Faculty of Engineering

Performance Testing for Slope Instability due to Suffusion via Site-Specific Response Analysis with Incorporation of Electrical Resistivity Tomography

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Performance Testing for Slope Instability due to Suffusion via Site-Specific Response Analysis with Incorporation of Electrical Resistivity Tomography

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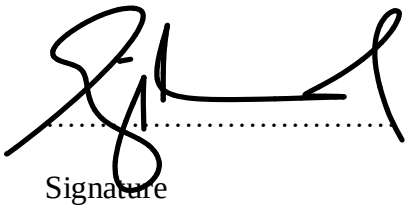
DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



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ABSTRACT

Soil instability had caused concerned in geotechnical engineering due to its consequences of failure and its effects to the structures above or surrounding it. The instability of soil is caused by either water, critical stress condition, or perilous void within the soil properties. The lack of proper consideration of critical void in soil or suffusion phenomenon causes soil defects and failures in cut-slopes that subsequently damaging to the economy and ecology. Many researches correlated internal soil instability with water or hydraulic conductivity. This research aims to investigate on internal soil instability caused by void limit state and migration of fines characterized by vibration specifically seismic soil amplification that resemble failure criterion caused by hydraulic load. Soil amplification obtained from sensible conversion of apparent resistivity (ohm.m) to shear wave velocity (m/s) captured by electrical resistivity tomography (ERT) experimental result at specific sites with cut slopes at Pan Borneo Highway, Sarawak, has been studied. Archie's law which determines porosity is used in this study, where correlation with experimental results have shown its reliability, proving that volume of void over total volume of soil (V_V/V_T) from soil phase diagram is attainable with ERT and it is equivalent to liquid limit of soil. Energy based analysis is used to actuate synthetic earthquake from underneath and simulates soil amplification, whether it exceeds design response spectra or within limit. Simplified amplitude limit of failure has been developed to alternate Fourier amplitude to propose ERT data collection and new approach to develop serviceability limit state (SLS) or design response limit. Data acquisition via ERT that sensibly converted to shear wave velocity and soil shear strength has been verified its compliance with the existing guideline for slope design from the public works department of Malaysia. Output of this research improved the reliability of design safety factor for any constructions by integrating advanced technology application. As a

result, ERT raw soil properties data that correlated well with soil liquid limit where volume of void over total void (V_V/V_T) is in equivalent and soil conductivity (σ) over soil resistivity (Ω) is consistent with liquidity index. This research also discovered that electrical conductivity against electrical resistivity, 1/Sigma (Σ^{-1}) ÷ Ohm (Ω) = 1 and is a threshold index of soil instability. It is also discovered that when the soil instability index higher than 1 the site-specific soil is unstable. Further research on the instability index is potential and beneficial to the geotechnical engineering industry for geo-hazard identification. In conclusion, this research is focused to give clear interpretation to ERT result and proved that it is useful for future diagnostic of soil stability and its optimum treatment required for future land use.

Keywords: Peak ground acceleration, soil amplification factor, soil instability, suffusion, design response spectra

Ujian Prestasi untuk Ketidakstabilan Cerun Akibat Suffusion melalui Analisis Tindak Balas Khusus Tapak dengan Penggabungan Tomografi Kerintangan Elektrik

ABSTRAK

Ketidakstabilan tanah telah menyebabkan kebimbangan dalam Kejuruteraan Geoteknik kerana akibat kegagalan dan kesannya kepada struktur di atas atau di sekelilingnya. Ketidakstabilan tanah disebabkan oleh sama ada air, keadaan tegasan kritikal, atau lompang berbahaya dalam sifat tanah. Kekurangan pertimbangan yang sewajarnya terhadap kekosongan kritikal dalam tanah atau fenomena suffusion menyebabkan kecacatan dan kegagalan tanah pada cerun-cerun yang kemudiannya merosakkan ekonomi dan ekologi. Banyak penyelidikan mengaitkan ketidakstabilan tanah dalaman dengan air atau kekonduksian hidraulik. Penyelidikan ini bertujuan untuk mengkaji ketidakstabilan dalaman tanah yang disebabkan oleh keadaan had lompang dan penghijrahan denda yang dicirikan oleh getaran khususnya penguatan tanah seismik yang menyerupai kriteria kegagalan yang disebabkan oleh beban hidraulik. Penguatan tanah yang diperolehi daripada penukaran sensitif kerintangan ketara (ohm.m) kepada halaju gelombang ricih (m/s) yang ditangkap melalui keputusan eksperimen tomograf kerintangan elektrik (ERT) di tapak tertentu dengan cerun potong di Lebuhraya Pan Borneo, Sarawak, akan dikaji. Hukum Archie yang menentukan keliangan dalam batuan digunakan dalam kajian ini, di mana korelasi dengan keputusan eksperimen akan menunjukkan kebolehpercayaannya, membuktikan bahawa isipadu lompang atas jumlah isipadu tanah (VV/VT) daripada rajah fasa tanah boleh dicapai dengan ERT dan ia adalah setara. kepada had cecair tanah. Analisis berasaskan tenaga digunakan untuk menggerakkan gempa bumi sintetik dari bawah dan mensimulasikan penguatan tanah, sama ada ia melebihi spektrum tindak balas reka bentuk atau dalam had. Had amplitud mudah kegagalan hendaklah dibangunkan untuk

menggantikan amplitud Fourier untuk mencadangkan pengumpulan data ERT dan pendekatan baharu untuk membangunkan keadaan had kebolehgunaan (SLS) atau had tindak balas reka bentuk. Pemerolehan data melalui ERT yang secara wajar ditukar kepada halaju gelombang ricih dan kekuatan ricih tanah disahkan pematuhannya dengan garis panduan sedia ada untuk reka bentuk cerun daripada Jabatan Kerja Raya. Hasil penyelidikan ini diharapkan dapat meningkatkan kebolehpercayaan faktor keselamatan reka bentuk untuk sebarang pembinaan dengan mengintegrasikan aplikasi teknologi canggih. Hasilnya, data sifat tanah mentah ERT yang berkorelasi baik dengan had cecair tanah di mana isipadu lompang atas jumlah lompang (VV/VT) adalah setara dan kekonduksian tanah (σ) terhadap kerintangan tanah (Ω) adalah konsisten dengan indeks kecairan. Kesimpulannya, penyelidikan ini difokuskan untuk memberi tafsiran yang jelas kepada hasil ERT dan membuktikan bahawa ia berguna untuk diagnostik masa hadapan kestabilan tanah dan rawatan optimumnya yang diperlukan untuk tanah yang digunakan pada masa hadapan.

Kata kunci: ***P****ecutan tanah puncak, faktor penguatan tanah, ketidakstabilan tanah, penyatuan, suffusion, spektrum tindak balas reka bentuk*

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LIST OF ABBREVIATIONS

AC	Alternating Current
AF	Amplification Factor
bpf	Blows Per Feet
DC	Direct Current
DEM	Discrete Element Method
DSHA	Deterministic Seismic Hazard Analysis
e	Void Ratio
ESO	Elastic Spectral Ordinates
ERT	Electrical Resistivity Tomography
FEM	Finite Element Method
FOS	Factor of Safety
GMPE	Ground Motion Prediction Equations
G-R	Gutenberg-Richter
IP	Polarization
LL	Liquid Limit
m	cementation exponent
MASW	Multichannel Analysis of Surface Waves
n	Porosity
PGA	Peak Ground Acceleration
PGD	Peak Ground Displacement
PGV	Peak Ground Velocity
PI	Plasticity Index
PL	Plasticity Limit

PSHA	Probabilistic Seismic Hazard Analysis
RVE	Representative Volumetric Elements
SASW	Spectral Analysis of Surface Waves
SF	Suffusion Factor
SHA	Seismic Hazard Analysis
SP	Self-Potential
SPT	Standard Penetration Test
VED	Viscous Energy Dissipation
Vs	Shear Wave Velocity
Wc	Water Content

LIST OF SYMBOLS

D_G	Grain diameter
d_{10}	Grain diameter of 10% passing
d_{30}	Grain diameter of 30% passing
d_{60}	Grain diameter of 60% passing
d_{90}	Grain diameter of 90% passing
Se	Elastic settlement
Sc	Primary settlement
Ss	Secondary settlement
ρ_o	Resistivity of rock
ρ_f	Resistivity of water
m	Cementation
φ	Porosity
E_n	Earthquake scenario
m_n	Magnitude
L_n	Location
r_n	Rate
η	Damping
Ω	Omega (unit of resistance)

CHAPTER 1

INTRODUCTION

1.1 Study Background

Internal erosion can take many different forms, can seriously endanger both human and animal life, and is capable of doing great harm to infrastructure (Liang et al., 2017; Masi et al., 2020; Huang et al., 2021). Piping and suffusion are two appearances of internal erosion. Different processes result in erosion, each of which is capable of causing destruction. Suffusion, also known as internal instability, is a long-term phenomenon whereby small soil particles are carried away by a soil seepage flow through spaces between larger ones (Dixon et al., 2011; Chetti et al., 2016). It indicates that a soil matrix's particle size distribution and the selective erosion of tiny particles from it do not match the requirements for self-filtering (Menad et al., 2019). Suffusion is more prone to arise in coarse, widely graded or gap-graded soils (such as some sandy gravels) (Bui et al., 2019). Internal instability is a common term used to characterize soils that are prone to suffusion. Suffusion, which is caused by seepage forces, is the mass movement of fine particles through the pore space of a coarser matrix (Yang et al., 2019) shown in Figure 1.1.

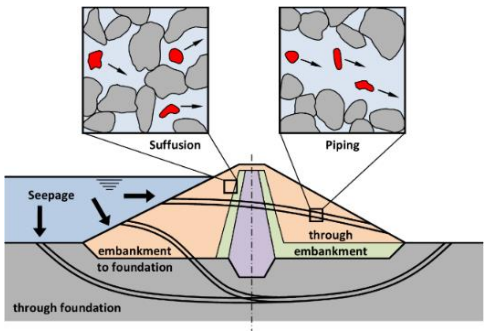

Figure 1.1: Internal Erosion Process (US Bureau of Reclamation, 2015)

Internal erosion of levees, earth dams, and foundations as well as watershed hillslopes is mostly caused by it (Feng et al., 2019). The impact of internal suffusion on a soil stratum's permeability, volumetric behaviour, and shear strength as well as the gradation are particularly concerning geo-mechanical soil parameters. Additionally, soil settlement has been connected to harm to earthen structures, buried utilities, buildings, and other structures.

The long-term impact that suffusion may have on the possibility for volumetric change to occur within a soil layer and the change in compressive strength is largely unexplored elements of geotechnical science. Additional knowledge on these internal erosion-related subjects can help with our understanding of the underlying mechanisms and processes, which will improve the way many earthen hydraulic structures are designed and protected from erosion's destructive impacts. Therefore, one of the primary mechanisms of internal erosion is suffusion, which results in selective erosion and progressive movement of tiny particles through the spaces in the soil skeleton created by coarse particles during seepage flow shown in Figure 1.2. Many hydraulic geo-structures, including embankment dams, dikes, levees, landslide dams, and natural deposits, exhibit seepage-induced suffusion (Wang, 2019; Yang et al., 2019).

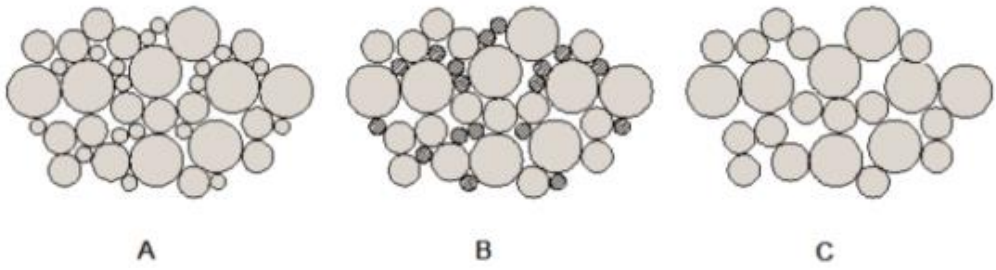

Figure 1.2: Progression of Suffusion; (A) Shows the Fine Particles Attached with Coarser Particles with a Seepage Line (B) Shows the Starting of Suffusion Influenced by Seepage and (C) Indicates the Suffusion in which the Fine Particles Flow with the Seepage Creating the Voids (Shwiyhat, 2010)

ERT is a quick and efficient non-destructive measurement technique for acquiring continuous soil subsurface resistivity profiles which is used in this research. Moisture variations and soil heterogeneities can be found using an ERT approach. ERT is becoming a prevalent tool in the field of geotechnical engineering (Masi et al., 2020). However, at this time, it only offers qualitative data. It can be difficult to determine quantitative geotechnical information about the subsurface from qualitative images, such as the moisture content, kind of soil, saturation degree, and Atterberg limits. Numerous studies have explained how pore fluid conductivity and surface conductance affect the electrical resistance of soil. To ascertain the impact of geotechnical features, electrical resistivity experiments have also been performed on commercial soils. Electrical resistivity must be associated with geotechnical parameters that can be measured in a laboratory because pore water and surface charge characterisation studies cannot be performed during a standard geotechnical investigation.

The natural disaster “earthquakes” is a set of vibrations on the surface of the earth which is caused by the generation of seismic waves due to rupture inside the earth during the release of accumulated energy (Shah et al., 2012). During an earthquake the delicate sediments may cause extensive amplification and increment in the span of ground motion, which may thus increase the seriousness of harm and devastation, this occurrence is generally termed as site effect (Laoumani et al., 2013; Sana et al., 2018). However, this study is focused on suffusion caused of failure through vibrations specifically soil amplification that has very close relation to soil shear wave velocity. The reason behind selecting seismic ground motion process that can cause soil failure instead of hydraulic loading because of the seismic hazard assessment carried out recently in Malaysia and the publish of Malaysia National Annex to Eurocode 8 by the Department of Standards Malaysia in 2017 proved that