Soil Dynamics and Earthquake Engineering 90 (2016) 240–249

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

Clarifying the differences between traditional liquefaction hazard maps and probabilistic liquefaction reference parameter maps

Kevin W. Franke [a,*], Kristin J. Ulmer [a], Levi T. Ekstrom [a], Jorge F. Meneses [b]

[a] Brigham Young University, 368 Clyde Building, Provo, UT 84602, United States
[b] Group Delta Consultants, Inc., 9245 Activity Road, Suite 103, San Diego, CA 92126, United States

ARTICLE INFO

Article history:
Received 8 January 2016
Received in revised form
7 August 2016
Accepted 12 August 2016

Keywords:
Liquefaction Hazard Maps
Probabilistic Liquefaction Hazard Analysis
Performance-based earthquake engineering
Performance-based reference parameter maps

ABSTRACT

Traditional liquefaction hazard maps are useful tools for preliminary engineering site assessment and policy development. However, these maps should not be used for site-specific liquefaction hazard assessment. Simplified probabilistic liquefaction analysis procedures can be used instead to perform site-specific liquefaction hazard assessment, but these procedures rely on probabilistic reference parameter maps that are not yet familiar to most engineering and geological practitioners. As a result, some professionals are questioning the differences between traditional liquefaction hazard maps and the new probabilistic reference parameter maps. This paper clarifies the differences between these two types of maps, and shows how each of these maps complements the other. New probabilistic reference parameter maps for liquefaction triggering and lateral spread displacement are developed and presented for San Diego, California, and simplified probabilistic equations necessary to use the reference parameter maps are summarized. An example map-based liquefaction triggering and lateral spread displacement analysis is performed for a representative site near San Diego Bay. Results of the analysis demonstrate that the probabilistic assessment confirms and augments the information conveyed by the traditional liquefaction hazard map.

1. Introduction

Regional mapping of liquefaction hazard (e.g., liquefaction triggering, liquefaction potential index, lateral spread displacement, free-field post-liquefaction settlement) and/or susceptibility has been performed by many researchers during the past 40 years. Beginning with the work of Youd and Hoose [1] and Youd and Perkins [2], most of these researchers began incorporating a geological approach in mapping liquefaction hazard because certain types of surficial geology and their age have been observed to correlate well to observed liquefaction susceptibility, and surficial geologic maps are typically available for most locations in the United States, as well as many locations throughout the world. As a result of these efforts, liquefaction susceptibility, triggering, and lateral spread displacement maps have become a useful preliminary assessment tool to assist owners, engineers, planners, policy-makers, and risk analysts in making informed decisions regarding their sites, and are now often used as a regulatory resource [3].

Despite the usefulness of regional liquefaction hazard maps for preliminary assessment of liquefaction hazards, these maps are not intended to be used for site-specific liquefaction hazard assessment for engineering design. Site-specific assessment of such hazards, including liquefaction triggering and lateral spread displacement, requires subsurface, site geometry, and seismic loading information pertaining to the site of interest. Recent research has suggested that a probabilistic approach to site-specific liquefaction hazard assessment (termed “probabilistic liquefaction hazard analysis” by Holzer [4]) produces more consistent estimates of liquefaction hazards across different seismic environments than conventional approaches [5–7]. To make the probabilistic approach available to a larger number of engineering practitioners, researchers have developed simplified probabilistic liquefaction triggering and lateral spread displacement analysis procedures [8–11]. These simplified probabilistic procedures require the development and use of hazard-targeted reference parameter maps for liquefaction triggering and lateral spread displacement. The values obtained from these reference parameter maps are subsequently corrected for site-specific geotechnical and topographical data to closely approximate the results that would be computed with a full probabilistic procedure at the return period(s) of interest.

With the introduction of simplified probabilistic liquefaction analysis procedures and corresponding reference parameter maps, some practitioners are beginning to question the differences

* Corresponding author.
E-mail address: kevin_franke@byu.edu (K.W. Franke).

http://dx.doi.org/10.1016/j.soildyn.2016.08.019
0267-7261/

between these reference parameter maps and traditional liquefaction hazard maps, particularly those who are not yet familiar or comfortable with the simplified probabilistic approach. For example, a common question that is asked of the authors by engineering and geology practitioners is whether the new reference parameter maps are intended to supersede or replace existing liquefaction hazard maps. This question demonstrates a fundamental misunderstanding of what the probabilistic reference parameter maps represent and how they are different from traditional liquefaction hazard maps.

This paper explores the differences between traditional liquefaction hazard maps and probabilistic reference parameter maps, and demonstrates how they are not intended to compete with one another, but rather *complement* and *complete* one another. For this demonstration, existing liquefaction hazard maps and new probabilistic reference parameter maps (at return periods of 475 and 2475 years) for a seismically active region (San Diego, California) are presented and compared. Simplified probabilistic procedures necessary for using the new reference parameter maps are presented. A demonstrative liquefaction triggering and lateral spread displacement assessment is performed for a representative site near San Diego Bay. Through this assessment, engineers will observe how traditional liquefaction hazard maps and probabilistic reference parameter maps can be used together to provide improved understanding of the liquefaction hazards at a given site, which will aid owners, designers, planners, and stake-holders in making informed and objective design decisions. While the probabilistic reference parameter maps presented in this paper are applicable specifically to the City of San Diego, the approach presented by the paper is applicable to any location for which both traditional liquefaction hazard/susceptibility maps and probabilistic reference parameter maps are available to engineers.

While this paper specifically focuses on the liquefaction hazards of triggering and lateral spreading, other hazards including post-liquefaction settlement, loss of shear strength, and increased lateral earth pressures are also important considerations that must be taken into account by engineers. As advances in dynamic soil mechanics and probabilistic earthquake engineering lead to greater understanding and improved predictive capabilities of these phenomena, simplified assessment methods and probabilistic reference parameter maps will eventually be developed for these additional hazards through future research.

2. Liquefaction hazard mapping

Current methods for mapping liquefaction hazards generally rely heavily upon correlations with mapped surficial geologic units [1,2]. This type of mapping uses criteria that relate surface geology and depositional age to liquefaction susceptibility (i.e., the "geological approach" [4]). If a particular liquefaction map considers seismic loading in addition to geologic susceptibility correlations, then the map likely estimates liquefaction triggering hazard [12].

To quantify and map the regional potential for triggering and subsequent effects, researchers have also considered available subsurface geotechnical information as well as estimates of regional ground motions (i.e., the "geotechnical approach;" Holzer 2008). Some researchers [13–16] have incorporated available geotechnical data directly with a simplified liquefaction triggering model [17–21], but the variability of triggering potential with depth requires simplifying assumptions to quantify and represent the three-dimensional phenomenon on a two-dimensional map. The most common assumption that is applied is to map only the results from the "critical layer," or the soil layer with the lowest computed factor of safety against liquefaction. Other researchers have avoided this problem by quantifying liquefaction triggering hazard with a different metric such as the liquefaction potential index (LPI) [22–25] or the liquefaction risk index (LRI) [26,27], both of which integrate the liquefaction triggering potential over depth to generate a single liquefaction hazard value that is easier to map, but more challenging for some engineers to interpret. Regardless of the metric used to quantify liquefaction triggering hazard, geostatistics such as kriging are required with the geotechnical approach to estimate geotechnical properties and corresponding liquefaction hazards at locations where no data are available [14,16,28].

In addition to liquefaction triggering potential, other researchers [2,16,28–31] have considered lateral spread potential to develop regional liquefaction ground deformation maps. These maps typically require the additional consideration of regional topography to estimate regional horizontal ground displacements.

Liquefaction triggering and deformation hazard maps are typically developed using a single ground motion scenario. This scenario may be defined in terms of a single seismic source, with a constant magnitude and variable source-to-site distance [28] or in terms of probabilistic ground motions corresponding to some single hazard level or return period [14]. For the latter case, in which probabilistic ground motions are used, it is important to clarify that the stated hazard level or return period associated with most liquefaction hazard maps corresponds to the ground motions used to develop the map, but not necessarily to the mapped liquefaction hazard itself. Additionally, some studies [e.g., 14, 25] have considered more than one probabilistic ground motion in the development of liquefaction hazard maps. These types of maps will be addressed in Section 3 below.

Because liquefaction hazard maps are usually developed by the regional characterization of geologically mapped units based on coarsely spaced field data, they should not be used for site-specific liquefaction hazard evaluation and engineering design [32]. To clarify this point, most liquefaction hazard maps explicitly state their appropriate use and limitations. For example, the geologic hazard and faults maps provided by the City of San Diego [33] explicitly state that "[the] maps do not furnish site specific information and should be used only as a guide when evaluating risk. [The maps] are intended to be an indicator of what to expect at your site and provide general geologic hazard information." Regardless, information provided by liquefaction hazard maps can still be quite valuable to an engineer performing a site-specific liquefaction hazard evaluation. Because liquefaction hazard maps are typically developed from correlations with surficial geologic units, they can help the engineer to see "the bigger picture" as it relates to the geologic depositional environment of the site, and to understand *why* liquefaction hazard possibly exists. Combining this geologic perspective with site-specific geotechnical data increases the engineer's overall knowledge and understanding of the site, and can help facilitate risk communication to owners, planners, policy-makers, and citizens.

3. Probabilistic analysis methods and reference parameter maps

Site-specific liquefaction triggering and lateral spread hazard assessment using empirical prediction models requires the characterization of seismic loading through the use of the peak ground surface acceleration, a_{max}, earthquake moment magnitude, M, and source-to-site distance, R to represent the design earthquake. The process of selecting these values is relatively straight-forward when analyzing the liquefaction hazard from a single seismic source. However, when analyzing liquefaction hazard from multiple possible seismic sources, the selection of these values becomes more complicated. Seismic hazard in such environments is