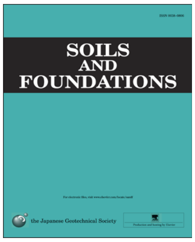
Soils and Foundations 2015;55(4):778–787

HOSTED BY

The Japanese Geotechnical Society

Soils and Foundations

www.sciencedirect.com
journal homepage: www.elsevier.com/locate/sandf



Moving towards an improved index for assessing liquefaction hazard: Lessons from historical data

Brett W. Maurer[a], Russell A. Green[a,*], Oliver-Denzil S. Taylor[b]

[a]Department of Civil & Environmental Engineering, Virginia Tech, Blacksburg, VA 24060, USA
[b]US Army Corps of Engineers, Engineering Research & Development Center, Vicksburg, MS 39180 USA

Received 10 July 2014; received in revised form 11 February 2015; accepted 15 March 2015
Available online 27 July 2015

Abstract

While Liquefaction Potential Index (LPI) has been used to assess liquefaction hazards worldwide, evaluations of LPI during recent earthquakes have found its performance to be inconsistent. In 1985, Ishihara considered the influence of the non-liquefied surface layer on the manifestation of liquefaction, and proposed an empirical approach to predict liquefaction surface effects. The study presented herein investigates the insights the boundary curves proposed by Ishihara may provide for improving the existing LPI framework. The result of the investigation is a novel Ishihara-inspired index, LPI_{ISH}. Its performance is evaluated using select liquefaction case histories and is compared to that of the existing LPI framework. For the selected case studies, LPI_{ISH} was found to be consonant with observed surface effects and showed improvement over LPI in mitigating false-positive predictions. Ultimately, the influence of non-liquefiable layers on surficial manifestation is complex, and further research is needed to fully elucidate and quantify these effects.

Keywords: Liquefaction; Liquefaction Potential Index; Earthquakes; Ishihara Boundary Curves; Ishihara-Inspired Index

1. Introduction

The objectives of this study are (1) to derive a novel liquefaction potential index (LPI) for assessing liquefaction hazard utilizing the Ishihara (1985) boundary curves for liquefaction surface effects; and (2) to evaluate the Ishihara-inspired index, LPI_{ISH}, using select liquefaction case histories, and compare its performance with that of the commonly-used Iwasaki et al. (1978) LPI procedure. While "simplified" liquefaction evaluation procedures (e.g., Robertson and Wride, 1998; Moss et al., 2006; Idriss and Boulanger, 2008) predict liquefaction triggering in particular strata, they do not predict the severity of liquefaction manifestation at the ground surface, which more directly correlates to damage potential and represents the cumulative response of a soil deposit. To serve this need, Iwasaki et al. (1978) proposed LPI, computed as

$$\text{LPI} = \int_{0}^{20\,m} F \cdot w(z)\, dz \tag{1}$$

In Eq. (1), $F = 1 - \text{FS}$ for $\text{FS} \leq 1$ and $F = 0$ for $\text{FS} > 1$, where FS is the factor of safety against liquefaction computed by a liquefaction evaluation procedure, and $w(z)$ is a depth weighting function given by $w(z) = 10 - 0.5z$, where $z =$ depth in meters. The severity of liquefaction manifestation is thus assumed to be proportional to the thickness of a liquefied layer, the proximity of the layer to the ground surface, and the amount by which FS is less than 1.0. Given this definition, LPI can range from 0 to 100. Based on Standard Penetration Test

---

*Corresponding author. Tel.: +1 540 231 9826; fax: 1 540 231 7532.
E-mail address: rugreen@vt.edu (R.A. Green).
Peer review under responsibility of The Japanese Geotechnical Society.

http://dx.doi.org/10.1016/j.sandf.2015.06.010
0038-0806/

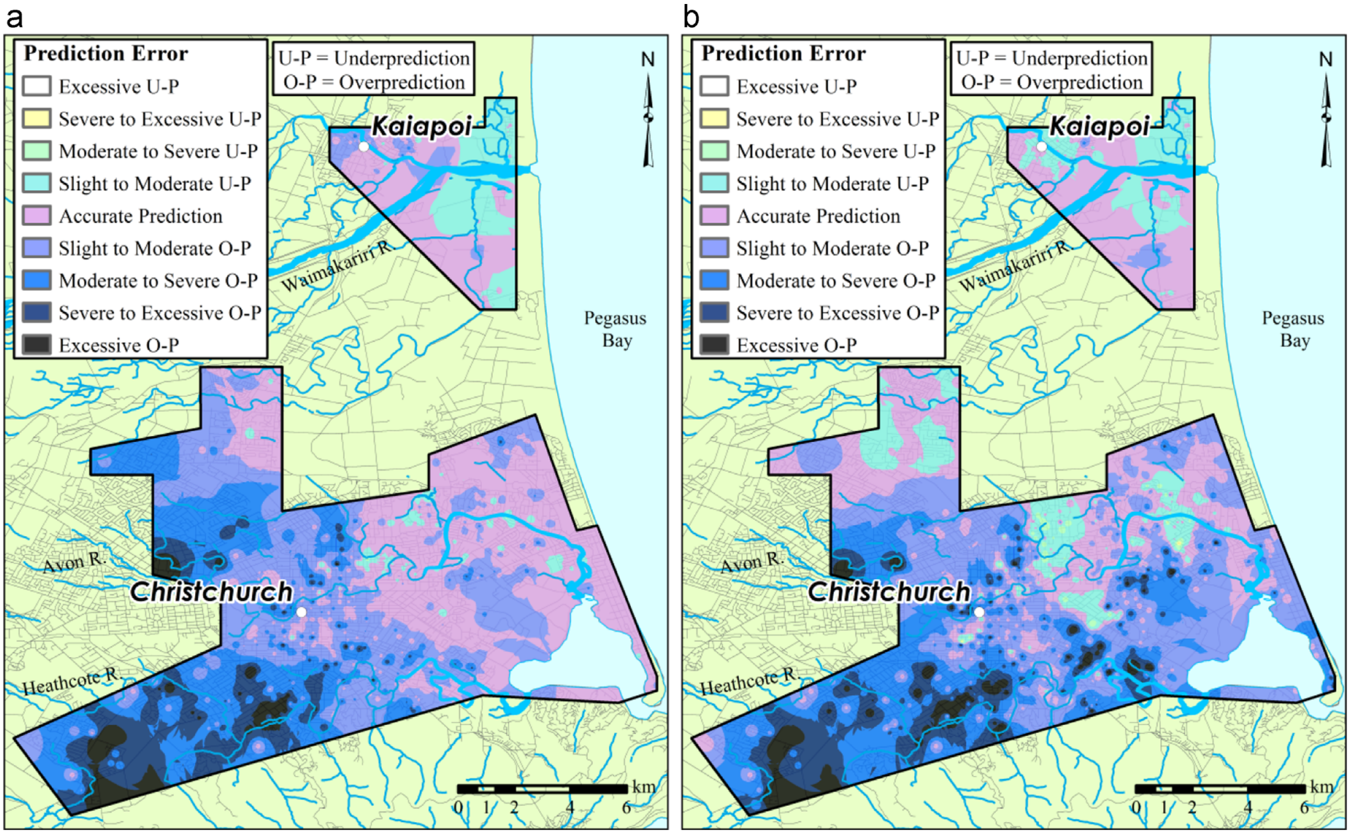


Fig. 1. Liquefaction severity prediction errors for the (a) M_w7.1 Darfield and (b) M_w6.2 Christchurch New Zealand earthquakes. After Maurer et al. (2014).

(SPT) data from 55 sites in Japan, Iwasaki et al. (1978) proposed that severe liquefaction should be expected at sites where LPI > 15 but not where LPI < 5. Using this criterion, LPI has been used to assess liquefaction hazards worldwide. However, researchers evaluating LPI during recent earthquakes have found its performance to be inconsistent, ranging from largely erroneous (Lee et al., 2003) to generally consonant but inaccurate for a non-trivial percent of sites (Toprak and Holzer, 2003). For example, Maurer et al. (2014) assessed the performance of LPI during the 2010–2011 Canterbury (NZ) earthquake sequence; prediction-errors from the M_w7.1 Darfield and M_w6.2 Christchurch earthquake are shown in Fig. 1, where over-predictions indicate the observed severity of liquefaction manifestation was less than predicted. It can be seen in Fig. 1 that while LPI performance was generally good, liquefaction severity was significantly over-predicted for a portion of the study-area. Given the inconsistent efficacy of the existing LPI framework and criterion for assessing risk due to liquefaction, further research is warranted.

In evaluating the performance of LPI during the Canterbury earthquakes, Maurer et al. (2014) found that predictions might be improved if LPI accounted for the characteristics of the non-liquefied strata, in addition to those of the liquefied strata. As seen in Eq. (1), the existing LPI framework assumes a simple form and does not account for the characteristics of non-liquefied soils, other than soils having an FS ≥ 1 not contributing to the computed LPI value. Since LPI asserts only that the severity of manifestation is linearly related to the FS and depth of liquefied strata, LPI predictions may be inherently poor for some soil profiles and/or loading scenarios. While the findings of Maurer et al. (2014) are significant, they are not altogether novel. In 1985, Ishihara recognized the influence of the non-liquefied capping layer on mitigating the surficial manifestation of liquefaction. He plotted observations of liquefaction surface effects using the thicknesses of the non-liquefied capping layer, H_1, and the liquefied strata, H_2, and proposed boundary curves for predicting liquefaction manifestation as a function of H_1, H_2, and peak ground acceleration (PGA). Ishihara (1985) initially proposed a single boundary curve, shown in Fig. 2a, using data from sites subjected to a PGA of 200 gal ($\sim 0.2g$); incorporating the work of others, a series of curves was then proposed corresponding to different PGAs, as shown in Fig. 2b. The proposed boundary curves indicate that for a given PGA, there is a limiting H_1 beyond which surface manifestations do not form regardless of H_2.

The boundary curves proposed by Ishihara (1985) for liquefaction surface effects may provide insight into how the existing LPI framework can be improved. Given the inconsistent performance of LPI for assessing liquefaction hazard, and considering its preeminent role in engineering practice, efforts to improve its efficacy are warranted. Accordingly, first a new index for assessing liquefaction hazard utilizing the Ishihara (1985) boundary curves for surficial manifestation of liquefaction is derived; and second the Ishihara-inspired index, LPI_{ISH}, is evaluated using select liquefaction case histories, and its performance is compared to that of the commonly-used