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Authors
Hudson, Kenneth S
Zimmaro, Paolo
Ulmer, Kristin
et al.

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LABORATORY COMPONENT OF NEXT GENERATION LIQUEFACTION DATABASE

K.S. Hudson(1), P. Zimmaro(2), C. Rangel(3), S.J. Brandenberg(4), J.P. Stewart(5)

(1) *Ph.D. Student, University of California Los Angeles, kenneth.s.hudson@gmail.com*
(2) *Project Scientist and Lecturer, University of California Los Angeles, pzimmaro@ucla.edu*
(3) *Ph.D. Student, University of California Los Angeles, rangel.claudia8@gmail.com*
(4) *Professor and Associate Dean, University of California Los Angeles, sjbrandenberg@g.ucla.edu*
(5) *Professor, University of California Los Angeles, jstewart@seas.ucla.ed*

Abstract

The Next Generation Liquefaction (NGL) project has developed an online relational database of liquefaction case histories to support model development, which is available online at http://nextgenerationliquefaction.org/ [1] [2]. The NGL field testing database was recently expanded to include the results of laboratory testing programs because such results can inform aspects of liquefaction models that are poorly constrained by case histories alone.

This paper describes the laboratory component of the NGL database including consolidation and shear testing. Shear testing is generally undrained and may involve, monotonic or cyclic loading using triaxial, or direct simple shear test equipment. Specimen data are organized by a schema describing tables, fields, and relationships among the tables. Information within the database is contained within tables, which contain fields (columns of information). The types of information available from a typical testing program that would be available in the laboratory component include stress, strain, and pore-pressure versus time as well as test type, pre-shear confining pressure, pre-shear deviatoric stress state, and others. Information uploaded to the database is reviewed by a database working group to verify consistency between uploaded data and source documents. The database is replicated in DesignSafe-CI [3] where users can write queries in Python scripts within Jupyter notebooks to interact with the data.

Keywords: Soil Liquefaction, Next-Generation Liquefaction, Laboratory Test, Relational Database, Jupyter Notebook

1. Introduction

Quantifying liquefaction susceptibility, triggering, and effects requires datasets that span a wide parameter space, and a modeling framework that is founded in first principles known to control soil response to undrained shear. The combination of a physically-meaningful modeling framework and a robust data set is required to develop robust semi-empirical models regressed from the data. The goal of the Next-Generation Liquefaction (NGL) database is to support this model building process by providing objective data. To date, the emphasis has been on field case histories of liquefaction and its effects, as well as no-ground failure cases [2] [4].

While this database will support model development over a certain parameter space, it is not adequate to constrain models over the parameter space required for application. As one example, liquefaction models need to be applicable over a wide range of vertical effective stresses, ranging from effectively zero up to perhaps 6 atm. The available case histories involve relatively shallow soils, and hence do not include high-overburden pressure cases. Extending models across broad parameters spaces require additional information, which can often be provided by laboratory studies of soil behavior. As a result, we have undertaken the task of expanding the NGL database schema of Brandenberg et al. [4] to allow for this information; this paper describes our initial work in this regard. Unlike case history sites, the laboratory data introduced here is not associated with a “site” in the database (i.e., a location where certain liquefaction-related effects have been observed).

2. Example Application: Liquefaction Susceptibility

Analyses of liquefaction-related hazards generally include three phases: (1) an assessment of liquefaction susceptibility (i.e., is the soil of a type that it could potentially liquefy if it were saturated and subjected to sufficiently strong ground motions); (2) for soil judged to be susceptible, an analysis to evaluate if expected shaking demands from future earthquakes are likely to trigger liquefaction; and (3) for sites where liquefaction is expected to be triggered, the expected levels of deformation and stability.

Several of the models required to evaluate liquefaction hazards require information beyond what can be provided directly from case histories, a prominent example of which is liquefaction susceptibility. The difficulty with using case histories to evaluate susceptibility is the potential for *false negatives* and *false positives*. In this context, a false positive is a case history of earthquake induced ground failure that is not caused by soil liquefaction. One such example is provided by bearing capacity failures of foundations on softened clays, such as occurred in Wufeng, Taiwan during the 1999 Chi-Chi earthquake (Fig. 1). The culprit in that case was strong inertial demands on the building foundations and strength loss from cyclic softening of the clays.

False negatives occur when soils at a site are susceptible to liquefaction, but either (1) liquefaction is triggered but its effects are not manifest at the ground surface or (2) liquefaction is not triggered because the strength of ground shaking is insufficient given the soil state. The first of these situations can occur if a thick non-liquefiable layer overlies a liquefiable layer [5]. Similarly, liquefaction can also occur in individual disconnected layers and not produce surface manifestations, as observed in Christchurch after the 2010-2011 Canterbury earthquake sequence [6].

As a result of these false negative and false positive issues, and given the definition of liquefaction susceptibility provided above, liquefaction susceptibility is poorly suited to analysis based solely on case history data. Laboratory test data provides a good alternative, with the potential to investigate pore pressures responses, stress-strain responses, and strength normalization behavior that is indicative of the fundamental behavior of a soil as being principally governed by granular particle interactions (i.e., sand-like) or by a cohesive soil matrix (i.e., clay-like).

The database described in this paper is intended as an archive for data of this type. We describe here the structure of the laboratory component of the NGL relational database and tools developed to query it.

Fig. 1 – Punched footings and intermediate slab heaving due to cyclic softening of high-plasticity clay in Wufang, Taiwan. Photo by R. Seed (1999).

3. Database Structure

A thorough description of the NGL database structure can be found in Brandenberg et al. [4]. The laboratory component, is built into the NGL relational database framework and is a structured database that can be queried using structured query language (SQL). A relational database is defined as a digital database that comprises various tables linked to one another by means of identifiers called keys. Each table has a primary key that uniquely identifies table entries. If two tables are linked, the primary key of a table is used as a so-called foreign key in another table. Primary-foreign key relationships produce the organized hierarchical structure of a database. Such organizational structure is called schema. The NGL laboratory component was developed in consultation with the NGL database working group (S.J. Brandenberg, K.O. Cetin, R.E.S. Moss, K.W. Franke, and P. Zimmaro). The schema presented here is mostly complete, but population of the database is ongoing and should continue indefinitely as more testing is done and researchers share data. The schema may have fields and/or tables added in the future if there is an interest in more types of datasets.

18 tables were added to the NGL database for the laboratory component with a specimen table at the top of the hierarchy. This specimen table will be joined to the sample table from the NGL schema allowing specimens to be associated with a site (under the NGL schema) or not (under the laboratory component schema). The hierarchy of the laboratory component schema is shown in Fig. 2. Table 1 contains descriptions for each table. There are 109 fields contained within the tables defined in Table 1 and shown in Fig. 2.

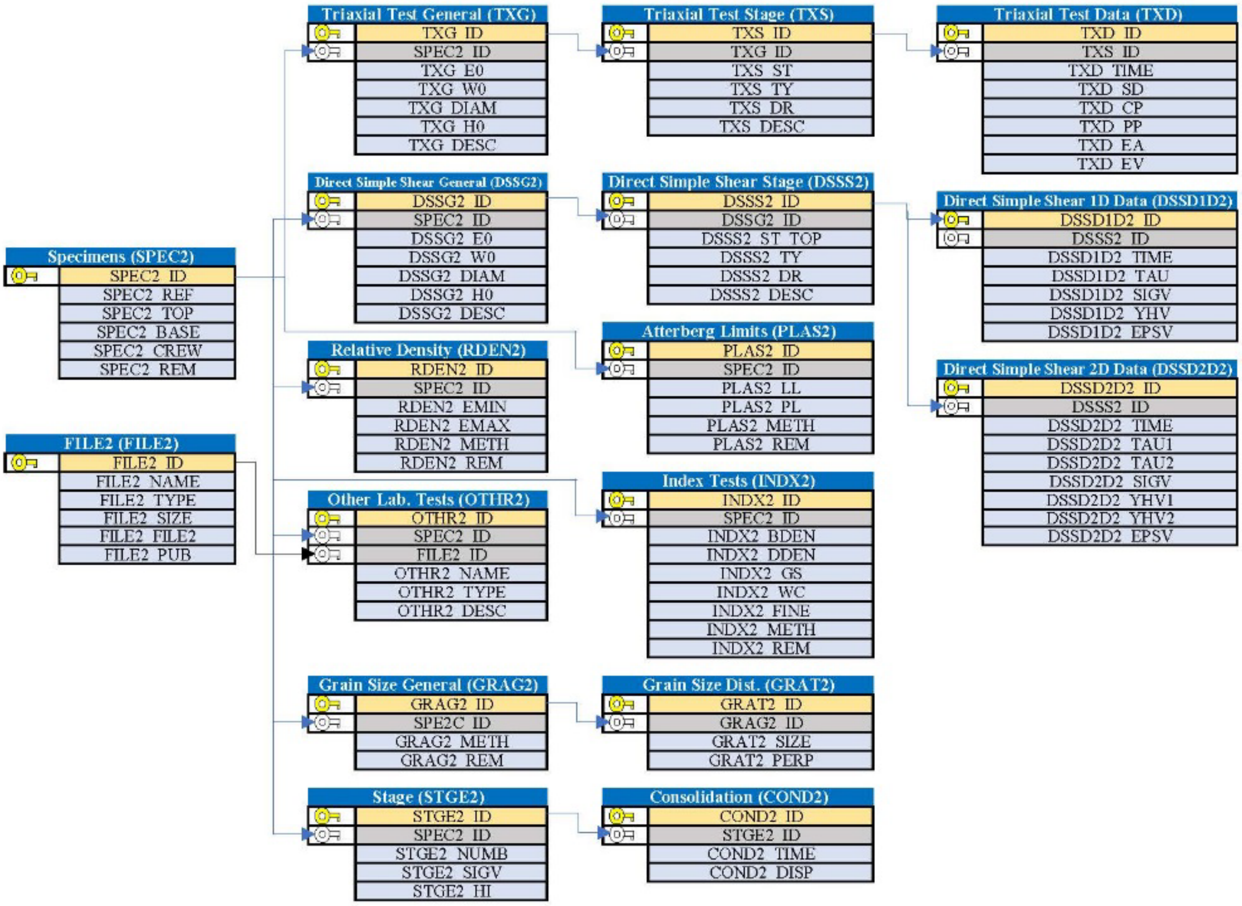

Fig. 2 – Laboratory component relational database schema showing relationships between tables using keys

The table names in Table 1 below also correspond to the primary keys of those tables (for example, table SPEC2 has a primary key SPEC2_ID). SPEC2_ID is used as a foreign key in the following tables: TXG, DSSG2, PLAS2, RDEN2, OTHR2, INDX2, GRAG2, and STGE2. The TXG table primary key, TXG_ID is used as a foreign key in the TXS table, which has a primary key TXS_ID that is used as a foreign key in the TXD table. Similarly, the DSSG2 table primary key, DSSG2_ID, is used as the foreign key in DSSS2 which has a primary key DSSS2_ID that is used as a foreign key in DSSD1D2 and DSSD2D2. The FILE2 table with a primary key FILE2_ID is used as a foreign key in the OTHR2 table, which therefore has two foreign keys, SPEC2_ID and FILE2_ID. GRAG2_ID is used as a foreign key in the GRAT2 table and STGE2_ID is used as a foreign key in the COND2 table.

Table 1 – List of tables in the laboratory component of the NGL database

Table Name	Table Description	Number of Fields
SPEC2	General information for laboratory tests, location of specimens	6
INDX2	Index tests include: density (ASTM D7263-09), water content (ASTM D2216-10), and Atterberg limit tests (ASTM D4318-10e1). Standards recommended for each test are in parentheses.	9
RDEN2	Relative density measurement	6
PLAS2	Plasticity test (i.e., Liquid limit and plasticity limit) information	6
GRAG2	General information for particle size distribution analysis	4
GRAT2	Test results (percent passing for a specific sieve) from particle size distribution analysis	4
OTHR2	Other tests not specified above. Any format of test results can be uploaded.	6
FILE2	Table storing supplemental files	5
DSSG2	Direct simple shear test general information	7
DSSS2	Information about each direct simple shear test stage	6
DSSD1D2	One-dimensional direct simple shear test data	7
DSSD2D2	Two-dimensional direct simple shear test data	9
TXG	Triaxial test general information	7
TXS	General information for triaxial test stages	6
TXD	Triaxial test data	9
STGE2	Consolidation test stage general information	5
COND2	Consolidation test data	4
SAMP_SPEC	Junction table between sample and specimen	3

To illustrate database functionality, consider the following example data entry:

- A hypothetical specimen is assigned an ID (SPEC2_ID), name (SPEC2_REF), and other metadata such as (1) the depth to the top and bottom of the specimen (SPEC2_TOP, SPEC2_BASE) if the specimen is from a boring (these would be left blank if the material was a synthetic mixture created in the lab), (2) name of the person or organization who did the testing (SPEC2_CREW), and (3) other remarks about the specimen (SPEC2_REM).
- Results of index testing, relative density measurements, grain size distribution analysis, or other testing is provided in tables INDX2, RDEN2, GRAG2/GRAT2, PLAS2, and OTHR2. That data is connected via the SPEC2_ID foreign key to the SPEC2 table. If consolidation tests were performed separate from triaxial or direct shear tests, then metadata from each stage of the consolidation tests such as final effective vertical stress and final height of the specimen (STGE2_SIGV and STGE2_HI, respectively) is entered into the STGE2 table and the consolidation data – time and displacement – are entered into the COND2 table. The COND2 table is linked via STGE2_ID as the foreign key which is linked to the SPEC2 table using the SPEC2_ID foreign key.

- Triaxial data is entered by first entering the general metadata for the triaxial test (TXG table) such as initial void ratio, water content, specimen diameter, initial height, and any descriptive information (TXG_E0, TXG_W0, TXG_DIAM, TXG_H0, and TXG_DESC, respectively). The triaxial test stage table (TXS) contains a foreign key to the TXG table and also contains fields for the stage number, type of stage (i.e. consolidation, monotonic loading, or cyclic loading), drainage (i.e. drained, undrained, or neither), and a description of the stage (TXS_ST, TXS_TY, TXS_DR, and TXS_DESC, respectively). The triaxial test data (TXD) table has a foreign key connecting it to the TXS table (TXS_ID) and has fields for time, deviator stress, cell pressure, pore pressure, axial strain, radial strain, and volumetric strain vectors (TXD_TIME, TXD_SD, TXD_CP, TXD_PP, TXD_EA, TXD_ER, TXD_EV, respectively).
- Direct simple shear tests are entered similarly to triaxial tests, however there is an option for entering 1 or 2-dimensional test data.

4. Data Querying and Visualization

The database can be queried using SQL libraries in Python through DesignSafe, that offers cloud-based computing tools and has the database replicated onto it every 24 hours. Python scripts are used in Jupyter notebooks on DesignSafe for querying the database. Jupyter notebooks are a server-client application that allows editing and running notebook documents in a web browser and combines rich text elements and computer code executed by a Python kernel [7]. Jupyter notebooks are published and available on DesignSafe in the NGL project partner data apps ([4] are references therein).

Fig. 3 and 4 presents a Jupyter notebook for visualizing triaxial test data. The user can select a specimen from the first dropdown menu and the tool populates the TestID dropdown menu with the triaxial tests that are all performed on that specimen (from the TXG table). Based on the selection from that dropdown, the tool populates the StageID dropdown with the stages for that particular test. The tool plots the data from the selected stage in 9 separate plots to help visualize it. Fig. 3 shows the consolidation stage and Fig. 4 shows the cyclic loading stage of a particular test.

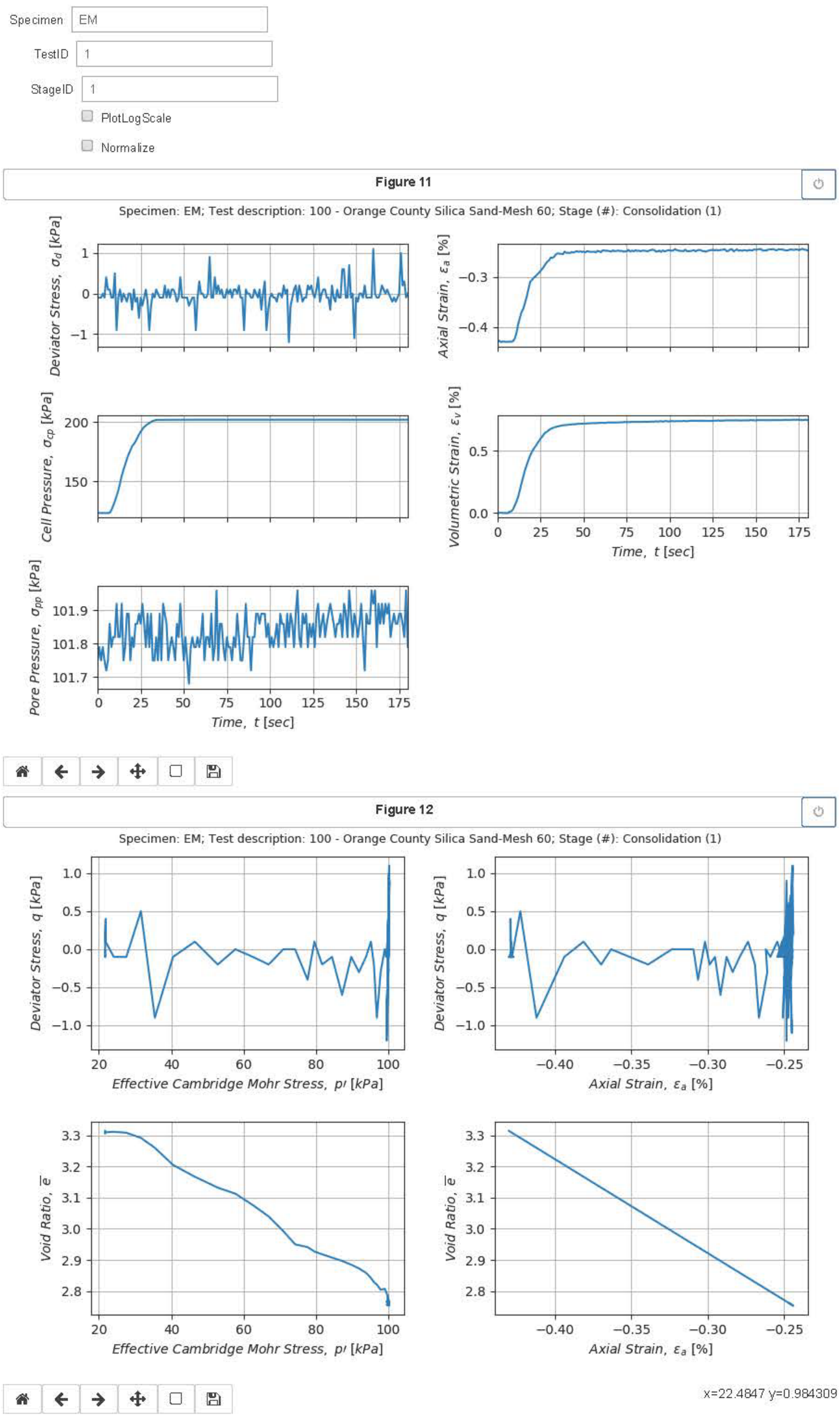

Fig. 3 – Output from the triaxial test viewer tool showing a consolidation stage

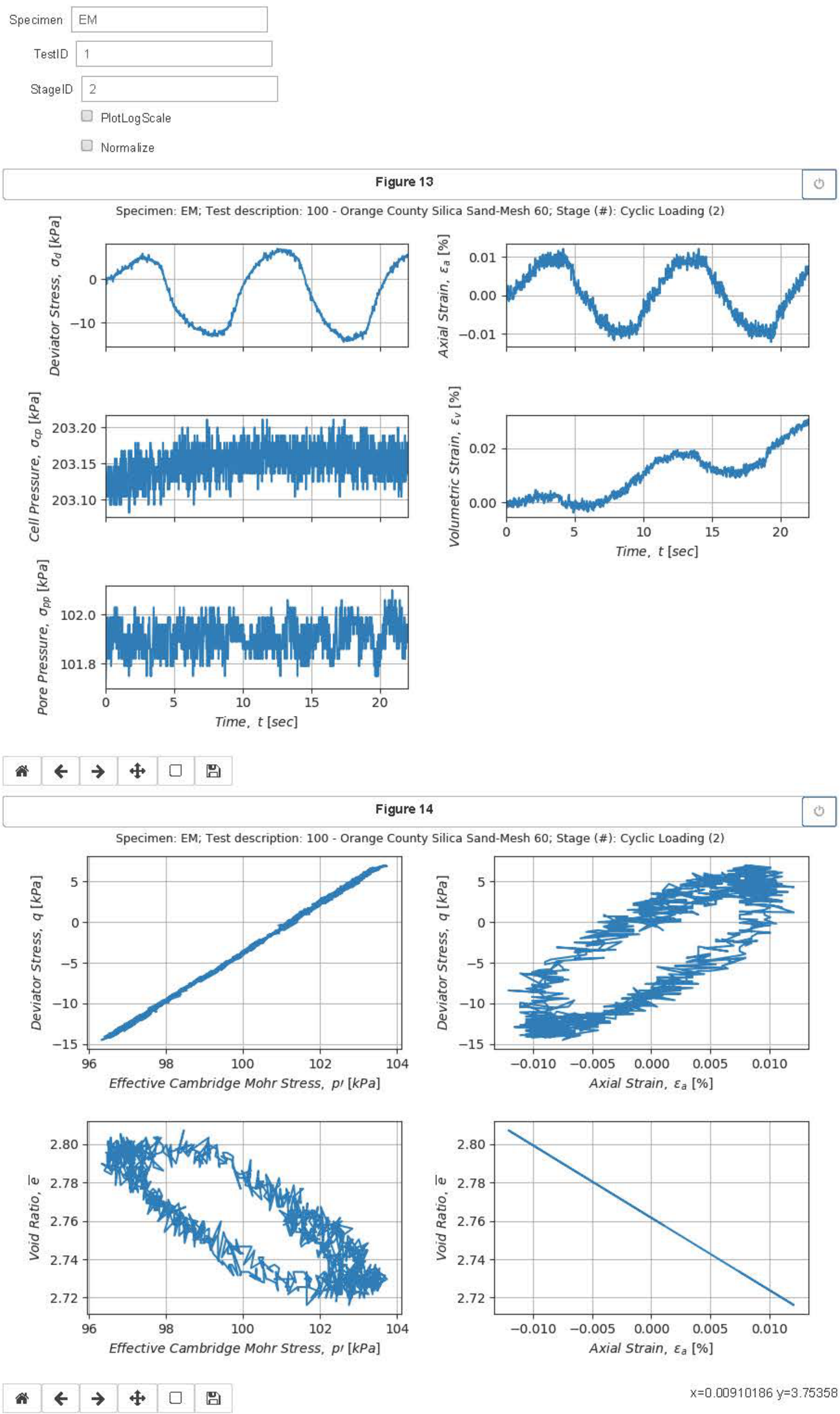

Fig. 4 – Output from the triaxial test viewer tool showing a cyclic loading stage

5. Conclusion

This paper presents the motivation for developing a laboratory component of the Next Generation Liquefaction (NGL) database, and the schema by which that database is organized. The laboratory component is organized according to a separate schema from the main NGL database, which that allows for laboratory test results to not be associated with a field observation “site”. Moreover, the schema allows relatively detailed data from laboratory tests to be entered. The database is replicated on DesignSafe where the data can be queried and visualized using Jupyter notebooks.

6. Acknowledgements

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7. Copyrights

8. References

References must be cited in the text in square brackets [1, 2], numbered according to the order in which they appear in the text, and listed at the end of the manuscript in a section called References, in the following format:

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