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# Depositional environment effects on observed liquefaction performance in silt swamps during the Canterbury earthquake sequence

Christine Z. Beyzaei[a,*], Jonathan D. Bray[b], Sjoerd van Ballegooy[c], Misko Cubrinovski[d], Sarah Bastin[e]

[a] SAGE Engineers, 1 Kaiser Plaza, Suite 1125, Oakland, CA 94612, USA
[b] University of California, Berkeley, 453 Davis Hall, Berkeley, CA 94720, USA
[c] Tonkin + Taylor, Ltd., 105 Carlton Gore Rd, Newmarket, Auckland 1023, New Zealand
[d] University of Canterbury, Civil/Mechanical Building, Private Bag 4800, Christchurch, New Zealand
[e] QuakeCoRE - NZ Centre for Earthquake Resilience, University of Canterbury, Civil/Mechanical Building, Private Bag 4800, Christchurch, New Zealand

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ABSTRACT

Stratified silty soils deposited in back-swamp settings are shown through regional CPT-based analyses to have mitigating effects on the manifestation of liquefaction in Christchurch. Liquefaction triggering within these deposits is inadequately captured by simplified liquefaction assessment methodologies. Differing near-surface geology and depositional environments indicated in historical documents explain in part the limitations of current liquefaction evaluation procedures in southwest Christchurch. The historical swamp areas are shown through a regional CPT study to contain stratified silt/sand deposits or thick silt layers. Consideration of depositional environment distinguishes between liquefaction performances that are not able to be differentiated through the CPT-based liquefaction triggering assessment alone. CPT resolution is shown to be insufficient to capture the thin layering at these stratified sites, and the simplified liquefaction assessment methods do not take into account the effects of the stratification on pore water pressure movement within a soil profile. Instead, continuous sampling and careful logging of high-quality samples provide important insights on stratification at these silty soil swamp sites and in discerning differences in stratigraphy resulting from differences in depositional environment.

## 1. Introduction

Liquefaction from the 2010–2011 Canterbury earthquake sequence damaged much of the built environment in Christchurch, New Zealand. State-of-practice liquefaction triggering procedures have been shown to correlate closely with observed liquefaction manifestations across much of Christchurch [1]. However, important cases where liquefaction was predicted by the simplified analyses yet not observed during post-earthquake reconnaissance have been documented in the southwest part of the city (i.e., “false-positive” sites) [1–4]. The Liquefaction Severity Number (LSN) is shown to capture much of the observed liquefaction-induced ground failure across Christchurch; however, it overestimates the amount of liquefaction damage observed in the southwest part of the city (Fig. 1). Current liquefaction assessment procedures implicitly pair liquefaction triggering and observed manifestations, as the empirically-based procedures are developed from case histories with post-earthquake observations of surface manifestations of liquefaction. It is therefore possible that some soil layers at these false-positive sites did liquefy at depth, but did not result in surface manifestations. In the current framework of liquefaction assessment, these are still considered “no-liquefaction” case histories.

The southwest part of Christchurch is known among local engineers for its silty soil conditions in which thinly inter-layered fine sands and silts are present. The over-estimation of the occurrence of liquefaction by state-of-practice liquefaction assessment procedures in southwestern Christchurch is the subject of a comprehensive study called the “silty soils project” undertaken by researchers at the Univ. of Canterbury, Univ. of California, Berkeley, the Univ. of Texas at Austin, and Tonkin + Taylor, Ltd. The liquefaction resistance of these silty soils is examined through field investigations, laboratory testing, and numerical analyses. Preliminary results are summarized in Beyzaei et al., 2015 [5], Stringer et al., 2015 [6], and a series of associated geotechnical reports [7]. These studies and publications focused on the site-specific geotechnical aspects of the observed over-estimation. The overall

* Corresponding author.
*E-mail addresses:* zbeyzaei@berkeley.edu (C.Z. Beyzaei), jonbray@berkeley.edu (J.D. Bray), SVanBallegooy@tonkintaylor.co.nz (S. van Ballegooy), misko.cubrinovski@canterbury.ac.nz (M. Cubrinovski), sarah.bastin@canterbury.ac.nz (S. Bastin).

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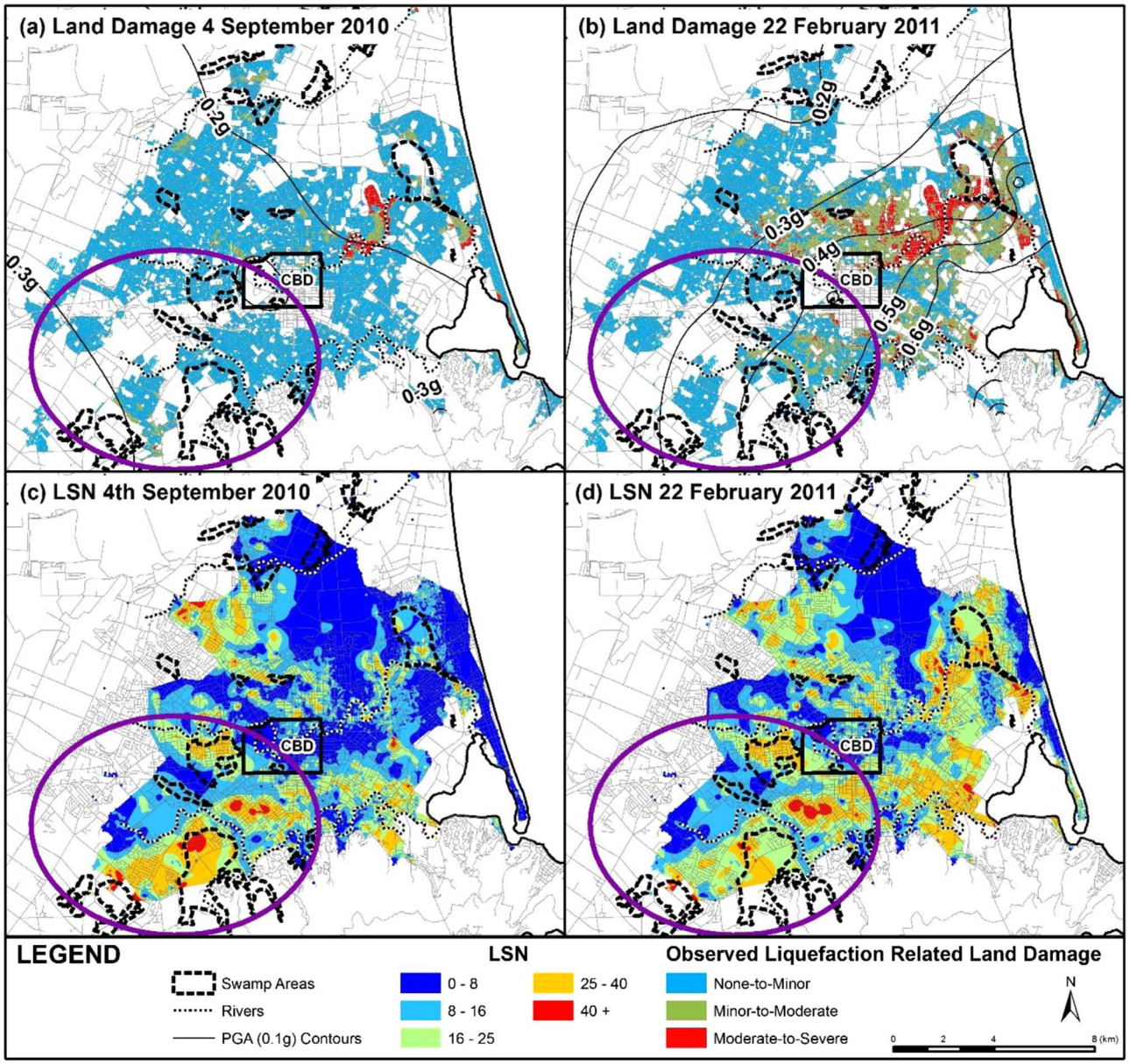


**Fig. 1.** (a, b) Liquefaction-related land damage observations, and (c, d) distribution of Liquefaction Severity Number (LSN) in Christchurch for the 4 SEP 2010 Darfield and 22 FEB 2011 Christchurch earthquakes, respectively. The Central Business District (CBD) is outlined, and the circled area indicates the study region of SW Christchurch. Note the over-estimation of LSN in the circled areas of (c, d) compared to observations in (a, b). Swamp zone outlines from [20]; median PGA contours from [31].

regional characteristics and depositional settings in which these false-positive sites occur have not been examined previously in detail. This is the aim of this paper.

This paper investigates the role of shallow surficial geology and the differing depositional environments in Christchurch on the applicability and effectiveness of current state-of-practice liquefaction assessment methods. Youd & Perkins (1978) [8], among others, identified the critical role of surficial geology on liquefaction susceptibility, and their work serves as the basis for many regional liquefaction susceptibility maps. However, the incorporation of surficial geology and depositional environment effects on liquefaction assessments are not often considered quantitatively on a project-specific basis in engineering practice, especially when there is an abundance of geotechnical investigation data available. The goal of this study is to provide regional and site-specific case history data that supports explicit consideration of depositional environment in a liquefaction assessment. In this paper, case histories that illustrate the subsurface conditions where liquefaction manifestations were over-estimated in the southwestern part of Christchurch are discussed with a focus on depositional environment and its role in liquefaction. Differing depositional environments throughout southwest Christchurch are investigated and compared with greater Christchurch through a regional assessment. Key factors are evaluated in the context of depositional environment, moving from more qualitative to quantitative observations. Implications for practice are also presented.

## 2. Depositional environment and shallow subsurface conditions

### 2.1. Importance of depositional environment in liquefaction assessments

Sedimentation process, age of deposition, and geologic history are outlined by Youd & Perkins [8] as key factors affecting liquefaction-induced ground failure susceptibility. Liquefaction assessments commonly qualitatively characterize sedimentary deposits by their general distribution of cohesionless sediments, and assign likelihoods of liquefaction susceptibility based on empirical observations. Seed [9] cites