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Publication Date
2019

Peer reviewed

Earthquake Geotechnical Engineering for Protection and Development of Environment and Constructions – Silvestri & Moraci (Eds)
 ISBN 978-0-367-14328-2

Quality control for next-generation liquefaction case histories

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ABSTRACT: The Next-Generation Liquefaction (NGL) database is an open-source, global database of liquefaction and non-ground failure case-histories. The database is part of a multi-year research effort with the main goal of developing improved procedures to evaluate liquefaction susceptibility, triggering, and consequences. In NGL, a case-history is defined as the intersection of three components: (1) a site, (2) an earthquake event, and (3) post-earthquake observations. The NGL database hosts case-histories used to develop existing liquefaction models, as well as new data derived from recent earthquakes such as the 2010-2011 Canterbury earthquake sequence, the 2011 Tohoku-Oki earthquake, and the 2012 Emilia earthquake. The database also hosts lateral spread case-histories, and a substantial number of liquefaction sites characterized by the presence of co-located recording stations. All of the data present in the NGL database are reviewed by the NGL Database Working Group. The NGL formal vetting process is described for an example case-history.

1 INTRODUCTION

The Next Generation Liquefaction (NGL) project is a collaborative research effort that comprises three main components: (1) an open-source case-history database (2) supporting studies focusing on effects that are not well constrained by case history data, and (3) development of empirical and/or semi-empirical susceptibility, triggering, and consequences models. After a brief description of the NGL case-history database and its structure, we describe the review process performed on each case history, and the current database population status.

The NGL database is a transparent, open source, community database of liquefaction and non-liquefaction case histories. In NGL a case history has three components (Stewart et al. 2016): (1) geotechnical site characterization (by means of site investigation and laboratory tests), (2) post-earthquake observations of liquefaction effects, or lack thereof, and (3) earthquake event and ground motion information.

The NGL database is developed using the My Structured Query Language (MySQL) relational database management system. The database schema (i.e. its organizational structure) comprises 55 tables with relationships between tables defined by primary/foreign key combinations. The database can be conceptually subdivided into four main sections: (1) general information, (2) site information, (3) event information, and (4) observations. Additional details about the NGL relational database and its structure are provided by Brandenberg et al. (2018) and at http://nextgenerationliquefaction.org/schema/index.html. The database graphical user interface (GUI) is hosted at http://www.nextgenerationliquefaction.org/(Zimmaro et al. 2019; DOI: 10.21222/C2J040). The NGL database GUI was developed using PHP: Hypertext Preprocessor (PHP), cakePHP, Hypertext Markup Language 5 (HTML5), and JavaScript. It also utilizes the Environmental Systems Research Institute (ESRI) Arc Geographic Information System (ArcGIS) Application Program Interface (API) and the Leaflet JavaScript API to organize and visualize the data geo-spatially. The NGL database GUI can be used to visualize, download, and upload case histories or information relevant to an existing case history.

After creating an NGL account, a user can visualize, download, and/or upload case histories. Data in the NGL database can be visualized on a map (*Map View* option in the main menu) or as an organized list of items (*List View* option). Figure 1a shows a screenshot of the *Map View*, while Figure 1b shows a screenshot of the *List View*. Case histories can be uploaded into the database following two procedures: (1) through a step-by-step procedure using the database GUI, or (2) using a comma-separated value (csv) template that replicates relevant fields in the NGL database schema. To better understand the meaning of each field in the database schema, we created a meta-dictionary (Figure 2, available at: http://nextgenerationliquefaction.org/schema/index.html) that contains information about each database entry. Information for each component of the database (site, observation, and event), can be uploaded, accessed, and/or modified by individual users or by members of a research team (i.e. groups of one or more users). The primary user (i.e., the person who creates the case history) can assign other users to be team members with various levels of permission to access information. When the team is ready to commit their data to the NGL database, they submit it for review. The data is publicly available at this time, but it is flagged as non-reviewed.

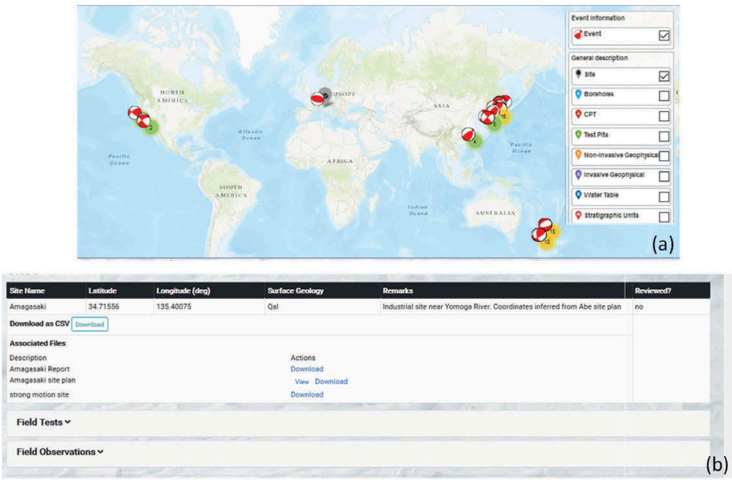


Figure 1. Screenshot of the NGL database GUI homepage: (a) *Map View*, (b) *List View*.

Column	Comments
SITE_ID	Unique ID (primary key) for entries in the SITE table
SITE_NAME	Site name
SITE_LAT	Latitude of the site (e.g., center of the site) in decimal degree following WGS84 system
SITE_LON	Longitude of the site (e.g., center of the site) in decimal degree following WGS84 system
SITE_GEOL	Description of surface geology. If available, indicate geology unit(s).
SITE_REM	Remarks

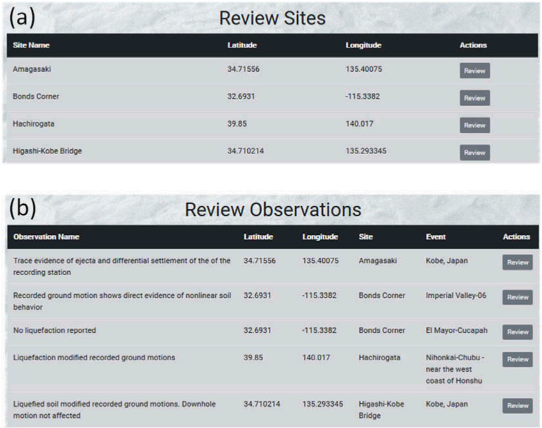
Figure 2. Meta-dictionary entries for one table in the NGL database (from http://nextgenerationliquefaction.org/schema/index.html).

2 CASE HISTORY REVIEW PROCESS

The NGL Database Working Group (NGL-WG) oversees the database population activities and coordinates the formal process of reviewing NGL case histories. The members of the NGL-WG are: Scott J. Brandenberg (chair), K. Onder Cetin, Robb E. S. Moss, Kevin W. Franke, and Paolo Zimmaro. Each case history in the database must be formally reviewed by two independent, anonymous reviewers before becoming an NGL case history. Reviewers look at information about the site, field investigations (and laboratory test results when available), and post-earthquake observations. The review is objective, and reviewers check that all required data fields are provided, information provided is clear, and that the data are consistent with the original source. Reviewer‘s subjective opinions about technical details of the case history are not included in the review process. For example, a reviewer would reject a boring log if the sampler type or drilling method is not specified, but would not reject a boring log if the reviewer‘s opinion is that the hammer type is unreliable. Subjective judgments are reserved for the model development phase of the NGL project. Each case history component is reviewed using a separate form within the NGL GUI, as illustrated in Figure 3a for site investigation results and in Figure 3b for post-earthquake observations. Post-earthquake observations represent the intersection of an earthquake event and a site. As a result, if a site is shaken by multiple earthquakes, and post-event information are available, that site may produce multiple case histories.

The Urayasu sea front lateral spread case history caused by the 2011 **M**9.1 Tohoku-Oki earthquake is used to illustrate the NGL review process. The first step of the process is verifying that the location of the site is consistent with source information, the name of the site is appropriate, and the new site does not duplicate an existing site. Figure 4a shows the location of the Urayasu sea front site in the NGL review panel, while Figure 4b shows it in the original source document (Stewart et al. 2016 in this case). The locations compare well. Furthermore, the name of the site is appropriate, and a site does not already exist at the same location in the NGL database. Therefore, the site information is approved by the reviewer by switching the *Approve* control button to *Yes*. Reviewers can also switch the *Approve* control button to *No*, and send comments/feedback to the user/team that uploaded that information using a tool available in the NGL GUI. Scrolling down the site page, the NGL review panel shows all field investigation results available at the site. Each field investigation entry can be plotted within the NGL database GUI. This allows reviewers to visualize cone penetration tests (CPT), borings with standard penetration tests (SPT), or shear wave velocity profiles (and dispersion curves for surface geophysical tests). Figure 5 shows the NGL plotting tool for SPT01 at the Urayasu sea front site. This illustrates that the review is conducted for each individual field investigation, enabling the reviewers and users to easily track which information is approved and which still needs work.

Once the site and test information are approved, the review process focuses on post-earthquake observations. There are four main information types that should be reviewed: (1)



(a) Review Sites

Site Name	Latitude	Longitude	Actions
Amagasaki	34.71556	135.40075	Review
Bonds Corner	32.6931	-115.3382	Review
Hachirogata	39.85	140.017	Review
Higashi-Kobe Bridge	34.710214	135.293345	Review

(b) Review Observations

Observation Name	Latitude	Longitude	Site	Event	Actions
Trace evidence of ejecta and differential settlement of the of the recording station	34.71556	135.40075	Amagasaki	Kobe, Japan	Review
Recorded ground motion shows direct evidence of nonlinear soil behavior	32.6931	-115.3382	Bonds Corner	Imperial Valley-06	Review
No liquefaction reported	32.6931	-115.3382	Bonds Corner	El Mayor-Cucapah	Review
Liquefaction modified recorded ground motions	39.85	140.017	Hachirogata	Nihonkai-Chubu - near the west coast of Honshu	Review
Liquefied soil modified recorded ground motions. Downhole motion not affected	34.710214	135.293345	Higashi-Kobe Bridge	Kobe, Japan	Review

Figure 3. Review panel for: (a) site and field investigation information; (b) post-earthquake observations.

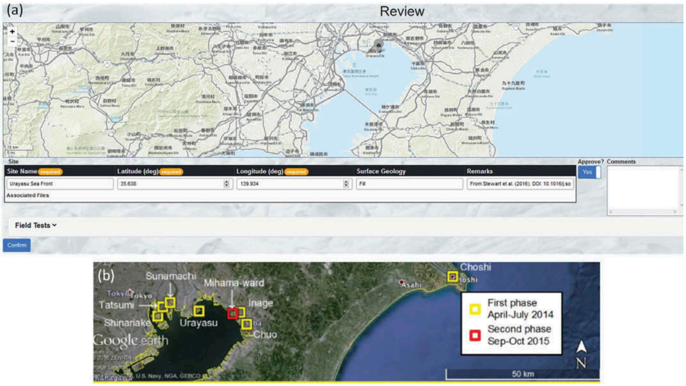


Figure 4. Site location of the Urayasu sea front: (a) in the NGL database review panel; (b) from the original source (Stewart et al. 2016).

location of the observation, (2) the overall description of the observation, (3) detailed descriptions (*Liquefaction Manifestations* and *Displacement Vectors* fields), and (4) ground motion intensity measures estimated or measured at the site. If supplemental files associated with observations (e.g., photos, maps) are available, they can be visualized and/or downloaded using the GUI (Figure 6). The *Liquefaction Manifestations* table (Figure 7), contains information on whether surface manifestations have been observed at the site and detailed descriptions about the observations (*Description* field in Figure 7). The *Ground Motion Intensity Measures* table contains the location of the recorded or estimated intensity measure, its magnitude, and associated standard deviation. It also contains the method used to obtain the ground motion (e.g., directly measured at site, interpolated from nearby records, or estimated from a ground motion model) (Figure 7).

Earthquake event information is uploaded by an event super-user, and is reviewed internally by the NGL-WG rather than through the GUI used to review site and observation data. Event data is obtained primarily from Next-Generation Attenuation (NGA) products (i.e., Bozorgnia et al. 2014 for the NGA-West2 project and Kishida et al. 2017 for NGA-Subduction). In the case of events that are not included in one of the NGA databases, relevant information is obtained from the following sources: (1) the Global Centroid-Moment-Tensor

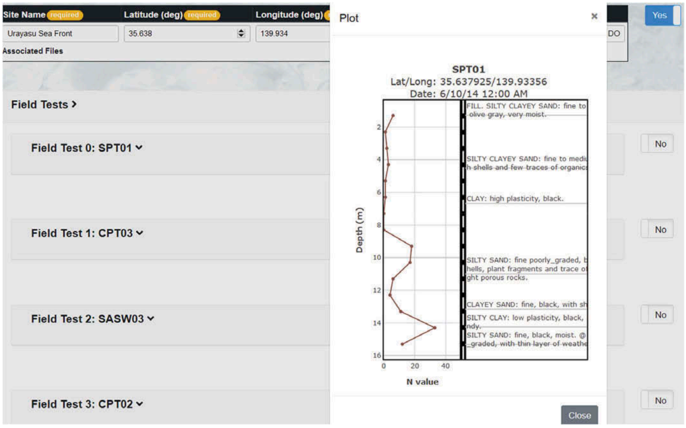


Figure 5. Field investigation visualization tool in the NGL review panel.

(CMT) Project (http://www.globalcmt.org/) – post-1976 events, (2) the United States Geological Survey (USGS) earthquake hazard program (https://earthquake.usgs.gov), (3) local/regional networks (e.g., K-NET, KiK-net for Japan, http://www.kyoshin.bosai.go.jp/; Central Weather Bureau for Taiwan, https://www.cwb.gov.tw; the European strong motion database for Europe, http://esm.mi.ingv.it/), and (4) the open technical literature.

3 DATABASE POPULATION STATUS

The NGL database population effort is currently ongoing. The database contains three main case history categories: (1) legacy case histories (i.e., used in previous susceptibility, triggering, and/or consequences models), (2) recent case histories (i.e., not present in previous databases), and (3) case histories characterized by sites where post-earthquake observations are available, with co-located recording stations (additional information about these case histories are provided by Kramer et al. 2016 and Greenfield 2017). We collect free-field and level ground case histories, as well as case histories where soil-structure interaction effects may be present. We also collect and compile lateral spread case histories. Such effort is performed in collaboration

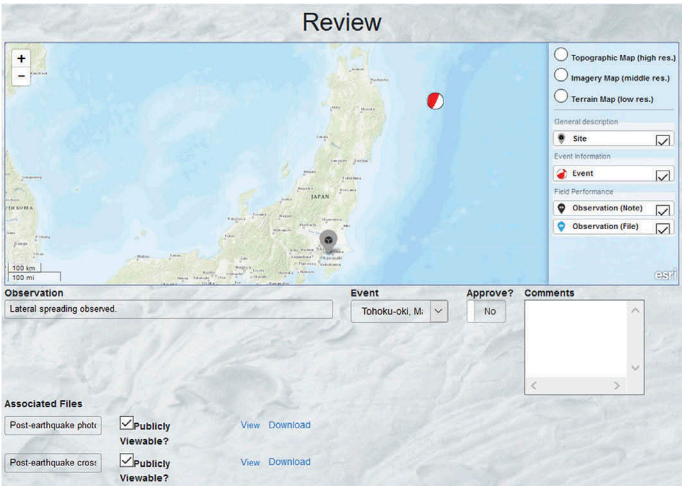


Figure 6. Post-earthquake observations review panel.

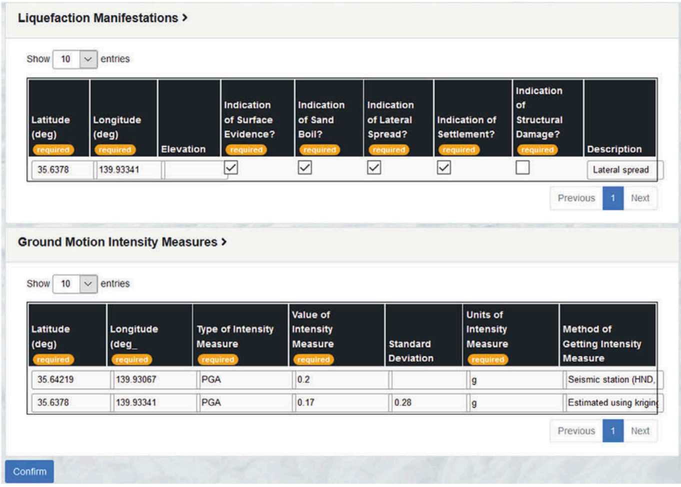


Figure 7. *Liquefaction Manifestations* and *Ground Motion Intensity Measures* tables in the NGL review panel for post-earthquake observations.

with the development of the NGL database for liquefaction-induced lateral spread project, under the auspices of the Pacific Earthquake Engineering Research (PEER) Center.

The NGL database currently hosts 144 publicly-available case histories from 29 earthquakes. Those case histories are currently under review. Additional case histories are already in the database, but not submitted for review yet. Table 1 summarizes the current population status of the NGL database. The current moment magnitude range is **M** = 5.8–9.1, while the range of peak ground acceleration (PGA) is 0.13–1.2g. Such PGA values are either estimated using various interpolation methods or obtained from acceleration time series when co-located recording stations (RS) are available. A total of 143 borings (including SPT), 141 CPT soundings, and 45 shear wave velocity profiles (from invasive and non-invasive geophysical tests) are currently available.

We are currently populating the NGL database with 210 free-field and level ground legacy case histories for which SPT results are available (Cetin et al. 2018). Among them, 113 are case histories for which surface manifestation of liquefaction has been observed, 95 are case histories with no surface manifestation, and two are labelled as marginal (i.e., observations are uncertain and likely at the boundary between liquefaction and non-ground failure). We are also collecting 182 free-field and level ground case histories for which CPT results are available (Moss et al. 2006). Among them, 139 were classified as liquefaction sites, while 43 are non-ground failure sites. Additionally, ~60 legacy lateral spread case histories will be compiled from available data sets (i.e., Youd et al. 2002). We anticipate that additional legacy case histories will be collected from other case history databases (i.e., Boulanger and Idriss 2012 and 2016; Kayen et al. 2013).

In addition to collecting legacy case histories, an objective of the NGL project is to develop high-value case histories from recent earthquake events. In recent years, several earthquakes (e.g., Tohoku-Oki, 2011, Japan; El Mayor Cucapah, 2010, Mexico; Canterbury sequence,

Table 1. Summary of case histories currently available in the NGL database.

	Legacy				New			
	SPT	CPT	V_S	Co-located RS	SPT	CPT	V_S	Co-located RS
Reviewed	-	-	-	-	-	-	-	-
Submitted (not yet reviewed)	24	37	11	11	32	26	14	20
In preparation (not yet submitted)	3	6	-	-	3	141	-	1

2010-2011, New Zealand; Emilia, 2012, Italy) generated liquefaction manifestations (or lack of surface evidences in liquefaction-prone areas), producing a large number of potential case histories. We are collecting information for each earthquake event and we are in the phase of populating the database with high-quality data obtained following the above-mentioned events and additional recent earthquakes.

The NGL database currently contains a total of eight case histories generated by the 2011 **M**9.1 Tohoku-Oki earthquake, including the lateral spread case history at Urayasu City described above, four case histories with co-located recording stations from Greenfield (2017), and three unpublished case histories at river-protection levee sites instrumented with recording stations. We also developed one case history produced by the 2010 **M**7.2 El Mayor Cucapah earthquake at the San Felipito bridges location (GEER 2010 and Turner et al. 2016).

The 2010-2011 Canterbury earthquake sequence produced widespread liquefaction in the Christchurch area. For many sites, observations are available following multiple earthquakes. As a result, hundreds of potential case histories may be developed from this sequence. The NGL database currently hosts 50 case histories obtained from Green et al. (2014) (25 sites with post-earthquake observations following the 2010 **M**7.0 Darfield and 2011 **M**6.2 Christchurch events). Another 135 case histories (Tonkin and Taylor, 2013) from 37 sites (each site has up to 6 post-earthquake observations) are currently in preparation.

The **M**5.8 2012 Emilia (Italy) earthquake produced widespread liquefaction along the Reno River. We are currently distilling available data (e.g., Emergeo Working Group 2012) to produce NGL case histories. One case history is currently publicly available online (San Carlo, via Risorgimento). Along with the Emilia 2012 earthquake, additional case histories generated by the following relatively low-magnitude events are targeted to be included in the database: (1) 2016 **M**5.8 Pawnee, Oklahoma (Clayton et al. 2016), (2) **M**5.0 Au Sable Fork, New York (Gingery 2003), and (3) **M**5.2 2009 Olancha, California (Holzer et al. 2010). Such case histories will further expand the magnitude range of the database.

4 CONCLUSION

In this paper we describe the NGL database, its graphical interface (available at http://www.nextgenerationliquefaction.org, DOI: 10.21222/C2J040), and its status. The database contains publicly available case histories of liquefaction and non-ground failure case histories.

We present the case history review process, which is a vital element of the project to ensure data quality. We also provide information and statistics on the current population status. We believe that transparent, open source, community databases of this sort are important for advancing research in soil liquefaction and its effects.

ACKNOWLEDGEMENTS

Financial support for the NGL project is provided by California Department of Transportation (Caltrans) through the Pacific Earthquake Engineering Research Center (PEER), and by the U.S. Nuclear Regulatory Commission (NRC) through the Southwest Research Institute (SWRI). This paper is an independent product of the Center for Nuclear Waste Regulatory Analyses and does not necessarily reflect the view or regulatory position of the U.S. Nuclear Regulatory Commission (NRC). The NRC staff views expressed herein are preliminary and do not constitute a final judgment or determination of the matters addressed or of the acceptability of any licensing action that may be under consideration at NRC.

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