

การส่งถ่ายแรงในแนวคิงจากเสาเข็มกลุ่มไปยังตัวกลางโพโรอีลาสติกหลายชั้น

นายนภดล ศรีภักดี

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต

สาขาวิชาวิศวกรรมโยธา ภาควิชาวิศวกรรมโยธา

คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย

ปีการศึกษา 2546

ISBN 974-17-5284-9

ลิขสิทธิ์ของจุฬาลงกรณ์มหาวิทยาลัย

VERTICAL LOAD TRANSFER FROM PILE GROUP TO MULTILAYERED POROELASTIC MEDIUM

Mr.Napadon Sormpakdee

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering in Civil Engineering

Department of Civil Engineering

Faculty of Engineering

Chulalongkorn University

Academic Year 2003

ISBN 974-17-5284-9

ขนาดล ศรภักดี : การส่งถ่ายแรงในแนวดิ่งจากเสาเข็มกลุ่มไปยังตัวกลางตัวกลางโพโรอีลาสติกหลายชั้น (VERTICAL LOAD TRANSFER FROM PILE GROUP TO MULTILAYERED POROELASTIC MEDIUM) อ. ที่ปรึกษา ผศ.ดร.ธีรพงศ์ เสนอจันทร์ชัย, จำนวน 67 หน้า, ISBN 974-17-5284-9

วิทยานิพนธ์ฉบับนี้ศึกษาการส่งถ่ายแรงของเสาเข็มกลุ่มรับแรงตามแนวดิ่งในตัวกลางชนิดโพโรอีลาสติกหลายชั้น ระบบของกลุ่มเสาเข็มและตัวกลางชนิดโพโรอีลาสติกประกอบด้วยวัสดุแข็งอีลาสติกในหนึ่งมิติและตัวกลางโพโรอีลาสติกหลายชั้น แต่ละชั้นของตัวกลางประพฤติตามทฤษฎีวัสดุโพโรอีลาสติกของ Biot การกระจายของการเคลื่อนที่ในแนวดิ่งของกลุ่มเสาเข็มสมมติให้อยู่ในรูปแบบอนุกรมของฟังก์ชันเอ็กโปเนนเชียลร่วมกับชุดของสัมประสิทธิ์ที่ยังไม่ทราบค่า ฟังก์ชันพลังงานศักย์ทั้งหมดของระบบกลุ่มเสาเข็มและตัวกลางโพโรอีลาสติกหลายชั้นจะถูกสร้างขึ้นโดยใช้หลักการสร้างฟังก์ชันพลังงานร่วมกับการใช้หลักการสร้างสตีเฟนเมตริกซ์ของตัวกลางโพโรอีลาสติกหลายชั้น จากหลักการพลังงานต่ำที่สุดของพลังงานศักย์รวมของระบบทั้งหมด ทำให้สามารถคำนวณหาค่าสัมประสิทธิ์ที่ถูกสมมติในข้างต้นโดยใช้วิธีการเชิงตัวเลขที่เหมาะสม และเมื่อแทนค่าสัมประสิทธิ์เหล่านี้จะสามารถหาการเคลื่อนที่และแรงกระทำในแนวแกนของกลุ่มเสาเข็มได้ วิทยานิพนธ์ฉบับนี้นำเสนอผลของรูปแบบของกลุ่มเสาเข็ม ลักษณะของชั้นตัวกลางและคุณสมบัติของวัสดุโพโรอีลาสติกต่อพฤติกรรมมารับแรงในแนวดิ่งของเสาเข็มกลุ่มในตัวกลางโพโรอีลาสติกหลายชั้น

ภาควิชา _____ วิศวกรรมโยธา _____

สาขาวิชา _____ วิศวกรรมโยธา _____

ปีการศึกษา _____ 2546 _____

ลายมือชื่อนิสิต _____ นชคณ ๑๖๖๓๓ _____

ลายมือชื่ออาจารย์ที่ปรึกษา _____ BmK _____

4370349021 : MAJOR CIVIL ENGINEERING

KEY WORD: QUASI-STATICS / LOAD TRANSFER / POROELASTICITY / AXIAL LOAD / PILE GROUP / MULTILAYERED HALF SPACE

NAPADON SORNPAKDEE : VERTICAL LOAD TRANSFER FROM PILE GROUP TO MULTILAYERED POROELASTIC MEDIUM. THESIS ADVISOR: TEERAPONG SENJUNTICHAI, Ph.D., 67 pp. ISBN 974-17-5284-9.

This thesis studies load transfer from a vertically loaded elastic pile group to a multi-layered poroelastic half-space. The pile group-poroelastic medium is decomposed into a group of one-dimensional fictitious elastic solids and an extended multi-layered poroelastic half-space. Each layer of the extended half-space is governed by Biot's theory of poroelasticity and the interaction problem is formulated in Laplace transform domain. The vertical displacement distribution of each pile is approximated by an exponential series with a set of arbitrary coefficients. Strain energy of the pile groups is expressed in terms of arbitrary coefficients. Displacement influence functions corresponding to a multi-layered half-space subjected to buried vertical patch loading are required in the formulation. They are obtained by employing an exact stiffness matrix method. Thereafter, strain energy of the extended half-space is expressed in terms of the unknown arbitrary coefficients. The minimization of total potential energy of the piles-half-space system yields a set of linear simultaneous equations to determine the arbitrary coefficients. Time domain solutions are obtained by using an appropriate numerical Laplace inversion scheme. Selected numerical results for vertically loaded pile groups in a multi-layered poroelastic medium are presented to portray the influence of the group configuration, the layering and the poroelastic material parameters on the quasi-static behavior of the pile group.

Department CIVIL ENGINEERING Student's signature Napadon Sornpakdee
 Field of study CIVIL ENGINEERING Advisor's signature Teerapong Senjuntichai
 Academic year 2003

ACKNOWLEDGEMENTS

The author wishes to express his deep appreciation and sincere thanks to his thesis advisor, Assistant Professor Dr. Teerapong Senjuntichai, for his kindness, invaluable advice and constant encouragement throughout his study in Chulalongkorn University. Grateful acknowledgements are due to Associate Professor Dr. Suthum Suriyamongkol and Assistant Professor Dr. Boonchai Ukritchon for their comments and serving in the thesis committee. He is greatly indebted to Professor Dr. R.K.N.D. Rajapakse at University of British Columbia, Canada, for providing comments on this thesis.

Thanks are also due to everyone who has helped directly and indirectly in the preparation of this thesis. Finally, the author would like to express his gratitude to his parents for their love and encouragement.

Napadon Sornpakdee

CONTENTS

	page
Abstract (Thai)	iv
Abstract (English)	v
Acknowledgements	vi
Contents	vii
List of Tables	ix
List of Figures	x
List of Symbols	xiv
Chapter I Introduction	1
1.1 General	1
1.2 Objectives of Present Study	2
1.3 Scopes of Present Study	2
1.4 Basic Assumptions	2
Chapter II Literature Reviews	4
Chapter III Theoretical Considerations	7
3.1 Basic Equations and General Solutions	7
3.2 Stiffness Matrix	10
3.3 Global Stiffness Matrix	12
3.4 Variational Formulation	12
3.5 The Inverse Laplace-Hankel Integral Transform	19
Chapter IV Numerical Solutions	21
4.1 Numerical Solution Scheme	21
4.2 Convergence and Numerical Stability of Present Solution	22
4.3 Comparison with Existing Solutions	23
4.4 Numerical Results and Discussion	25

CONTENTS (Cont.)

page

Chapter V Conclusion	28
References	59
Appendices	62
Appendix A	63
Appendix B	64
Appendix C	65
Biography	67

LIST OF TABLES

Table	page
Table 1. Convergence of axial stiffness (K_v) for an axially loaded pile group in a homogeneous poroelastic half-space with respect to ξ_L	30
Table 2. Convergence of axial stiffness (K_v) for an axially loaded pile group in a homogeneous poroelastic half-space with respect to Nt	31
Table 3. Comparison of solutions for single pile in a nonhomogeneous elastic medium with rigid base	31
Table 4. Layered soil properties for a multi-layered elastic medium with rigid base	32
Table 5. Comparison of settlement influence factor (I_w) for single pile in a multi-layered elastic medium with rigid base	32
Table 6. Comparison of interaction factor for two piles in a multi-layered elastic medium with rigid base	32
Table 7. Material properties of poroelastic layered systems in Figure 12	32

LIST OF FIGURES

Figure	page
Figure 1. Axially loaded pile group in a multi-layered poroelastic half-space.....	33
Figure 2. Decomposition of pile group-half-space system :	
(a) Extended multi-layered poroelastic half-space subjected to body force field	
(b) Discretization of fictitious piles	34
Figure 3. (a) Geometry of axially loaded pile group in a homogeneous elastic half-space	
(b) configurations of pile group	35
Figure 4. Convergence of solutions with N_e for an elastic pile group embedded in a homogeneous poroelastic half-space vary L/a :	
(a) $L = 40a$; (b) $L = 60a$; (c) $L = 80a$; (d) $L = 100a$	36
Figure 5. Comparison of axial stiffness (K_v) with L/a for axially loaded pile group(P1, P2, P3 and P4) embedded in a homogeneous elastic half-space	38
Figure 6. Comparison of axial stiffness (K_v) with L/a for axially loaded pile group(P5) embedded in a homogeneous elastic half-space ...	38
Figure 7. Comparison of group reduction factor(R_G) with d/a for axially loaded pile group embedded in a homogeneous elastic half-space	39

LIST OF FIGURES (Cont.)

Figure	page
Figure 8. Comparison of distribution of shear stress along pile for single pile embedded in a homogeneous elastic half-space	39
Figure 9. Axially loaded single pile in a nonhomogeneous medium :	
(a) nonhomogeneous elastic medium with rigid base	
(b) nonhomogeneous elastic half-space	40
Figure 10. Comparison of axial stiffness with ρ for axially loaded single pile embedded in a nonhomogeneous elastic half-space :	
(a) $L = 20a$; (b) $L = 40a$	41
Figure 11. Axially loaded pile group in a multi-layered elastic medium with rigid base	42
Figure 12. Axially loaded pile group in a multi-layered poroelastic medium :	
(a) multi-layered poroelastic half-space ;	
(b) multi-layered poroelastic medium with rigid base	43
Figure 13. Axial stiffness for different spacing between center of piles in a multi-layered poroelastic half-space with $\kappa^{(1)}/\kappa^{(2)} = 0.1$ and $L = 40a$: (a) $Ep^* = 1e+6$; (b) $Ep^* = 1e+2$	44

LIST OF FIGURES (Cont.)

Figure	page
Figure 14. Profile of non-dimensional pile settlement for axially loaded pile group in a multi-layered poroelastic half-space along z axis with $\kappa^{(1)}/\kappa^{(2)} = 0.1$; $Ep^* = 1e+2$: (a) $L = 20a$; (b) $L = 40a$; (c) $L = 60a$; (d) $L = 100a$	45
Figure 15. Non-dimensional pile settlement at $z = 0$ for an axially loaded pile group in a multi-layered poroelastic half-space with $\kappa^{(1)}/\kappa^{(2)} = 0.1$: single pile; (b) two piles; (c) three piles; (d) four piles.....	47
Figure 16. Non-dimensional pile settlement at $z = L$ for an axially loaded pile group in a multi-layered poroelastic half-space with $\kappa^{(1)}/\kappa^{(2)} = 0.1$: (a) single pile; (b) two piles; (c) three piles; (d) four piles.....	49
Figure 17. Time history of axial stiffness for an axially loaded pile group in a multi-layered poroelastic half-space with $L = 40a$ for different ratio $\kappa^{(1)}/\kappa^{(2)}$: (a) single pile; (b) two piles; (c) three piles; (d) four piles	51
Figure 18. Axial stiffness for an axially loaded pile group in a multi-layered poroelastic half-space with $\kappa^{(1)}/\kappa^{(2)} = 10$ and $L = 40a$: (a) single pile; (b) two piles; (c) three piles; (d) four piles	53

LIST OF FIGURES (Cont.)

Figure	page
Figure 19. Axial stiffness for an axially loaded pile group in a multi-layered poroelastic half-space with $\kappa^{(1)}/\kappa^{(2)} = 0.001$ and $L = 40a$: (a) single pile; (b) two piles; (c) three piles; (d) four piles	55
Figure 20. Time history of axial stiffness for an axially loaded pile group in a multi-layered poroelastic medium with rigid base for two piles $\kappa^{(1)}/\kappa^{(2)} = 0.1$; $L = 40a$ $\kappa^{(1)}/\kappa^{(2)}$ and different ratio H/L : (a) $Ep^* = 1e+6$; (b) $Ep^* = 1e+2$	57
Figure 21. Time history of axial stiffness for an axially loaded pile group in a multi-layered poroelastic medium with rigid base for four piles $\kappa^{(1)}/\kappa^{(2)} = 0.1$; $L = 40a$ $\kappa^{(1)}/\kappa^{(2)}$ and different ratio H/L : $Ep^* = 1e+6$; (b) $Ep^* = 1e+2$	58

LIST OF SYMBOLS

a^i	Radius of the i^{th} pile
\bar{B}_k^j	Total body force on the disk element corresponding to the k^{th} node of the j^{th} pile
c	Consolidation coefficient
d	Spacing between center to center of piles
$Es_{(k)}$	Modulus of elasticity of the k^{th} layer
Ep^i	Moduli of elasticity of the i^{th} pile
$\bar{f}_{kl}^{i,j}$	Vertical displacement at the k^{th} nodal point of the i^{th} pile due to a vertical body force of unit intensity acting over the disk element corresponding to the l^{th} node of the j^{th} pile
$\mathbf{F}^{i,j}$	Matrix of vertical displacement influence function at nodal point of the i^{th} pile due to a vertical body force of unit intensity acting over the disk element of the j^{th} pile
H	Depth of rigid base
I_w	Settlement influence factor
Kv	Axial stiffness
L	Total length of pile
Ne	Total number of elements used for discretizing the pile
Nl	Total number of layer of medium
Np	Total number of piles in group
Nt	Number of arbitrary coefficient used for the assumed displacement
p	Excess pore fluid pressure
q_i	Fluid discharge in the i^{th} direction
$Q^{(n)}$	Applied fluid source at the n^{th} interface
r	Radial coordinate

LIST OF SYMBOLS (Cont.)

R_G	Group reduction factor
s	Laplace transform parameter
t	Time variable
t^*	Non-dimensional time
$T_i^{(n)}$	Applied traction in the i^{th} direction at the n^{th} interface
u_i	Average displacement of solid matrix in the i^{th} direction
Uh_g	Strain energy of the extended half-space in Laplace domain
Up_g	Strain energy of the fictitious pile group in Laplace domain
\bar{V}^i	Vertical load applied at i^{th} pile in Laplace domain
w^i	Assumed displacement of the i^{th} pile in time domain
w^*	Non-dimensionalized piles settlement
W_g	Potential energy of the vertical load in Laplace domain
z	Vertical coordinate
Δ_0	Displacement at the pile top ($z = 0$)
Δt_k^i	Thickness of the k^{th} element of the i^{th} pile
α_m^i	Arbitrary coefficient in the assumed displacement profile of the i^{th} pile in time domain
β_{km}^j	Intensity of the body force acting on the disk element corresponding to the k^{th} node of the j^{th} pile when the vertical displacements of the fictitious contact surface equal to the m^{th} exponential term of equation (3.37)
ε	Dilatation of solid matrix

LIST OF SYMBOLS (Cont.)

ε_{ij}	Strain components of solid matrix
κ	Coefficient of permeability
μ	Shear modulus of homogeneous half-space
ν	Drained Poisson's ratio
ν_u	Undrained Poisson's ratio
ξ	Hankel transform parameter
σ_{ij}	Total stress components of bulk material
ψ_i	Fluid displacement relative to solid matrix in the i^{th} direction
ρ	Degree of nonhomogeneity
ζ	Variation of fluid volume per unit reference volume
π	Total potential energy functional of the pile group-multi-layered medium system in the Laplace domain