

## A NEW REAL BENCHMARK EXAMPLE FOR DATA-DRIVEN SITE CHARACTERIZATION

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This study proposes new benchmark examples for data-driven site characterization (DDSC) based on actual data that was collected at the premises of Ohmoto Gumi Co., Ltd. in the city of Okayama, Japan. The site is named “Ohmoto site” in this paper. The physical volume of this example is a 20 m long × 24 m wide × 20 m deep cuboid. Site investigation and laboratory testing were conducted at the site for creating benchmark datasets. This paper outlines the new benchmark examples based on Ohmoto site data.

*Keywords:* Benchmark example, data-driven site characterization, unconfined compression test, dynamic cone penetration test, ambient noise tomography, electric resistance tomography, soil profile.

### 1. Introduction

Decision-making in geotechnical engineering is always related to a project at a specific site, and it is natural for data-driven site characterization (DDSC) to attract the most attention in geotechnical practice (Phoon et al. (2022a)). Traditional site characterization mainly relies on engineering judgment and practitioners’ experience to derive 3D stratigraphic profiles or 3D spatial distribution of soil properties. In recent years, the increasing availability of large-scale, high-resolution datasets and advancements in computational methods have paved the way for data-driven approaches in geotechnical engineering. Many DDSC methods have been developed because of the advancement in machine learning (ML) algorithms. There is a large volume of papers on ML in geotechnics, and more than 30% of ML applications in geotechnics are about site characterization (Phoon and Zhang 2023). Ultimately, the goal of DDSC is to provide a more complete picture of a site’s conditions, so that stakeholders can make informed decisions about how best to manage. Since this goal can be achieved through numerous routes, various DDSC methods with different features are being proposed for various purposes. When reviewing the literature on ML or DDSC in geotechnics, it is important to note that many studies/researchers evaluate the proposed methods based on their own validation methods or data, making it challenging to compare the performance of different models across studies. This makes comparison of performance between different DDSC methods difficult.

In order to measure the performance of the DDSC method in a balanced and unbiased way, Phoon et al. (2022b) proposed standard benchmark examples for DDSC and a benchmarking procedure. The benchmark examples are based on the synthetic cone penetration test data and are plausible outcomes of some idealized stratigraphy (called virtual ground). Training and validation datasets are proposed to guide the demonstration of the performance to showcase: (1) ability to handle the attributes of real-world datasets directly, (2) generality over a range of ground conditions encountered in practice, (3) strengths and limitations compared to other methods using a common set of performance metrics, and (4) practicality in terms of computational resources needed to solve full-scale 3D problems. While the benchmark examples proposed by Phoon et al. (2022b) are useful to compare different DDSC methods, they are based on synthetic data and have much room for improvement. It is ideal to create benchmark examples based on real world data.

This study proposes a new benchmark example for DDSC based on real ground. The premises of Ohmoto Gumi Co., Ltd, which is located at Kaigan Street, Minami Ward, Okayama City, were used as the “real ground” for the benchmark example. This site is called “Ohmoto site” in this paper. Several site investigations including geophysical surveys and penetration tests were conducted to collect large amounts of data for creating a benchmark example. Several laboratory tests were also conducted to measure physical and mechanical properties of soils of the target ground. This paper outlines the site investigations conducted at this Ohmoto site and describes a potential benchmark example based on the data collected at Ohmoto site.

### 2. Site Description

Ohmoto site is located at Kaigan Street area, South of Minami ward in Okayama city, Okayama (Fig. 1 (a)). Kaigan Street area is reclaimed land created during a land reclamation project conducted in the 1940s, and the topography of the area is flat. No buildings currently exist onsite, but there is evidence of demolition of previously existing structures. The site is bare soil with little or no vegetation (Fig. 1 (b)).

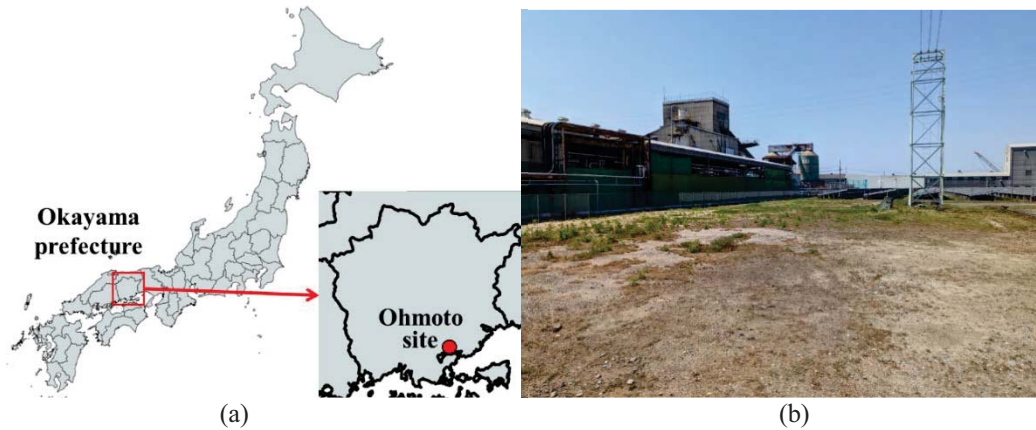


Fig. 1. Ohmoto site; (a) Location of Ohmoto site; (b) Photo of Ohmoto site.

### 3. Site Investigation and Laboratory Testing

Site investigations and laboratory testing were conducted at this site for collecting data for the benchmark example. Fig. 2 shows the site and investigation plan for Ohmoto site, indicating locations of dynamic cone penetration (DCP) test and borings. This section outlines the site investigation, in-situ testing, and laboratory testing conducted to collect data for the benchmark example.

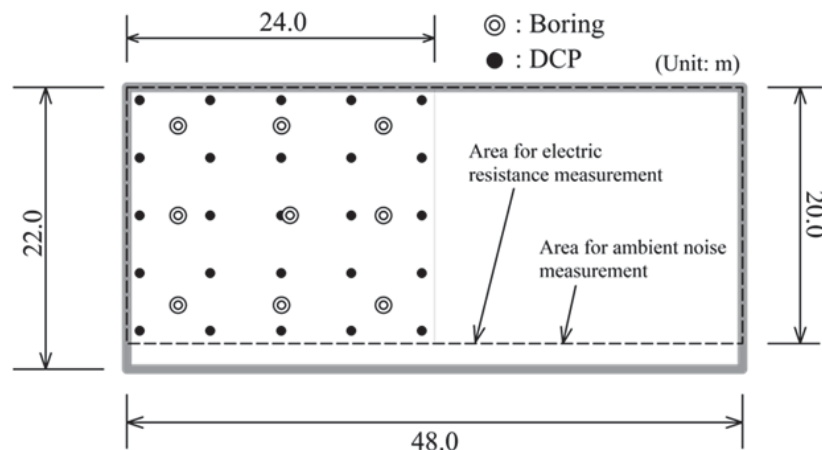


Fig. 2. Site investigation plan for Ohmoto site.

#### 3.1. Site investigation

##### 3.1.1. Ambient noise measurement and tomography

Ambient noise measurement was conducted to create three-dimensional (3D) S wave velocity structure through ambient noise tomography. Fig. 3 shows a measurement of ambient noise. Geophones were placed at 4-meter intervals. Fig. 4 shows the S wave velocity structure reconstructed by ambient noise tomography.



Fig. 3. Ambient noise measurement; (a) Layout of geophones; (b) Three component geophones.

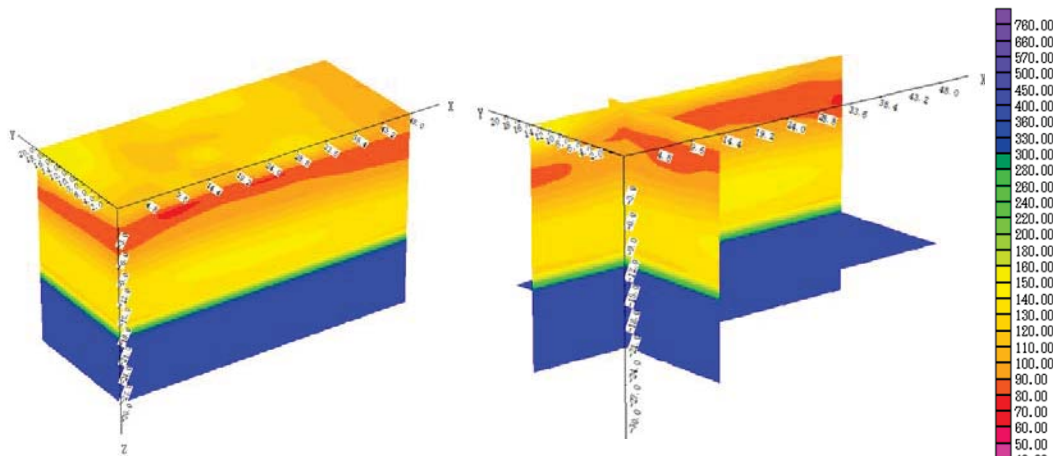


Fig. 4. Result of ambient noise tomography.

**3.1.2. Electric resistivity measurement and tomography**

Electric resistivity was measured at the site to image sub-surface structures through electric resistivity tomography (ERT). Fig. 5 shows the setup for a survey with several electrodes along a straight line attached to a multi-core cable. Fig. 6 shows a plan view of resistivity reconstructed by ERT.



Fig. 5. Electric resistance measurement; (a) Setup of electrodes; (b) Resistivity meter.

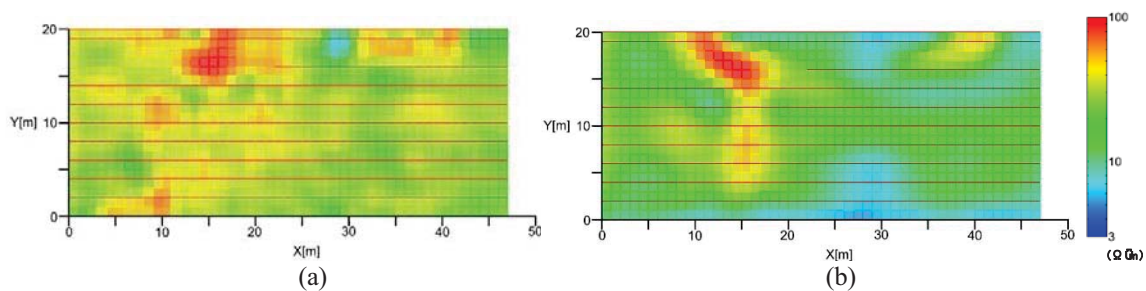


Fig. 6. Results of electric resistance tomography (plan view); (a) At depth of 2 meter; (b) At depth of 4 meter.

**3.1.3. Dynamic cone penetrometer (DCP)**

The DCP test was conducted at 25 locations with spacings ranging from 4.5 to 6.5 meters (Fig. 2). Fig. 7 (a) shows the DCP equipment used at Ohmoto site. The cone was driven until it reached the bearing layer, approximately 20 meters below the ground surface. Fig. 7 (b) shows examples of depth profile of blow count ( $N_d$  value). The profiles fluctuates and some spikes or abrupt changes can be observed.

**3.1.4. Borehole drilling and sampling**

To investigate soil stratification of the ground, borehole drilling and sampling were conducted at nine locations with spacings 8 meters (Fig. 2). The drilling was conducted until it reached the bearing layer,

approximately 20 meters below the ground surface. The sampling was conducted from 3 m and 19 m depth, and the total length of the soil samples were about 16 m. The soil samples were used for soil stratification and laboratory testing.

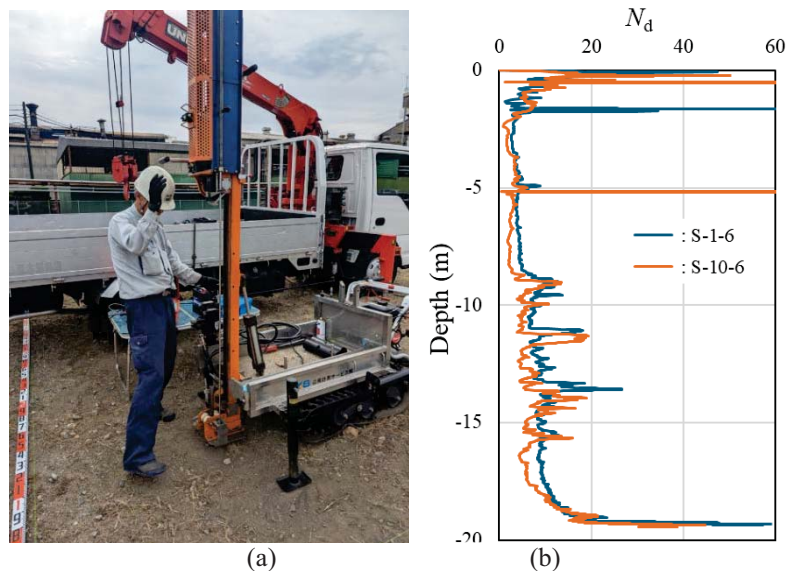


Fig. 7. Dynamic cone penetrometer; (a) Equipment; (b) Depth profile of  $N_d$ .

### 3.2. Laboratory testing

#### 3.2.1. Unconfined compression test

Unconfined compression tests were conducted for the soil specimens sampled from Ohmoto site. About 40 specimens were obtained from one borehole, and 390 tests were performed in total to measure the unconfined compression strength  $q_u$  and elastic modulus  $E_{50}$ . Fig 8 shows the test equipment and three examples of stress-strain curves.

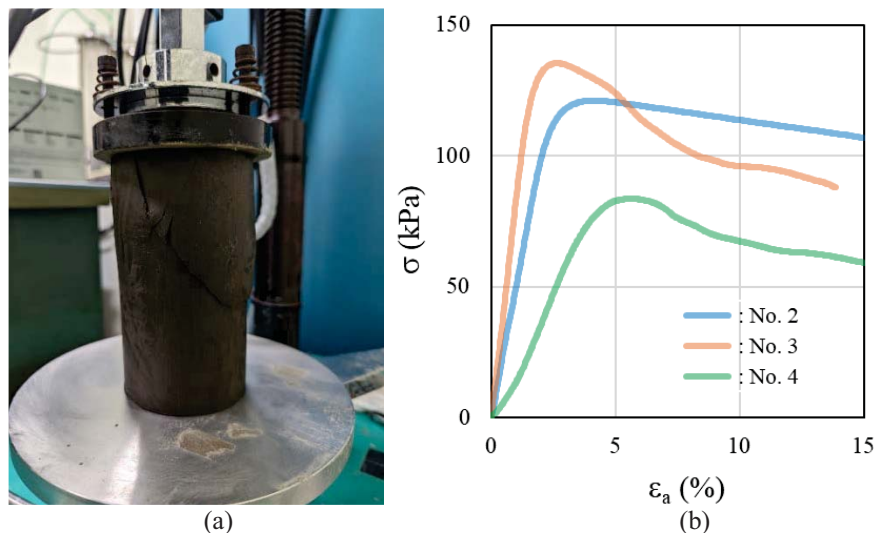


Fig. 8. Unconfined compression test; (a) Test equipment; (b) Stress-strain curves.

#### 3.2.3. Other laboratory tests

Other laboratory tests include 1) Atterberg limit test, 2) sieve analysis test, and 3) natural water content of a soil sample.

### 4. Possible Real Benchmark Examples based on Ohmoto Site

Since several types of geotechnical data, S wave velocity structure,  $N_d$  value, unconfined compressive strength  $q_u$  etc, were collected at Ohmoto site, several types of DDSC benchmark examples can be proposed. This section presented potential benchmark examples for DDSC.

Fig. 9 (a) shows a plan view of potential benchmark example based solely on DCP data. The purpose of this benchmarking is to estimate spatial distribution of  $N_d$  value using only three DCP profiles. Rest of DCP profiles (22 profiles) will be used for validation. In this benchmarking, any three DCP profiles can be selected. Potential performance metric includes root-mean-square error (RMSE) between estimated and actual  $N_d$  profiles. Fig. 9 (b) presents a plan view of another benchmark example for soil stratification. In this benchmarking, only three DCP profiles and one boring log are used for soil stratification, and rest of the DCP and boring logs are used for validation. Accuracy or Identification Rate (IR) (Shuku 2023) can be used as performance metric for this benchmark example.

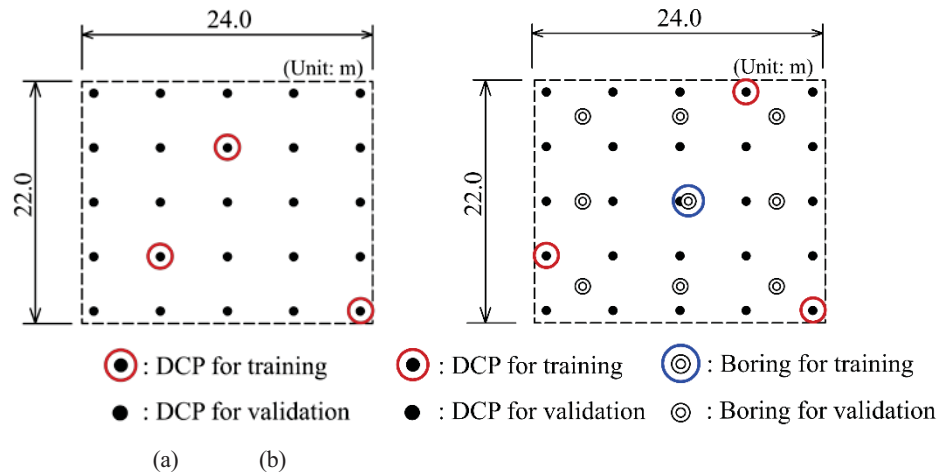


Fig. 9. Potential benchmark examples based on Ohmoto site; (a) Estimation for spatial distribution of  $N_d$ ; (b) Soil stratification.

One key complication in DDSC is that real data is MUSIC-3X (multivariate, uncertain and unique, sparse, incomplete, and potentially corrupted with “3X” denoting three-dimensional spatial variation) (Phoon et al. 2022a), and real benchmark examples based on MUSIC-3X data can be created from the data from Ohmoto site. Proposing more comprehensive benchmark examples is left for future study.

## 5. Summary

This paper proposes new real-world benchmark examples for DDSC. A site investigation, including various in-situ and laboratory tests, was conducted at the Ohmoto site located south of Okayama City, and the testing outline is presented in this paper. Additionally, potential benchmark examples based on the Ohmoto site are introduced. The benchmarking procedure and MUSIC-3X benchmark examples remain to be developed, and these will be addressed in future research.

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## References

- Phoon, K.K., J. Ching, and T. Shuku (2022a). Challenges in data-driven site characterization. *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards* 16(1), 114-126.
- Phoon, K. K., T. Shuku, J. Ching and I. Yoshida (2022b). Benchmark examples for data-driven site characterization. *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards* 16(4), 599-621.
- Phoon, K. K. and W. Zhang (2023). Future of machine learning in geotechnics. *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards* 17(1), 7-22.
- Shuku, T. (2023). Data-driven site characterization. *Uncertainty, Modeling, and Decision Making in Geotechnics*. CRC Press, 143-175.