THE EFFECT OF LIMITED SITE INVESTIGATIONS ON THE DESIGN AND PERFORMANCE OF PILE FOUNDATIONS

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To my wife Dian Andini, my sons Alif Ardian Arsyad and
Muhammad Terzaghi Ramadhan,
and my parents Muhammad Arsyad Kadiro and Yusniar Yusuf

Preface

The work described in this thesis was undertaken over the period of 2 years, between July 2006 and July 2008, within School of Civil, Environmental, and Mining Engineering at the University of Adelaide. Throughout the thesis, all materials, techniques, concepts and conclusions obtained from other sources have been acknowledged in the text.

Abstract

The research presented in this thesis focuses on the quantification of the effect of limited site investigations on the design and performance of pile foundations. Limited site investigation is one of the main causes of structural foundation failures. Over the last 30 years, most site investigations conducted for infrastructure projects have been dictated by minimum cost and time of completion, rather than meeting the need to appropriately characterise soil properties (Institution of Civil Engineers 1991; Jaksa et al. 2003). As a result, limited site investigations remain common, resulting in a higher risk of structural foundation failure, unforeseen additional construction, and/or repair costs. Also, limited site investigations can result in over-designing foundations, leading to increased and unnecessary cost (ASFE 1996).

Based on the reliability examination method for site investigations introduced by Jaksa et al. (2003) and performed by Goldsworthy (2006), this research investigated the effect of limited site investigations on the design of pile foundations. This was achieved by generating three-dimensional random fields to obtain a virtual site consisting of soil properties at certain levels of variability, and by simulating various numbers of cone penetration tests (CPTs) and pile foundations on the generated site. Once the site and the CPTs were simulated, the cone tip resistance (q_c) was profiled along the vertical and horizontal axes.

The simulated q_c profiles yielded by the CPTs were then used to compute axial pile load capacity termed the pile foundation design based on site investigations (SI). In parallel, the axial pile load capacity of the simulated pile foundation utilising the "true" cone tip resistance along the simulated pile was also determined. This is termed "the true" design, or the benchmark pile foundation design, and referred to as pile foundation design based on complete knowledge (CK). At the end of this process, the research compared the pile foundation designs based on SI and those based on CK. The reliability of the foundation design based on SI was analysed with a probabilistic approach, using the Monte Carlo technique.

The results indicated that limited site investigations have a significant impact on the design of pile foundations. The results showed that minimum sampling efforts result in a high risk of over- or under-designing piles. More intensive sampling efforts, in contrast, led to a low risk of under- or over-design. The results also indicated that the levels of spatial variability of the soil are notable factors that affect the effectiveness of site investigations. These results will assist geotechnical engineers in planning a site investigation in a more rational manner with knowledge of the associated risks.

Statement of Originality

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being made available for loan and photocopying.

Signed : .... Date:………………………..

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Notation

A_n	Net sectional area of pile toe
A_b	Cross-sectional area of pile base
APS	Australian Partnership Scholarship
A_{si}	Surface area of the pile shaft in contact with the soil
A_s	Gross surface area of the pile shaft
ASTM	American Standard of Testing Materials
CK	Complete Knowledge
CLPD	Centre of Learning and Professional Development
COV	Coefficients of variation
CPT	Cone Penetration Test
D	Diameter or width of the pile
DFT	Discrete Fourier transform
DMT	Dilatometer test
E	Young Modulus
FFT	Fast Fourier transform
f_i	Average unit skin friction of the soil layer i
FOSM	First order second moment
f_s	Sleeve friction of the CPT
f_{su}	Ultimate friction value along the pile shaft
GA	Geometric average
GIS	Geographic information system
GLS	Generalised least-squares
i	Soil layer

HA	Harmonic average
i^{+h}	Distance between the two points, X^i *and* X^{i+h}
KBS	Knowledge Base System
k_c	Penetrometer load capacity factor
LAS	Local average subdivision
LCPC	Laboratoire Central des Ponts et Chausseés, France
LFRD	Load and resistance factor design
MA	Moving average
m_ψ	Sample mean
n	Number of soil layers along the pile shaft
N	SPT number
N_b	Standard penetration number, N, at pile base
n_t	total population size
OLS	Ordinary least-squares
P	Probability of over-design or under-design
PDA	Pile driving analyser
Q_{all}	Allowable load capacity of a single pile
Q_b	Ultimate load at the pile base
Q_{CK}	Pile load capacity based on the complete soil properties
q_b	Unit load at the pile base
q_c	Cone tip resistance
q_{eq}	Equivalent cone resistance at the level of the pile tip
Q_S	Ultimate load along the pile shaft
Q_{SI}	Pile load capacity based on site investigations
q_u	unit load of the pile
Q_{ult}	Ultimate load of the soil at the pile base
q_s	Limit unit skin friction at the level of the layer i, and l_i

R_d	Radial distance between a borehole and a pile
SA	Standard arithmetic average
SAPAC	South Australian Partnership for Advanced Computing
SF	Safety factor
SI	Site investigation
SOF	Scale of fluctuation
SPT	Standard penetration test
TBM	Turning bands method
TT	Triaxial test
$Var(\mu)$	Variance of the sample mean
W	Weight of pile
$X(x + \tau)$	Sample at a distance τ from position x
$X(x)$	Sample at position x
X_i	Value of property X at location i
X_{i+h}	Value of property X at location
X_{ln}	Log normal variable
μ	Mean
$\lvert\tau_j\rvert$	Separation distance
$\xi(z)$	Soil property
σ^2	Sample standard deviation
σ_e^2	Variance of equipment errors
δ_I	Estimated displacement
ρ_{ij}	Correlation coefficient between the i^{th} and j^{th} sample
σ_m^2	Total variance of measurement
σ_p^2	Variance of procedural errors
σ_r^2	Variance of random errors
σ_{sv}^2	Variance of soil variability

θ	Scale of fluctuation
Ψ	Sample data
μ_{lnx}	Mean of log normal variable
σ_{lnx}	Standard deviation of log normal variable