THESIS

JAMES COOK UNIVERSITY

SCHOOL OF ENGINEERING

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LOAD-DEFORMATION BEHAVIOUR
OF FOUNDATIONS
UNDER VERTICAL AND OBLIQUE LOADS

Kate Johnson

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ABSTRACT

The work in this thesis explores the load-deformation behaviour of shallow and pile foundations under axial and oblique loads.

- A statistical review was performed on five popular shallow foundation settlement methods, which showed that different prediction methods could give highly variable results for the same foundation and soil conditions. The probability of failure charts allowing direct comparison between methods is presented, based on the statistical work.

There are 40+ settlement methods available for predicting the settlement of shallow foundations in granular soil. There is no way to account for the differences between settlement methods, other than assume one specific design criterion for every method. For example, limiting the settlement of a shallow foundation to 25 mm is a design criterion that is commonly used. From previous statistical work, it is shown that the Terzaghi and Peck method is more conservative than the method developed by Berardi and Lancellotta. The work in this thesis produced 'probability of failure charts', and the charts give the probability that the settlement for the commonly used methods will exceed an actual design value in the field. These charts allow users to design shallow foundations on the basis of an acceptable failure probability, instead of using one settlement criterion for every settlement method.

- A finite element analysis was performed on obliquely loaded piles. The analysis showed that the axial and lateral load components, and moment capacity of a pile is reduced if multiple load types act in unison. Combination loading also affects the pile head displacement. The oblique interaction charts herein allow the ultimate capacity and pile head displacement for a pile under combination loading to be estimated.

From the literature review of pile foundations, it is found that the influence due to combination loading is not well defined (i.e. axial loads, lateral loads and moments all acting at once). Previous work has shown that combination loading reduces the ultimate capacity of a pile, and the influence on pile head displacement has not been quantified. The influence of combination loading on pile capacity and settlement was explored, with the use of a finite element computer package entitled ABAQUS. The results from the numerical modelling are summarised into easy-to-use design charts, allowing the user to quantify the reduction in ultimate capacity and influence in settlement.

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- Mr Andrew Guazzo worked with me for the experimental pile phase (Chapter 6). Andrew and I spent a great deal of time setting up apparatuses, testing the small-scale piles and analysing the results. Andrew had a very good attitude even when we were shovelling 7 tonne of sand back and forth.
- Mr Paul Lemcke worked with me exploring the influence of pile shape on the capacity of a pile. Paul was patient while we worked some long days and late nights to obtain a numerical ABAQUS model, which would be suitable for the pile shape research.

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Finally, I have chosen two poems to close the acknowledgement section of this thesis.

> Does the road wind up-hill all the way?
>   Yes, to the very end.
> Will the day's journey take the whole long day?
>   From morn to night, my friend.
>
> Christina Rossetti

> "Over the Mountains
> Of the Moon
> Down the Valley of the Shadow,
> Ride, boldly ride,"
> The shade replied,
> "If you seek for Eldorado!"
>
> Edgar Allan Poe

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NOTATIONS

The following symbols have been used in multiple locations throughout the document.

Symbol	Definition	Units
a	minimum possible value for x	[-]
b	maximum possible value for x	[-]
B	width of footing	[m]
c	cohesion	[kPa]
C	axial compression component of oblique load	[kN]
C_{ER}	hammer efficiency factor	[-]
CIP	cast-in-place pile	[-]
C_N	overburden correction factor	[-]
d	pile diameter	[m]
D_r	relative density	[%]
e	void ratio (used in Chapter 4)	[-]
e	load eccentricity (used in Chapter 6)	[m]
e_{cv}	critical void ratio	[-]
E_s	Young's modulus for sand	[MPa]
FOS	factor of safety	[-]
H_u	ultimate lateral capacity under combined uplift and lateral load	[kN]
H_{ult}	ultimate horizontal load	[kN]
H_{uo}	ultimate lateral capacity under pure lateral load (used by Eckersley et al.(1996))	[kN]
ID	impact driven pile	[-]
K_o	at rest earth coefficient	[-]
L	lateral load	[kN]
L_b	embedment length of pile	[m]
M	applied moment	[kN.m]
M_{ult}	ultimate moment capacity of the pile	[kN.m]
N	uncorrected blow count or field blow count	[blows/100mm]
N_{60}	blow count corrected for hammer efficiency	[blows/100mm]

$(N_1)_{60}$, N_{corr}	blow count corrected for hammer efficiency and overburden	[blows/100mm]
p_a	atmospheric pressure	[kPa]
p_f	probability of failure	[-]
p_u	soil pressure at depth z	[kPa]
q_f	ultimate failure pressure on footing	[kPa]
q_o	surcharge on soil surface	[kPa]
Q_b	end bearing load	[kN]
Q_f	shaft friction load	[kN]
Q_{ult}	ultimate bearing load	[kN]
S_x	standard deviation	[-]
T_{un}	net uplift capacity	[kN]
T_{ug}	gross uplift capacity	[kN]
u	pore water pressure	[kPa]
u_x	displacement of the centre of the pile head in x-direction	[mm]
u_y	displacement of the centre of the pile head in y-direction	[mm]
u_z	displacement of the centre of the pile head in z-direction	[mm]
U	axial uplift	[kN]
W	effective weight of the pile	[kN]
x	settlement ratio	[-]
$\bar{x}$	average settlement ratio	[-]
z	depth from soil surface	[m]
Z_r	depth of rotation point	[m]
$\beta(1)$	coefficient of skewness	[-]
$\beta(2)$	coefficient of kurtosis	[-]
ε_a	axial strain	[-]
ε_x,	normal strain in x direction	[-]
ε_y	normal strain in y direction	[-]
ε_z	normal strain in z direction	[-]
ϕ	friction angle	[°]

ϕ'_{cv}	effective friction angle at critical void	[°]
	≈ residual effective friction angle	
ϕ'_{max}	peak effective friction angle	[°]
σ	normal stress	[kPa]
σ_f	failure normal stress	[kPa]
σ'_v	effective vertical stress Overburden Pressure	[kPa]
σ_x	normal stress in x direction	[kPa]
σ_y	normal stress in y direction	[kPa]
σ_z	normal stress in z direction	[kPa]
σ_1	major principle stress	[kPa]
σ_2	intermediate principle stress	[kPa]
σ_3	minor principle stress	[kPa]
τ	shear stress	[kPa]
τ_f	failure shear stress	[kPa]
ρ	density of sand and pile	[kg/m^3]
μ	coefficient of friction	[-]
ψ	dilation angle (ψ)	[°]