

**ESTIMATION OF BEARING CAPACITY OF DRIVEN
PILES USING NUMERICAL MODELING**

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Degree of Master of Science in Geotechnical Engineering

Department of Civil Engineering

University of Moratuwa

Sri Lanka

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Thesis submitted in partial fulfillment of the requirements for the degree Master of
Science in Geotechnical Engineering

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DECLARATION

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ABSTRACT

Piling is a blend of art and science. While choosing a suitable pile type and the installation method lie in the artistic aspect, scientific dimensions allow engineers to study the behavior of installed elements under different types of loading.

The nature of the interaction between a pile and the soil it contacts is significantly influenced by the method of installation used. This interaction cannot be accurately predicted based solely on the physical properties of the materials involved. Different methods are used to determine the bearing capacity of piles, including static equations, dynamic equations, empirical methods, numerical methods, computer software programs, and pile static load tests. However, it is important to note that each of these approaches may yield different values for the bearing capacity of piles, and rarely do any two methods produce identical computed capacities.

According to Randolph M. F. (1992), achieving precise estimates of axial pile capacity in various soil types is a challenge and often results in a margin of error of approximately $\pm 30\%$

During the last few decades, there has been swift and substantial progress in the analytical methods employed in pile design. This advancement not only validated traditional empirical approaches but also led to their replacement with more robust theoretical foundations.

In intricate geotechnical projects, when dealing with complex load combinations or substantial interaction with adjacent structures, engineers often turn to the Finite Element Method (FEM) for analysis. However, an exception to this trend is observed in the design of driven piles or soil-displacement piles, where a different approach is typically employed to determine factors such as pile capacity and performance.

In the modeling of displacement piles, it is essential to compile the installation effects resulting from different installing techniques with the most applicable constitutive model to obtain an accurate result by simulating real soil behavior. With the evolution of computational power, different numerical techniques can be employed successfully in standard FE analysis using soil parameters obtained from cost-effective site investigations to lead to a more realistic load-settlement response for driven piles or soil-displacement piles.

Key words: *Empirical methods; Finite Element Method; Installation effects; Displacement piles*

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NOTATIONS

All symbols and abbreviations used in this thesis are provided and defined directly in text, figures or they are enclosed to the equations. Here, the full notation is additionally submitted.

Symbols

Latin Letters

c	-	Cohesion
c_a	-	Undrained pile-soil adhesion
c_u, s_u	-	Characteristic undisturbed undrained shear strength
\bar{c}_u	-	Peak undrained cohesion
d	-	Diameter
d_i	-	Depth factors
e	-	Void ratio
f_R	-	Friction ratio
f_{avg}	-	Average unit skin frictional resistance
f_u	-	Unit ultimate skin friction
l or h	-	Length
m	-	Gradient
p^{ref}	-	Reference stress level
p'_o	-	Effective overburden pressure
q_b	-	Unit base resistance
q_c	-	Point resistance
q_l	-	Limiting resistance
q_u	-	Undrained compressive strength
q_{ult}	-	Ultimate bearing pressure
q_s	-	Sleeve resistance

r or r_o	-	radius
s_i	-	Shape factors
w_L	-	Plastic limit
z	-	Depth
A_b	-	Area of pile base
B	-	Breadth of the foundation
C	-	Perimeter/ Constant for chapter 2.9.3.3
C_1, C_2	-	Constants for chapter 2.12.2.2
C_c	-	Compression index
C_N	-	Adjustment factor for effective overburden pressure
C_s	-	Swelling index
D	-	Depth of the foundation
D_r or RD	-	Relative density
E_a	-	Actual hammer Energy
E_{in}	-	Input Energy
E_r	-	Energy Ratio
E_{rb}	-	Standard Energy Ratio
E_{oed}^{ref}	-	Reference oedometer stiffness
E_{50}^{ref}	-	Triaxial stiffness at 50% strength
E_0	-	Initial stiffness
F	-	Length factor
G'	-	Shear modulus
I_p, PI	-	Plasticity Index
I_r	-	Rigidity index

I_{rr}	-	Reduced rigidity index
I_p	-	Plasticity index
K_s	-	Coefficient of lateral earth pressure
K_o	-	Coefficient of lateral earth pressure at rest
L	-	Length
N	-	SPT blow count
N_i	-	Bearing capacity factor
P_a	-	Atmospheric pressure
P°	-	Limiting effective stress at the base level of the pile
Q	-	Total load
Q_b	-	Base resistance
Q_s	-	Shaft resistance
Q_u	-	Total ultimate load
Q_{su}	-	Ultimate shaft resistance
Q_{bu}	-	Ultimate base resistance
S	-	Settlement
W	-	Weight of the pile
Z_c	-	Critical Depth

Greek Letters

α	-	Adhesion factor
β	-	Coefficient in chapter 2.9.3.4
γ	-	Unit Weight
δ	-	Angle of friction between pile and soil
η_i	-	SPT adjustment factors
κ^*	-	Parameter for Chapter 3.13.3.6

λ	-	Dimensionless coefficient in chapter 2.9.3.2
λ^*	-	Parameter for Chapter 3.13.3.6
$\overline{\sigma}'_o$	-	Mean effective vertical stress
σ_v	-	Vertical stress
σ'_v	-	Effective vertical stress
σ_{vb}	-	Vertical stress of the soil at level of pile base
σ'_{vb}	-	Limiting effective vertical stress of the soil at level of pile base
$\overline{\sigma}'_0$	-	Average effective vertical stress
τ	-	Shear strength
$\overline{\tau}_s$	-	Unit shaft resistance
\emptyset	-	Angle of Internal Friction
\emptyset_u	-	Friction angle at undrained condition
\emptyset'_1	-	Original drained value of angle of friction
\emptyset'_2 or \emptyset'_R	-	Remolded drained value of angle of friction
ψ	-	Dilatancy angle
ϵ_v	-	Volumetric strain

Abbreviations

ASTM	-	American Society for Testing and Materials
API	-	American Petroleum Institute
BH	-	Bore hole
CAPWAP	-	Case Pile Wave Analysis Program
CD	-	Consolidated Drained
CPT	-	Cone Penetration Test
CU	-	Consolidated Undrained

EPRI	-	Electric Power Research Institute
Eq.	-	Equation
FEM	-	Finite Element Method
Fig.	-	Figure
HS	-	Hardening Soil
ICTAD	-	Institute for Construction Training and Development
LE	-	Linear Elastic
MC	-	Mohr- Coulomb
MLT	-	Maintained Load Test
NC	-	Normally Consolidated
NGI	-	Norwegian Geotechnical Institute
OC	-	Over Consolidated
PDA	-	Pile Dynamic Analysis
PDI	-	Pile Dynamic Integrity
PI	-	Plasticity Index
SPT	-	Standard Penetration Test
FEM	-	Finite Element Method