Proceedings of the 21st ICSMGE, Vienna, Austria, 14 – 19 June 2026. Pistrol, Adam & Schweiger (eds.)
Published by: ÖGG, Austrian Society for Geomechanics, Salzburg, Austria, ISBN 978-3-9503898-4-5
https://doi.org/10.53243/ICSMGE2026-2293

Evaluation of moisture content by hyperspectral imaging

Koji Nakashima, Katsuyuki Kawai
Department of Civil and Environmental Engineering, Kindai University, Japan, knakashima@civileng.kindai.ac.jp

ABSTRACT: One of the challenges in geotechnical engineering is developing practical investigation methods and design techniques for construction sites and geo-disaster sites. For this, safe, economical, and nondestructive techniques to investigate soil ground conditions are needed to obtain spatial geotechnical information. In this context, materials identification using spectral imaging techniques has been introduced in various fields, with promising applications for geotechnical engineering. This study focuses on moisture content, which is important for evaluating soil conditions, and investigates the applicability of spectral imaging techniques to evaluate this soil property. Spectral images were acquired for sandy soil, kaolin clay, and marine clay at various moisture conditions using a near-infrared hyperspectral camera. The relationship between the moisture content and spectral characteristics was then investigated. The results confirmed that the reflectance spectral intensity of around λ=1450 nm, which is the absorption wavelength band of water, decreased as the moisture content increased, regardless of soil type. Differences in the shape of the spectrum were observed depending on the type of soil. In particular, the results for marine clay showed significant differences compared to those of sandy soil and kaolin. Furthermore, A color map of the spectral intensity suggests that a hyperspectral camera can prove useful to visually evaluate the spatial heterogeneity of soil moisture conditions.

KEYWORDS: Spectral imaging, hyperspectral camera, moisture content.

1 INTRODUCTION

The proper evaluation of ground and soil conditions at construction sites and for disaster investigations is important from economic and safety perspectives. To clarify ground conditions, laboratory and field tests are generally conducted to determine the mechanical properties of soils. However, these tests can only evaluate a limited area of investigation, and they require time and labor. Even when qualitative testing of soil condition is acceptable, the interpretation of results rests on the experience and knowledge of the engineer. Considering these problems, nondestructive measurement techniques and analytical methods for spatial clarification of ground conditions is needed.

Recently, spectral cameras have emerged as a promising new measurement technique to evaluate ground conditions. For example, spectral imaging has been utilized to determine the types of minerals, rock (Galdams et al., 2019) and their microstructures (van Ruitenbeek et al., 2019). In addition, spectral imaging is also useful for identifying landslide sites, as shown in studies using UAV-mounted multispectral cameras (Gantimurova et al., 2021).

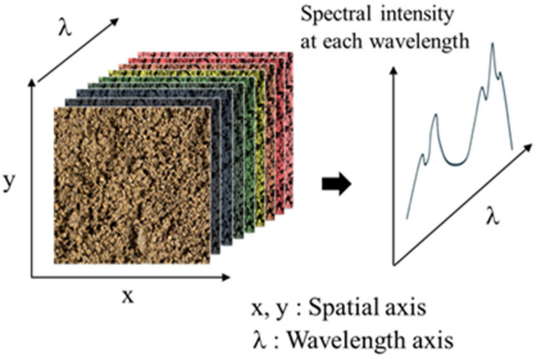


Figure 1. Principle of spectral imaging.

Figure 2. Hyperspectral camera (Pika IR-L).

A measurement technique that can spatially determine ground moisture conditions in a nondestructive manner would be useful in a variety of fields. For example, moisture conditions are often adjusted to improve soil compaction. However, it is difficult to quantitatively control the moisture conditions of large quantities of soil, a task which often relies on an engineer's experience and instinct. In addition, understanding landslide moisture conditions, particularly the surface layer of a collapsed slope, is useful for identifying the source of the disaster and for rapidly implementing post-disaster restoration activities. Despite this need, there is little research evaluating the use of spectral imaging to characterize soil moisture conditions. To confirm the usefulness of spectral cameras, it is necessary to clarify spectral characteristics and differences for different soil types.

In this study, several types of soil samples were prepared at various moisture contents, and spectral reflectance was obtained using a near-infrared hyperspectral camera. The relationships between moisture content and spectral characteristics were then investigated.

2 HYPERSPECTRAL CAMERA

A hyperspectral camera is a camera that precisely and finely separates light and acquires information by wavelength, as shown in Figure 1. The hyperspectral camera used in this study, a Pika IR-L (Resonon), is shown in Figure 2. The acquirable wavelength range of the camera is from λ=925 nm to 1700 nm, and the spectral reflectance can be divided into 236 wavelength bands with a wavelength resolution of 5.9 nm.

Water exhibits large absorption spectra at λ=1450 nm, 1940 nm, and 2900 nm, which are in the near-infrared region (λ>780 nm). Therefore, the hyperspectral camera used in this study has the potential to capture differences in spectral characteristics due to changes in moisture conditions and to evaluate the moisture content of soil by analyzing the spectral reflectance intensity at around λ=1450 nm.

3 SAMPLE PREPARATION AND TEST PROCEDURES

Sandy soil (Masado), kaolin clay, and marine clay were used as test materials. Sandy soil was prepared by adding water in

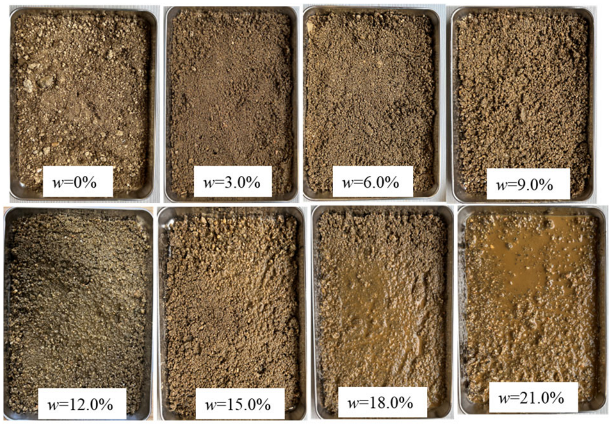
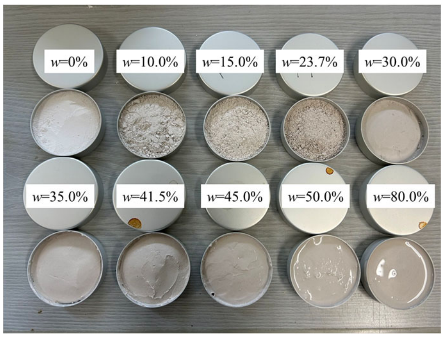
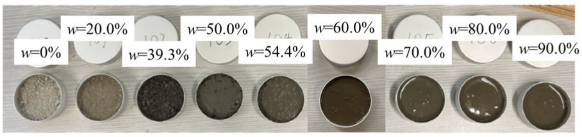


Figure 3. Sandy soil adjusted moisture content.



(a) Kaolin clay



(b) Marine clay

Figure 4. Clayey soil adjusted moisture content.

Table 1. Moisture content measurement.

(a) Sandy soil

Moisture content % (Target)	0.0	3.0	6.0	9.0	12.0	15.0	18.0	21.0
Moisture content % (Measurement)	0.0	3.1	7.6	8.5	10.5	13.5	15.5	19.0

(b) Kaolin clay

Moisture content % (Target)	0.0	10.0	15.0	23.7 (w_P)	30.0	35.0	41.5 (w_L)	45.0	50.0	80.0
Moisture content % (Measurement)	0.4	9.7	16.3	23.8	30.6	35.6	40.0	42.4	47.8	74.0

(c) Marine clay

Moisture content % (Target)	0.0	20.0	39.3 (w_P)	50.0	54.4 (w_L)	60.0	70.0	80.0	90.0
Moisture content % (Measurement)	1.6	21.5	40.1	50.9	53.6	57.0	69.0	72.9	88.3

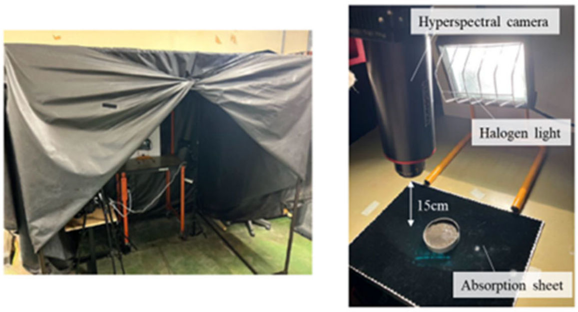


Figure 5. Overview of test equipment.

moisture content increments of w=3.0%, from 0% to 21.0% moisture content (Figure 3). For clayey soils, liquid limit and plastic limit tests (JIS A 1205) were conducted in advance to determine the sample moisture contents. The plastic limit for kaolin clay was w_P=23.7%, and the liquid limit was w_L=41.5%. The plastic and liquid limits of marine clay were w_P=39.3% and w_L=54.5%, respectively. According to the plasticity chart, kaolin clay was classified as low liquid limit clay (CL) and marine clay as high liquid limit silt (MH). Water was added to the materials to include conditions (i) below the plastic limit, (ii) above the plastic limit and below the liquid limit, and (iii) above the liquid limit. The samples were then placed in stainless steel petri dishes (Figure 4).

Table 1 shows the measured moisture contents. After the spectral tests, the test materials were dried, and moisture content measurements were obtained using the oven-drying method. For the sandy soil, the average of the three samples taken from different locations in the vat was used as the measured value.

The tests were conducted in a dark room using a halogen light containing near-infrared light as a light source. The test materials were placed on a sheet that absorbs near-infrared light, and the hyperspectral camera was set at a height of about 0.15m

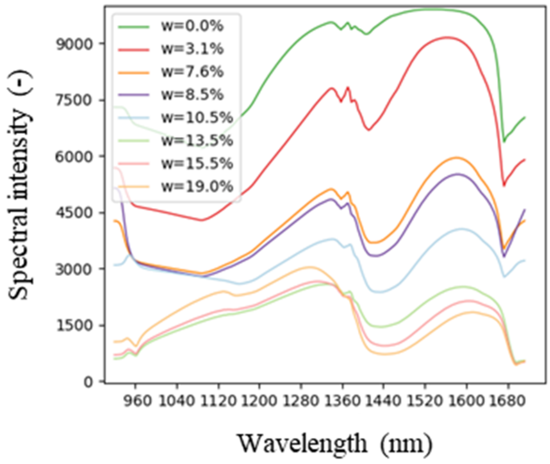


Figure 6. Spectral intensity (Sandy soil).

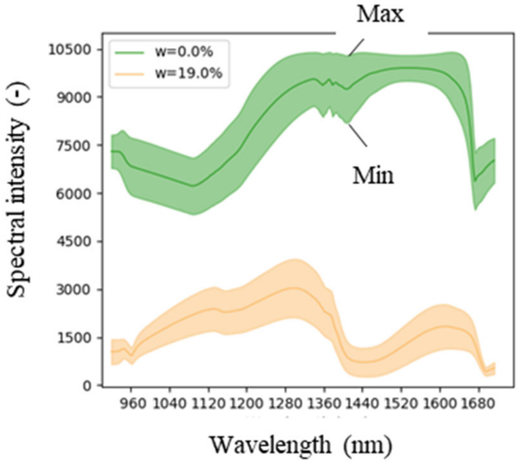


Figure 7. Spectral intensity variation.

above the materials (Figure 5).

4 TEST RESULTS

4.1 *Relationship between spectral intensity and moisture content*

Figure 6 shows the average spectral intensity captured for the sandy soil at each moisture content. As the moisture content increases, the average spectral intensity decreases in all wavelength bands, especially around λ=1450 nm, which is the absorption wavelength band of water. The spectral intensities show a significant change between the moisture content of w=0% and 7.6%. In this range, the color of the sandy soil visually changed with greater moisture content. Furthermore, the spectral shape appears roughly the same when the moisture content exceeds w=13.5%. This is because water gradually exuded onto the soil surface around w=13.5%, and no significant difference in the moisture condition is observed after this.

Figure 7 shows the maximum and minimum values of the spectral intensity at w=0% and 19.0%. The larger the width of the spectral intensity bounded by the maximum and minimum values, the greater the moisture content variation within the analysis area. These results confirmed that the variation in results becomes smaller as the moisture content increases. Under low moisture content conditions, water was not uniformly mixed into the soil, which appears to be reflected in these spectral characteristics. In actual construction sites, this ability to evaluate the non-uniformity of moisture conditions using spectral cameras would be another useful application of the technique.

Figures 8 and 9 show the average spectral intensities of

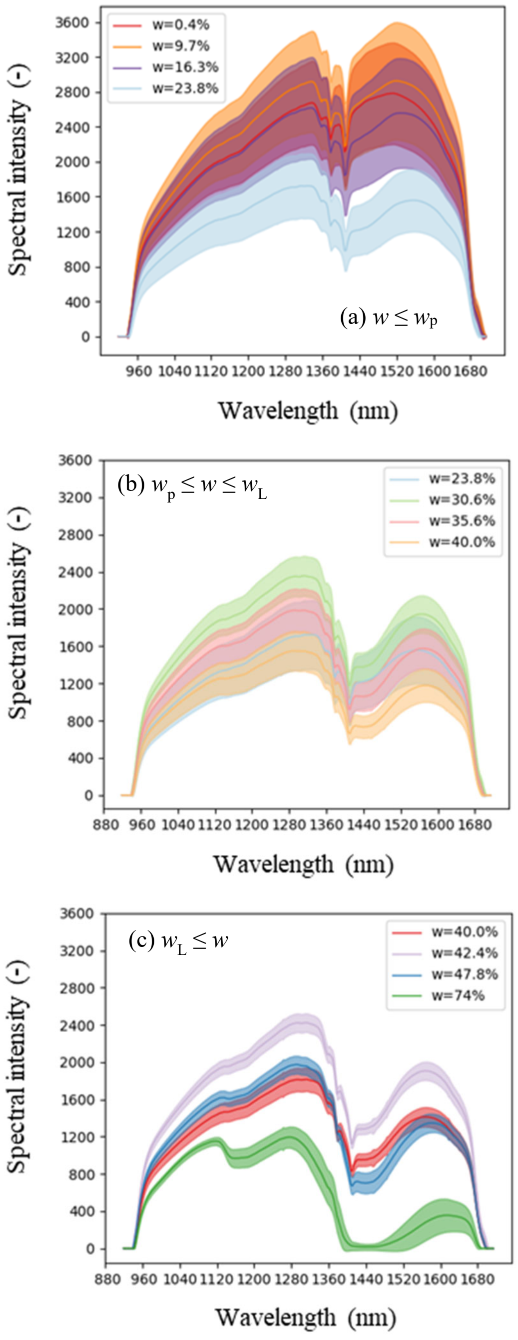


Figure 8. Spectral intensity (Kaolin clay).

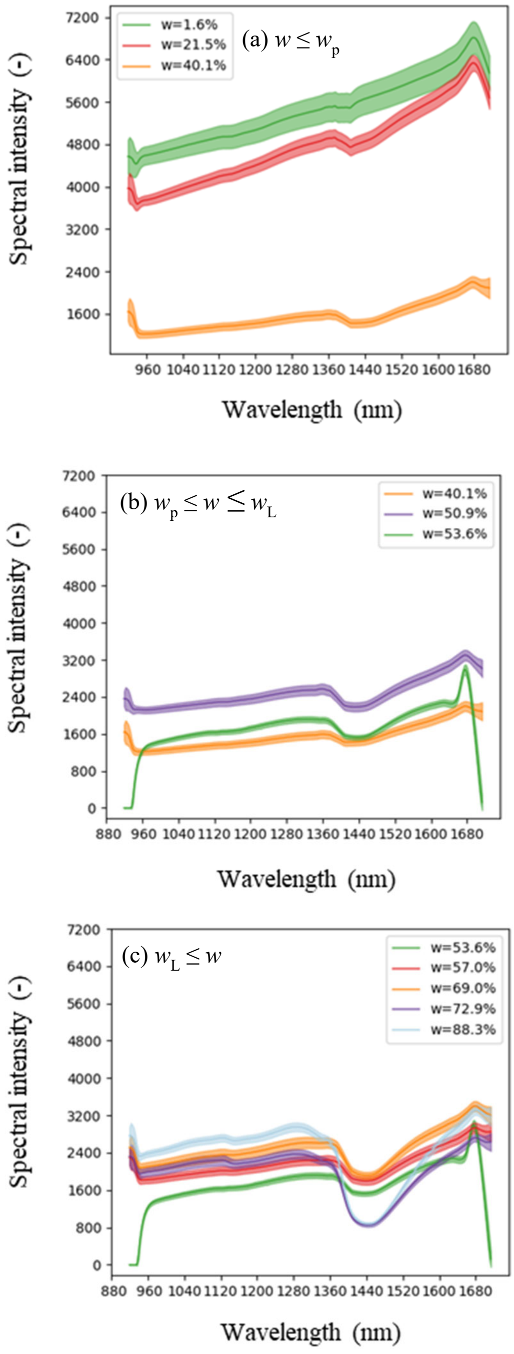


Figure 9. Spectral intensity (Marine clay).

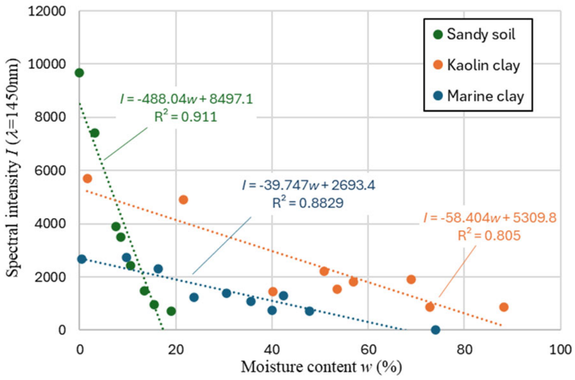


Figure 10. Relationship between spectral intensity and moisture content (λ=1450 nm).

kaolin clay and marine clay. The results for kaolin clay show that the spectral intensity decreases as the moisture content increases. Like the sandy soil, this tendency is more remarkable around λ=1450 nm. For marine clays, however, although the spectral intensity decreases as the moisture content increases, a marked decrease in the spectral intensity at around λ=1450 nm can be observed when the moisture content exceeds the liquid limit. Furthermore, in marine clays, no significant differences in the spectral intensities are observed for moisture contents above the plastic limit. In other words, determining the moisture content for clayey soils such as the marine clay above the plastic limit is likely difficult to do in detail using a hyperspectral camera. For kaolin clay, the non-uniformity of moisture conditions is large at lower moisture contents, and decreases at higher moisture contents, especially above the liquid limit, whereas for marine clays, the non-uniformity of moisture conditions is small, even if the moisture content is low. Water compatibility differs depending on the clay type, and the maritime clay was easier to mix uniformly with water during sample preparation. Comparing Figures 6, 8, and 9, the shape of the spectrum differs depending on the type of soil, with marine clay showing a significant difference compared to sandy soil and kaolin clay. This is because the reflective characteristics of each wavelength differ depending on the type of minerals that compose the soil. Particularly, spectral response of clay minerals results from vibrations of structural water molecules, hydroxyl groups, the silicate framework, and interlayer cations (Yitagesu et al., 2011).

Figure 10 shows the spectral intensity at λ=1450 nm for each moisture content. There is a proportional relationship between the moisture content and the spectral intensity for all soils. The parameters in the approximate equation are expected to vary depending on the type of soil. This points to a need to analyze a variety of soils to establish the relationship between various material constants and parameters in the equation.

4.2 *Spatial distribution of moisture content*

A color map of the spectral intensity was created for the sandy soil, and the spatial water distribution is shown in Figure 11. Blue areas indicate low reflectance spectral intensity at λ=1450 nm. For the results of w=0%, most areas reflect λ=1450 nm light; however, as the moisture content increases, the areas with low reflection intensity increase. In addition, although water was added so that the entire soil had the target moisture content, the spatial distribution of results exhibited a non-uniform moisture condition. This corresponds to the result that the lower the moisture content, the greater the variation in the spectral intensity in the analysis area. From this, we determine that a hyperspectral camera has the potential to visually evaluate the spatial heterogeneity of the water distribution.

5 CONCLUSIONS

In this study, the applicability of a hyperspectral camera to evaluate the moisture content of various types of soil was investigated. The following conclusions were drawn:

(1) Regardless of the soil type, as the moisture content increases, the reflectance spectral intensity around λ=1450 nm decreases, and this relationship is represented proportionally.
(2) The shape of the reflectance spectrum differs depending on the type of soil, and the spectrum of marine clay differs significantly from that of sandy soil and kaolin clay.
(3) A color map of the spectral intensity suggests that the spatial heterogeneity of water distribution can be evaluated visually by using a hyperspectral camera.

6 ACKNOWLEDGEMENTS

This work was supported by Grant-in-Aid for Scientific Research (25K17686).

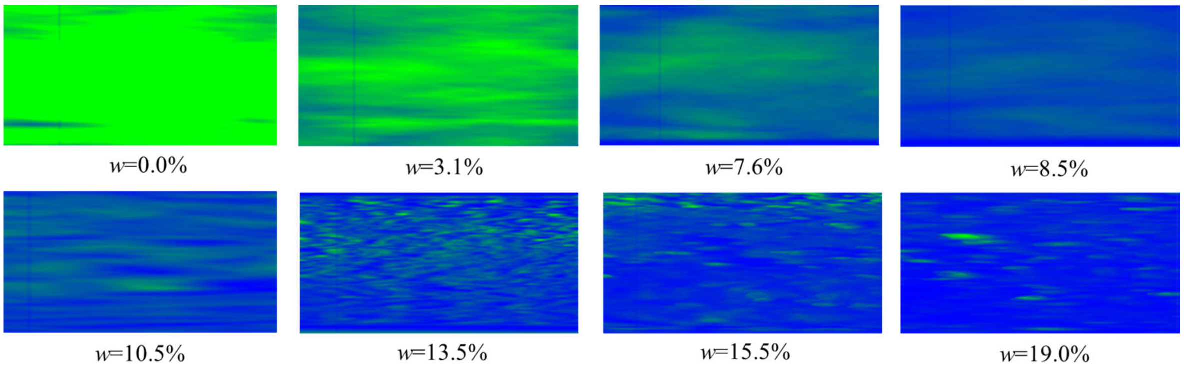
7 REFERENCES

Galdams, F.J., Perez, G.A., Estévez, P.A., and Adams M. 2019. Rock lithological classification by hyperspectral, range 3D and color images, *Chemometrics and Intelligent Laboratory Systems*, 189, 138-148.

Gantimurova, S., Parshin, A., and Erofeev, V., 2021, GIS-based landslide susceptibility mapping of the Circum-Baikal railway in Russia using UAV data, *Remote Sensing*, 13(18), 3629.

van Ruitenbeek, F.J.A., van der Werff, H.M.A., Bakker, W.H., van der Meer F.D. and Hein K.A.A. 2019. Measuring rock microstructure in hyperspectral mineral maps, *Remote Sensing of Environment*, 220, 94-109.

Yitagesu, F.A., van der Meer, F., van der Werff, H., Hecker, C. 2011. Spectral characteristics of clay minerals in the 2.5-14 µm wavelength region, *Applied Clay Science*, 53(4), 581-591.



w=0.0% w=3.1% w=7.6% w=8.5%

w=10.5% w=13.5% w=15.5% w=19.0%

Figure 11. Spectral intensity color map (λ=1450 nm).