at the research site, predominantly clay with high moisture content, are a major factor in reducing resistance, thereby increasing the effectiveness of the grounding system. Effectiveness calculations showed that all points performed above 200%, with some even reaching over 4000%, confirming the grounding system's ability to optimally channel lightning currents to the ground.

Overall, the grounding system at the research location can be categorized as safe, reliable, and in accordance with international standards, and is able to provide comprehensive protection for buildings, electronic equipment, and human safety from the dangers of lightning strikes.

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