The 2022 World Congress on
Advances in Civil, Environmental, & Materials Research (ACEM22)
16-19, August, 2022, GECE, Seoul, Korea

Estimation of liquid limit of cohesive soil using vision-based vibrometry

Matthew Sands[1)], Soonkie Nam[2)], Xiaoming Yang[2)], and *Jinki Kim[3)]

[1), 3)] Department of Mechanical Engineering, Georgia Southern University, Statesboro GA, USA
[2)] Department of Civil Engineering and Construction, Georgia Southern University, Statesboro GA, USA
[3)] jinkikim@georgiasouthern.edu

ABSTRACT

The reliability of civil engineering structures and construction processes is fundamentally dependent on their foundation structures and supporting ground. Thus, understanding the response of the soil under certain loading conditions is significantly important. As it is well known that certain soil characteristics are highly dependent on water content (Lu, 2019), it is critical to accurately measure and identify the status of the soils in terms of water contents. Liquid limit is one of the soil index properties to define such characteristics, but a certain consistency is required in the standard as the results can be affected by the proficiency of the operator (ASTM, 2005). On the other hand, dynamic properties of soils are also necessary in many different applications and current testing methods often require special equipment in the laboratory, which are often expensive and sensitive to test conditions. In order to address this concern and advance the state of the art, this research explores a novel method to determine the elastic modulus and liquid limit of soil by employing vision-based vibration analysis approaches. In this study, the modal characteristics of a cohesive soil column are extracted from videos by utilizing phase-based motion estimation (Wadhwa, 2013).

Small Kaolin clay cylindrical samples (65 mm in height and 19 mm in diameter) are fabricated with water contents ranging from 33% to 40%. The column samples sit freely on a horizontal table attached to an electromagnetic shaker (V406, Brüel & Kjær). The samples are randomly excited with frequencies ranging from 10 Hz to 250 Hz with 0.01 g root-mean-square amplitude. The vibration of the clay samples is simultaneously measured by a laser displacement sensor (optoNCDT 1420, Micro-Epsilon) at a sampling rate of 4000 Hz and a 1.3 megapixel (1280x1024 CMOS sensor) high speed camera (Chronos 1.4, Kron Technologies) equipped with a 12.5 - 75 mm f/1.2 zoom lens. Resolutions (400 × 1020 pixels) and frame rates (1000 frames per second) for the video are selected to record as much of the structure's spatiotemporal data as possible. By utilizing the proposed method that analyzes the optical flow in every pixel of the se-

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[1)] Graduate Student

ries of images that effectively represents the motion of corresponding points of the soil specimen within the field of view of the camera, the vibration characteristics of the entire soil specimen could be assessed in a non-contact and non-destructive manner.

Figure 1(a) shows the spectral amplitudes around the fundamental resonance frequency (flexural mode) of the clay specimen. The frequency responses are fitted to a Lorentzian distribution to estimate the resonance frequency at the peak. It is clearly observed that the resonance frequency decreases as the water content level increases, which indicate the elastic modulus of clay decreases with higher water content level. On the other hand, the samples with water content level higher than 38% did not exhibit flexural resonance but gradually fall back as random excitation was applied (Figure 1(c)), which corresponds to the liquid limit (37.5 %) that was experimentally determined by Casagrande method (ASTM, 2005).

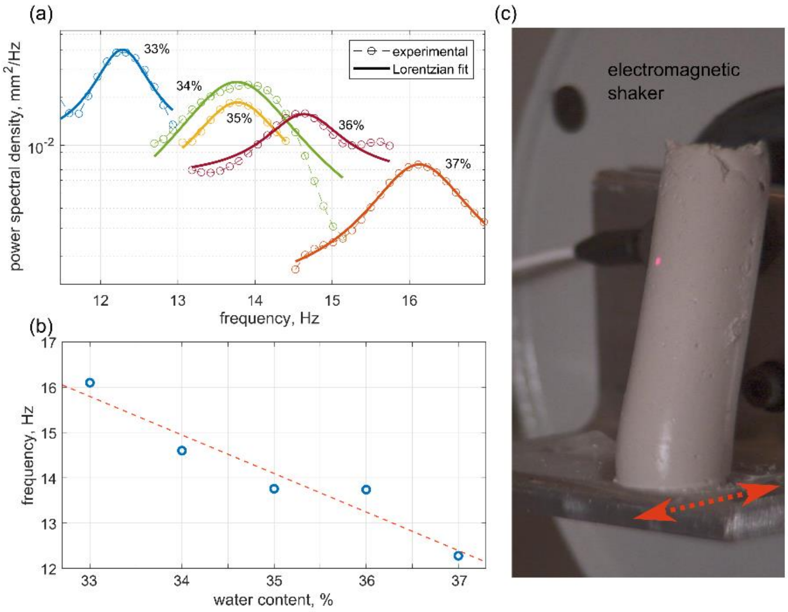

Figure 1. (a) Frequency responses near the fundamental resonance frequency for flexural vibrations of clay samples with various water content levels. (b) Fundamental resonance frequency as a function of water content level. (c) Clay sample (38%) laid back as randomly excited by the electromagnetic shaker in the direction of the arrow.

The experimental investigation results compared with traditional water content measurements for various water content level verify that the proposed method reliably and straightforwardly identifies the liquid limit of clay. It is envisioned that since the resonance frequencies are relatively low, the proposed method could be applied with a relatively inexpensive and readily available raspberry pi camera modules for practical applications in field operations.

REFERENCES

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