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RESEARCH ARTICLE

Analysis of Subsurface Hardness during the Wet and Dry Seasons in the Rice Fields of Semarang Village, Bengkulu City, Using the MASW Seismic Method

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Abstract

The mechanical properties of soil in agricultural land are greatly influenced by seasonal changes, which can affect productivity and food security. This study aims to analyze the effects of wet and dry seasons on the mechanical properties of subsoil in the rice fields of Semarang Village, Bengkulu City, and their implications for land management that supports food security. The method used was Multichannel Analysis of Surface Waves (MASW) with data acquisition at 24 points using 24 geophones (2 m spacing, 5 m offset). The data was then processed using WinMASW Professional 5.0 software to obtain a 2D model of shear wave velocity (Vs) and Poisson's Ratio to a depth of 30 m. The results showed that during the wet season, the soil was dominated by low Vs values (< 350 m/s) and high Poisson's Ratios (0.4 0.45), indicating saturated and soft conditions. Conversely, during the dry season, Vs values increased (600–1200 m/s) with lower Poisson Ratios (0.35–0.4), indicating a denser and stiffer subsurface medium. These findings confirm that seasonal variations in water content greatly affect the mechanical properties of the soil. Therefore, MASW-based analysis can be used as a basis for planning adaptive water and agricultural land management to support food security in tropical climates.

Keywords: Dry Season, MASW, Poisson’s Ratio, Shear Wave Velocity, Wet Season

1. Introduction

Agriculture has a direct impact on food supply and economic sustainability of communities, making it an important part of national development. The main commodity in Indonesia is rice, which is greatly influenced by rice field productivity, physical soil conditions, land stability, and water availability, all of which greatly affect rice field productivity (Septiaji et al., 2024). An important factor in maintaining rice field productivity is preserving soil characteristics with adequate water retention capacity and good mechanical stability (Putri et al., 2025).

Seasonal changes that affect water content and particle structure are among the factors that influence the physical characteristics of soil (Naz et al., 2024). Indonesia experiences two main seasons, namely the rainy season and the dry season (Azizah et al., 2018). Rainfall classification can be used to identify seasonal patterns in Indonesia, with rainfall exceeding 200 mm per month defined as a wet month, while rainfall below 100 mm per month is defined as a dry month (Sideng et al., 2022).

Soil moisture and density affect the physical properties of soil due to seasonal changes (Islami, 2019), which result in changes in the mechanical response of the soil below the surface (Muna et al., 2017). Soil in rice fields becomes quite soft and tends to be saturated with water throughout the rainy season (Yu et al., 2020), while soil becomes denser and harder in the dry season when moisture decreases drastically (Wu et al., 2023). The amount of water available to plants, stress distribution, porosity, and soil water retention capacity are influenced by seasonal changes (Alghamdi et al., 2024).

Elastic parameters that describe mechanical behavior can be used to quantitatively evaluate the physical and mechanical properties of soil that has undergone deformation (Buntoro et al., 2021). Among several parameters that can be used, one of them is shear wave velocity (Mulyana et al., 2026). The mechanical properties of rocks and soils can be analyzed using shear waves because they can accurately determine the stiffness, density, and condition of geological layers (Susilanto et al., 2020). Additionally, Vs data provides a detailed overview of subsurface lithology, where lower values often indicate the presence of loose alluvial layers or soil with low bearing capacity (Apriana et al., 2025). Meanwhile, the ratio of lateral strain to longitudinal strain in a medium is called the Poisson's ratio (Manangi et al., 2020).

To describe the elasticity variation and deformation response to stress in soil materials, the Poisson's ratio parameter can be used (Dearnia et al., 2019). Environmental conditions such as seasonal changes can affect the characteristics of the subsurface through significant water infiltration (Listyani and Ridayati, 2024). According to the results of research conducted by Yan et al. (2023), the saturation level of a material affects the magnitude of the Poisson's ratio. Poisson's ratio is very sensitive to changes in water content and saturation levels. The Poisson's ratio increases in water-saturated soil during the rainy season (Thota et al., 2021), while the Poisson's ratio decreases when the soil becomes compact and lacks water content during the dry season (Marchenko et al., 2018).

The use of the Poisson's ratio not only provides estimates of material rigidity through the Vs value, but also offers a comprehensive understanding of the deformation mechanism of soil when subjected to loads (Manangi et al., 2020). The use of these parameters aims to analyze crucial agronomic indicators such as water retention capacity, saturation threshold, and seasonal soil adaptability, so that productive agriculture can adapt to seasonal changes.

Research on the subsurface conditions of Bengkulu City has developed well. Hadi et al. (2021) have mapped the subsurface conditions in Bengkulu City using the microtremor method. However, the study did not discuss the effect of seasonal variations on soil flexibility values, even though analyzing seasonal changes in soil moisture content can determine soil elasticity values, which can later be used to manage productive agricultural land so that productive agriculture can be used for food security.

In this study because it is non-destructive, can describe Vs variations, Poisson ratio, and the effects of the seasonal changes. The non-destructive application of the MASW method make it suitable for observing the subsurface in active agricultural land (Prakoso et al., 2017). This study was conducted to gain a deeper understanding of the differences in soil flexibility between the rainy and dry seasons in the rice fields of Semarang Village, Bengkulu City, with the aim of providing information that can be used in food security, water management, and land conservation.

2. Methods

2.1 Study Location

The geological structure in Bengkulu City is the result of tectonic and sedimentation processes along the West Sumatra fault line. The types of rocks that form it include lake deposits, igneous rocks, alluvial deposits, alluvial terraces, and the Bintunan formation (Mase and Farid, 2020). The most abundant materials forming alluvial terraces are mud, clay, gravel, and sand, while materials consisting of a mixture of gravel with clay and mud form lake deposits. The relatively loose and porous lithology results in a high water storage capacity, making it susceptible to seasonal changes.

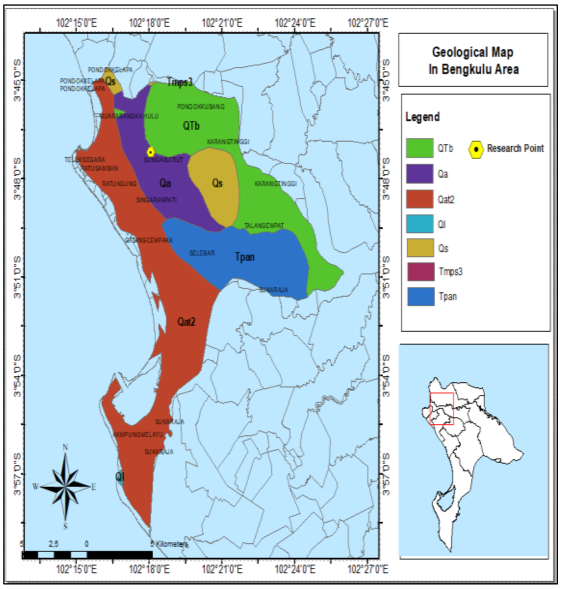

Fig. 1. Map of the area showing the geological conditions of Bengkulu City

The research was conducted in a rice field area located in Semarang village, where the physical condition of the soil is in the alluvial deposit zone. Seasonal rainfall and irrigation techniques significantly affect the variation in water content in this layer. During the dry season, the soil loses its moisture. As a result of the reduced water content, the physical condition of the soil tends to become hard and stiff; conversely, during the rainy season, the soil becomes saturated and soft. This has a major influence on the Poisson's ratio and shear wave values, which is why it is an important topic of discussion in this study. The distribution of measurement points in the study area is shown in Figure 2.

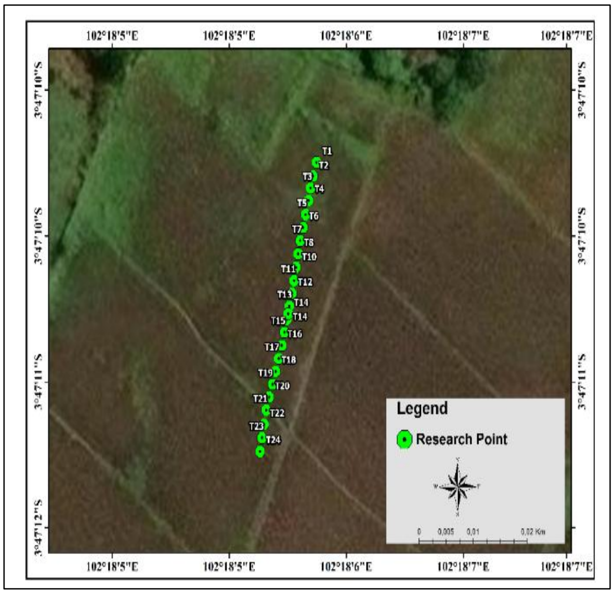

Fig. 2. Map of MASW Survey Locations

2.2 Acquisition Data

Field data acquisition was carried out using the Multichannel Analysis of Surface Waves (MASW) method. Data collection used a PASI 16824P digital seismograph with a configuration of 24 vertical 4.5 Hz geophones. The spread was 50 meters long with a spacing of 2 meters between geophones and an offset of 5 meters from the source. The seismic source used was a 10 kg hammer source striking a metal plate, with three stacks at each point to improve the signal-to-noise ratio. The MASW data acquisition scheme was adapted from Park et al. (1999) and is shown in Figure 3.

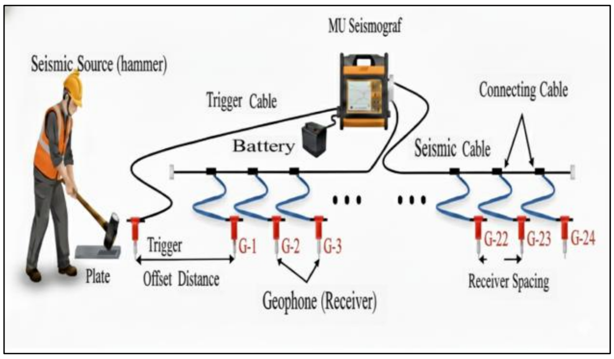

Fig. 3. MASW data acquisition scheme

The Rayleigh waves generated have a frequency range of 1-50 Hz. The recording duration for each shot is 512 ms with a sampling interval of 125 μs. To reduce noise, data collection is carried out far from residential areas and highways. Good data is characterized by clear and consistent Rayleigh surface waves across all geophones (Laksono and Rasimeng, 2017).

2.3 Data Processing

Data processing in this study was performed using WinMASW Professional 5.0 software. The data processing stage began with a filtering process using a low-pass filter with a 50 Hz cut-off frequency to eliminate high-frequency noise while preserving the integrity of the seismic signal in the 1–50 Hz range. The seismic wave time series data was then transformed from the time domain to the frequency domain using Fourier Transformation to obtain the dispersion spectrum. Fourier Transformation is defined in Equation (1). (Azhar et al., 2021).

$$F(\omega) = \int_{-\infty}^{\infty} f(t)e^{-i\omega t}dt \tag{1}$$

The next step is to pick the dispersion curve, which is the selection of dominant points on the dispersion spectrum that represent the fundamental Rayleigh wave mode (Figure 4b). The resulting dispersion curve, which describes the relationship between phase velocity and frequency, is then used as input for the inversion process to obtain a 1D profile of shear wave velocity (Vs) (Irwandi et al., 2021). The 1D profiles of all measurement points are then interpolated laterally using Surfer 20 software to create a 2D Vs model.

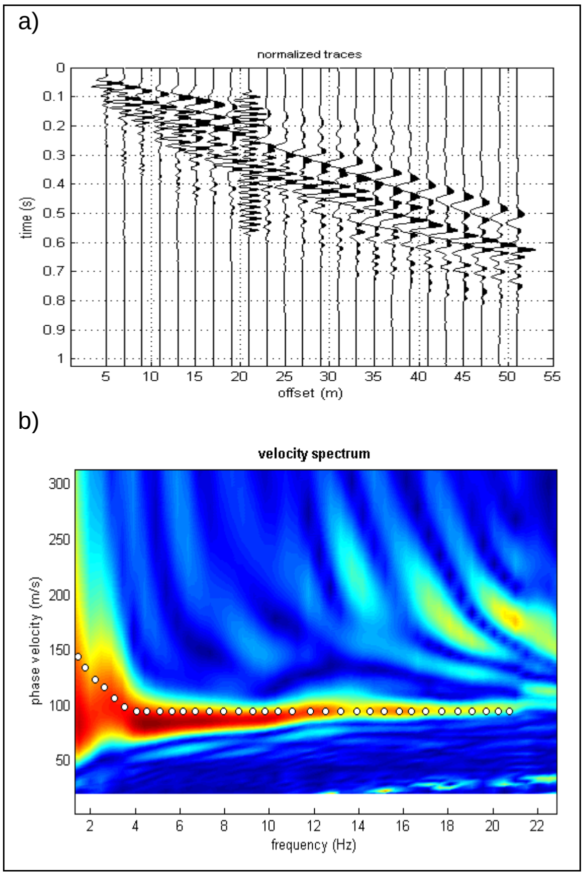

Fig. 4. (a) Example of seismic wave recording data, (b) Example of a picked dispersion curve

The Poisson's Ratio ( ) value is calculated from the Vs value and the primary wave velocity (Vp) derived from empirical relationships during the inversion process. The Poisson's Ratio calculation uses Equation (2) (Aryaseta *et al.*, 2022).

$$\sigma = \frac{1}{2}\left(\frac{(Vp/Vs)^2 - 2}{(Vp/Vs)^2 - 1}\right) \tag{2}$$

The 2D Poisson's ratio profile was then created using the same method as the Vs profile. Analysis of these two parameters (Vs and Poisson's ratio) to a depth of 30 meters was used to analyze the differences in soil mechanical properties between the rainy and dry seasons.

4. Result

The purpose of this method is to obtain Vs values and Poisson ratios to see the differences between these values in the dry and wet seasons. The results of field data acquisition were processed using WinMASW 5.0 Professional software. The inversion process was conducted by defining a four-layer model and specifying the initial search space for Vs values and layer thicknesses. The iteration process continued until convergence was achieved, characterized by the alignment of the Mean Model and the Fittest Model, and the attainment of a final misfit value of 0.5. According to the winMASW analysis, this value represents a 'very good' inversion quality. These optimized values, as referenced in Tables 1 and 2, were subsequently used to create 2D models using Surfer 20, producing the Vs distribution model in Figure 5 and the Poisson's ratio model in Figure 6.

Table 1. Classification of Land Site Classes based on (Zacharias, 2023).

Rock Type	Rock/Soil Description	Vs (m/s)
A	Hard Rock	> 1500
B	Medium Rock	750 – 1500
C	Hard Soil and Soft Rock	350 – 750
D	Medium Soil	175 – 350
E	Soft Soil	< 175

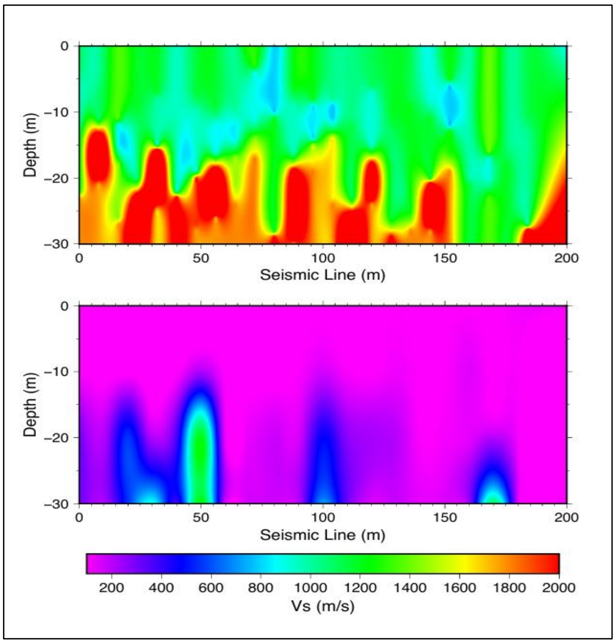

Fig. 5. 2D cross-section model of Vs during the wet season (top) and dry season (bottom)

Figure 5 shows a 2D cross-sectional model of Vs values during the wet and dry seasons. During the wet season (top figure), Vs values are dominated by velocities < 350 m/s, especially in shallow layers to a depth of 10–15 m. Based on Table 1, this range falls within class D (Medium Soil, 175–350 m/s) to class E (Soft Soil, <175 m/s). The decrease in shear strength and effective stress is caused by high water saturation during the rainy season, resulting in softer soil. There is a zone of medium-density rock with a Vs value of 700–1500 m/s at a depth of 20–30 m. This explain the presence of bedrock or denser material at medium depths.

Meanwhile, throughout the dry season (figure below), Vs values indicate higher velocities, with 600-1200 m/s dominating most depths. These values indicate a transition from stiffer soil to more compact material, based on the classification of hard soil/soft rock (350-750 m/s). Small Vs values (<350 m/s) are only seen locally during the dry season, indicating that, in general, soil conditions are stiffer than during the rainy season due to reduced pore water content.

The contrast between the two seasonal conditions shows the significant effect of soil moisture on the Vs value. During the wet seaon, a decrease in effective stress increases pore pressure,causing a decrease in shear wave velocity and soil type tending towards medium to soft textured soils. Meanwhile, during the dry season, reduced moisture increases capillary stress (suction) between soil particle , incearesing subsurface stiffness and producing large Vs value. These result are consistent with the findings of Abuawad et al. (2024), who explain that variations in moisture conditions significantly affect shear wave velocity

Table 2. Rocks types based on Poisson's ratio (Ji et al., 2018).

Material Type	Poisson Ratio
Saturated Clay	0.4-0.5
Unsaturated Clay	0.1-0.3
Sandy Clay	0.2-0.3
Silt	0.3-0.35
Sand	0.15-0.4

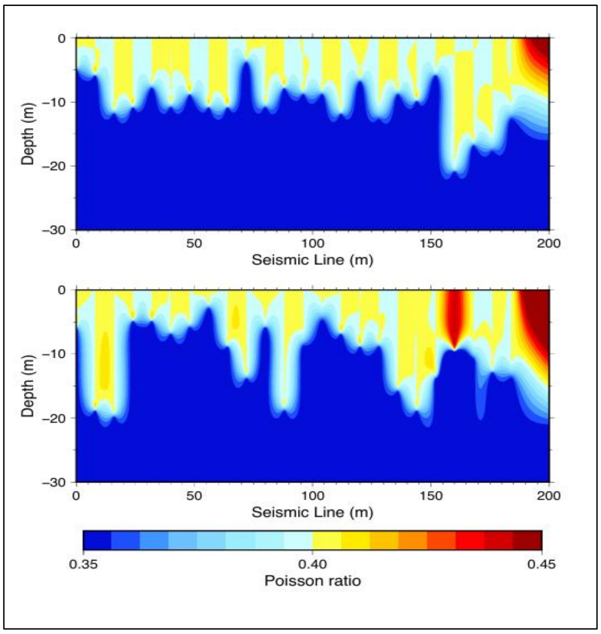

Fig. 6. Poisson ratio during the dry season (bottom) and during the rainy season (top)

Figure 6 shows a 2D Poisson ratio model throughout the wet and dry seasons, as well as material classification based on Table 2. The rainy season model (top image) shows that shallow layers at a depth of apromaximately 0-10 m have a Poisson ratio ranging from 0.40 to 0.45, which is dominant at this depth and coresponds to saturated clay. This condition indicates that the soil layer experiences high water infiltration during the wet season, causing the Poisson ratio value to increase towards the upper limit (0.5). In addition, an anomaly zone with avalue exceeding 0.43 (red color) appears on the east side of the survey line (approximately 150-200 m), which further indicates the presence of saturated oil with a low consolidation value.

At depths greater than 15 m, the Poisson ratio tends to decrease to a range of 0.35-0.38 (light blue), which is suitable for mud This indicates a change from saturated clay in the shallow layers to more stable mud layers at greater depths than before. This proves that the material at depths of more than 15 m is quite dense with lower porosity values, which hinders the penetration or seepage of surface water and means that only slight moisture is likely to be present at depth.

The dry season model has a similar geographical pattern, with lower Poisson ratios generally found in shallow subsurface layers. The Poisson ratio ranges from 0.35 to 0.40, referring to the table of values for slightly saturated mud and clay layer materials that dominate the ± 10 meter layer. Water content decreases due to evapotranspiration, as evidenced by a decrease in saturation levels, which also causes the Poisson ratio to decrease from around 0.45 to 0.35. There is an anomaly zone with a higher Poisson ratio of around (0.4–0.45) located at a depth of 150–200 meters, although it is not as severe as during the rainy season. This proves that there is a zone that can hold more water and stabilize humidity throughout the dry season.

This study is in line with the opinion of Yan et al. (2023),
who stated that soil saturation has a positive correlation with the Poisson's ratio value. This is reflected in the significant decrease in the Poisson ratio that occurs as the amount of water content decreases during the dry and wet seasons.

The Vs and Poisson ratio values show a fairly consistent response to changes in water content. Throughout the wet season, high Poisson ratio values and low Vs values decribe softer saturated soil. Throughout the dry season, the Poisson ratio decreases and the Vs value increases, decribing stiffer and semi-saturated soil due to to increased capillary tension. The persistent anomaly zone to the east of the line describes a zone with a fairly high level of water retention. In general, these two parameters confirm that moisture variations can determine and stiffness and saturation of the soil beneath the surface at the study site.

6. Conclusions

The result of the study explain that seasonal conditions have a significant impact on mechanical properties of soil in the rice fields of Semarang Village, Bengkulu City. During the wet season, the Poisson ratio has a high value (0.4-0.45) and a low Vs value (<350 m/s), indicating that the soil is saturated with water, soft, and less compact. Meanwhile, during the dry season, lower Poisson ratio (0.35-0.4) with higher values (600-1200m/s) indicate denser, harder, and stiffer soil due to reduced water content. The soil's ability to retain water and the stability of the subsoil are influenced by the differences in mechanical properties between the dry and rainy seasons. The soil's ability to retain water and the stability of the subsoil play a very important role in regulating agricultural productivity and food security.

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