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Evaluation of Liquefaction Potential of Diyala Soil Under Seismic Load Using SPT Data

A Thesis Submitted to the Council of the College of Engineering / University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

BY

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صدق

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To.........

The late my dear father (may Allah have mercy on him), who supported me morally

My dear mother, the light of my eyes

My brother and sisters who spared no effort in supporting me

My wife who stood by me through thick and thin

My children, to the souls of my liver

Our honorable teachers who taught and rewarded us their knowledge. Every-one, who wishes me success in my life,

I dedicate this humble work.

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ABSTRACT

In general soil liquefaction is the transition of soil from a solid state to a fluid state as a result of increasing the pore water pressure and reducing the effective stress when the soil is subjected to periodic loads. Standard penetration testing is one of the on-site methods used to find the geotechnical engineering properties of the soil and used for determining factor of safety and liquefaction potential index. The soil liquefaction is one of the main causes of loss of life and major damage to residential structures and water line systems. The purpose of this study is to determine the probability of liquefaction resulting from earthquakes in the soil of Diyala Governorate based on the Standard Penetration Test (SPT). The case study selected is Diyala Governorate, which is one of the governorates of Iraq and is located in the eastern part of it and near the confluence of the Arabian and Iranian plates. The factor of safety of Diyala Governorate soil was determined using four world-famous methods which are (Japanese, Workshop NCEER 1997, Vancouver 2007, Boulanger and Idriss 2014) and then compared. The method of

Boulanger and Idriss 2014 was chosen as the most appropriate method for determining the liquefaction of Diyala soil.

The second part of this study is investigating the soil properties of 265 boreholes over most of the study area. Liquefaction potential index is determined for these boreholes and using the map program (ArcMap(GIS) 10.3) to draw eight maps for eight different seismic values (4 , 4.5 , 5 , 5.5 , 6 , 6.5 , 7 , 7.5). These maps show that the places in which liquefaction is likely to occur or not. It was found from the collected data that most of Diyala soil is clay, meaning that liquefaction does not occur, but some areas in which sandy soil exists with different proportions in upper layer have ability to liquefaction, such as some region in Mandali city.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

SYMBOLS	Term
C_B	Correction factor of nonstandard borehole diameters
C_E	Correction factor of hammer energy
C_N	Correction factor of overburden pressure
C_R	Correction factor of rod length
C_S	Correction factor of split spoons
D_{50}	Mean grain size
D_r	Relative density
G_s	Specific gravity
H_i	Thickness of layers
K_α	Correction factor for ground slope
K_σ	Correction factor for effective overburden stress
P_a	Atmospheric pressure
W_i	Weighting factor
a_{max}	Peak surface acceleration
r_d	Stiffness reduction coefficient factor
σ'_v	Effective overburden pressure
σ_v	Total overburden pressure
CRR	Cyclic Resistance Ratio
CSR	Cyclic Stress Ratio
Cu	Uniformity coefficient
d	Diameter
e	Void ratio
FC	Fine content

FS	Factor of Safety
g	Acceleration of gravity
Ɣdry	Dry unit weight
Ɣsat	Saturated unit weight
Ip	Plasticity index
LL	Liquid Limit
LPI	Liquefaction Potential Index
M	Earthquake Magnitude
MSF	Magnitude Scaling Factor
N	SPT blow Count
Nb	BPT N
Ns	SPT N
Vs	Shear Wave Velocity
W.T	Ground Water Table
Z	Depth
ω	Moisture content

LIST OF ABBREVIATIONS

Abbreviation	Term
ASTMD	American Society for Testing and Materials for laboratory Tests
BPT	Baker Penetration Test
CPT	Cone Penetration Test
CVR	Critical Void Ratio
EMSC	(European Mediterranean Seismological Centre)
IDW	Inverse Distance Weighting
IRIS	(Incorporated Research Institutions for Seismology)
IRSC	(Iranian Seismological Center)
NCEER	National Center for Earthquake Engineering Research
NPR	Nationale Praktijk Richtlijn
SPT	Standard Penetration Test
USCS	(Unified Soil Classification System)

CHAPTER ONE

INTRODUCTION

1.1 General

Liquefaction is the loss of strength and stiffness of a saturated soil as a result of seismic shaking or quick loading. Other factors, such as static loading, blasting, pile driving, tide fluctuations, and vibration of the machine can trigger soil liquefaction in addition to earthquakes. During the past earthquakes around the world, liquefaction and related phenomena caused massive damage to infrastructure. During an earthquake, cyclic shear strain in a deposits of saturated bulk sand causes pore-water pressure to gradually build up. Liquefaction is expected to occur when the pore-water pressure reaches the initial confining pressure or a five percent double amplitude strain is achieved (Ishihara, 1993).

Liquefaction became a major issue when began to disrupt human and social activities by interfering with the operation of infrastructure as illustrated in Figure (1.1), as well as following fast urbanization caused by the expansion of cities on reclaimed lands. Liquefaction induced ground failures have been a major source of damage in previous earthquakes. Bridges, buildings, subterranean pipes, and lifeline utilities, among other things, are all affected by liquefaction in various ways. The term has been mentioned "spontaneous liquefaction" by (Terzaghi & Peck, 1948) to explain how land-slides were triggered by the abrupt loss to the strength in loose and saturated sand. Later, during the Niigata (1964), Alaska (1964), Loma Prieta (1989), Kobe (1995), and Chi-Chi (1999) earthquakes, it was thought to be the main source of severe damage as well as the failure of the San Fernando Dam (1971). It's crucial to remember that liquefaction isn't always caused by earthquakes. During the recent decade, liquefaction incidents in loosely sand in old open pit mines have grown in Germany. Because of the catastrophic liquefaction potential and its associated phenomena, to understand the behavior of undrained for soils under cyclic and static loads, a lot of research has been done, as well as to develop design and prediction methodologies. Significant studies have been done to identify soils that are prone to liquefaction using correlations obtained from field testing like CPT or SPT tests (Robertson et al., 1994; Youd & Idriss, 2001; Robertson, 2015).

Figure 1-1 Liquefaction of flat areas. Condominium Brisas del Sol and railway near Concepción (Verdugo, 2011)

1.2 **Soil Liquefaction**

Soil liquefaction caused by earthquakes is a one of the source of death and damage to infrastructure and lifeline systems, among other things. Numerous field and laboratory investigations have revealed that soil liquefaction is a catastrophic failure phenomenon in which saturated soil loses its strength and failed soils acquire sufficient mobility to allow movement from meters to kilometers. Soil liquefaction can result in sand boils, substantial landslides, surface settlement, lateral spreading, lateral displacement of bridge supports, building settling and tilting, and failure of waterfront structures, among other things (Das & Muduli, 2011).

Flow liquefaction and cyclic liquefaction are two different types of soil liquefaction. When the shear stress necessary for the static equilibrium of the soil is greater than the shear strength of the soil in its liquid form, flow liquefaction can occur. Even if the static shear force is smaller than the liquefied soil's shear strength, cyclic liquefaction occurs. Both static and cyclic shear stress induce the deformations in this case. During earthquake shaking, deformations usually happen in stages. During an earthquake, it can cause a significant permanent deformity. In comparison to flow liquefaction, cyclic liquefaction occurs under a significantly broader range of soil and site conditions. However, its impact can range from negligible to disastrous. The boundary curve produces liquefaction resistance of a soil for a particular soil resistance index, such as the corrected SPT blow count, which is commonly expressed as the cycle resistance ratio (CRR). The liquefaction potential of a soil is evaluated in terms of a factor of safety (FS), which is defined as the ratio of cyclic resistance ratio (CRR) to cyclic stress ratio (CSR), under a particular seismic loading, which is commonly stated as the cyclic stress ratio (CSR). The way of expressing the liquefaction potential of soil in terms of (FS) is known as a deterministic method, and it is widely used by geotechnical specialists due to its ease of application (Muduli, 2013).

1.3 **Objectives of the Study**

Soil liquefaction behaviors depend on several factors, and intended assessment methods based on case history and laboratory experiences for any given area may not be satisfied with other parts of the world. The objective of the present research is to evaluate the liquefaction potential of soil using Boulanger and Idriss 2014 method based on SPT test data.

The objectives of this study are.

1. Evaluation in the risk for soil liquefaction in Diyala Province.
2. Creating tables showing the risks of the liquefaction.
3. To assess the risk of liquefaction and create liquefaction hazard maps.
4. Comparison between several methods and choosing the appropriate method to calculate the liquefaction potential of soil in Diyala Province.
5. Reducing cost in the liquefaction accounts for future projects by referring to the tables and maps that were found, and knowing whether the soil of the site to be built on is liquefiable or not.

1.4 **Thesis Layout**

This thesis consists of five chapters and the chapters have been organized in following order:

Chapter 1 presents a brief introduction, the soil liquefaction, the objectives of the research, and thesis layout which sets the for the entire thesis.

In Chapter 2, a comprehensive overview of the literature on liquefaction susceptibility analysis is offered. This chapter discusses the different approaches to liquefaction effects analysis, in-situ test based methodologies to assess liquefaction susceptibility, analysis methods, and analysis tools. Liquefaction related damages and the methods for determining the liquefaction potential were also discussed.

The third chapter discusses the geological characteristics of Diyala Province.

Chapter four explains the calculations and the results obtained, which is choosing the appropriate method for determining the liquefaction, finding the safety factor with depth, finding the LPI, and finding maps of Diyala Province that show where the liquefaction occurs or not, and discussing the results.

In the chapter five finding points that clarify the accounts and points that are recommendations for future studies.