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Title: Cyclic Softening and Post Cyclic Volume Change of Fine-Grained Soil

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Abstract

A relational database for geotechnical laboratory test data is developed and described herein. The relational database is implemented as part of the Next Generation Liquefaction (NGL) project, and is an extension of the NGL database which contains information about sites, earthquakes, and observations of liquefaction manifestations (or lack thereof) at field sites following earthquakes. The database provides an organizational structure for laboratory test data, which to date has typically not been made publicly available by authors beyond the typical publication channels involving data plots in reports and papers. We believe that making laboratory data publicly available in its digital form has tremendous value for the geotechnical earthquake engineering community, and the database presented herein is therefore an important contribution to our field. We first describe the motivation for creating the database, followed by a discussion of the database's organizational structure, or schema. We then describe the datasets that have been added to the database and show example queries. We present the manner in which users may interact with the data through the graphical user interface in the future, and how users can interact with a copy of the database in DesignSafe. We then describe updates to the control system for the UCLA direct simple shear test device and present the results of testing performed under this contract , which was significantly impacted by the COVID-19 pandemic.

1.0 Introduction

Liquefaction of cohesionless sandy and silty soils is a critical ground failure mechanism, having produced ground deformations and instabilities during many past earthquakes, including for example, tilting of the Kawagishi Cho apartment buildings in Niigata in 1964, settlement and tilting of small residential structures in Japan during the 2011 Tohoku earthquake, and destruction of many residences in New Zealand during the Canterbury earthquake sequence in 2010 and 2011. Additional striking occurrences of ground failure have occurred in fine-grained soils. For example, the 1964 Great Alaska Earthquake (**M**=9.3) induced two especially notable landslides, the Fourth Avenue and L Street slides, which damaged structures in Anchorage (Fig. 1) as a result of the cyclic failure of Bootlegger Cove clay underlying a thick gravel deposit (Idriss 1985, Brandenberg and Idriss 2002). The 1999 Chi-Chi, Taiwan Earthquake (M=7.6) induced significant incidents of ground failure in Wufeng, Taiwan, where peak ground accelerations were about 0.7 g. Typical damage consisted of footings punching into the soil and intermediate slabs heaving, as shown in Fig. 2 (Chu et al. 2008). Soils beneath these structures were low-plasticity clays with water contents near the liquid limit. Similar failures were observed beneath structures in Adapazari, Turkey following the Kocaeli earthquake (e.g., Bray et al. 2004) in soils with high fines contents and variable (but generally small) levels of plasticity. Databases that document ground failure, foundation performance, and geotechnical conditions are available for three cities in Taiwan (http://peer.berkeley.edu/lifelines/research_projects/3A02/index.html) for the Chi Chi earthquake and Adapazari (http://peer.berkeley.edu/publications/turkey/adapazari/) for the Kocaeli earthquake. One of the striking features of these foundation failures involving fine-grained soils is that ground failure often did not occur in the free-field, being localized instead beneath foundations.

Figure 1. The head of the Fourth Avenue landslide induced by the 1964 Great Alaska Earthquake (Hansen 1971).

Figure 2. Typical foundation failure (punched footings and intermediate slab heaving). Chu et al. 2008. Photo by R. Seed (1999).

The Turkey and Taiwan case studies motivated a substantial re-evaluation of the manner in which fine-grained soils should be analyzed in practice, which has some bearing on the proposed work and hence is worth exploring here. This work by Bray and Sancio (2006) and Boulanger and Idriss (2007) focused on the question of liquefaction susceptibility, which is the first step in a liquefaction potential evaluation (susceptibility is followed by analyses of triggering and effects; non-susceptible materials are analyzed using different procedures). The Bray and Sancio (2006) and Boulanger and Idriss (2007) research was motivated by the failure of previous susceptibility criteria (widely known as the Chinese criteria, Seed and Idriss, 1982) to adequately predict observed ground failure patterns in these events (Sancio et al., 2002; Chu et al., 2004).

Bray and Sancio (2006) studied the liquefaction susceptibility of soils in Adapazari based on case studies observed during the Kocaeli, Turkey earthquake. Liquefaction was defined by Bray and Sancio in the traditional way — dramatic loss of shear strength and stiffness resulting from increased pore-water pressure and reduced effective stress. Their definition includes cyclic mobility behavior, wherein the tendency of a soil to dilate at large stress ratios during drained loading is manifested as a reduction in pore pressure in undrained loading. Many of their laboratory tests exhibited stress-strain behavior that resembles cyclic tests on non-plastic soils, and is consistent with this traditional definition of liquefaction. For example, the stress-controlled cyclic triaxial test in Fig. 3 clearly shows cyclic mobility behavior in which each progressive cycle mobilized larger strain than the preceding cycle, and exhibited a strain-hardening inverted S-shaped behavior associated with suppression of the dilative tendency of the clay in undrained loading.

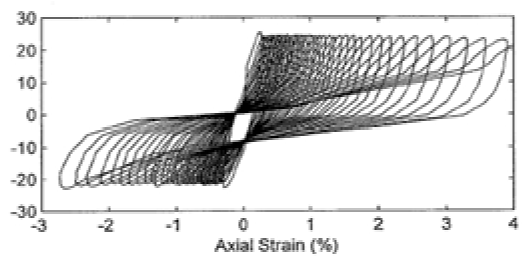

Figure 3. Cyclic triaxial test of clay specimen C11-P2A with PI=11 and LL=32 (Sancio 2003).

Boulanger and Idriss (2007) suggested an alternative approach in which fine-grained soils are conceptualized as being either "sand-like" or "clay-like" in their mechanical behavior. Examples of sand-like and clay-like behavior are shown in Fig. 4. The Sacramento River sand specimen exhibits cyclic mobility behavior and dilative strain-hardening, whereas the Cloverdale clay does not exhibit the dilative strain-hardening behavior. However, both soils accumulate strain with repeated loading cycles. Furthermore, clay-like soil is characterized by the critical state line and isotropic consolidation line being parallel straight lines in e-logv' space, whereas sand-like soils have a curved critical state line and non-unique isotropic consolidation line. These features result in normalization of monotonic undrained shear strength of clay-like soil with consolidation stress and overconsolidation ratio (e.g., Ladd 1991), whereas a similar normalization does not exist for sands. Furthermore, clay-like soils (excluding quick clays) may lose strength during cyclic loading, but they exhibit much less potential for strength loss than sand-like soils. Boulanger and Idriss found that the transition between sand-like and clay-like behavior occurs over a relatively narrow range of 4<PI<7, and suggest that 7 be used as the boundary in the absence of site-specific cyclic testing.

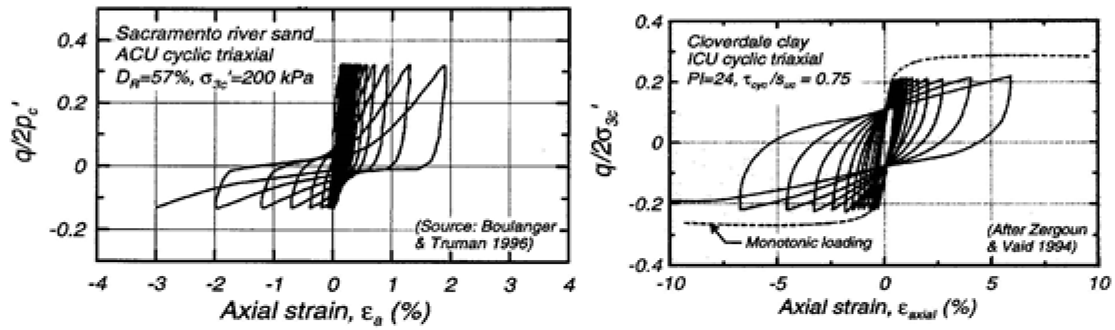

Figure 4. Comparison of "sand-like" behavior in cyclic triaxial testing of Sacramento River sand, and "clay-like" behavior exhibited by Cloverdale clay (Boulanger and Idriss, 2007).

Bray and Sancio (2006) and Boulanger and Idriss (2007) recommended significantly different ranges of PI over which the soils exhibited traditional liquefaction behavior. Bray and Sancio (2006) found that soils with PI up to 18 could liquefy and exhibit behavior consistent with sands in a reasonable number of cycles, while Boulanger and Idriss (2007) found that PI=7 was the upper bound for "sand-like" behavior. Furthermore, Bray and Sancio (2006) explicitly include wc/LL in their susceptibility criteria, while the Boulanger and Idriss (2007) procedure applies a reduction factor to the monotonic undrained shear strength (which is related to wc/LL). The reduction factor has recently been found to be PI-dependent, as shown in Fig. 5, with lower values of the reduction factor below PI around 10, and higher values above PI around 18. The data points in Fig. 5 show data originally plotted by Boulanger and Idriss (2007) along with the outcome of recent testing conducted in the UCLA advanced geotechnical laboratory (labeled "Current study") and several other recent studies conducted by other researchers. The figure shows how the assessment of strength loss potential of fine-grained soils is rapidly evolving, and establishes a need for more testing and publicly available test data.

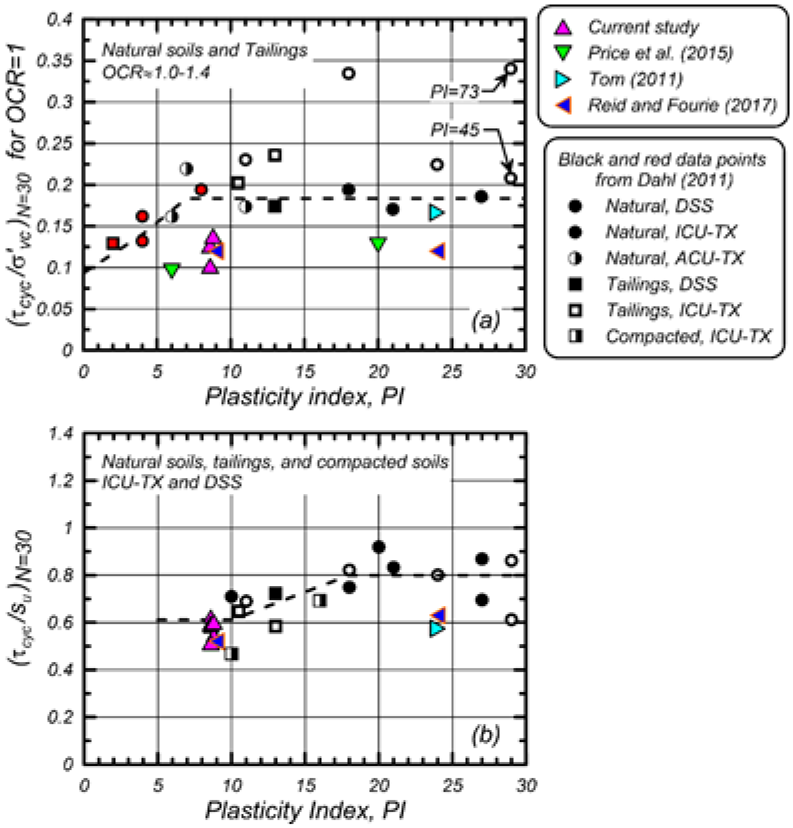

Figure 5. Comparison of updated CSR and cyc/su vs. number of loading cycles (N) relationships from Dahl (2011) and recent experimental results from testing mineral mixtures and reconstituted specimens

Although differences exist in the various methods for analyzing cyclic failure of fine-grained soils, there is nearly universal agreement that laboratory testing is the best approach for assessing strength-loss potential. Laboratory test data is often presented through figures in papers and reports, and perhaps synthesized into summary plots, but the digital data files are often not made publicly available. Researchers often gain fundamental insights and make new discoveries by interpreting data in ways that differ from the interpretation methodologies adopted by the original author(s). The original data is very important for facilitating this form of discovery, particularly as we move into a "big data" world and adopt powerful methods such as machine learning and artificial intelligence to help guide our empirical discoveries. Furthermore, data that is not properly archived, curated, and published may end up being forgotten by the scientific community. For these reasons, there is generally a consensus among the scientific community that databases are important for the future of natural hazards research (e.g., Rathje et al. 2017).

This report presents a relational database for laboratory tests that is part of the Next Generation Liquefaction (NGL) database (Zimmaro et al. 2019; Brandenberg et al. 2020). The report first presents the database schema, which is the organizational structure of the database. We then discuss the data that has been migrated into the database, and provide a summary of current data resources, and how to access them through the graphical user interface (GUI). We then discuss scripts that have been developed to interact with data in the database. Finally, we briefly discuss testing conducted at the UCLA advanced geotechnical laboratory under this contract.

2.0 Relational Database

The word "database" is often used by the natural hazards community in a rather loose manner to mean a collection of data files. However, this is not the definition widely agreed upon by the data science community. Rather a relational database (RDB) is a structured body of information organized into inter-related tables formally described by a schema. Tables are related to each other by shared fields called keys, where a primary key is a unique identifier for each record, and a foreign key is a field in one table that identifies a record in another table. Properly structured RDB's eliminate the need for repeated data fields, minimize potential for errors in curated data, and provide a common functional structure for the data they contain.

2.1 Database Schema

The structure of the NGL database has changed from the version presented in Brandenberg et al. (2020) with the addition of the laboratory component and restructuring of some of the tables for a more efficient and intuitive schema. The schema for the laboratory component is presented in Fig. 6. Many components of the NGL schema are omitted from Fig. 6 for brevity and clarity, but the rest of the NGL schema, including the field data, earthquake data, and observation data can be found at http://nextgenerationliquefaction.org/schema/index.html.

The highest level table for the laboratory component is the “LAB” table, which contains a primary key “LAB_ID” along with the name, location, and description of the lab. The next table in the hierarchy is the “LAB_PROGRAM” table, which contains a primary key “LAB_PROGRAM_ID” and a foreign key “LAB_ID” to establish a relationship between the laboratory testing program and the laboratory where it was performed. A single laboratory may have many different lab testing programs. Any NGL users associated with a lab testing program are linked via a junction table called “LAB_PROGRAM_USER”, which contains only a primary key, a foreign key for the “LAB_PROGRAM” table and a foreign key for the “USER” table. The purpose of a junction table is to enable a “one-to-many” relationship in which many users may be associated with a single lab testing program. Similarly, samples are associated with a laboratory testing program through the “LAB_PROGRAM_SAMPLE” junction table. A sample can either be created in a laboratory (e.g., by blending and hydrating clay minerals) or it can come from a field testing program. If a sample comes from a field testing program, the “SAMP_TEST” junction table establishes a relationship between the sample and field test from which it came.

A specimen tested in a laboratory device is described by the “SPEC” table, which contains a foreign key to the sample table. The “SPEC_ID” field is then a foreign key for a series of possible laboratory tests that could be performed, including grain size distribution, plasticity, various index tests, density measurements, consolidation, triaxial, direct simple shear, and “others” for any tests that were not captured in this list. The tables “Relative Density”, “Atterberg Limits”, and “Index Tests” contain information about these tests within a single table. By contrast, the triaxial, direct simple shear, and consolidation laboratory tests are more complicated and involve stages that must be fully documented. To provide this documentation, each of these tests has a general table, a stages table, and a data table. The general tables (TXG, DSSG, and CONG, for triaxial, direct simple shear, and consolidation, respectively) contain test-specific information about the specimen including initial void ratio, initial water content, diameter, height, and a specimen description. Information about loading stages are then entered into the appropriate stage tables (TXS, DSSS, CON_STGE for triaxial, direct simple shear, and consolidation, respectively) that contain a foreign key from the appropriate general table, and data arising from these load stages are entered into appropriate data tables (TXD, DSSD1D, DSSD2D, COND for triaxial, one-dimensional direct simple shear, two-dimensional direct simple shear, and consolidation, respectively), which contain the appropriate load stage ID as a foreign key.

As an example of the database structure, a direct simple shear test might consist of a consolidation stage in which the specimen is consolidated to a desired pressure, followed by a cyclic loading stage in which the specimen is cyclically sheared, followed by a post-cyclic reconsolidation stage. In this case, the test would have one entry in the SPEC table, one entry in the DSSG table, two entries in the DSSS table, and all of the data from each stage would be stored in many entries in the DSSD table. It is important to include data from all of these stages to track the evolution of the specimen response throughout the test. Measurements made during each stage are the same for a particular laboratory test. In some cases, a quantity remains constant during the test. For example, in a constant height direct simple shear test, the vertical strain field “DSSD1D_EPSV” would be anticipated to be constant. However, we believe it is important to measure the vertical strain to verify that constant height conditions were achieved, and these data should be included. Similarly shear stress and shear strain should be zero during the consolidation phase of a direct simple shear test (assuming the specimen is consolidated without a static shear bias), but these measurements are nevertheless required as part of documentation of the stage. Atterberg Limits tests and other simple tests may be performed on samples associated with more complicated lab tests, and can be linked by matching a SAMPLE_ID foreign key in the Atterberg Limits table with that in the general table for the more complicated lab test.

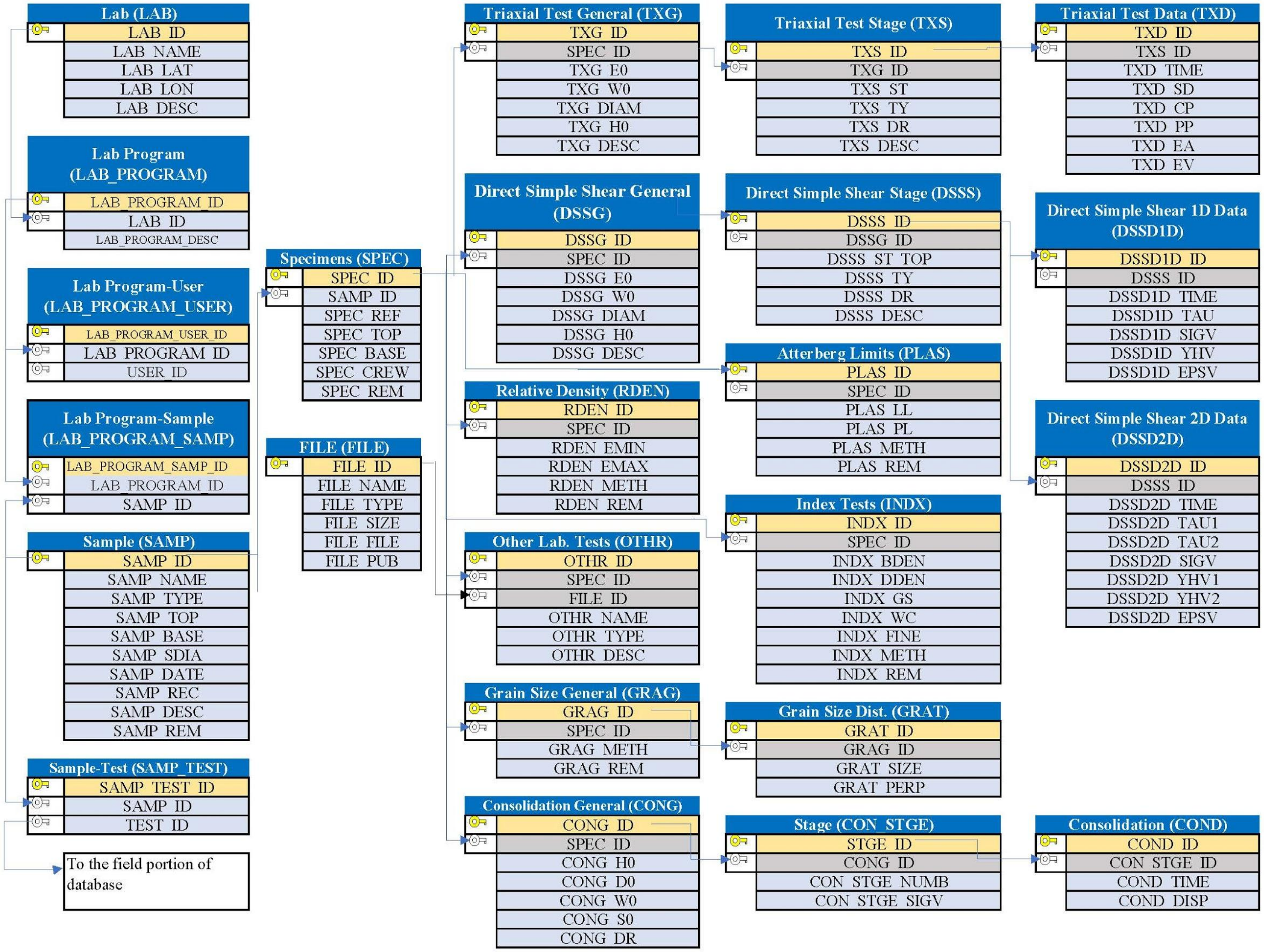

Figure 6. Relational database schema for laboratory component of NGL database.

2.2 Database Population

2.2.1 Laboratories

Four laboratories have been entered into the NGL database (Table 1). The first laboratory with LAB_ID=0 is called “UNKNOWN”, and is assigned to laboratory data that has been published in the literature without an indication of where the laboratory test was performed. The three other laboratories are the University of Canterbury Geomechanics Laboratory, the UCLA Advanced Geotechnical Laboratory, and the Tokyo Soil Research Co. Ltd. laboratory.

Table 1. Laboratories in NGL database (last accessed 3/16/2021).

LAB_ID	LAB_NAME	LAB_LAT (degrees)	LAB_LON (degrees)	LAB_DESC
0	UNKNOWN	0	0	None/Unknown
1	University of Canterbury Geomechanics Laboratory	-43.5226	172.5794	Houses a CKC electropneumatic triaxial testing device
2	UCLA Advanced Geotechnical Laboratory	34.0692	-118.4427	Direct Simple Shear Device, Consolidometers, etc.
3	Tokyo Soil Research co. Ltd.	36.0594	140.1427	Triaxial testing device, Oedometers, etc.

2.2.2 Laboratory Test Programs

The database currently contains five laboratory testing programs performed at four different laboratories, as defined in Table 2. These testing programs include 1. a triaxial testing program performed on specimens of fine-grained soil obtained from field samples at the University of Canterbury Geomechanics Laboratory following the Canterbury earthquake sequence (Beyzaei, 2017), 2. Cyclic and monotonic direct simple shear tests performed on samples of sand constructed in the UCLA Advanced

Geotechnical Laboratory (Eslami, 2017), 3. Monotonic triaxial compression and consolidation tests performed at the Tokyo Soil Research Co. Ltd. laboratory on samples from Mihama ward with varying levels of liquefaction susceptibility (Tokyo Soil Research, 2016), and 4. Laboratory tests performed on soils from the Wildlife liquefaction array in the Imperial Valley. Note that LAB_PROGRAM_ID skips from 3 to 5. This is because a program was created in between 3 and 5, and was assigned a primary key value of 4. However, no laboratory data has been entered yet for this program, so it is omitted from Table 2. Several additional testing programs have also been created, but do not yet have laboratory data associated with them and are therefore omitted from Table 2. The number of tests performed as part of each test program are also indicated in Table 2.

Table 2. Laboratory test programs and number of tests in each program in NGL database (last accessed 3/16/2021).

LAB_PROGRAM_ID	LAB_ID	LAB_PROGRAM_DESC	Number of Tests By Type						
			TXG	DSSG	CONG	GRAG	PLAS	RDEN	INDX
1	1	Testing of samples from sites associated with the Canterbury Earthquake Sequence (Beyzaei, 2017)	42	0	0	56	38	6	35
2	2	Monotonic triaxial tests on Orange Co. Silica Sand (Eslami, 2017)	14	0	0	0	0	0	0
3	3	Testing on samples from Mihama Ward associated with 2011 Tohoku earthquake (Tokyo Soils, 2016)	7	0	0	0	0	0	7
5	0	Lab testing associated with Graded area east of New River at SW edge of Brawley	0	0	0	5	2	0	0
7	2	Monotonic and Cyclic direct simple shear testing on clay-silt blends (Eslami, 2017)	0	52	3	0	3	0	0
8	2	Testing of remolded samples from Mihama Ward (Eslami, 2017)	0	0	1	0	0	0	0

2.3 Accessing Through Graphical User Interface

The NGL database features a graphical user interface (GUI) at https://nextgenerationliquefaction.org/ that displays field test data, earthquake event data, and observations at field sites following earthquakes. A screenshot of the GUI is shown in Fig. 7. The GUI currently does not display laboratory test data, but this feature is being developed as part of the broader NGL project organized though the Southwest Research Institute and will be released soon. We envision that a toggle switch will be added to the "General description" field in the toolbar on the right that will enable users to click on and off the location of laboratories. Clicking on a laboratory icon will bring up a menu of the test programs associated with that laboratory. Users will then be able to select a test program and view/download data from laboratory tests associated with that program in the GUI.

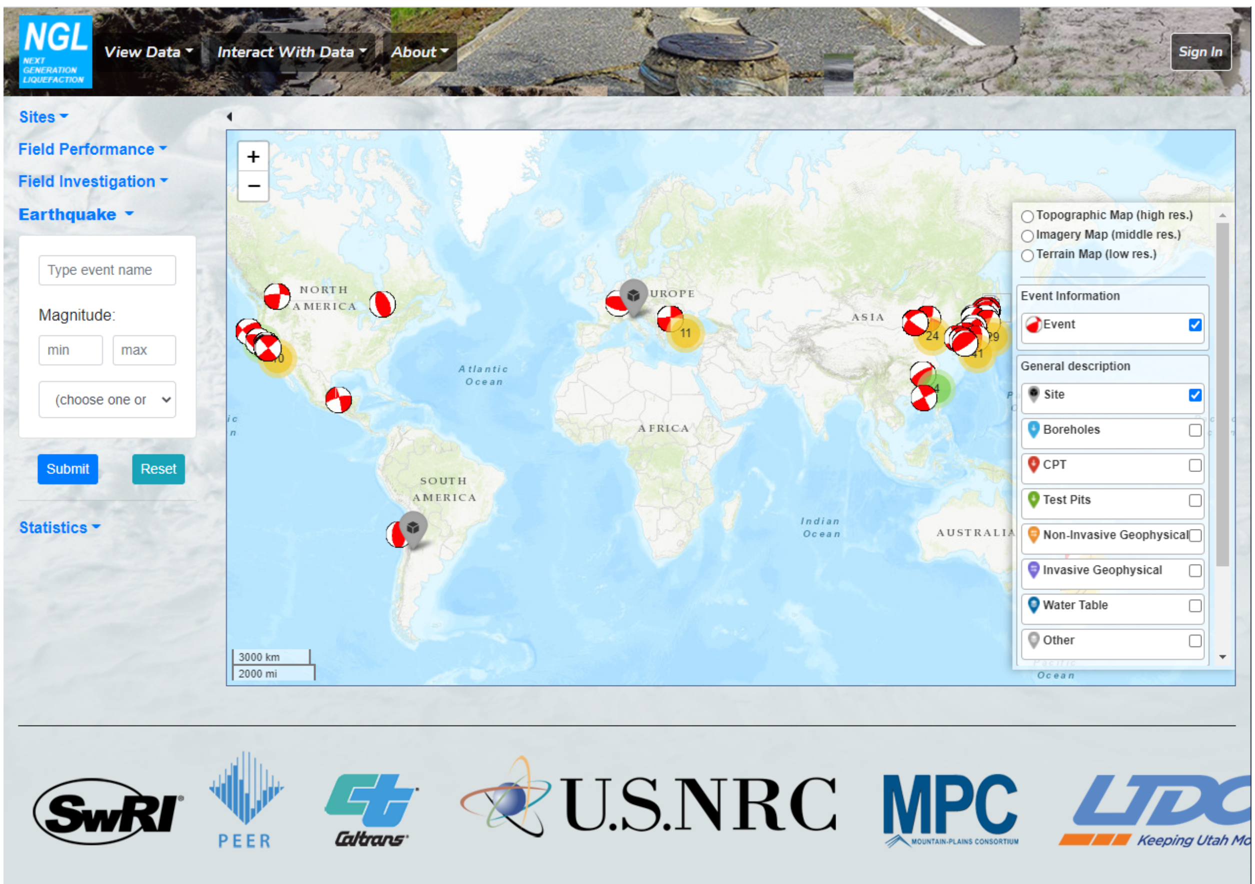

Figure 7. Next generation liquefaction graphical user interface. https://nextgenerationliquefaction.org/, accessed 03/16/2021.

2.4 Interacting With Data in DesignSafe

The GUI will enable users to view or download data from a particular test program, but we envision that users may want to do more with the data than we can reasonably enable through a web interface. For this reason, the NGL database is replicated daily to DesignSafe (Rathje et al. 2017). The DesignSafe copy of the database can be accessed by users via Python scripts in Jupyter notebooks using the pymysql package. Figure 8 is an example Jupyter notebook used to query the data presented in Table 2. The first 3 lines are import statements for the pymysql, numpy, and pandas packages used in the script. Line 4 connects to the database using credentials defined in the previous cell and omitted from Fig. 8 for security. Line 5 defines a cursor used to query the database. Line 7 defines the types of tests we are interested in querying, and line 8 defines a Python dictionary called "output" where data are stored. Line 10 is a SQL query that obtains the LAB_PROGRAM_ID, LAB_ID, and LAB_PROGRAM_DESC fields from the LAB_PROGRAM database, and sorts them in ascending order by LAB_PROGRAM_ID. Line 11 executes the query, and line 12 fetches data generated by the query. Lines 13 through 15 initialize arrays into which the LAB_PROGRAM_ID, LAB_ID, and LAB_PROGRAM_DESC fields are stored, and lines 16 through 19 populates these fields using a "for" loop. Lines 20 to 22 places these arrays into the output dictionary. Lines 24 through 31 query the database to count the number of different types of tests for each test type, and for each value of the LAB_PROGRAM_ID field, values are appended to the appropriate column in the output field. Finally, the output field is placed into a Pandas dataframe and displayed in the output field.

The query defined in lines 26 through 28 warrants further discussion. In this case, we use the "COUNT" function in SQL to sum the number of fields that meet a particular condition. On line 26, the command "+ t + '.' + t + '_ID)" will take the current value of the test_type list, and use it to generate the appropriate quantity to query. For example, for test_type = 'TXG' and lab_program_id = 1, the SQL query would be as follows:

```
SELECT COUNT TXG.TXG_ID FROM SAMP INNER JOIN LAB_PROGRAM_SAMP ON SAMP.SAMP_ID =
LAB_PROGRAM_SAMP.SAMP_ID INNER JOIN SPEC ON SPEC.SAMP_ID = SAMP.SAMP_ID INNER JOIN
TXG ON TXG.SPEC_ID = SPEC.SPEC_ID WHERE LAB_PROGRAM_ID = 1
```

This query returns the number of TXG_ID values from the TXG table where LAB_PROGRAM_ID = 1. To obtain this value, connections among tables must be performed using the foreign key structure established in the database schema. This is accomplished using INNER JOIN statements, which will join tables together where they share a common key.

jupyter USGS_report_queries Last Checkpoint: 3 hours ago (unsaved changes)

In [82]:

```python
import pymysql
import numpy as np
import pandas as pd
conn = pymysql.connect(host=HOST, port=PORT, user=USER, passwd=PASS, db=DB)
cursor = conn.cursor()

test_type = ['TXG', 'DSSG', 'CONG', 'GRAG', 'PLAS', 'RDEN', 'INDX']
output = {'LAB_PROGRAM_ID':[], 'LAB_ID':[], 'LAB_PROGRAM_DESC':[], 'TXG':[], 'DSSG':[], 'CONG':[], 'GRAG':[], 'PLAS':[], 'RD

sql = 'SELECT LAB_PROGRAM_ID, LAB_ID, LAB_PROGRAM_DESC FROM LAB_PROGRAM ORDER BY LAB_PROGRAM_ID ASC'
cursor.execute(sql)
data = cursor.fetchall()
lab_program_id = []
lab_id = []
lab_program_desc = []
for d in data:
    lab_program_id.append(d[0])
    lab_id.append(d[1])
    lab_program_desc.append(d[2])
output['LAB_PROGRAM_ID'] = lab_program_id
output['LAB_ID'] = lab_id
output['LAB_PROGRAM_DESC'] = lab_program_desc

for t in test_type:
    for lpi in lab_program_id:
        sql = 'SELECT COUNT(' + t + '.' + t + '_ID) FROM SAMP INNER JOIN LAB_PROGRAM_SAMP ON '
        sql += 'SAMP.SAMP_ID = LAB_PROGRAM_SAMP.SAMP_ID INNER JOIN SPEC ON SPEC.SAMP_ID = SAMP.SAMP_ID '
        sql += 'INNER JOIN ' + t + ' ON ' + t + '.SPEC_ID = SPEC.SPEC_ID WHERE LAB_PROGRAM_ID = ' + str(lpi)
        cursor.execute(sql)
        res = cursor.fetchone()[0]
        output[t].append(res)
df = pd.DataFrame(output)
df
```

Out[82]:

	LAB_PROGRAM_ID	LAB_ID	LAB_PROGRAM_DESC	TXG	DSSG	CONG	GRAG	PLAS	RDEN	INDX
0	1	1	Testing of samples from sites associated with ...	42	0	0	56	38	6	35
1	2	2	Cyclic and monotonic direct simple shear on Or...	14	52	3	0	0	0	0
2	3	3	Testing on samples from Mihama Ward associated...	7	0	0	0	0	0	7
3	4	0	Lab testing associated with Shengcong et al. (...	0	0	0	0	0	0	0
4	5	0	Lab testing associated with Graded area east o...	0	0	0	5	2	0	0
5	6	7	Lab testing associated with 1979-1981 with CPT...	0	1	0	1	0	0	0

Figure 8. Example query of the number of tests of the various types stored in the NGL database.

A benefit of using Jupyter to interact with the data is the built-in data processing and plotting capabilities afforded by Python. Example data from LAB_PROGRAM_ID = 2 are plotted in Fig. 9. This figure shows monotonic direct simple shear test results for three different blends of fine-grained soil, including plots of normalized shear stress versus normalized vertical effective stress, and normalized shear stress versus shear strain. These data were queried from the relational database and plotted using a Jupyter notebook, as described later. A total of 52 different shearing tests were performed on 3 different blends of soil. In a typical file repository, information about each blend would generally be repeated and included along with the experimental data. However, this approach increases the potential for data entry errors. A user might enter the percent silt as 95% in one file, and 92% in a different file, even though the two blends were the same. In a relational database, a table would be established to describe the mineral blends, and the information about those blends would only be entered once. The primary key for a particular mineral blend would then be included as a foreign key in a different table containing the experimental results for a particular shear test to establish a relationship between the mineral blend and the shear test. Similar relationships could be established for other test types, such as Atterberg Limits, specific gravity, consolidation, etc. Significant thought is required to develop a well-formed schema for a relational database to accommodate the various types of information typically recorded in an experimental testing program. As an example, Brandenberg et al. (2018) describe the relational database developed for the Next Generation Liquefaction project for the purpose of curating field case history data, including site investigation data, post-earthquake observations, and event/ground motion data.

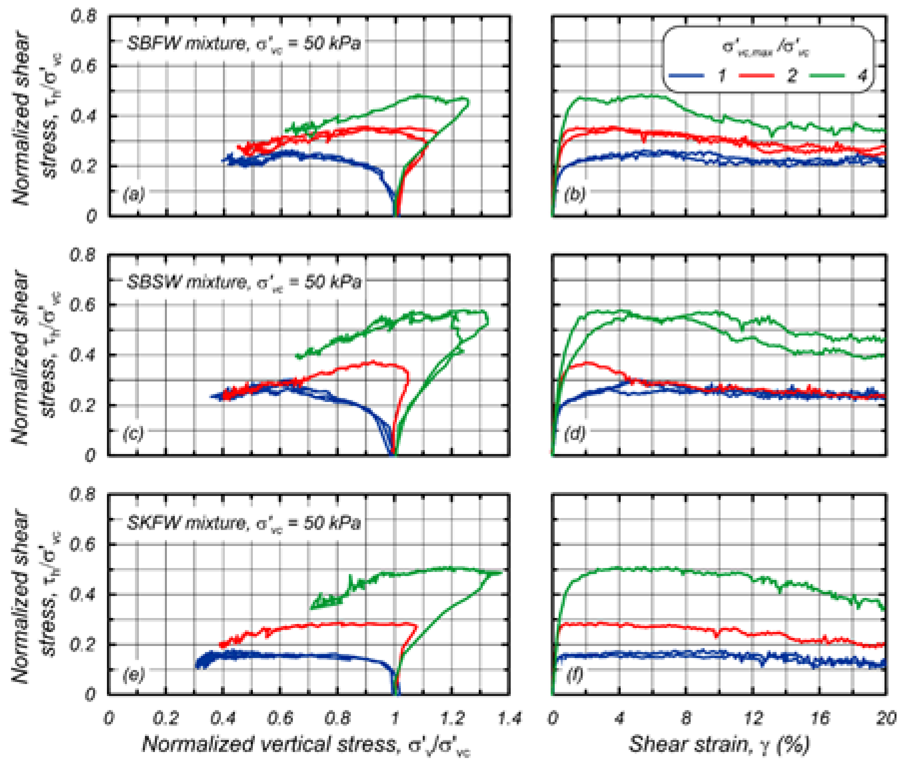

Figure 9. Constant-height monotonic DSS responses of mixtures. Stress-paths and stress-strain curves for (a) and (b): Silt-Bentonite fresh water blend (SBFW), (c) and (d): Silt-Bentonite salt water blend (SBSW), and (e) and (f): Silt-Kaolinite fresh water blend (SKFW). Source: Eslami (2017)

Jupyter notebooks have been written to query the laboratory component of the database and plot simple shear and triaxial tests that are stored within the database. The user can select from dropdown menus the sample, specimen, test ID, and stage ID as shown in Fig. 10. The notebook then plots interactive figures that the user can manipulate and download as desired. Example plots from the simple shear and triaxial tools are shown in Figs. 11 to 14.

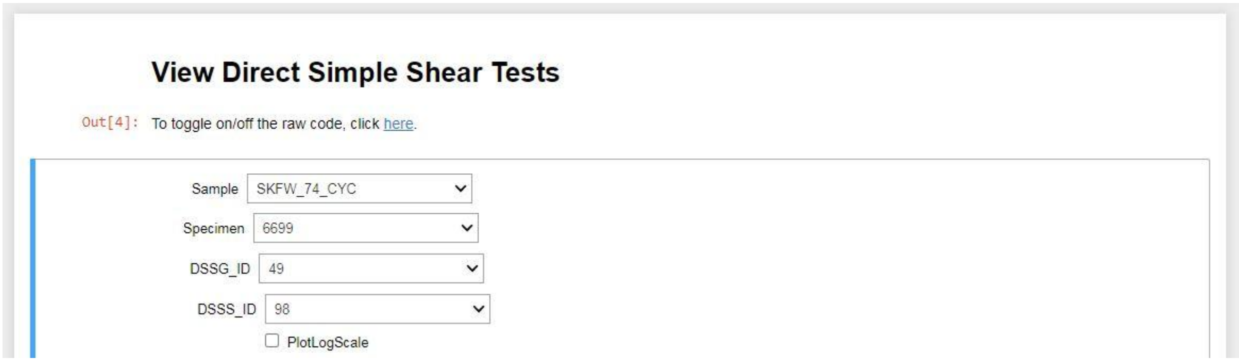

Figure 10. Simple Shear Test Viewer drop down menus and header.

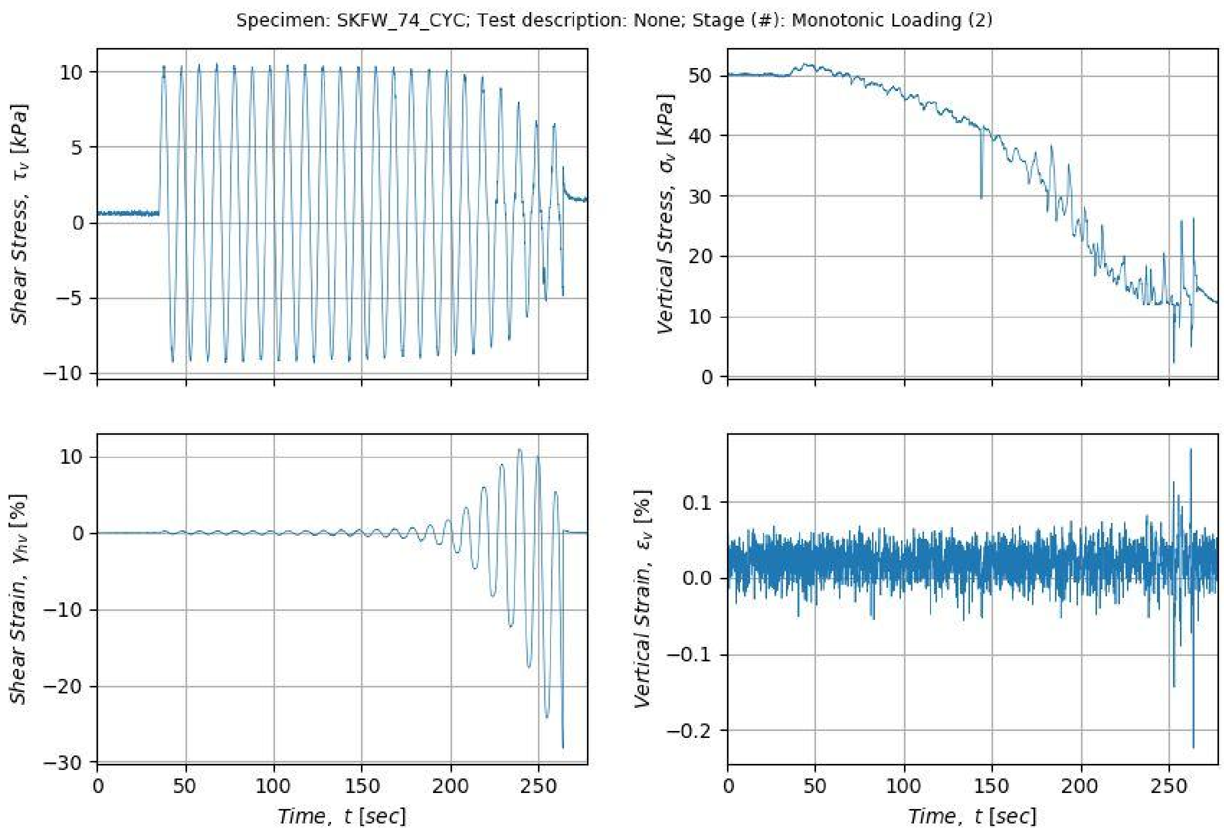

Figure 11. Example figure from the DSSD_Viewer Jupyter Notebook presenting time series data from a constant height simple shear cyclic test performed by Mandro Eslami on a fine-grained soil blend.

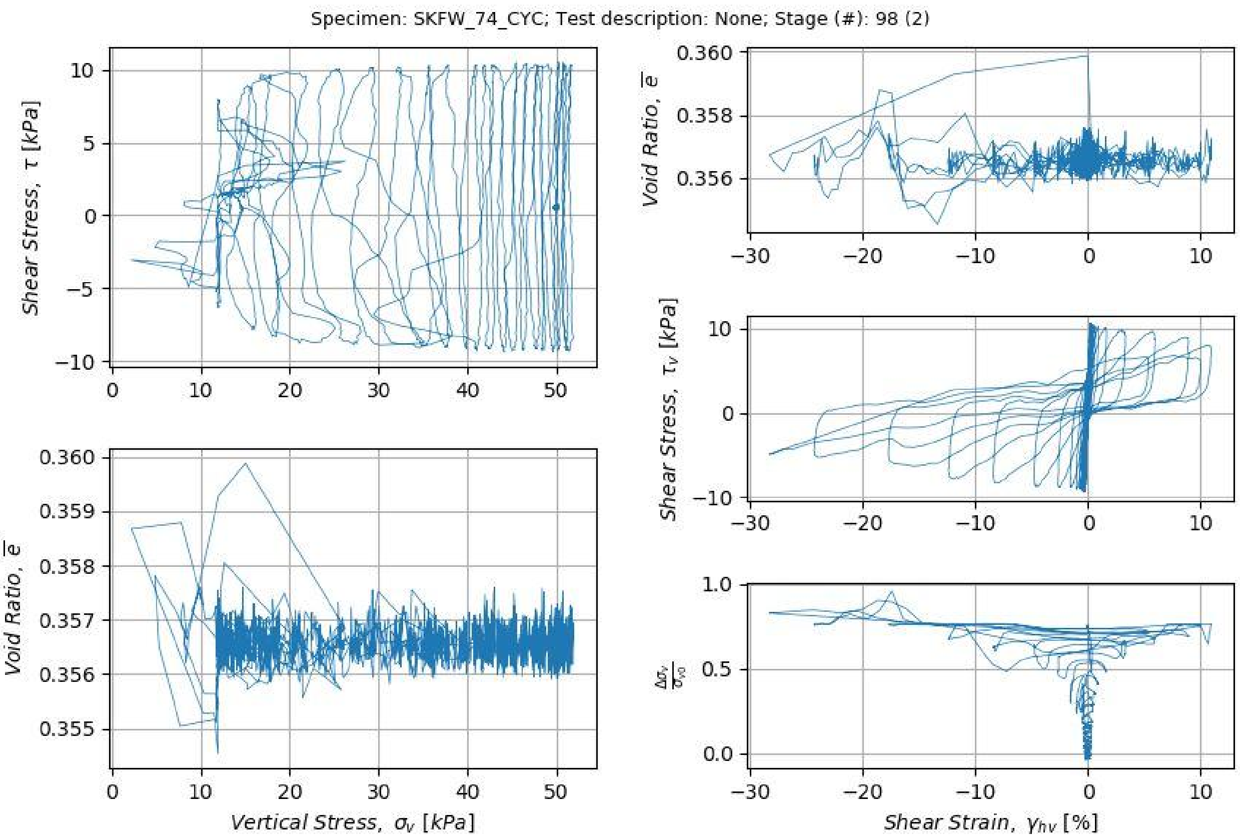

Figure 12. Example figure from the DSSD_Viewer Jupyter Notebook presenting derived relationships from a constant height simple shear cyclic test performed by Mandro Eslami on a fine-grained soil blend.

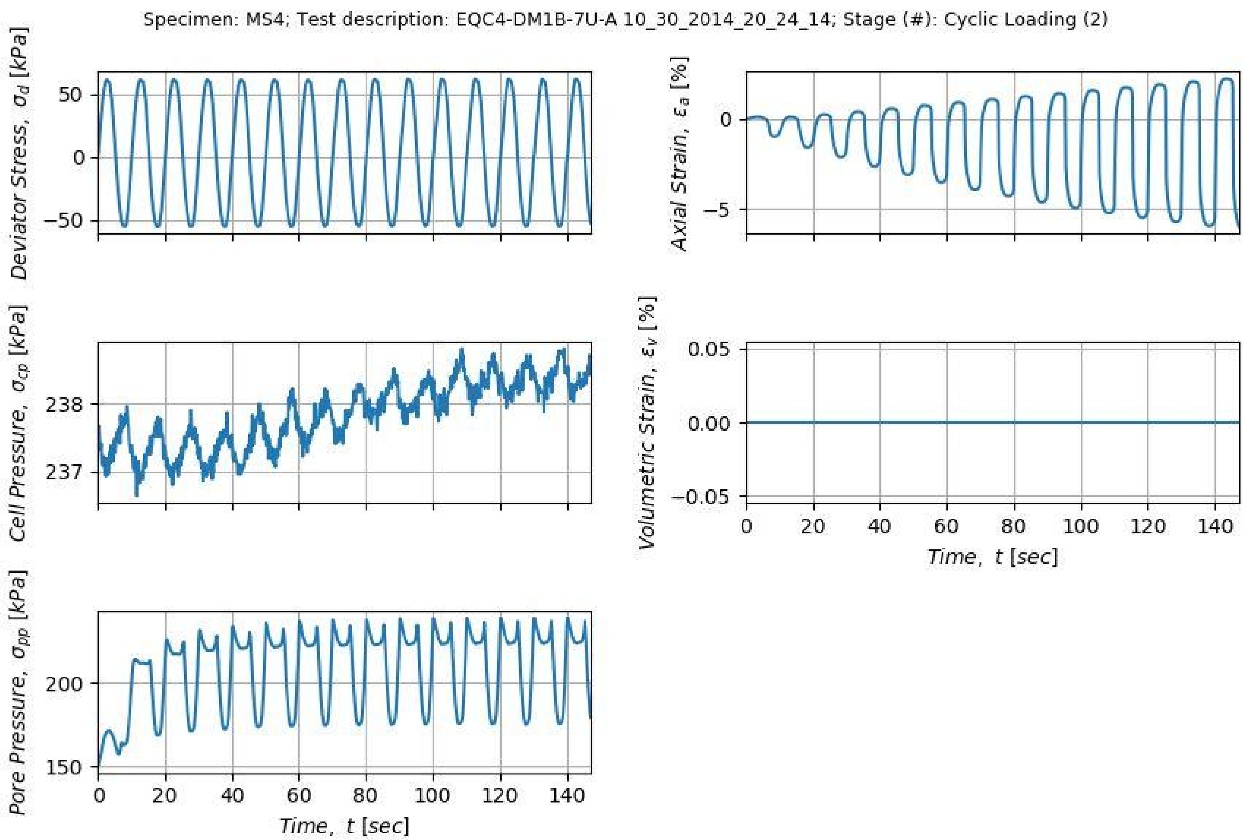

Figure 13. Example figure from the TX_Viewer Jupyter Notebook presenting time series data from a cyclic triaxial test performed by Christine Beyzaei on a specimen from a site in New Zealand.

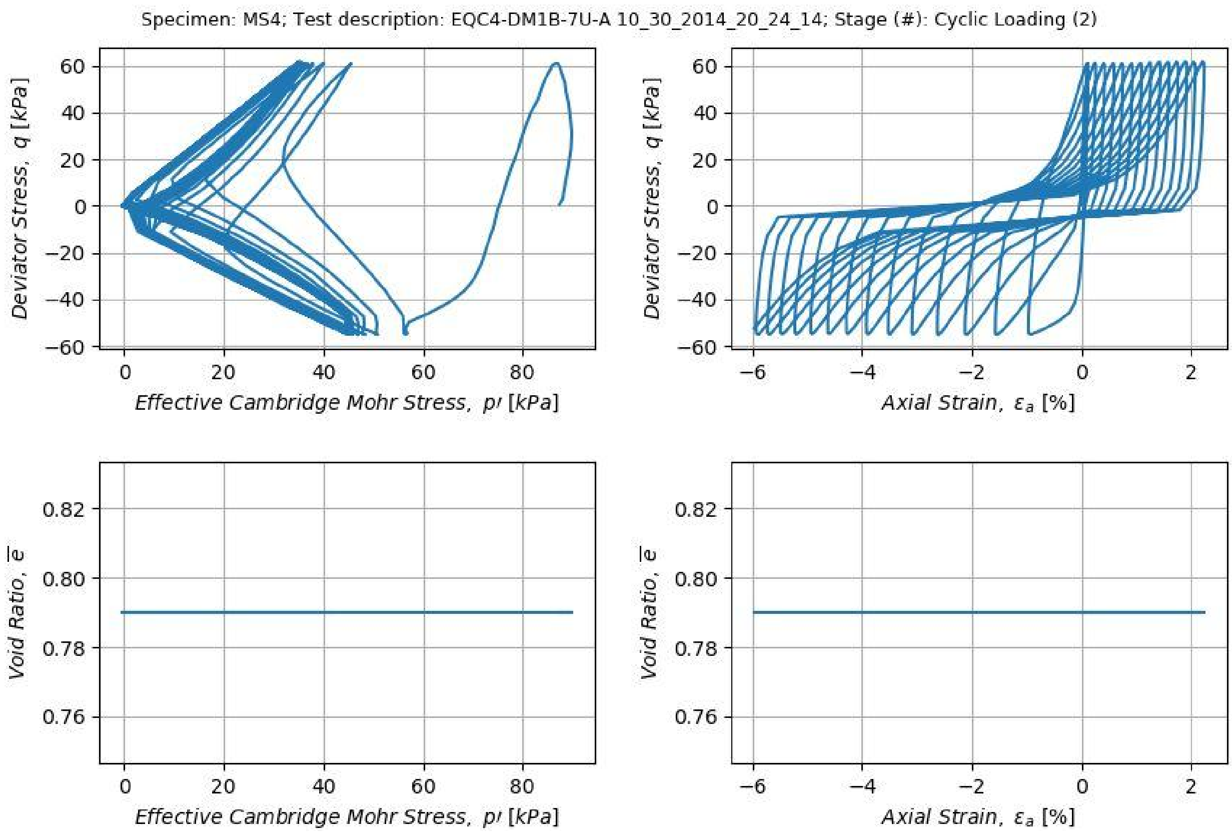

Figure 14. Example figure from the TX_Viewer Jupyter Notebook presenting derived relationships from a cyclic triaxial test performed by Christine Beyzaei on a specimen from a site in New Zealand.

3.0 Laboratory Testing

Our original scope of work included laboratory testing of soils from Mihama Ward. We did not make the progress we had envisioned on this scope item for two reasons. First, our laboratory was shut down from March 13, 2020 through the end of June 2020 due to the COVID-19 pandemic. We had just begun organizing the Mihama Ward soils and had developed a testing plan when the shutdown occurred. We ultimately were able to follow University protocols to regain access to our lab when the control system for the direct simple shear testing device ceased functioning. We implemented a new control system, and are still in the process of debugging the new control system to perform high quality test results. Our focus has been on replicating previous test results using well-characterized sands in our laboratory and we have not yet progressed to the point that we are confident in our ability to obtain high quality test results for the Mihama Ward soils. We still plan to perform this testing, but we were unable to complete it as part of the scope of work covered in this report. The time we would have spent performing lab tests and analyzing the results has instead been spent on developing the database and populating it with high quality laboratory data from other, pre-existing testing programs.

One consolidation test was performed on a reconstituted sample that had a previous consolidation test performed on it by Tokyo Soils. The results were significantly different when compared to those provided by Tokyo soils, likely due to the specimen being remolded and the remolding process involving fresh water instead of salt water. Clays with salt water in the voids can have significantly different behavior when compared to the same clay with fresh water. The sample would have been saturated with salt water due to the site's proximity to the bay. Therefore, the sample will be remolded again, this time using salt water, and have a consolidation test performed on it to see how the results change.

4.0 Conclusions

A relational database has been developed for laboratory tests performed to study the liquefaction behavior of soils, and is implemented within the Next Generation Liquefaction database. The organizational structure of the database (i.e., the schema) is presented herein, which is important for understanding the types of laboratory tests in the database, and for structuring SQL queries to retrieve data from the database. Some laboratory test programs have already been entered into the database, and we anticipate that the database will grow significantly due to future contributions by the geotechnical earthquake engineering community. We are still developing the graphical user interface to interact with the laboratory database, and anticipate it will be ready within one month from the time of submission of this report. The database is replicated daily to DesignSafe, enabling users to query and plot data. Several Jupyter notebooks for querying and plotting data are presented herein.

We did not make as much progress on our own laboratory testing as we had anticipated due to the COVID-19 pandemic, and due to upgrades to the control system for our direct simple shear device. We do anticipate performing these tests in the near future, and the data will be added to the database.

We believe that the database presented herein is a significant contribution to the geotechnical earthquake engineering field. All too frequently, laboratory test studies are performed so that the authors of the study can draw conclusions and move on. Rarely are these laboratory test data reused by other researchers. We believe there is significant potential for this database to grow into an essential resource for our community by providing users with a central location to find the laboratory test data they seek.

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