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Processing, Visualization, and Analysis of Direct Simple Shear Test Data Using Jupyter Notebooks in the DesignSafe Cyberinfrastructure

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ABSTRACT

Two Jupyter notebooks are prepared for visualizing, analyzing, and post-processing data from constant-height direct simple shear tests performed on three fine-grained soil mixtures. The experimental data and Jupyter notebooks are available and implemented in the DesignSafe cyberinfrastructure (www.designsafe-ci.org). To categorize the dataset, the experiments are grouped into three events based on their designations for the mixtures tested in the lab. Each experiment contains two stages; consolidation and shear, including time series of load, displacement, stress, strain, equivalent excess pore-water pressure etc. The data has been categorized in this manner to facilitate the use of the visualization notebook and to locate specific tests in the dataset. A spreadsheet similar to the AGS4 format was created to provide metadata about the soil specimens that were tested. The data plotter notebook visualizes the experimental data. A separate analysis notebook creates an environment for the user to combine outcomes of multiple tests, synthesize the data, and enables regression analyses for finding critical state lines, shear strength normalization parameters, and generates CSR vs. number of uniform cycles for cyclic tests for arbitrary strain levels.

INTRODUCTION

It is common practice to process laboratory testing data using Microsoft Excel, MATLAB, Mathcad or other computer programs and to store them either on individual hard drives or online cloud services such as Box, Dropbox, or Google Drive. Often, the data is not shared with other researchers or practitioners and gaining access to data that was collected some years ago, can be fairly difficult to obtain for re-use. Further, as datasets get larger and more complex, new methodologies become necessary to facilitate shortening processing times and to increase robustness in research work.

To manage data derived from an experimental research project on cyclic and monotonic behavior of fine-grained soils and to make it available for public use, the tools and services available in DesignSafe cyberinfrastructure were used [Rathje et al. (2017)]. DesignSafe is an NSF funded platform for natural hazards research, that embraces a “cloud” strategy for data generated in natural hazards engineering research, and supports research workflows, data analysis, and visualization.

Two Jupyter notebooks [formerly IPython, Perez and Granger (2007)] were developed and used to visualize, analyze, and post-process the data obtained from monotonic and cyclic laboratory simple shear testing that were collected during the research study. The data are stored on the DesignSafe server currently, are being curated (i.e., organized and categorized with accompanying metadata), and will soon be published for public re-use. The Jupyter platform was selected because it permits us to interact with the data on the server rather than first having to download the data before processing. In this manner, the data processing and visualization tools can be housed with the official published data, which is an attractive feature for data sharing and preservation. This paper describes some details of the experimental data and focuses mainly on the Jupyter notebooks, the visualization tools, and the curation process.

EXPERIMENTAL DATA AND USER INTERFACE

The experimental program consisted of Direct Simple Shear (DSS) laboratory tests on three different soil mixtures that were blended in the laboratory; SBFW, SBSW, and SKFW. These mixtures contain predominantly silt (S) and are mixed with varying amounts of clay minerals; either bentonite (B) or kaolinite (K), and are blended with either fresh deionized water (FW) or saline water (SW) with a concentration of 35 g/L of NaCl. The clay fractions were adjusted to achieve a plasticity index $PI = 9$, and were 5% for the SBFW blend, 10% for the SBSW blend, and 22% for the SKFW blend. A higher bentonite fraction was required for the SBSW blend than for the SBFW blend because the sodium cations in the salt interacted with the bentonite mineral grains, inducing flocculation. Strength testing was performed to gain insights into the effects of changes in mineral compositions and pore-fluid salinity on cyclic behavior of low-plasticity fine-grained soils. Further details of the testing program and the results of the experiments can be found in Eslami (2017).

To fully understand the fundamentals of the behavior of the mixtures, sets of monotonic and cyclic DSS tests were performed at varying overconsolidation ratios (OCR), and most tests were performed at consolidation stress of $\sigma'_{vc} = 50$ kPa. After each specimen was trimmed to the desired dimensions (66 mm diameter and 28 mm height), they were put inside a wire-reinforced rubber membrane that permits vertical strains by significantly limiting horizontal strains (essentially K_0 conditions), then placed inside the simple shear device and consolidated to the desired pressure. Following this stage, the specimen is ready to be sheared under constant-height undrained conditions. Consolidating the specimens was performed by incrementally increasing the vertical load. Monotonic shearing was performed under strain-controlled conditions, whereas the cyclic shearing tests were performed under stress-controlled conditions. Data for both stages of

each experiment (consolidation and shear) is uploaded on DesignSafe. Data from each stage is a “.txt” file, which includes time series of load, displacement, stress, strain, equivalent excess pore-water pressure, and other quantities processed from data acquisition recordings. The name of each file includes the ID of the soil mixture, the number or ID of the test, its type (monotonic or cyclic), and the abbreviation for the test stage; Consolidation (C), or Shear (S). Files are named this way to simplify the process of locating the test data file through the Jupyter code, and to make it easier for a potential user for understanding what each file contains.

The Jupyter interface was designed so that a potential user can easily find the soil mixture, test type, and stage of the test they desire for visualization, re-use, or processing. The Jupyter notebook is located in the same folder as the text files of the experimental data. Once the notebook is launched and the code cells are executed by the user, the corresponding user interface appears as shown in Figure 1. The user can then select the desired soil mixture and the type and stage of the DSS experiments. The strain level (%) adjustment bar enables the user to adjust the maximum plotted strain level. This is useful for both monotonic and cyclic tests. The strain slider is also useful for defining a failure criterion for cycle counting purposes for cyclic tests.

Soil Mixture (Event): ☒ SBFW ☐ SKFW ☐ SBSW

DSS Test Type: ☒ Monotonic ☐ Cyclic

Test Stage: ☒ Consolidation ☐ Shear

Strain Level(%): 3.00

Tests ID:

- SBFW_26_MON_C
- SBFW_27_MON_C
- SBFW_28_MON_C
- SBFW_50_MON_C
- SBFW_51_MON_C
- SBFW_55_MON_C
- SBFW_85_MON_C

Details of Test Cases:

- SBFW_26_MON_C: None
- SBFW_27_MON_C: None
- SBFW_28_MON_C: None
- SBFW_50_MON_C: None
- SBFW_51_MON_C: None
- SBFW_55_MON_C: None
- SBFW_85_MON_C: None

Save Figure

Figure 1. User interface of the Jupyter notebook on DesignSafe

DATA VISUALIZATION NOTEBOOK

A data visualization notebook was prepared that enables plotting and visualizing the data for each stage of a test. Figure 2 shows: (1) vertical effective stress (σ'_v) versus time, and (2) axial strain (ϵ_a) versus time. The void ratio of the specimen is measured before the specimen is put in the DSS device, and after shearing has finished. Therefore, these quantities are not plotted on a graph, but are provided in a separate spreadsheet labeled “Description” in the dataset, where metadata for each test is compiled. This information is made available to the user (and downloadable) once a specific test is chosen in the user interface.

Figure 2. Plots generated for the consolidation stage of each DSS test.

Example plots for a cyclic shear test are shown in Figure 3, and include two sets of plots: (1) time series of cyclic shear stress (τ_{cyc}), cyclic shear strain (γ), and equivalent excess pore water pressure (u_e), and (2) normalized stress paths including τ_{cyc}/σ'_{vc} versus σ'_v/σ'_{vc} , τ_{cyc}/σ'_{vc} versus γ , as well as γ and u_e versus number of loading cycles. These plots are interactive, meaning that options such as zooming in and out of the plots, pan view, saving the plots, and seeing coordinates of each point on the graphs are available to the user. Also, multiple tests can be plotted on one set of graphs and exported as .png files to the user's local computer.

DATA SYNTHESIS NOTEBOOK

A separate Jupyter notebook was developed that enables synthesizing results of multiple tests. For example, outcomes of multiple monotonic shearing tests of one mixture can be used for fitting a critical state line (if reached during a test) or a failure state line (defined at a user-specified shear strain) having the functional form $e_c = e_0 - \Gamma \cdot \ln(\sigma'_{vc})$. These lines can be compared to the normal consolidation line (NCL) of the soil mixture to assess whether the soil exhibits strength normalization (i.e. when the lines are parallel in the semi log e - $\log \sigma'_{vc}$ space). Another use of this notebook, is for developing relationships between the undrained shear strength ratio (s_u/σ'_{vc}) and OCR in the form of $s_u = S \cdot \sigma'_{vc} \cdot OCR^m$ [by Ladd (1991)], where S is the undrained shear strength ratio for normally consolidated soils, and m is the exponent of the regressed line when s_u/σ'_{vc} and OCR are plotted in log-log space. The notebook produces values of undrained shear strength ratio of the mixtures at any arbitrary strain level the user defines, and plots these points (for multiple tests at varying OCR) and produces a regressed power fit. Example plots of critical state lines and undrained strength ratio versus OCR are presented in Figure 4.

(a)

(b)

Figure 3. Plots generated for cyclic shearing stage of a test: (a) time series, and (b) stress paths, stress-strain, shear strain versus N, and r_u versus N

For cyclic testing, the notebook is capable of plotting combinations of cyclic stress ratio (CSR) and the number of uniform loading cycles (N) required to reach a specified failure criterion (i.e. shear strain level that the user defines). The code regresses the data and generates a power

function in the form $CRR = aN^{-b}$. For consistency among all cyclic tests, the CSR is calculated based on the average of the first two peaks (positive and negative directions of loading) of cyclic sinusoidal loading. An example plot of normally consolidated specimens of the SBFW soil mixtures for a failure criterion of 3% peak shear strain are presented in Figure 5, and the resulting regressed power function is provided inside the graph. Similarly, these plots are made interactive and can be saved to the user's local computer as a .png file.

Figure 4. (a) void ratio versus effective stress and regressed critical state line; (b) peak undrained strength ratio versus OCR and resulting regressed functional form

Figure 5. CSR versus N plot and resulting regressed functional form generated by synthesis Jupyter notebook

The key benefit of organizing data processing notebooks in this manner is that new tests can easily be incorporated, and processed in a uniform manner, once they are uploaded to DesignSafe. In the future, data from other users could also potentially be incorporated through data sharing utilities in DesignSafe. Having the ability to process and visualize large amounts of data without having to first download the data to a local PC is an attractive feature facilitated by the Jupyter implementation in DesignSafe.

CURATING THE DATASET

DesignSafe offers a data curation and publication pipeline intended to make data available for reuse, and these features are being utilized herein. These activities include managing, organizing, describing, cleaning, preserving, and archiving data. These processes add value to the data, allowing it to become an integral part of the body of academic knowledge (Beagrie, 2004). To facilitate data curation, DS-CI developed an interactive pipeline that guides researchers to assign their data to categories that represent the main processes of an engineering experiment (Esteva et al., 2016). It is part of the researchers work to decide how to utilize the categories provided, to map the structure of their research projects so that every dataset shows a particular configuration.

The curation interface provides documentation options such as: selecting specialized terms from a menu, entering free explanatory text, and adding tags to describe the steps, instruments, and data involved in a geotechnical experiment. As the curation progresses, the GUI generates a tree and a browsing interface showing data in relation to the process that it derives from, representing the complex data structure and its provenance. Next, the publication pipeline steers users into reviewing the tree representation and the descriptions, conducts automated verification that the files and information required for data understandability are in place, and assigns global unique digital object identifiers (DOI) to the published data. Each unique DOI generates a citation and constitutes a permanent link that will always point to the referenced dataset, regardless if its Web location changes over time.

Though the dataset of the DSS experiments mentioned herein are not yet published, they are curated and helped improving the overall research project management and our documentation practices. A screenshot of the currently curated dataset on DesignSafe is provided in Figure 6. For the curation process, each of the three mixtures (i.e. SBFW, SBSW, and SKFW) were assigned as a separate event of the DSS experiments ran in this project.

CONCLUSIONS

A series of cyclic and monotonic direct simple shear experiments was conducted on three low-plasticity fine-grained mixtures prepared in the laboratory. The corresponding data files and two Jupyter notebooks were made available on DesignSafe Cyber Infrastructure to manage the data, visualize and post-process the data, and to later curate and publish the dataset. One Jupyter code is specifically made for visualizing the different quantities measured during the experiments, and

another notebook can be used specifically for synthesizing the results of multiple experiments, whether monotonic or cyclic.

The collaborative cloud-based approach to data management presented in this paper is a departure from the standard approach in which data are stored and processed locally by the researcher who collected the data. The standard approach typically results in data loss because the researcher, often a PhD student, retains the data files on a local computer where they are not available to the public and often not properly documented and curated. Furthermore, utilizing data processing scripts that reside in the cloud with the data provides added benefit that the end-to-end workflow is documented, curated, and available along with the data where it will always be available for public re-use.

Projects'

Experiment Cyclic testing of low-plasticity fine grained soils at PI = 9

Cyclic testing of low-plasticity fine grained soils at PI = 9

Description

Date of Publication: (Appears when published) Authors:

DOI: (Appears when published)

Experimental Facility: University of California Los Angeles

Experiment Type: Direct Simple Shear

Equipment Type: UCLA Bi-Directional Simple Shear

Event Data: SBFW Mixture Link to: Model Configuration Sensor List

Name	Size	Last modified
SBFW_26_MON_C.txt	2.8 MB	10/16/17 3:53 PM
SBFW_26_MON_S.txt	3.5 MB	10/16/17 3:53 PM
SBFW_27_MON_C.txt	3.2 MB	10/16/17 3:53 PM
SBFW_27_MON_S.txt	3.6 MB	10/16/17 3:53 PM
SBFW_28_MON_C.txt	1.8 MB	10/16/17 3:53 PM
SBFW_28_MON_S.txt	3.5 MB	10/16/17 3:53 PM

Event Data: SBSW Mixture Link to: Model Configuration Sensor List

Name	Size	Last modified
SBFW_26_MON_C.txt	2.8 MB	10/16/17 3:53 PM

Figure 6. Screenshot of the preview of the curated dataset on DesignSafe

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