FOUNDATION ANALYSIS AND DESIGN

Fifth Edition

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COMPUTER PROGRAM DISCLAIMER
Neither the publisher nor the author warrants the included programs to execute other that the displayed output if the data are correctly entered into the computer. Any use of these programs to solve problem other that those displayed or for which data sets are provided is the sole responsibility of the user. This includes making a correct problem model, obtaining the necessary input data (including any estimated values), and interpreting the output.

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PREFACE

This fifth edition continues the format of the previous four editions for providing current state-of-art (SOA) and state-of-practice (SOP) methods in Foundation Engineering. From author-user interaction I have concluded that SOP tends to lag SOA on the average of about 10 years. There is a range, however, where a few larger organizations are at the cutting edge of technology and many—particularly the smaller firms—are at varying intermediate stages.

This textbook, which is also widely used as a practitioner's reference, includes SOP material but with major emphasis on SOA. The latter is accomplished by including a mix of practice, "how to," and latest suggested design/analysis methodology. This produces a text compatible with the general goals of the American Society of Civil Engineers (ASCE) and other professional organizations, which have determined that technical graduates have a postgraduate period of only 5 to 7 years before obsolescence becomes a factor in their practice.

Design methods tend to vary between geographic regions, partly from instructors' influences and partly because there are few "design absolutes." As a consequence it is necessary to include the generally accepted alternative methods but to temper these with recommendations and suggestions on their use. This allows the user access to regional differences and provides "averaged" design results or the option to select the most appropriate alternative on a site-specific basis. Although these comments may appear overly practice-oriented, the fact is that the student must be aware of these real-world conflicts, geographical differences, and alternatives so as to be productive upon graduation.

This book emphasizes computer methods and the Finite-Element Method (FEM), involving matrix methods given in the previous editions, to reflect the widespread use of the personal computer and of the FEM in practice. Be aware, however, that the finite-element method does not have a unique definition. To some practitioners it is any mathematical representation of the continua (beams, plates, or solids) using discrete (or finite) elements. To other practitioners the FEM definition is reserved only for modeling the soil mass and the interfacing structural elements—sometimes this is called "soil-structure interaction" modeling.

In this textbook the former definition is used, for it is the one that is most widely practiced and given in most textbooks devoted solely to the FEM.

This textbook gives sufficient background theory for a FEM model so that the average user should have little difficulty using this method for design/analysis of those types of soil-structure interfacings used herein. It does make the modest assumption that most students at the level of this textbook have been exposed to some FEM and matrix methodology in statics; elementary structures; and the required university-level math courses. As a further aid there are computer programs (already compiled on an accompanying diskette) so the user does not have to become involved in FEM programming to use the methodology given.

WHAT'S NEW

This book has been substantially revised to include appropriate new material and expanded discussion of previous material. A large number of figures have been modified and several new ones added. I was able to do this with only a small increase in the total page count since providing the computer programs on diskette freed for text pages that had been used for program listings. Specifically these changes include but are not limited to the following:

a. Revision of text examples and problems so they are *all* in SI. Only two or three exceptions occur in examples that were originally published in Fps and for which a user would have to put forth too much effort to reconvert the material for verification.

b. I added five additional computer programs to the basic package so there are now 16 on the diskette. Nearly all of the data sets for the examples used in the textbook that can be used with the included programs are also on the program diskette. These will be extremely valuable for users to obtain computer output quickly in a more readable size. A number of problems at the ends of chapters are based on the user making a copy of the included data file for editing and execution.

c. I have revised the problems so that if an applicable computer program is on the diskette it will have to be used.

d. I have corrected several equations and figures from the previous edition.

e. I have revised the method for footings with overturning (in Chapter 8) to use the methodology first proposed by Meyerhof in 1953 for both bearing capacity and for the actual base design.

f. I have enlarged the discussion on lateral pressures in Chapter 11.

g. I have generally improved on the example format so that the computations are easier to follow.

The book is not a literature survey, but an extensive reference list is required to supplement and lend authority to the material presented as well as to give professional credit to those contributing to the advance in knowledge and practice. Because of text space I have had to limit use of references to seldom more than one or two for any topic covered. However, I tried to cite references that contained the most recent and most extensive reference lists so that the interested reader can easily make any follow-up verification or background fill-in with only a minimal literature search effort. If limiting the reference list has omitted any important contribution, I am sincerely regretful. Also I hope that junior authors are not offended by the practice of using "et al." where there are more than two coauthors.

A broad range of subject matter is necessary if one is to achieve reasonabe coverage of the subject of Foundation Engineering as defined by the text scope given in Chapter 1. The subject matter ranges in computational difficulty from requiring use of advanced programmable calculators through digital computers. This range of material allows the book to be used in Civil, Structural, Architectural, and Construction Engineering curricula through a judicious selection of topics and for a minimum of two courses.

This edition—although almost completely rewritten—retains most of the organization of the fourth edition since that edition was also substantially rewritten. This edition has focused more on cleaning up and clarifying those topics requested by users or deemed necessary by the author.

A principal difference between this and the fourth edition is to provide the computer programs from that edition on a diskette in compiled format. All of the programs were edited to allow the user to input data from screen requests. Where the data file is extensive, the user has the option of creating the data file and saving it to disk for later revision using a screen editor so that parametric studies can be easily made. Other than adding the screen routines, the programs are essentially those of the fourth edition. The reason for this is a number of instructors obtained copies of those programs in source code from the author (others had their students type in the programs) so it would be counterproductive to revise the programs substantially so that program users do not get quite the same output order using fifth edition programs compared with those from the fourth edition. Also, when those users obtained the programs in source code, a user's manual was provided giving the input variable names, order of input, and units.

As in previous editions a very substantial number of examples are included. The examples carried over have been extensively reworked and/or new ones added with a reasonably detailed explanation of steps in arriving at the solution. As in previous editions I have attempted to include examples that are realistic—at least within limits of available text space. Often they have been cited from published works so the instructor can require the student to do some background research to gain an appreciation of the difficulty associated with trying to use the published work of others from professional journals. Where the example is handworked, comments and discussion of the results and what the next step in the design process might be are usually given. Where computer output is used, some comments are always given on how to make output checks to see if a correct solution has been obtained for that model. This practice supplements the prior text discussion about the computer program.

I wish to express appreciation to the many users of this text, both in the United States and abroad, who have written or called with comments or constructive criticism or simply to make inquiry about a procedure. I should also like to thank those who took part in the McGraw-Hill user survey to provide input for this revision including Y. S. Chae, Rutgers University—Busch Campus; K. L. Bergesen, Iowa State University; M. Gunaratne, University of Southern Florida; C. W. Lovell, Purdue University; Mete Oner, Oklahoma State University; and Stein Sture, University of Colorado.

Finally I have to acknowledge the very considerable contribution of my wife, Faye, who helped with figure and reference checking and the myriad other busy work details necessary to produce the manuscript.

Joseph E. Bowles

ABOUT THE COMPUTER PROGRAMS

Software to accompany this text is available separately.
To obtain, please contact McGraw-Hill office nearest you or your local bookstore.

When ordering the diskette, please quote PART NO. 0-07-114811-D.

The 16 computer programs on the diskette in *fname*.**EXE** format *will execute either with or without a math coprocessor on your system.* These programs will execute on any IBM or compatible system that uses PC-DOS or MS-DOS for the operating system. They will operate in Windows™ environment but as "DOS" programs. A computer system with a hard disk is recommended but not required. There is an installation program on the diskette to assist you in putting the programs onto your system.

The 16 programs are in Subdirectory EXE as follows:

BEARING	Program to compute bearing capacity factors for Hansen, Meyerhof, and Vesić methods (new)
FAD3DPG	3-dimensional pile group analysis using a "rigid" pile cap (**B-10**)
FADBEMLP	Beam on elastic foundation and lateral pile analysis (**B-5**)
FADDYNF1	Dynamic base analysis with uncoupled modes (**B-11**)
FADMAT	Mat/plate analysis using the FGM (**B-6**)
FADSPABW	Sheet-pile/braced excavation wall analysis (**B-9**)
FFACTOR	To compute a number of factors (K_a, K_p, I_s, I_f, earthquake, etc.) used in Foundation Design (new)
LAYERSOL	for bearing capacity on a layered soil (**B-1**)
SMBLP1	Boussinesq lateral pressure for a number of surcharge load cases (**B-8**)
SMBRGNP	Bearing capacity factors for base on a slope (**B-2**)
SMBWVP	Vertical pressure using either Boussinesq or Westergaard method (**B-4**, but Westergaard option is new)
SMNMWEST	Vertical pressure beneath corner of a rectangle using either the Newmark or Westergaard method (**B-3**)

SMTWEDGE	Trial-wedge method for lateral wall force (**B-7**)
UFACTOR	Obtain Terzaghi consolidation percent U versus time factor T (new)
WEDGE	Obtain passive earth force for horizontal and sloping dredge lines for adjusting modulus of subgrade reaction k_s (new)
WORK	Work method (see in Chap. 2) for estimating preconsolidation pressure for a curved e versus log p plot (new)

There are 50 data sets included with the programs in subdirectory DATA. The data sets are keyed to the program output in the text. Note that if these programs accept a disk file as input, they output the file name with the output for a project record.

There is additional user's information about some of the above programs and a summary of other programs noted in the text (programs B-12 through B-31 and several others that are available from the author) in the disk file README.DOC, which you should read and print out. Note that "new" indicates new programs—others with B-numbers are essentially the same as listed in the fourth edition of this textbook.

There is some information on input data organization, parameter identifications, and limitations in the disk file USERMANL.DOC, which you should also print. Consider putting these two printouts in a file folder for rapid reference.

SPECIAL USER NOTE

For more rapid turn-around of inquiries, downloading of program lists/costs, errata, possible formation of a users group, and similar purposes, use the following Web page address (it has e-mail capabilities):

http://www.bcscom.com/fad5e/

If you are on the Internet, you should use this contact method instead of the regular mail address and telephone number in the README.DOC file on the diskette.

LIST OF PRIMARY SYMBOLS USED IN TEXT

The following is a list of symbols used throughout the text. Additionally, most symbols are identified where they are used, or first used if use is different than given below. Not all symbols or subscripts are shown.

A = area, or used as a coefficient; may be subscripted

ADM = ACI 318-: *A*lternate *D*esign *M*ethod (uses actual unfactored design loads)

a = area or is used as a coefficient

B = least lateral base dimensions (sometimes is $2B$); pile group width

B_p = pedestal diameter

B' = $B/2$ when base dimension = B

B_q = cone pore pressure increase ratio

C_C = compression index (Chaps. 2 and 5)

C'_C = compression ratio (Chap. 2)

C_r = recompression index (Chaps. 2 and 5)

C_p = percent clay (material finer than 0.002 mm)

C_α = secondary compression index

CD = consolidated drained

CU = consolidated undrained

CPT = cone penetration test

CIUC = consolidated isotropically undrained compression test

CK_oUC = consolidated in K_o-conditions, undrained compression test

CK_oUE = consolidated in K_o-conditions, undrained extension test

CK_oDSS = consolidated in K_o-conditions, direct simple shear test

c = cohesion of soil
c.g. = center of gravity (or mass)
c_i = damping constants used in Chap. 20 ($i = x, y, z$, and θ_i)
c_v = coefficient of consolidation (Chap. 2)
D = depth of footing or pile base; pile diameter or width
D_b = diameter of anchor bolt circle for industrial bases
D_c = total thickness of a concrete base slab
D_r = relative density
DMT = flat *d*ilato*m*eter *t*est
d = effective depth of a concrete base slab (to c.g.'s of rebars)
E_c = modulus of elasticity of concrete
E_p = modulus of elasticity of pile material (Chap. 20)
E_s = stress-strain modulus or modulus of deformation (also modulus of elasticity) of soil; may include additional subscripts to indicate method of determination
E_i = energy coefficient symbols used in Chap. 3 to identify SPT values
e = void ratio
e_o = in situ void ratio
F_o, F = dynamic forces as used in Chap. 20; F_o = basic value; F = value at ωt
$f'c$ = 28-day compressive strength of concrete
f_y = yield strength of steel rebars, piles and other steel members
f_a = allowable steel stress
FVST = field vane shear test (*also* VST *or* FVT)
FEM = finite element method; *also* fixed-end-moment, *see context of usage*
G' = shear stress-strain modulus of soil or other material computed using Eq. (*b*) of Sec. 2-14 or by dynamic methods given in Chap. 20
G = specific gravity, for any material other than soil
G_s = specific gravity of soil grains making up a given soil mass
GWT = groundwater table
H = influence depth of footing (Chap. 5); stratum thickness; also used for wall height in Chaps. 11–15, and for hydraulic head in Chap. 2
I = moment of inertia of cross-section
ID = inside diamter of a round section
I_i = settlement influence coefficients used in Chap. 5
I_P = plasticity index = $w_L - w_P$
$I_{\theta i}$ = mass inertia for rotation modes in Chap. 20
J_a = coefficient defined in Chap. 20
J = torsion moment of inertia
J = Joules (an energy term), N · m, but not a bending moment, which is also N · m
K = ratio of lateral to vertical stress
K_o = in situ (or at rest) lateral/vertical stress ratio

K_a = active earth pressure coefficient = $\tan^2(45 - \phi/2)$
K_p = passive earth pressure coefficient = $\tan^2(45 + \phi/2)$
K_z = vertical soil spring for beam-on-elastic foundations, mats and vibrating bases
K_i = horizontal dynamic soil springs; $i = x, y$ as used in Chap. 20
$K_{\theta i}$ = rotational dynamic springs; $i = x, y$, and z used in Chap. 20
k = coefficient of permeability; k_x, k_y = horizontal and vertical values
k_s = modulus of subgrade reaction either vertical or horizontal
k_s' = k_sB used as a beam loading in Chap. 9
L = base or footing length; also pile length; may be subscripted with p = pile, etc.
LF = load factor
M = computed moment from loads
M_u = ultimate (factored) moment as used for ACI Strength Design
m = exponent; also used for mass = W/g in Chap. 20
N = SPT blow count
N_b = number of anchor bolts in a circle of diameter D_b
N_i = SPT blow count at i = efficiency of 55, 60, 70, etc., percent; also used as stability number
N_i' = corrected SPT blow count at i = efficiency
N_k = cone bearing factor
N_{kt} = adjusted cone bearing factor
n = porosity; also used as an exponent; number of piles in a group
OD = outside diamter of a circular section
OCR = overconsolidation ratio
OMC = optimum moisture content—usually in percent
P_a = wall force due to active earth pressure
P_p = wall force due to passive earth pressure
p_o = in situ vertical pressure at some depth z
p_o' = effective vertical pressure at some depth z
p_c' = effective preconsolidation pressure at some depth z
Q = vertical force (also V and sometimes P)
q = overburden pressure = γz used interchangeably with p_o
$\bar{q}$ = effective overburden pressure (same as p_o') but symbol usually used when computing bearing capacity
q_c = cone bearing pressure
q_T = cone bearing pressure corrected for any pore pressure effects
q_o = footing (or base) contact pressure
q_{ult} = ultimate computed bearing pressure
q_a = allowable bearing pressure
q_u = unconfined compression strength (**always**)
R = resultant force—usually against a wall, as in Chap. 11

RQD = rock quality designation (a ratio)
S = degree of saturation (defined in Chap. 2)—**always**
S = section modulus
S_t = sensitivity of clay (Chap. 2)
SCP = soil-cement-pile (usually produced in-place)
SF = safety factor (also called a stability number)
s = shear strength; pile spacing
s_u = undrained shear strength (often $s_u = q_u/2$)
SPT = standard penetration test
T = time factor for consolidation analyses; Torque measured in a field vane shear test (FVST)
t_f = flange thickness of a rolled section
t_w = web thickness of a rolled section
U = undrained soil state
U = percent consolidation
USD = ultimate strength design (ACI 318-) and uses ϕ-factors
u = pore water (or neutral) pressure
u_c = measured pore pressure at the tip of a piezocone
V_b' = bearing capacity factor used on Fig. 3-22
w = water content; w_N = natural (in situ); w_L = liquid limit; w_P = plastic limit
$\bar{x}$ = horizontal location of load resultant R in x–y plane
$\bar{y}$ = vertical location of load resultant R in x–y plane; eccentricity of a rotating mass in Chap. 20 as $F = m_e \bar{y} \omega^2$
Z_i = Hetenyi plate bending factors
z = depth of interest from ground surface
α = angle used in Chap. 4; cohesion reduction factor in Chap. 16
β = slope angle of ground or backfill; skin resistance factor in Chap. 16
β_d = part of solution of differential equation or internal damping coefficient used in Chap. 20
γ = unit weight of material; subscript is used with γ to identify type or state, as c = concrete, dry, wet, sat, etc.
γ' = effective unit weight computed, as $\gamma' = \gamma - \gamma_W$.
δ = angle of friction between materials, as pile-to-soil, etc.
ΔH = settlement of foundation as used in Chap. 5 and Chap. 18
ΔH_g = pile group settlement (Chap. 18)
ΔH_p = single-pile settlement (Chap. 18)
Δq = stress increase in stratum from footing or pile load
Δu = excess pore water pressure
ϵ = strain = $\Delta q/E_s$ (or q/E_s) or $\Delta L/L_o$
η = base tilt angle in Chap. 4; factor in Chap. 18
κ_i = multipliers for dynamic springs K_i in Chap. 20

λ = multiplier for Chap. 16; with subscripts is dynamic damping multiplier of Chap. 20; also used in Chap. 18

μ = Poisson's ratio (used throughout—defined in Chap. 2)

ρ = mass density of soil or other material; also used as rupture angle of soil wedge retained by a wall; also factor used in Chap. 18 for pile settlement computations

σ_i = pressure or stress; i = direction as x, y, or z

σ_o = effective *mean* normal pressure computed as $(\sigma_1 + \sigma_2 + \sigma_3)/3$

ϕ = angle of internal friction

ϕ' = effective angle of internal friction

ω = frequency as used in Chap. 20

τ = sometimes used instead of s to indicate shear strength