DRISI
CALTRANS DIVISION OF RESEARCH, INNOVATION AND SYSTEM INFORMATION
TRANSFORMING IDEAS INTO SOLUTIONS

Research Results

Liquefaction-Induced Ground Settlement Procedure

Bridge research to improve guidelines in the evaluation of post-earthquake liquefaction effects to bridge structures for an enhanced seismic performance transportation network

Geotechnical/ Structures

February 2023

Project Title:
Liquefaction-Induced Ground Settlement Procedure

Task Number: 3985

Start Date: October 1, 2021

Completion Date: September 30, 2022

Task Manager:
Sharon Yen
Senior Transportation Engineer
sharon.yen@dot.ca.gov

WHAT WAS THE NEED?

Practicing engineers require robust procedures to estimate post-liquefaction volumetric settlement, which is a key component of liquefaction effects on bridges, roads, and ports in the State of California. Research on the effects of the recent earthquakes on the ground in New Zealand provides a unique opportunity to obtain a comprehensive understanding of how sites with different subsurface conditions perform in major earthquakes with various levels of liquefaction. Rarely has the detailed information about ground performance been available to the degree that exists in Christchurch and Wellington, New Zealand. The study takes advantage of this opportunity to advance the understanding and practice in liquefaction engineering. To assess structure performance, a better procedure is needed to estimate liquefaction effects to bridge foundations.

WHAT WAS OUR GOAL?

The primary objective of the project was to develop a new probabilistic method for estimating post-liquefaction volumetric settlement capitalizing on recent data from New Zealand. The project incorporated liquefaction-induced settlement data from several earthquakes (e.g., 2013 & 2016 Wellington earthquakes and 2010-2011 Christchurch earthquakes) to broaden the existing database from older earthquakes (e.g., 1989 Loma Prieta earthquake) to make the new probabilistic method robust. Investigating liquefaction effects, such as ground settlement, to provide invaluable information that will serve as benchmarks to the California Department of Transportation (Caltrans) understanding of soil liquefaction characteristics. Insights from the study can improve current empirical liquefaction effects assessment procedures.

Caltrans

DRISI provides solutions and knowledge that improves California's transportation system

WHAT DID WE DO?

Under the project, various assessments have been done:

1. Examined well-documented case histories of ground performance for three soil conditions at the Port of Wellington: gravel fill, sand fill, and silty soil.
2. Characterized the ground conditions and liquefaction-induced volumetric settlement at 13 free-field sites at the port.
3. Combined the Wellington data with other case history data to develop a probabilistic method for estimating volumetric reconsolidation ground settlement, which assesses uncertainty.

The study identified the strengths and limitations of current procedures for evaluating liquefaction-induced volumetric reconsolidation ground settlement and employed the excellent case histories of ground performance at the port to discern the reasons for the different levels of observed ground settlement. The project has developed a new method for estimating 1D post-liquefaction settlement.

WHAT WAS THE OUTCOME?

Liquefaction-induced settlement on structures mechanisms is shear, volumetric, and ejecta. To better understand liquefaction-induced settlement, closer examination of soil response at the element level and soil deposit performance through system response is needed. Post-liquefaction volumetric strain models are developed to capture soil response. 205 field case histories (163 natural soil deposits and 42 hydraulic fills) of liquefaction-induced ground settlement have been studied. Cone Penetration Test (CPT)-based liquefaction ground settlement estimate has been developed. Consistent with studied case histories and laboratory database of post-liquefaction testing, probabilistic CPT-based models have been developed to estimate free-field liquefaction ground settlement. A calibration factor is derived to adjust the estimates of natural soil deposits. Soil behavior factor and magnitude factor have also been incorporated in the model.

WHAT IS THE BENEFIT?

Simplified liquefaction triggering procedures and post-liquefaction settlement procedures provide useful insights, but they cannot explain the different levels of ground and facilities damage during three major New Zealand earthquakes affecting the Port of Wellington (Mw6.5 2013 Cook Strait, Mw6.6 2013 Lake Grassmere, and Mw7.8 2016 Kaikoura events). This sequence of earthquakes, each event with its different effects on the major port facilities in Wellington, warrants further study. Performance-based earthquake engineering (PBEE) requires analytical tools that can discern varying levels of seismic performance. These well-recorded earthquakes, the comprehensive subsurface investigations already performed, and the well-documented performance of the ground at the port provide an exceptional opportunity to evaluate the capabilities of current procedures and to support development of an improved procedure for evaluating ground performance at sites involving liquefaction by combining the Wellington data with those from other important earthquakes, such as those in the 2010-2011 Canterbury earthquake sequence. The newly available case histories of ground performance, including those in Wellington and Christchurch, provide an unparalleled opportunity to develop robust probabilistic-based simplified procedures that can capture the different ground settlements measured at the port during these events.

Learning from observations after design level earthquakes is invaluable to advancing understanding in earthquake engineering. This project developed a new probabilistic 1D post-liquefaction volumetric settlement procedure for use by Caltrans engineers and consultants.

IMAGES

Figure 1: Examples of liquefaction effects.
(Courtesy of John Bray, UCB)

Figure 2: : Examples of liquefaction effects at Christchurch, NZ.
(Courtesy of John Bray, UCB)