INSTRUCTION REPORT K-82-7

USER'S GUIDE: COMPUTER PROGRAM FOR BEARING CAPACITY ANALYSES OF SHALLOW FOUNDATIONS (CBEAR)

by

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A report under the Computer-Aided Structural
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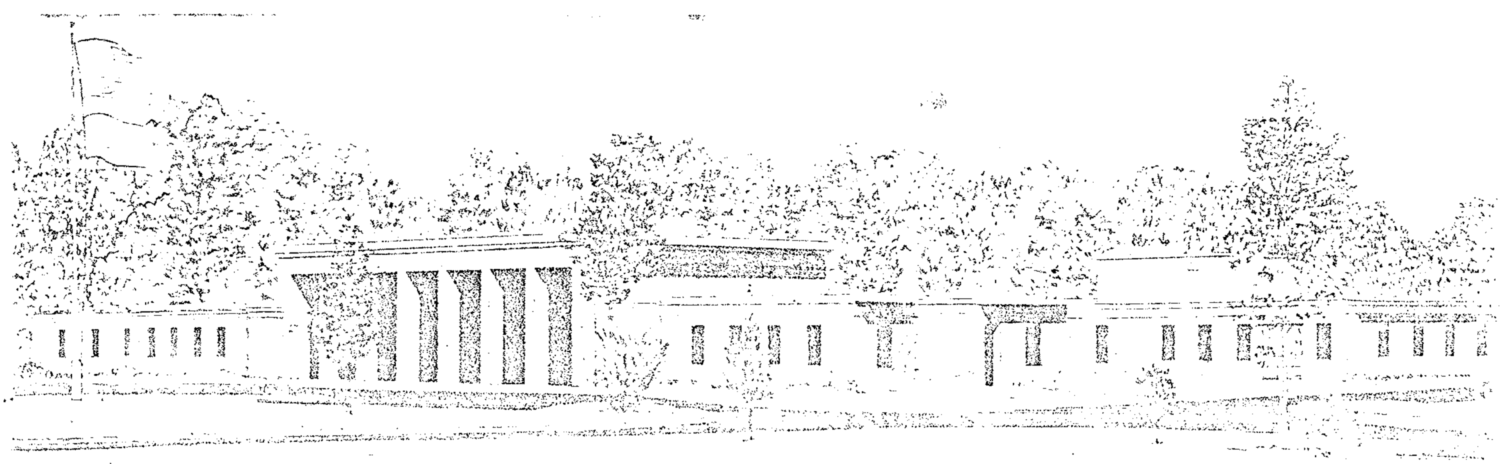

Prepared for Office, Chief of Engineers, U. S. Army
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CATEGORY B

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM Bearing Capacity Analysis of Shallow Foundations (CBEAR) (I0017)	PROGRAM NO. 741-F3-R0107

PREPARING AGENCY U. S. Army Engineer Waterways Experiment Station, Automatic Data Processing Center, P. O. Box 631, Vicksburg, MS 39180

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
Reed L. Mosher Michael E. Pace	June 1982	Final	OP

A. PURPOSE OF PROGRAM

This program can be used for the analysis of the bearing capacity of shallow strip, rectangular, square, or circular foundations on one- or two-layer soil systems. The bearing capacity can be computed considering the effects of embedment of the foundation, inclination of the foundation base, inclined loads, a sloping soil surface, eccentric loads in three dimensions, submerged soil, or surcharge.

B. PROGRAM SPECIFICATIONS

Timesharing FORTRAN Program.

C. METHODS

The bearing capacity of an infinite strip footing is derived based on the classical theory of plasticity using limit equilibrium analysis. The soil behavior is assumed to be as follows: (a)Mohr-Coulomb failure criteria govern; (b)shear strength at any point is independent of strain; (c)elastic deformations are negligible with respect to plastic deformations; and (d)volume change due to stress is negligible.

D. EQUIPMENT DETAILS

E. INPUT-OUTPUT

Data is input from a prepared data file in free field format or from the user's terminal during execution. If the data are input from a terminal the user may enter data by using key command words or by following a prompting sequence. Output from the program may be directed to a file or printed at the user's terminal.

F. ADDITIONAL REMARKS

Program is available through the CORPS on WES DPS/1, CSC H6000 at Macon, GA, and Boeing Computer Services.

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READ INSTRUCTIONS BEFORE COMPLETING FORM

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

CBEAR (Computer program)
Computer programs
Foundations
Soil mechanics

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This user's guide documents a computer program called CBEAR that can be used for analysis of the bearing capacity of shallow strip, rectangular, square, or circular foundations on one- or two-layer soil systems. The bearing capacity can be computed considering the effects of:

a. Embedment of the foundation.

b. Inclination of the foundation base.

(Continued)

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20. ABSTRACT (Continued).

c. Inclined loads.

d. A sloping soil surface.

e. Eccentric loads in three dimension.

f. Submerged soil.

g. Surcharge.

This document contains a brief description of the analysis procedures employed in the program and instructions for the input and execution of the program. Appendices are included containing hand computations of example problems; detailed criteria specifications that were used in program development as well as the analytical procedures used by the program; comparison of the different procedures investigated in the development of the criteria specifications; and numerical comparisons for the investigated procedures.

The program was developed from specifications furnished by the Corps of Engineers' Computer-Aided Structural Engineering (CASE) Project Task Group on Geotechnical Aspects of CASE.

DEPARTMENT OF THE ARMY
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11 March 1985

Errata Sheet

No. 1

USER'S GUIDE: COMPUTER PROGRAM FOR BEARING CAPACITY

CAPACITY ANALYSES OF SHALLOW FOUNDATIONS (CBEAR)

Instruction Report K-82-7

June 1982

Page 3, Conversion Factor Table: Under "To Obtain," third reading should be changed to kilopascals, and fourth reading should be changed to pascals.

PREFACE

This user's guide documents a computer program called CBEAR that can be used to perform bearing capacity analyses on shallow foundations. The work in writing the computer program and the user's guide was accomplished with funds provided to the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., by the Civil Works Directorate of the Office, Chief of Engineers, U. S. Army (OCE), under the Geotechnical Aspects of the Computer-Aided Structural Engineering (CASE) Project.

Specifications for the program were provided by members of the CASE Task Group on Geotechnical Aspects of CASE:

Mr. Thomas Wolff, St. Louis District (Chairman)
Mr. Lavane D. Dempsay, St. Paul District
Mr. Roger Brown, South Atlantic Division
Mr. Earl V. Edris, Jr., WES
Mr. Rixby J. Hardy, OCE
Mr. Reed L. Mosher, WES
Mr. Phillip Napolitano, New Orleans District
Dr. N. Radhakrishnan, WES

The specifications were compiled by Mr. Dana Humphrey, Foundation and Materials Branch, St. Louis District, under the guidance of Mr. Wolff.

The main analysis algorithm was written by Mr. Gordon L. Muster II and Dr. Michael W. O'Neill, Department of Civil Engineering, University of Houston, under Contract No. DACW39-80-M-4524. Additions and modifications were made to the code by Mr. Mosher and Mr. Michael E. Pace, Computer-Aided Design Group, Automatic Data Processing (ADP) Center, WES.

This report was written by Messrs. Mosher and Pace. Appendices B, C, and D are an edited version of Mr. Humphrey's specifications report. The work was managed and coordinated by Dr. Radhakrishnan, Special Technical Assistant, ADP Center, WES, and CASE Project Manager. Mr. Hardy, Geotechnical Branch, Civil Works Directorate, was the OCE point of contact. Mr. Donald L. Neumann was Chief of the ADP Center, WES.

Commanders and Directors of WES during the development of the program and the publication of this report were COL N. P. Conover, CE, and COL T. C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, INCH-POUND TO METRIC (SI) UNITS OF MEASUREMENT

Inch-pound units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
kips (1000 lb force)	4.448222	kilonewtons
kips (force) per square foot	47.880263	pascals
pounds (force) per square foot	47.880263	kilopascals
pounds (mass) per cubic foot	16.018463	kilograms per cubic metre

USER'S GUIDE: COMPUTER PROGRAM FOR BEARING CAPACITY ANALYSES OF SHALLOW FOUNDATIONS (CBEAR)

PART I: INTRODUCTION

Purpose of Program CBEAR

1. CBEAR is a computer program for analysis of the bearing capacity of shallow strip, rectangular, square, or circular foundations on one- or two-layer soil systems.* The bearing capacity can be computed considering the effects of:

   a. Embedment of the foundation.
   b. Inclination of the foundation base.
   c. Inclined loads.
   d. A sloping soil surface.
   e. Eccentric loads in three dimensions.
   f. Submerged soil.
   g. Surcharges.

Scope

2. Part II gives a brief description of the analysis procedures employed in the program. Part III presents instructions for the input and execution of the program. Example runs with hand computations are presented in Appendix A. Appendix B presents the detailed criteria

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* CBEAR is designated I0017 in the Conversationally Oriented Real-Time Program-Generating System (CORPS) library. Three sheets entitled "PROGRAM INFORMATION" have been hand-inserted inside the front cover of this report. They present general information on the program and describe how it can be accessed. If procedures used to access this and other CORPS library programs should change, recipients of this report will be furnished a revised version of the "PROGRAM INFORMATION."

specifications that were used in program development as well as the analytical procedures used by the program. Appendix C presents a comparison of the different procedures investigated in the development of the criteria specifications. Appendix D presents numerical comparison for the procedures discussed in Appendix C.

PART II: ANALYSIS PROCEDURE

Introduction

3. The bearing capacity of an infinite strip footing is derived based on the classical theory of plasticity using limit equilibrium analysis. The soil behavior is assumed to be as follows (Vesic 1967):

- a. Mohr-Coulomb failure criteria govern.
- b. Shear strength at any point is independent of strain.
- c. Elastic deformations are negligible with respect to plastic deformations.
- d. Volume change due to stress is negligible.

These assumptions describe the behavior of a rigid, perfectly plastic material which would exhibit the stress-strain relationship shown in Figure 1.

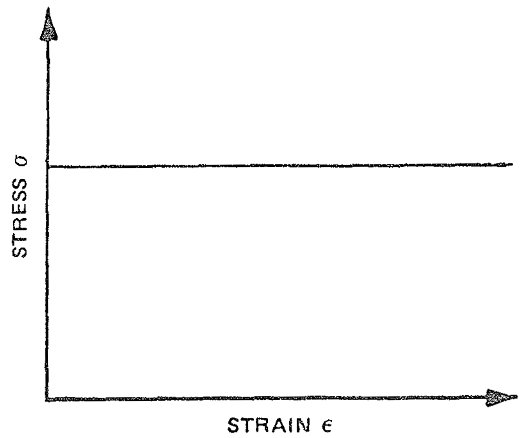

Figure 1. Stress-strain relationship for a rigid, perfectly plastic material

4. The first theoretical solution of this problem is attributed to Prandtl and Reissner in the early 1920's. Their solution was for a punch being pressed into a semi-infinite, weightless continuum. The punch was modelled as a distributed infinite strip load (Vesic 1967). The failure pattern, as illustrated in Figure 2, consisted of three zones of shear:

a. I: Rankine active zone.

b. II: Rankine passive zone.

c. III: Radial shear zone.

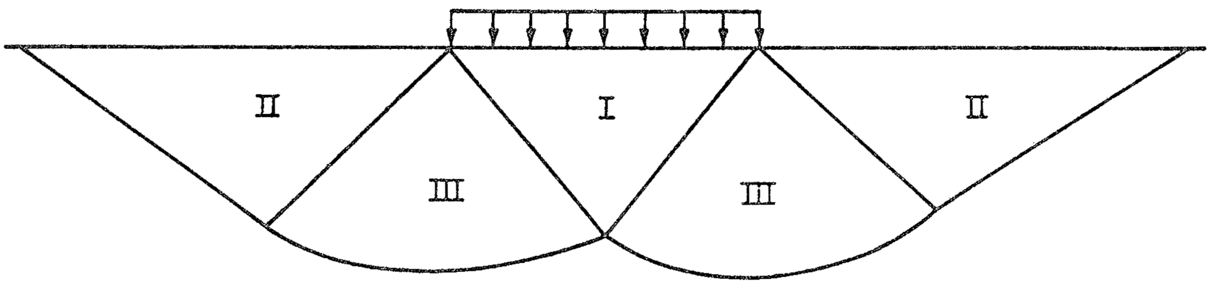

Figure 2. Shear zone at failure of an earth supported strip footing

5. Terzaghi (1943) defined this type of failure mechanism as a general shear failure and derived the following equation for bearing capacity of a continuous footing:

$$Q_D = B\left(cN_c + \gamma D_f N_q + \gamma \frac{B}{2} N_\gamma\right)$$

where B equals width of the footing. The bearing capacity factors N_c, N_q, and N_γ are dependent only on the angle of internal friction ϕ.

6. Meyerhof (1963), Vesic (1975), and others have derived various bearing capacity factors and have applied correction factors to the general bearing capacity equation proposed by Terzaghi. The correction factors account for variations in loading geometry and soil conditions. The bearing capacity factors and correction factors used in this program are those of Vesic (1975) and Meyerhof (1963). The correction factors presented in the generalized bearing capacity equations are not necessary for all problems encountered by the practicing engineer and should not be used blindly. Appendix B should be read if the user is unfamiliar with the use of these correction factors.

Generalized Bearing Capacity Equation

7. The form of the generalized bearing capacity equation used by the program is:

$$q = \zeta_c \zeta_{cd} \zeta_{ci} \zeta_{ct} \zeta_{cg} cN_c + \zeta_q \zeta_{qd} \zeta_{qi} \zeta_{qt} \zeta_{qg} q_o N_q + \frac{\zeta_\gamma \zeta_{\gamma d} \zeta_{\gamma i} \zeta_{\gamma t} \zeta_{\gamma g} B\gamma N_\gamma}{2}$$

where

q = vertical component of the ultimate unit bearing capacity of the foundation

N_c, N_q, N_γ = bearing capacity factors

$\zeta_c, \zeta_q, \zeta_\gamma$ = shape factors

$\zeta_{cd}, \zeta_{qd}, \zeta_{\gamma d}$ = embedment factors

$\zeta_{ci}, \zeta_{qi}, \zeta_{\gamma i}$ = inclination factors

$\zeta_{ct}, \zeta_{qt}, \zeta_{\gamma t}$ = base tilt factors

$\zeta_{cg}, \zeta_{qg}, \zeta_{\gamma g}$ = ground slope factors

c = cohesion

γ = unit weight of the soil

B = effective base width

L = effective base length

q_o = effective overburden pressure on a plane passing through the base of the footing

Bearing capacity factors (N_c , N_q , N_γ)

8. The bearing capacity factors used in the program are those derived by Meyerhof (1963) for a shallow horizontal strip footing under a vertical load. They are:

For $\phi > 0°$,

$$N_c = (N_q - 1) \cot \phi$$

$$N_q = e^{\pi \tan \phi} N_\phi$$

$$N_\gamma = (N_q - 1) \tan 1.4\phi$$

For $\phi = 0°$,

$$N_c = 5.14$$

where

$$N_\phi = \tan^2 \left(\frac{\pi}{4} + \frac{\phi}{2}\right)$$

ϕ = angle of internal friction

Shape factors (ζ_c , ζ_q , ζ_γ)

9. The shape factors computed by the program were presented by Meyerhof (1963):

$$\zeta_c = 1 + 0.2N_\phi \frac{B}{L}$$

For $\phi = 0°$,

$$\zeta_q = \zeta_\gamma = 1$$

For $\phi > 10°$,

$$\zeta_q = \zeta_\gamma = 1 + 0.1N_\phi \frac{B}{L}$$

For $0° < \phi \leq 10°$, a linear interpolation between 1 for $\phi = 0°$ and $1 + 0.1N_\phi(B/L)$ for $\phi = 10°$ is used.

Embedment factors (ζ_{cd} , ζ_{qd} , $\zeta_{\gamma d}$)

10. The embedment factors used are according to Meyerhof (1963):

$$\zeta_{cd} = 1 + 0.2 \frac{D}{B} \tan\left(45 + \frac{\phi}{2}\right)$$

where D is the depth of embedment at the base of the footing.

For $\phi = 0°$,

$$\zeta_{qd} = \zeta_{\gamma d} = 1.0$$

For $\phi > 10°$,

$$\zeta_{qd} = \zeta_{\gamma d} = 1.0 + 0.1 \frac{D}{B} \tan\left(45° + \frac{\phi}{2}\right)$$

For $0° < \phi \leq 10°$, a linear interpolation between 1 for $\phi = 0°$ and $1 + 0.1 \tan(45° + 10°/2)$ for $\phi = 10°$ is used. The depth D and the base width B are shown in Figure 3.

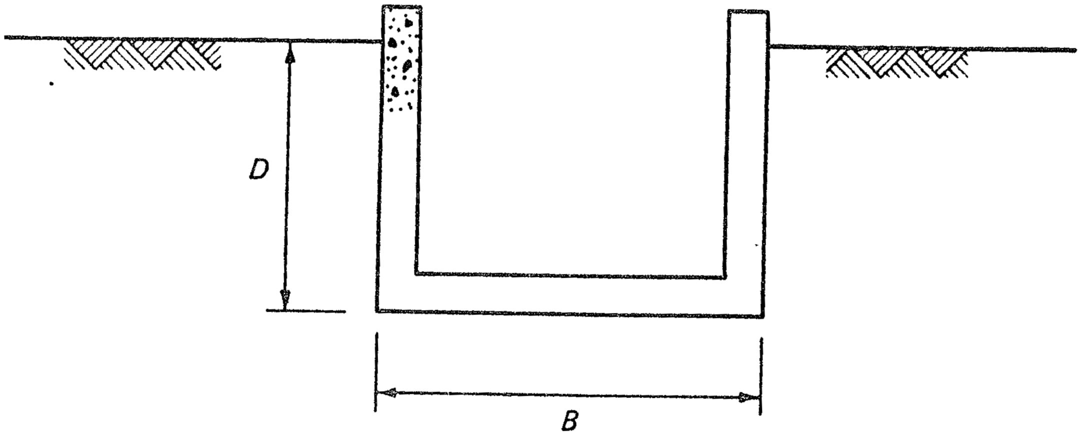

Figure 3. Embedment of footing

Inclination factors (ζ_{ci} , ζ_{qi} , $\zeta_{\gamma i}$)

11. The inclination factors are computed according to Meyerhof (1963):

$$\zeta_{ci} = \zeta_{qi} = \left(1 - \frac{\delta}{90}\right)^2$$

where δ is the angle of inclination of the load from the vertical as shown in Figure 4.

For $\delta \leq \phi$,

$$\zeta_{\gamma i} = \left(1 - \frac{\delta}{\phi}\right)^2$$

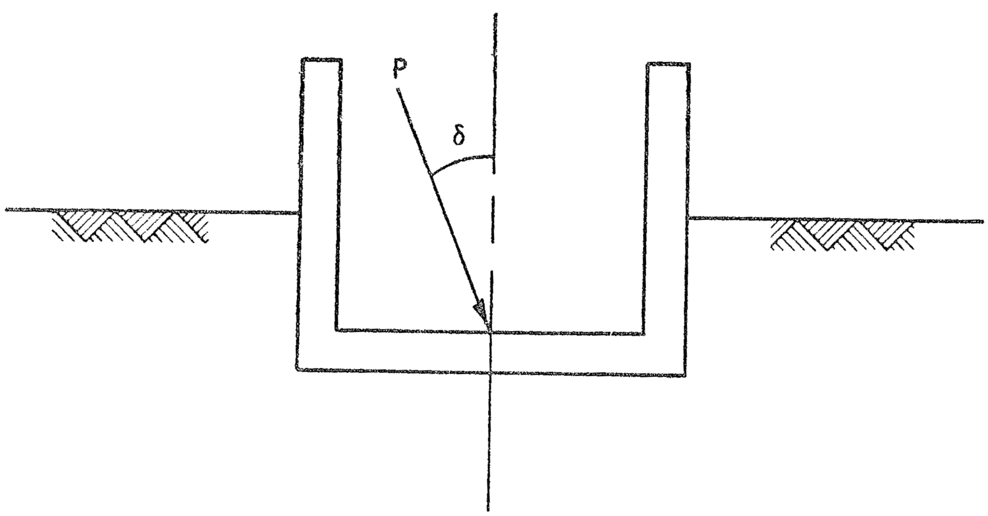

Figure 4. Footing with an inclined load

For $\delta > \phi$,

$$\zeta_{\gamma i} = 0$$

Base tilt factors (ζ_{ct} , ζ_{qt} , $\zeta_{\gamma t}$)

12. The base tilt factors computed by the program are according to Vesic (1975):

$$\zeta_{qt} = \zeta_{\gamma t} = (1 - \alpha \tan \phi)^2$$

where α is the slope of the base of the footing shown in Figure 5.

For $\phi = 0°$,

$$\zeta_{ct} = 1 - \left(2 \frac{\alpha}{\pi + 2}\right)$$

For $\phi > 0°$,

$$\zeta_{ct} = \zeta_{qt} - \frac{1 - \zeta_{qt}}{N_c \tan \phi}$$

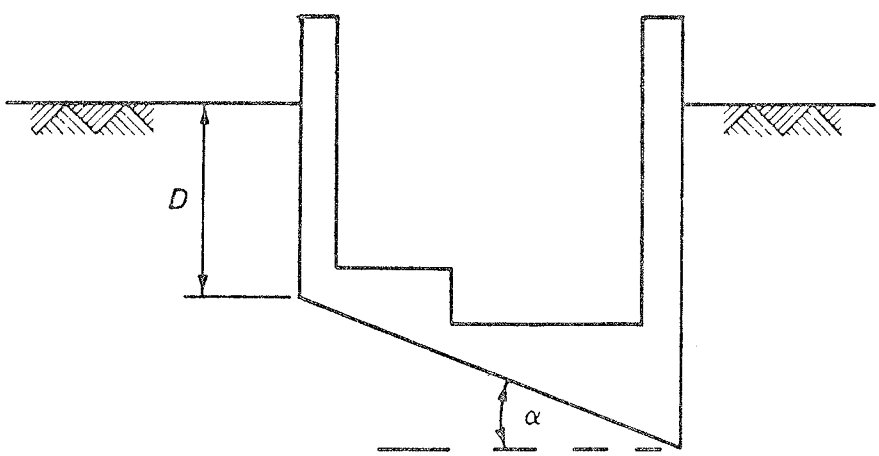

Figure 5. Footing with a tilted base

Ground slope factors (ζ_{cg} , ζ_{qg} , $\zeta_{\gamma g}$)

13. The program computes the ground slope factors according to Vesic (1975):

$$\zeta_{qg} = \zeta_{\gamma g} = (1 - \tan \beta)^2$$

where β is the slope of the surface of soil as shown in Figure 6.

For $\phi = 0°$,

$$\zeta_{cg} = 1 - \left(2 \frac{\beta}{\pi + 2}\right)$$

$$N_\gamma = -2 \sin \beta$$

For $\phi > 0°$,

$$\zeta_{cg} = \zeta_{qg} - \frac{1 - \zeta_{qg}}{N_c \tan \phi}$$

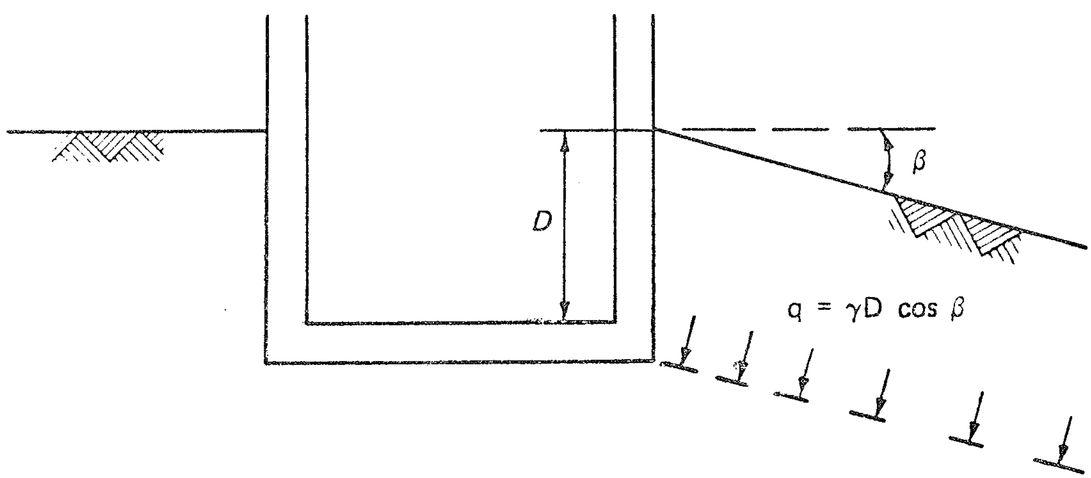

Figure 6. Footing with a sloped surface

Effective Foundation Dimensions

14. An approximate method of Meyerhof (1963) is employed by the program for adjusting the foundation dimensions for eccentric loadings:

For strips footings (Figure 7),

$$B' = B - 2.0e_x$$

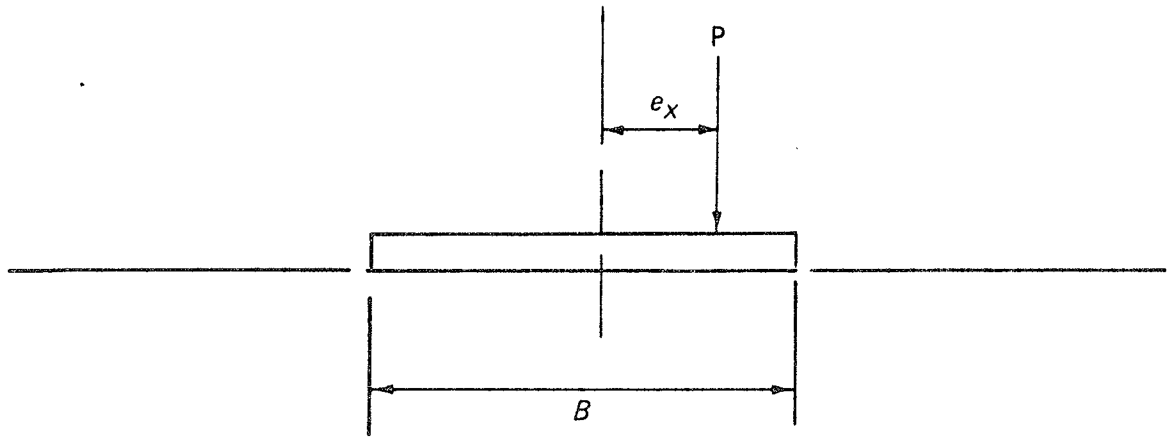

Figure 7. Strip footing with an eccentric loading

For rectangular footings (Figure 8),

$$B' = B - 2.0e_x$$

$$L' = L - 2.0e_z$$

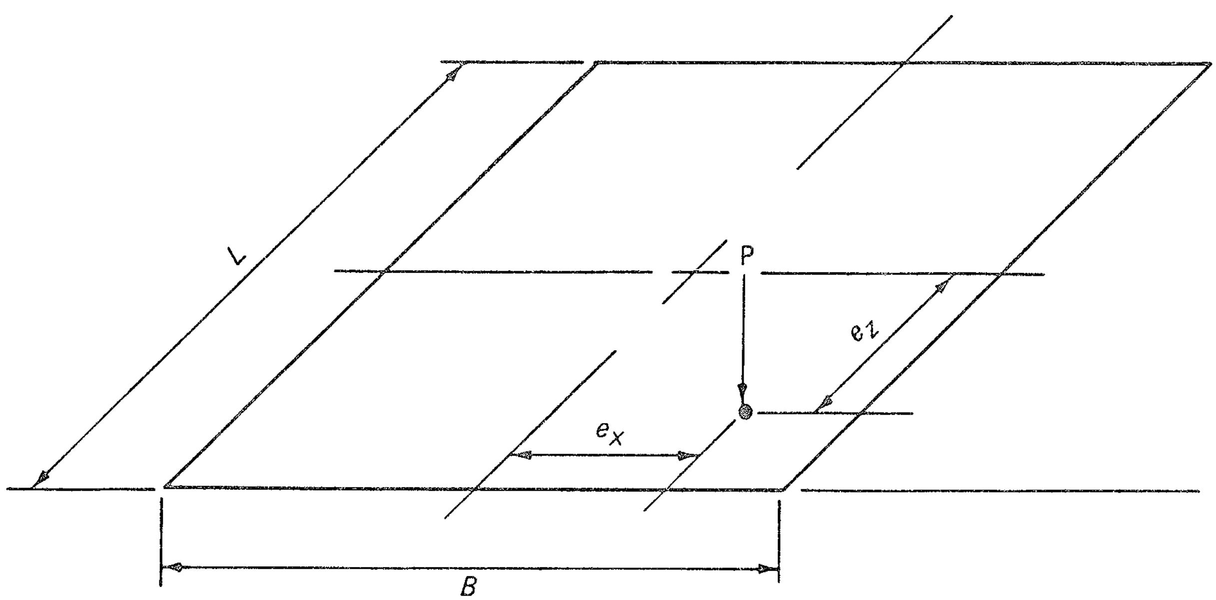

Figure 8. Rectangular footing with an eccentric loading

Net and Gross Ultimate Bearing Capacity

15. CBEAR will compute the net or gross ultimate bearing capacity

for a footing as requested by the user. The net ultimate bearing capacity q' is defined as the load that can be applied to the soil at the base of the footing in excess of the load applied by the overburden. The gross ultimate bearing capacity q is the total load that can be applied at the base.

$$q' = q - \gamma D$$

$$q = cN_c + q_o N_q + \gamma \frac{\beta}{2} N_\gamma$$

$$q' = \left(cN_c + q_o N_q + \gamma \frac{\beta}{2} N_\gamma\right) - \gamma D$$

$$q_o = \gamma D$$

$$q' = cN_c + \gamma D N_q - \gamma D + \gamma \frac{\beta}{2} N_\gamma$$

or,

$$q' = cN_c + \gamma D(N_q - 1) + \gamma \frac{\beta}{2} N_\gamma$$

Analyzing a Two-Layer Soil System

16. A two-layered soil system can be analyzed with CBEAR. Depending on the type of soil and its strength parameters, the program has alternative processors for computing the bearing capacity of footings:

   a. If the subsoil (lower layer) is greater than one footing width below the base of the footings, the effect of this layer is ignored.

   b. If the shear strength of the soil at the base of the footing, which is defined as

$$S_1 = c + q_o(\tan \phi)$$

   does not vary more than 50 percent from the shear strength of the soil one footing width below the center of the base of the footing, which is defined as

$$S_2 = c' + q_o' (\tan \phi')$$

   (where q_o' is in situ vertical effective stress one footing width below the center of the footing), the method of Sowers (1962) described in Appendix B (page B12) is used.

c. If the criterion described in b above is not met, and a softer clay ($\phi = 0°$) overlies stiffer clay ($\phi = 0°$), or a stiffer clay ($\phi = 0°$) overlies a softer clay ($\phi = 0°$), method II and method III described in Appendix B (pages B13 and B14), respectively, are used.

d. For all other cases, the method of Perloff and Baron (1976), described in Appendix B (pages B14-B17), is used for translation of an equivalent footing to the surface of the lower layer.

PART III: INPUT GUIDE

Source of Input

17. Data may be input from a prepared data file or from the user's terminal during execution. If the data are input from a terminal, the user may enter data by using key command words or by following a prompting sequence.

Data Format

18. All input data, whether supplied from a data file or from the terminal, are read in free-field format. In addition:

- a. Data items must be separated by one or more blank spaces (commas are not allowed as delimiters).
- b. Integer numbers must be in nondecimal form.
- c. Real numbers may be in decimal form, nondecimal form, or E format.
- d. User responses to all requests for program control may be abbreviated by the first letter of the word. For example, in response to

DO YOU WANT A PLOT OF THE INPUT? YES OR NO.

the user may enter Y or N. Striking a carriage return in response to any YES or NO question implies a negative response; i.e., the answer NO will be assumed.

Data Entry from Terminal

19. Two methods of data entry from the terminal are available to the user. The first is for the less experienced user of the program. This method employs a prompting sequence which requires the user to answer requests for data in a given order. It is explained in detail later in this report. The second method allows the user freedom in the order of data entry and requires less time. The input information is

entered by typing in command words and the accompanying data. The program provides a list of these command words at the beginning of the data entry sequence:

```
NAME = TITLE OF RUN          END   = INPUT COMPLETE
BASE = BASE DATA             LOAD  = LOAD DATA
SCHG = SURCHARGE DATA        NCOM  = NO COMMENT
SOIL = SOIL DATA             STOP  = ENDS PROGRAM
SUBS = SUBSOIL DATA          NSUB  = NO SUBSOIL
WATR = WATER DATA            NSCHG = NO SURCHARGE
COMM = COMMENT CARD          NWATR = NO WATER
CONT = CONTINUOUS            NLOAD = NO LOAD
FINI = FINITE                COMO  = RESTORES COMM
CIRC = CIRCULAR
```

If the command words requiring data input are entered alone, a list of variable words and the definitions of the variables associated with the command are listed at the terminal.

Data Entry from File

20. Data may be entered from a prepared data file. The procedure for constructing a data file is the same as that for entering data from the terminal by the method described above; command words and all subsequent data are simply typed in. In addition, all lines of input must be preceded by a line number.

21. The title of the run must always be entered first to indicate a new run. There is no limit to the number of runs which may be included in a data file, and it is important that each have a title.

22. The command word STOP may be used to terminate the run from the data file or the terminal. If the command word STOP is omitted from the data file, control is returned to the terminal. As many data files as desired may be used in one run of the program. After one file is exhausted, the user is given the chance to enter additional runs either from the terminal or from another data file. If the command word STOP is used at the end of any data file, then the user will not have the option to enter additional problems and program execution will be terminated.

Input Description

General

23. Besides being used in data entry, command words also control and modify the input and output of the program. The following is an explanation of the command words, requirements, and variables for data input. If data are input from a file, then all lines of data must be preceded by a line number.

24. The input information is divided into these sections:

a. Title of run.

b. Footing type.

c. Base description.

d. Soil description.

e. Subsoil description.

f. Water table description.

g. Applied load.

h. Surcharge soil description.

i. Termination.

All units are in pounds and feet except where otherwise noted.

25. When data are entered from the terminal, the title may be entered at any time. The footing type must be the first of the remaining data items to be input. The base and soil descriptions must be entered next but may be entered in any order. The footing type, base description, and soil description are always required as input data. When entering from a prepared data file, the title of the run, footing type, base description, and soil description must be entered first. The title of the run is required and must always be the first item entered when data are entered from a prepared data file.

26. Surcharge soil, subsoil, and water table descriptions and the applied load are optional and should be entered after the data items mentioned above.

27. In the following input description, [LN] is used to denote the need for a line number when data are supplied from a predetermined input file. Single quotes ('NN') denote use of alphanumeric

information; underscore denotes the minimal amount of characters required.

Input information

28. Title of run:

   a. [LN] 'NAME' - title (60 characters or less).

   b. NOTE: If data are entered from a data file, then the title must be entered before any other command. If two or more runs are joined together, then the title will indicate a new run.

29. Footing type:

   a. [LN] 'CONTINUOUS' 'GROSS'

      [LN] 'FINITE' 'NET'

      [LN] 'CIRCULAR'

   b. NOTE: The footing type may be abbreviated to the first four characters. GROSS or NET must be entered to indicate the pressure type. If no pressure type is entered, then NET is assumed. A circular footing is analyzed as a square footing. If the effective base dimensions of a footing result in a square, then the footing is analyzed as a square.

30. Base description:

   a. [LN] 'BASE' X1 Y1 X2 Y2 LENGTH

   b. Definitions (see Figure 9):

      'BASE' - command word
      X1 - X coordinate, left side of baseline
      Y1 - Y coordinate, left side of baseline
      X2 - X coordinate, right side of baseline

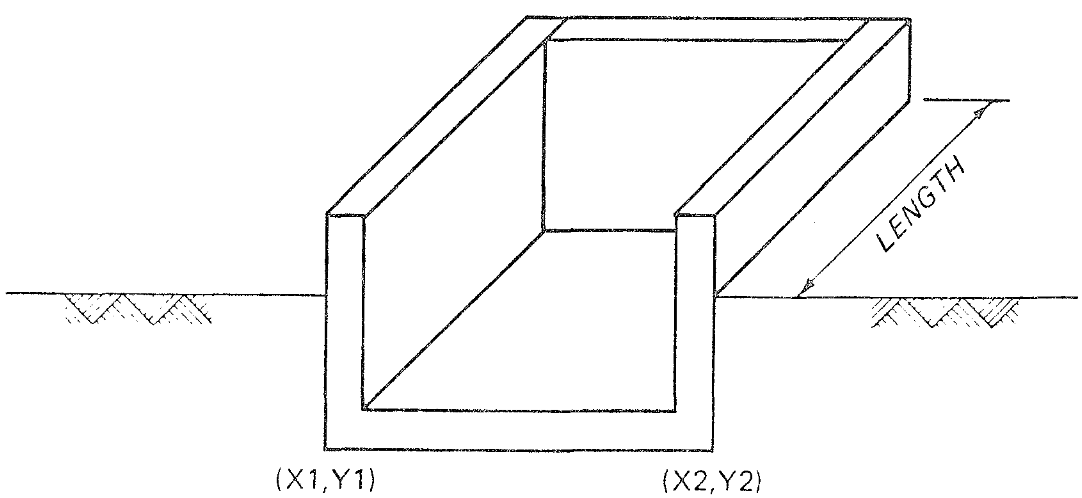

Figure 9. Base description

Y2 - Y coordinate, right side of baseline
LENGTH - length of base in Z direction

c. NOTE: Input length only if TYPE = FINITE; i.e., for a square or rectangular footing.

31. Soil description:

a. [LN] 'SOIL' XS1 YS1 XS2 YS2 SOILGM SOILGS PHI C

b. Definitions:

'SOIL' - command word
XS1 - X coordinate, left side of soil line
YS1 - Y coordinate, left side of soil line
XS2 - X coordinate, right side of soil line
YS2 - Y coordinate, right side of soil line
(see Figure 10)
SOILGM - moist unit weight (pcf)
SOILGS - saturated unit weight (pcf)
PHI - angle of internal friction (deg)
C - cohesion (psf)

32. Surcharge description (optional):

a. [LN] 'SCHG' SCHGNO YSCHG SURCGM SURCGS

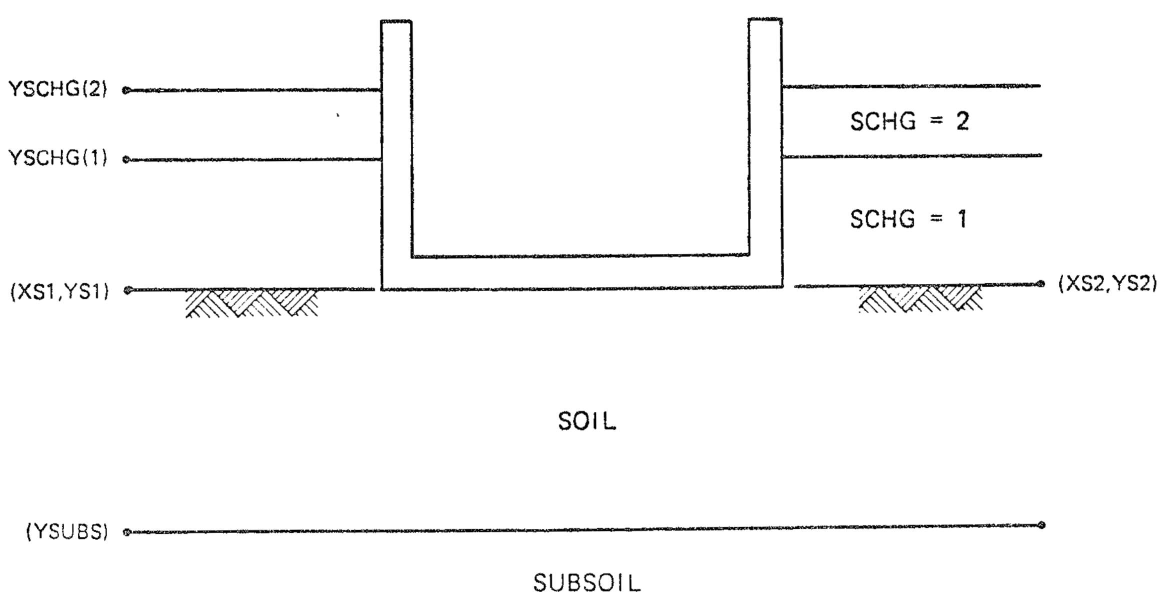

Figure 10. Soil profile

b. Definition:

'SCHG' - command word
SCHGNO - number of the surcharge layer (1 or 2)
YSCHG - Y coordinate, top of surcharge layer (see Figure 10)
SURCGM - moist unit weight (pcf)
SURCGS - saturated unit weight (pcf)
(Surcharge 2 parameters are the same as surcharge 1 parameters)

c. RESTRICTION: Not allowed if surcharges are included with a sloping soil layer; the surcharge data will be ignored.

33. Subsoil description (optional):

a. [LN] 'SUBS' YSUBS SUBSGM SUBSGS SUBPHI SUBC

b. Definitions:

'SUBS' - command word
YSUBS - Y coordinate, top of subsoil layer (see Figure 10)
SUBSGM - moist unit weight (pcf)
SUBSGS - saturated unit weight (pcf)
SUBPHI - angle of internal friction (deg)
SUBC - cohesion (psf)

c. RESTRICTION: Subsoil data will be ignored if the soil layer is sloping.

34. Water table description (optional):

a. [LN] 'WATR' YWATER WTRWGT

b. Definitions:

'WATR' - command word
YWATER - Y coordinate of water table
WTRWGT - unit weight of water (pcf)

c. NOTE: If WTRWGT is not input, then the default is 62.4 (pcf).*

35. Applied load (optional):

a. [LN] 'LOAD' P XP ZP ALPHA

b. Definitions (see Figure 11):

'LOAD' - command word
P - applied load (kips)
XP - X coordinate, base application point

---

* A table of factors for converting inch-pound units of measurement to metric (SI) units is presented on page 3.

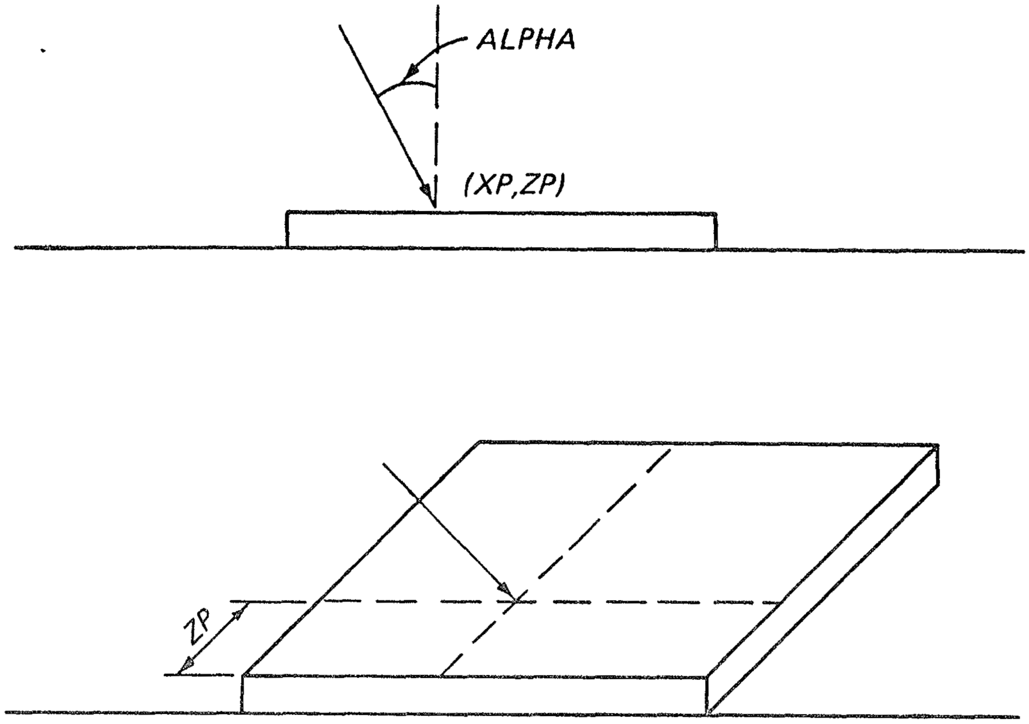

Figure 11. Load description

ZP - Z coordinate, base application point
ALPHA - inclination of load clockwise from vertical (deg)

c. NOTE: Whenever an eccentric load is encountered with a layered system (a soil and a subsoil), only the equivalent concentric footing is considered in calculations. When projecting an equivalent footing onto the interface of the soil and subsoil, only the equivalent concentric footing is considered. If an inclined load or inclined base is specified along with a layered system, the program will ignore load inclination entirely and will treat the base as level and as being at the elevation of the centroid of the base.

36. Other optional commands:

a. [LN] 'NLOAD' - erases load data.

b. [LN] 'NWATR' - erases water table data.

c. [LN] 'NSUB' - erases subsoil data.

d. [LN] 'NSCHG' - erases surcharge data.

e. [LN] 'COMM' - provides for comment, as follows:

(1) The user may enter up to 22 lines of alphanumeric characters that are 60 characters or less in length.

(2) Comments are printed out after the title.

(3) If a totally new comment is entered, then the NCOM command should be entered first.

f. [LN] 'NCOM' - suppresses current comment.

g. [LN] 'COMO' - restores previous comments.

h. NOTE: All of the above commands may be entered anywhere prior to the 'END' command.

37. Termination:

a. 'END' - causes termination of the input sequence and begins the execution sequence.

b. NOTE: This command signifies the end of data input. If data were being entered from a file, then this would signify the end of the run. If another run was to follow, the title of the next run would follow the END card. As many runs as desired may be prepared. The end of the final run will signify the end of the file, or the command STOP may be added at the end of the final run.

Examples of Terminal and File Input

38. If the user decides to enter data from the terminal without prompting, then a list of all the command words is printed. The program will then prompt the user, and the user will type in a command word and any subsequent data. An example follows:

```
LIST OF COMMAND WORDS

NAME = TITLE OF RUN       CONT = CONTINUOUS        STOP  = ENDS PROGRAM
BASE = BASE DATA          FINI = FINITE            NSUB  = NO SUBSOIL
SCHG = SURCHARGE DATA     CIRC = CIRCULAR          NSCHG = NO SURCHARGE
SOIL = SOIL DATA          END  = INPUT COMPLETE    NLOAD = NO LOAD
SUBS = SUBSOIL DATA       LOAD = LOAD DATA         COMO  = RESTORES COMM
COMM = COMMENT CARD       NCOM = NO COMMENT        NWATR = NO WATER
WATR = WATER DATA
= NAME TEST RUN 1
= FINITE
= BASE  15  15  35  15  20
= SOIL   5  25  55  75  120  120  0  800
= SUBS   5  135  135  0  2500
= WATR   5  62.4
= END
```

39. Entry from a data file is in the same format except that all lines of input must be preceded by a line number:

```
100 NAME TEST RUN 1
110 FINITE NET
120 BASE 15  15  35  15  20
130 SOIL  5  25  55  25  125  120  0  800
140 SUBS  5  135  135  0  2500
150 WATR  5  62.4
160 END
```

Options

Prompting

40. If the user should choose to enter data from the terminal, then the question

```
DO YOU WANT PROMPTING?  YES OR NO.
```

is asked. If prompting is requested, then a sequence of questions will be asked for all the data. The title, type of footing, base description and soil description must be entered. Any data that are not needed can be deleted. To delete the water table description, zeros may be entered. To delete the applied load, any negative number may be entered. An example follows:

```
DO YOU WANT PROMPTING?  YES OR NO.
=Y

ENTER TITLE - 60 CHARACTERS OR LESS
=EXAMPLE PROBLEM

BASE CONFIGURATION - FINITE,CIRCULAR,CONTINUOUS
=FINI

ENTER PRESURE TYPE - GROSS OR NET
=NET

BASE LINE,ENTER VALUES UNDER HEADINGS

     LEFT SIDE                  RIGHT SIDE
ELEVATION  X-COORD       ELEVATION  X-COORD
   (FT)       (FT)          (FT)       (FT)
=0  10  0  25
```

BASE DIMENSION

LENGTH
=60

SOIL DESCRIPTION,ENTER

NUMBER LAYERS BELOW THE BASE,1 OR 2
(2 IS THE SUBSOIL)
=1

LAYER NO. 1

LEFT SIDE ELEVATION (FT)	X-COORD (FT)	RIGHT SIDE ELEVATION (FT)	X-COORD (FT)

=6 0 6 55

SOIL PROPERTIES

LAYER NO.	INTERNAL FRICTION ANGLE (DEG)	COHESION (PSF)	UNIT WEIGHT MOIST (PCF)	UNIT WEIGHT SATURATED (PCF)

=1 15 1000 130 130

SURCHARGE DESCRIPTION,ENTER

NUMBER OF SURCHARGE LAYERS (0,1,OR 2)
=2

SURCHARGE PROFILE

LAYER NO.	SURFACE ELEVATION (FT)	UNIT WEIGHT MOIST (PCF)	UNIT WEIGHT SATURATION (PCF)

=1 15 90 90
=2 11 120 120
WATER TABLE DESCRIPTION,ENTER

ELEVATION OF WATER TABLE	UNIT WEIGHT OF WATER

=0 0.0 [No water included in problem]

LOAD DESCRIPTION,ENTER

APPLIED LOAD (KIPS)
=-9 [No load applied]

DO YOU WANT AN ECHO OF THE INPUT? ENTER YES OR NO.
=N

Editing

41. After data have been entered, the user has the option to review and edit the input data. The question,

DO YOU WANT TO EDIT THE DATA? YES OR NO.

will be asked. If the user answers with YES, then the list of command words will be listed. All the user must do to correct data is reenter the command word and variables that contained the mistake. If one variable is incorrect, then all variables for that particular command word must be reentered. The command word alone may be entered to obtain a list of the variables and the definitions that are associated with that command word.

Rerun problem with a different combination of factors

42. The user is given a chance to make his own combination of factors. The question

DO YOU WANT YOUR OWN COMBINATION OF FACTORS? YES OR NO.

is asked. If the user answers YES, then a table containing all the factors is printed out, and the user selects the desired ones to be used in recalculating the final answer. Up to six values may be entered on a line. To continue the solution, a carriage return is entered. As many combinations as desired may be made. After each combination, the user is asked if another combination of factors is desired. An example showing this sequence follows:

SUMMARY OF BEARING CAPACITY FACTORS

FACTORS	C	Q	G
BEARING CAP.	NC	NQ	NG
SHAPE - CONC	FC	FQ	FG
EMBEDMENT	FCD	FQD	FGD
INCLINATION	FCI	FQI	FGI
BASE TILT	FCT	FQT	FGT
GROUND SLOPE	FCG	FQG	FGG

```
ENTER BEARING CAPACITY FACTORS TO BE USED IN
COMPUTATION.(MAX. 6 TO A LINE)
=NC NQ NG
=

          COMBINED EFFECTS
          Q = FNC + FNQ + FNG =              16.667 (KIPS/FT**2)

DO YOU WANT YOUR OWN COMBINATION OF FACTORS?  YES OR NO.
=N
```

If the user answers YES to this question, then the sequence repeats.

Rerun problem with modifications

43. The user has the option to rerun the current problem but with modifications. The question

```
DO YOU WANT TO MODIFY CURRENT DATA AND RERUN PROBLEM?  YES OR NO.
```

is asked. If the user answers YES, then a list of the command words is printed, and the user may modify the current data by entering a command word and the new data. When all modifications have been made, the user simply enters the command word END, and the program is run with the modified data. All options may be applied to the modified run, such as obtaining an echoprint of input or exercising the option to rerun the problem with a different combination of factors.

44. Example computer runs are shown in Appendix A along with hand computations.

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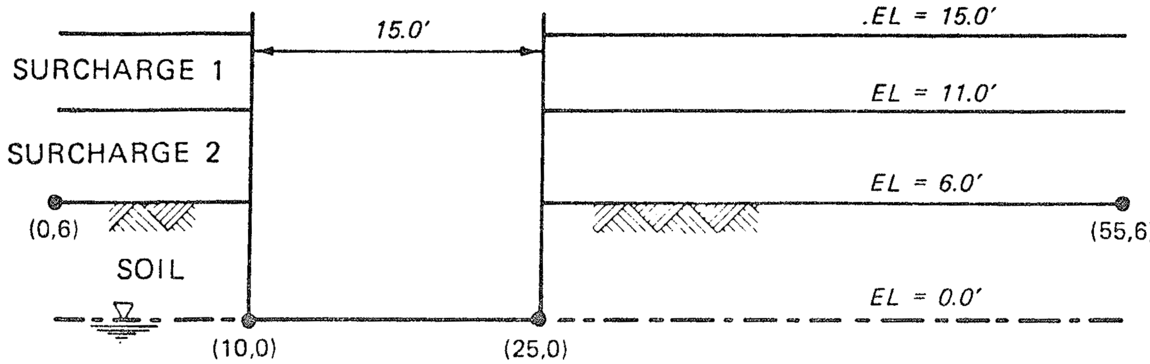
__________. 1970. "Research on Bearing Capacity of Soils," (unpublished).

__________. 1975. "Bearing Capacity of Shallow Foundations," Foundation Engineering Handbook, H. F. Winterkorn and H. Y. Fang, ed., Van Nostrand Reinhold, New York, pp 121-147.

APPENDIX A: EXAMPLE RUNS AND HAND VERIFICATIONS

Example 1: Footings with Surcharge Soil Layers



Soil Properties

	Cohesion c, psf	Angle of Internal Friction ϕ, deg	Unit Weight, pcf Moist	Saturated
Surcharge 1			90.0	90.0
Surcharge 2			120.0	120.0
Soil	1000.0	15.0	130.0	130.0

Input Data File BCP1

```
100 NAME TEST RUN 1 (Data List 'NAME' - Title)
110 FINITE NET (Footing Type)
120 BASE 10 0 25 0 60 (Data List 'BASE' - X1 Y1 X2 Y2 LENGTH)
130 SOIL 0 6 55 6 130 130 15 1000 (Data List 'SOIL' - XS1 YS1 XS2 YS2 SOILGM SOILGS PHI C)
140 SCHG 1 15 90 90 (Data List 'SCHG' 1-XSCHG SURCGM SURCGS)
150 SCHG 2 11 120 120 (Data List 'SCHG' 2-XSCHG SURCGM SURCGS)
160 WATR 0 62.4 (Data List 'WATR'-YWATER WTRWGT)
170 END ('END' - End of Data Entry)

*
```

```
        08/10/81    16.214


    PROGRAM CBEAR - BEARING CAPACITY ANALYSIS

    TIME: 16:13: 3                         DATE:  8/10/81

IS INPUT FROM TERMINAL OR A FILE?
ENTER T OR F
=F

ENTER DATA FILE NAME
=BCP1

WILL OUTPUT GO TO THE TERMINAL, FILE, OR BOTH?
ENTER T, F, OR B
=B

ENTER NAME FOR OUTPUT FILE OR
ENTER A CARRIAGE RETURN IF OUTPUT IS NOT TO BE SAVED
=BCP10


***** INPUT COMPLETE *****

DO YOU WANT AN ECHOPRINT OF THE INPUT? YES OR NO.
=Y
```

PROGRAM CBEAR - BEARING CAPACITY ANALYSIS

TIME: 16:15:11 DATE: 8/10/81

I.--INPUT DATA

1.--HEADING

TEST RUN 1

2.--BASE DESCRIPTION

2.A--BASE LINE

LEFT SIDE POINT NO.	LEFT SIDE ELEVATION (FT)	LEFT SIDE X-COORD (FT)	RIGHT SIDE POINT NO.	RIGHT SIDE ELEVATION (FT)	RIGHT SIDE X-COORD (FT)
1	0.	10.0	1	0.	25.0

2.B--BASE CONFIGURATION

FINITE

FOUNDATION BASE WIDTH = 15.0(FT)
FOUNDATION BASE LENGTH = 60.0(FT)

3.--SOIL DESCRIPTION

3.A--SOIL PROFILE

LAYER NO. 1

LEFT SIDE POINT NO.	LEFT SIDE ELEVATION (FT)	LEFT SIDE X-COORD (FT)	RIGHT SIDE POINT NO.	RIGHT SIDE ELEVATION (FT)	RIGHT SIDE X-COORD (FT)
1	6.0	HORIZ.	1	6.0	HORIZ.

3.B--SOIL PROPERTIES

LAYER NO.	INTERNAL FRICTION ANGLE (DEG)	COHESION (PSF)	UNIT WEIGHT MOIST (PCF)	UNIT WEIGHT SATURATED (PCF)
1	15.0	1000.0	130.0	130.0

4.--SURCHARGE DESCRIPTION

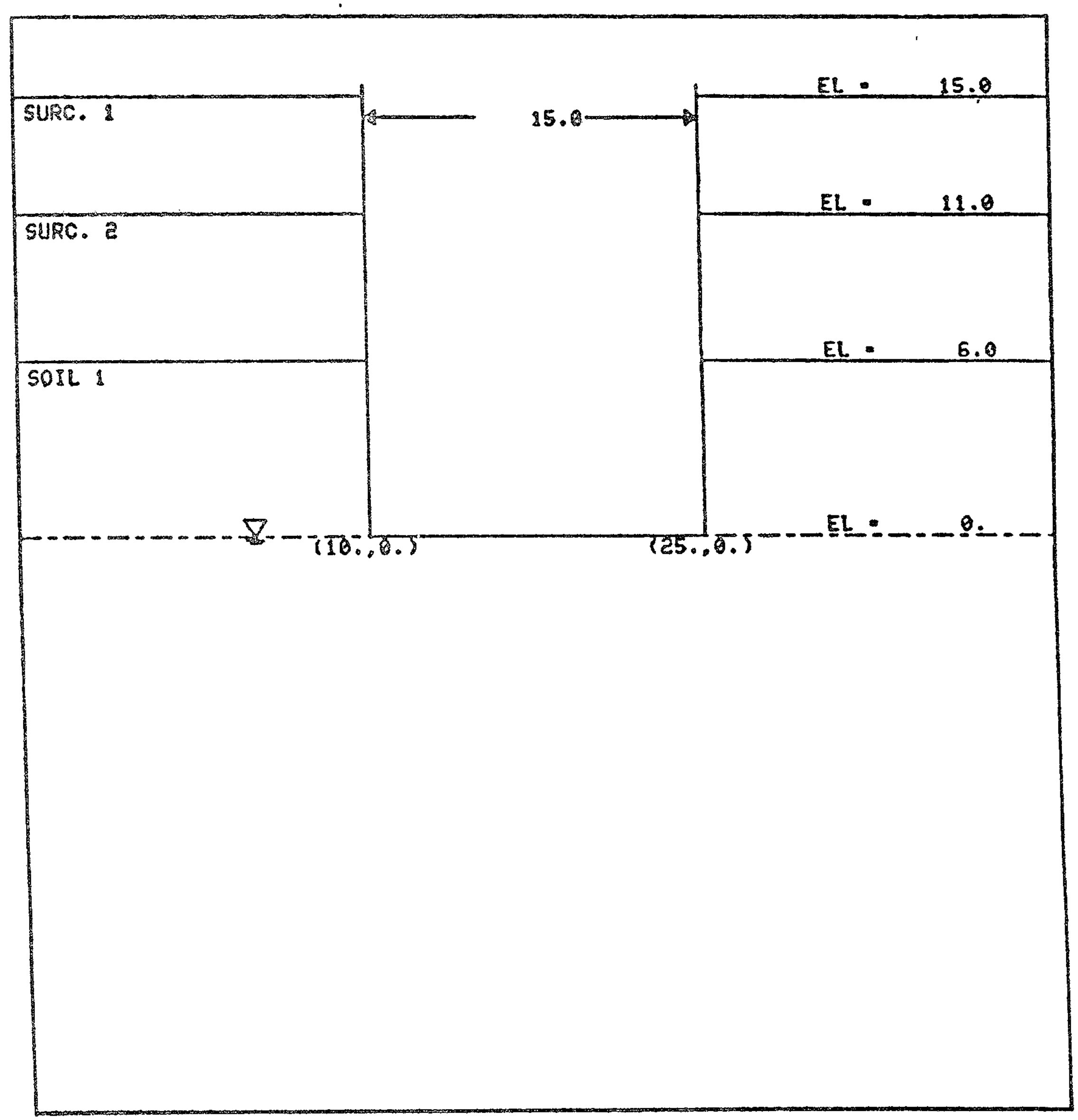
LAYER NO.	SURFACE ELEVATION (FT)	UNIT WEIGHT MOIST (PCF)	UNIT WEIGHT SATURATION (PCF)
1	15.0	90.0	90.0
2	11.0	120.0	120.0

TABLE SOIL PROPERTIES

LAYER	C (PSF)	PHI (DEG)	UNIT WEIGHT MOIST (PCF)	UNIT WEIGHT SAT. (PCF)
SUR. 1			90.0	90.0
SUR. 2			120.0	120.0
SOIL 1	1000.0	15.0	130.0	130.0

ALL MEASUREMENTS ON PLOT ARE IN FEET.
THIS PLOT IS NOT DRAWN TO SCALE.

TEST RUN 1



```
5.--WATER TABLE DESCRIPTION

   ELEVATION OF WATER TABLE =      0.  (FT)
   UNIT WEIGHT OF WATER     =     62.4 (PCF)

DO YOU WANT TO EDIT YOUR DATA? YES OR NO.
=N



DO YOU WANT A PLOT OF THE INPUT? YES OR NO.
=Y
```

PROGRAM CBEAR - BEARING CAPACITY ANALYSIS

TIME: 9:48:39 DATE: 4/16/82

II.--RESULTS

1.--HEADING

TEST RUN 1

2.--SUMMARY OF RESULTS

2.A--EFFECTIVE BASE DIMENSION

EFFECTIVE BASE WIDTH = 15.0 (FT)
EFFECTIVE BASE LENGTH = 60.0 (FT)

2.B--SUMMARY OF BEARING CAPACITY FACTORS

FACTORS	C	Q	G	UBC - NET (KIPS/FT**2)
BEARING CAP.	10.98	3.94	1.13	16.667
SHAPE - CONC	1.08492	1.04246	1.04246	17.840
*INCLINATION	1.00000	1.00000	1.00000	17.840
*BASE TILT	1.00000	1.00000	1.00000	17.840
*GROUND SLOPE	1.00000	1.00000	1.00000	17.840
*EMBEDMENT	1.26065	1.13032	1.13032	21.717

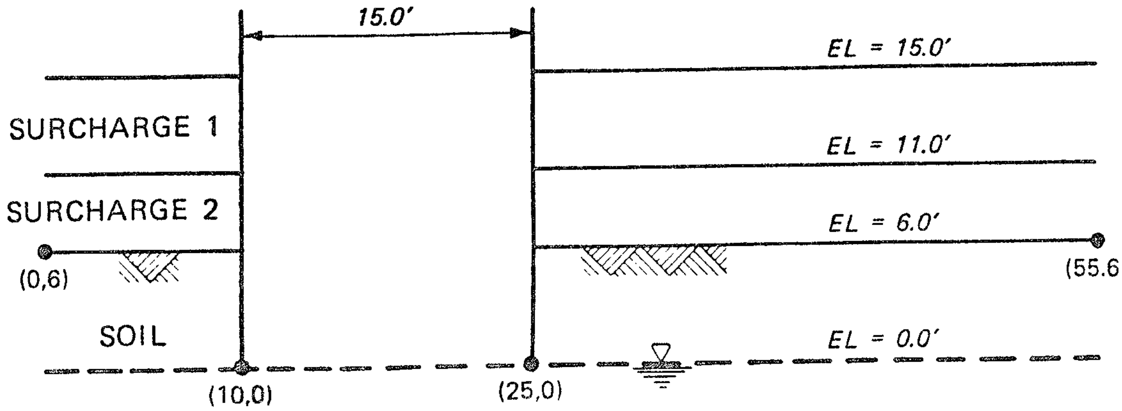
	FNC +	FNQ +	FNG =	Q
COMBINE EFFECTS OF FACTORS	15.013	6.030	0.674	21.717

* FOR THE APPLICATION OF THESE FACTORS TO YOUR PROBLEM SEE APPENDIX B IN THE PROGRAM DOCUMENTATION.

DO YOU WANT YOUR OWN COMBINATION OF FACTORS? YES OR NO.
=

```
      SUMMARY OF BEARING CAPACITY FACTORS

    FACTORS           C              Q              G
------------ ------------ ------------ ------------

BEARING CAP.      NC             NQ             NG

SHAPE - CONC      FC             FQ             FG

EMBEDMENT         FCD            FQD            FGD

INCLINATION       FCI            FQI            FGI

BASE TILT         FCT            FQT            FGT

GROUND SLOPE      FCG            FQG            FGG

ENTER BEARING CAPACITY FACTORS TO BE USED IN
COMPUTATION.(MAX. 6 TO A LINE)
=NC NQ NG
=

    COMBINED EFFECTS
    ----------------
    Q = FNC + FNQ + FNG =          18.407 (KIPS/FT**2)

DO YOU WANT YOUR OWN COMBINATION OF FACTORS? YES OR NO.
=N



DO YOU WANT TO MODIFY CURRENT DATA AND RERUN
THE PROBLEM? YES OR NO.
=N

DO YOU WANT TO MAKE ANOTHER RUN? YES OR NO.
=N

*
```

Example 1: Hand Verification



Soil Properties

	Cohesion c , psf	Angle of Internal Friction ϕ , deg	Unit Weight, pcf Moist	Unit Weight, pcf Saturated
Surcharge 1			90.0	90.0
Surcharge 2			120.0	120.0
Soil	1000.0	15.0	130.0	130.0

Bearing capacity factors

The following are the theoretical bearing capacity factors for a shallow horizontal footing under a vertical load:

$$N_\phi = \tan^2\left(\frac{\pi}{4} + \frac{\phi}{2}\right)$$

$$= \tan^2\left(45 + \frac{15}{2}\right)$$

$$= 1.70$$

$$N_q = e^{\pi \tan\phi} N_\phi$$

$$= e^{\pi \tan(15)}(1.70)$$

$$= 3.94$$

$$N_c = (N_q - 1)\cot\phi$$

$$= (3.94 - 1)\cot 15$$

$$= 10.98$$

$$N_\gamma = (N_q - 1)\tan(1.4\phi)$$

$$= (3.94 - 1)\tan[1.4(15)]$$

$$= 1.13$$

Shape factors

Shape factors are used to account for other geometrical configurations:

$$\delta_c = 1 + 0.2N_\phi \frac{B'}{L'}$$

$$= 1 + 0.2(3.94)\left(\frac{15}{60}\right)$$

$$= 1.085$$

$$\delta_q = \delta_\gamma = 1 + 0.1N_\phi \frac{B'}{L'} \quad \text{for} \quad \phi > 10$$

$$= 1 + 0.1(3.94)\left(\frac{15}{60}\right)$$

$$= 1.042$$

Embedment factors

Since the structure is embedded, these factors will be calculated:

$$\delta_{cd} = 1 + 0.2\,\frac{D}{B}\tan\left(45 + \frac{\phi}{2}\right)$$

$$= 1 + 0.2\left(\frac{15}{15}\right)\tan\left(45 + \frac{15}{2}\right)$$

$$= 1.261$$

$$\delta_{qd} = \delta_{\gamma d} = 1 + 0.1\,\frac{D}{B}\tan\left(45 + \frac{\phi}{2}\right)$$

$$= 1 + 0.1\left(\frac{15}{15}\right)\tan\left(45 + \frac{15}{2}\right)$$

$$= 1.130$$

Base tilt factors

$$\delta_{ct} = \delta_{qt} = \delta_{\gamma t} = 1$$

Inclination factors

$$\delta_{ci} = \delta_{qi} = \delta_{\gamma i} = 1$$

Ground slope factors

$$\delta_{cg} = \delta_{qg} = \delta_{\gamma g} = 1$$

Influence of water table

Since the water level is at the top of the soil layer, the submerged unit weight will be used:

$$\gamma_{sub} = \gamma_m - \gamma_w$$

$$= 130 - 62.4 = 67.6 \text{ pcf}$$

Effective overburden pressure

This is the pressure due to the soil and/or surface loads above the base of the footing:

$$q_o = \sum_{i=1}^{n} d_i \gamma'_{mi}$$

$$= 6 \text{ ft } (130 \text{ pcf}) + 5 \text{ ft } (120 \text{ pcf}) + 4 \text{ ft } (90 \text{ pcf})$$

$$= 1740 \text{ psf}$$

$$= 1.740 \text{ ksf}$$

Bearing capacity - net

Each bearing capacity is calculated, beginning with the bearing capacity factors and then adding one set of factors at a time:

$$Q = cN_c + q_o(N_q - 1) + \frac{B'}{2}\gamma N_\gamma$$

$$= 1000(10.98) + 1740(3.94 - 1) + \frac{15}{2}(130.0 - 62.4)(1.13)$$

$$= 10{,}980.00 + 5115.60 + \frac{1145.82}{2}$$

$$= 16{,}668 \text{ psf}$$

$$= 16.67 \text{ ksf}$$

$$Q = \delta_c cN_c + \delta_q q_o(N_q - 1) + \delta_\gamma \frac{B'}{2}\gamma N_\gamma$$

$$= 1.085(1000)(10.98) + 1.042(1740)(3.94 - 1) + 1.042\left(\frac{15}{2}\right)(67.6)(1.13)$$

$$= 11{,}913.30 + 5330.45 + 596.97$$

$$= 17{,}841 \text{ psf}$$

$$= 17.84 \text{ ksf}$$

$$Q = \delta_{cd}\delta_c N_c + \delta_{qd}\delta_q q_o(N_q - 1) + \delta_{\gamma d}\delta_\gamma \frac{B'}{2}\gamma N_\gamma$$

$$= 1.261(1.085)(1000)(10.98) + 1.13(1.042)(1740)(2.94) + 1.13(1.042)(7.5)(67.6)(1.13)$$

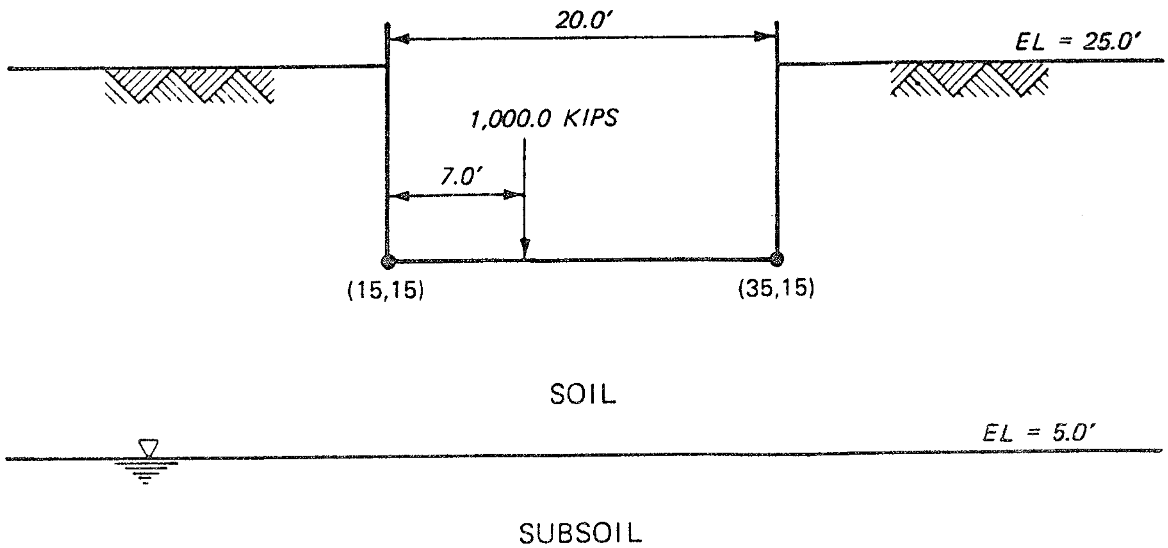
$$= 15{,}022 + 6023 + 674.6$$

$$= 21{,}721 \text{ psf}$$

$$= 21.72 \text{ ksf}$$

Base tilt, inclination, and ground slope factors are equal to 1, so the final bearing capacity would not change. The final bearing capacity is 21.72 ksf.

Example 2: Footings with Subsoil and Eccentric Loads



Soil Properties

	Cohesion c , psf	Angle of Internal Friction ϕ , deg	Unit Weight, pcf Moist	Saturated
Soil	800.0	0.0	120.0	120.0
Subsoil	2500.0	0.0	135.0	135.0

Input Data File BCP2

```
100 NAME TEST RUN 2 (Data List 'NAME' - Title)
110 FINITE (Footing Type)
120 BASE 15 15 35 15 20 (Data List 'BASE' - X1 Y1 X2 Y2 LENGTH)
130 SOIL 5 25 55 25 120 120 0 800 (Data List 'SOIL' - XS1 YS1 XS2 YS2 SOILGM SOILGS PHI C)
140 SUBS 5 135 135 0 2500 (Data List 'SUBS' - YSUBS SUBSGM SUBSGS SUBPHI SUBC)
150 WATR 5 62.4 (Data List 'WATR' - YWATER WTRWCT)
160 LOAD 1000 22 10 0 (Data List 'LOAD' - P XP ZP ALPHA)
170 END ('END' - End of Data Entry)

*
```

```
        08/10/81     16.415

    PROGRAM CBEAR - BEARING CAPACITY ANALYSIS

    TIME: 16:25: 1                          DATE:  8/10/81

IS INPUT FROM TERMINAL OR A FILE?
ENTER T OR F
=F

ENTER DATA FILE NAME
=BCP2

WILL OUTPUT GO TO THE TERMINAL, FILE,OR BOTH?
ENTER T, F, OR B
=B

ENTER NAME FOR OUTPUT FILE OR
ENTER A CARRIAGE RETURN IF OUTPUT IS NOT TO BE SAVED
=BCP20


***** INPUT COMPLETE *****

DO YOU WANT AN ECHOPRINT OF THE INPUT? YES OR NO.
=Y
```

PROGRAM CBEAR - BEARING CAPACITY ANALYSIS

TIME: 16:26:21 DATE: 8/10/81

I.--INPUT DATA

1.--HEADING

TEST RUN 2

2.--BASE DESCRIPTION

2.A--BASELINE

	LEFT SIDE			RIGHT SIDE	
POINT NO.	ELEVATION (FT)	X-COORD (FT)	POINT NO.	ELEVATION (FT)	X-COORD (FT)
1	15.0	15.0	1	15.0	35.0

2.B--BASE CONFIGURATION

FINITE

FOUNDATION BASE WIDTH = 20.0
FOUNDATION BASE LENGTH = 20.0

3.--SOIL DESCRIPTION

3.A--SOIL PROFILE

LAYER NO. 1

	LEFT SIDE			RIGHT SIDE	
POINT NO.	ELEVATION (FT)	X-COORD (FT)	POINT NO.	ELEVATION (FT)	X-COORD (FT)
1	25.0	HORIZ.	1	25.0	HORIZ.

SUBSOIL LAYER

ELEVATION (FT)

5.0

3.B--SOIL PROPERTIES

LAYER NO.	INTERNAL FRICTION ANGLE (DEG)	COHESION (PSF)	UNIT WEIGHT MOIST (PCF)	UNIT WEIGHT SATURATED (PCF)
1	0.	800.0	120.0	120.0
SUBSOIL	0.	2500.0	135.0	135.0

5.--WATER TABLE DESCRIPTION

ELEVATION OF WATER TABLE = 5.0 (FT)
UNIT WEIGHT OF WATER = 62.4 (PCF)

```
6.--LOAD DESCRIPTION

  APPLIED LOAD                         =    1000.0 (KIPS)
   X-COORD OF APPLIED LOAD             =      22.0 (FT)
   Z-COORD OF APPLIED LOAD             =      10.0 (FT)
   ANGLE INCLINATION OF APPLIED LOAD   =       0.  (DEG)

DO YOU WANT TO EDIT YOUR DATA? YES OR NO.
=N




DO YOU WANT A PLOT OF THE INPUT? YES OR NO.
=Y
```

TABLE SOIL PROPERTIES

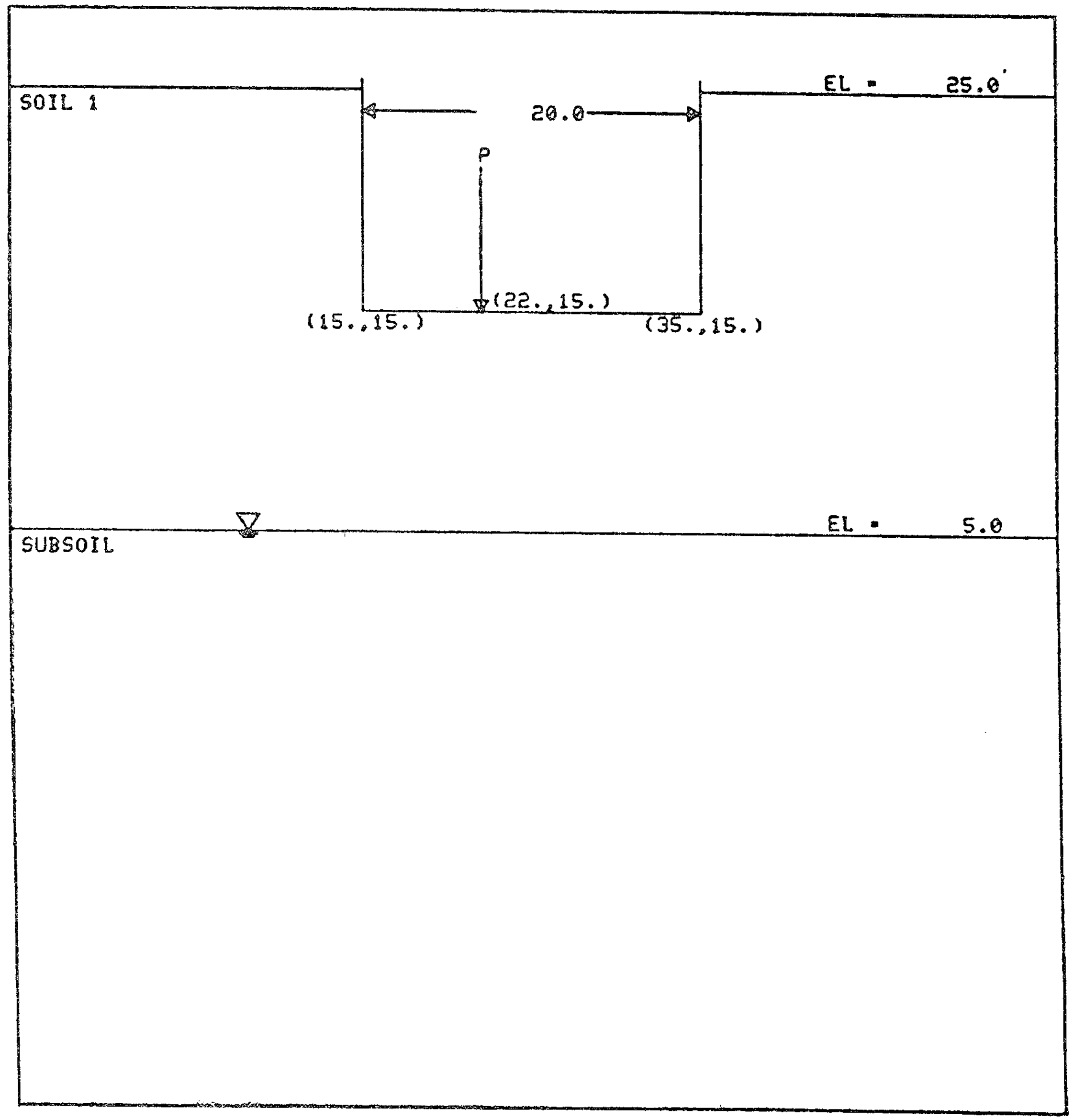
LAYER	C (PSF)	PHI (DEG)	UNIT WEIGHT MOIST (PCF)	UNIT WEIGHT SAT. (PCF)
SOIL 1	800.0	0.	120.0	120.0
SUBS	2500.0	0.	135.0	135.0

LOAD DATA

P = 1000.0 KIPS AT 0. DEGREES

ALL MEASUREMENTS ON PLOT ARE IN FEET.
THIS PLOT IS NOT DRAWN TO SCALE.

TEST RUN 2



DO YOU WANT TO CONTINUE THE SOLUTION? YES OR NO.
=YES

PROGRAM CBEAR - BEARING CAPACITY ANALYSIS

TIME: 16:29:38 DATE: 8/10/81

II.--RESULTS

1.--HEADING

TEST RUN 2

2.--SUMMARY OF RESULTS

2.A--EFFECTIVE BASE DIMENSION

EFFECTIVE BASE WIDTH = 14.0 (FT)
EFFECTIVE BASE LENGTH = 20.0 (FT)

2.B--SUMMARY OF BEARING CAPACITY FACTORS

FACTORS	C	Q	G	UBC - NET (KIPS/FT**2)
BEARING CAP.	5.14	1.00	0.	4.112
SHAPE - CONC	1.20000	1.00000	1.00000	4.934
SHAPE - ECC.	1.14000	1.00000	1.00000	4.688
*INCLINATION	1.00000	1.00000	1.00000	4.688
*BASE TILT	1.00000	1.00000	1.00000	4.688
*GROUND SLOPE	1.00000	1.00000	1.00000	4.688
*EMBEDMENT	1.00000	1.00000	1.00000	4.688

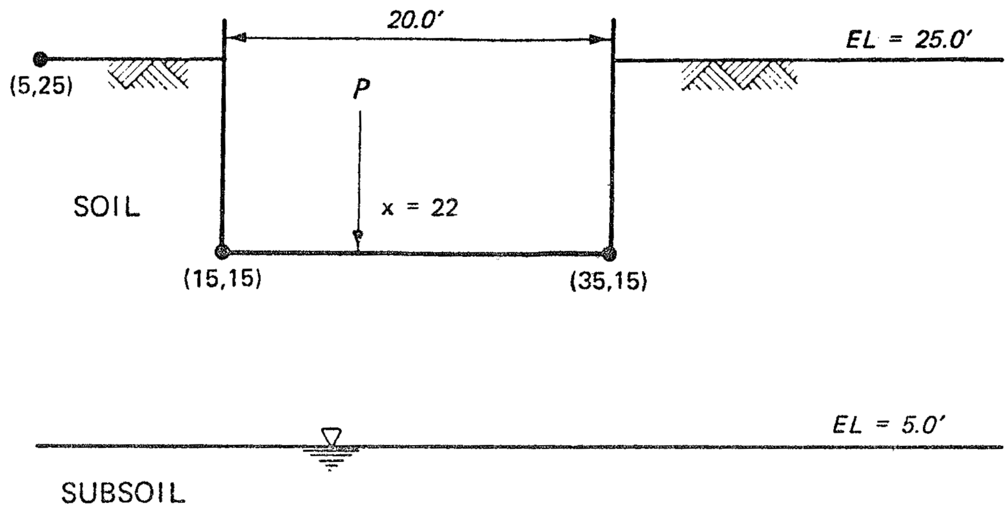
	FNC +	FNQ +	FNG =	Q
COMBINED EFFECTS OF FACTORS	4.415	0.	0.	4.415

THE FACTOR OF SAFETY FOR BEARING CAPACITY = 1.24

* FOR THE APPLICATION OF THESE FACTORS TO YOUR
PROBLEM SEE APPENDIX B IN THE PROGRAM DOCUMENTATION.

```
    NO COMBINATION OF FACTORS IS ALLOWED. *

DO YOU WANT TO MODIFY CURRENT DATA AND RERUN
THE PROBLEM? YES OR NO.
=N

DO YOU WANT TO MAKE ANOTHER RUN? YES OR NO.
=N

*
```

Example 2: Hand Verification



Soil Properties

	Cohesion c , psf	Angle of Internal Friction ϕ , deg	Unit Weight, pcf Moist	Unit Weight, pcf Saturated
Soil	800.0	0.0	120.0	120.0
Subsoil	2500.0	0.0	135.0	135.0

Load Data

P = 1000 kips at 0.0 deg

Bearing capacity factors

The following are the theoretical bearing capacity factors for a shallow horizontal footing under a vertical load:

$$N_\phi = \tan^2\left(\frac{\pi}{4} + \frac{\phi}{2}\right)$$

$$= \tan^2\left(45 + \frac{0}{2}\right)$$

$$= 1.000$$

$$N_q = e^{\pi \tan\phi} N_\phi$$

$$= e^{\pi(0)}(1.000)$$

$$= 1.000$$

$$N_c = 5.14 \quad \text{because} \quad \phi < 1.0$$

$$N_\gamma = (N_q - 1) \tan (1.4\phi)$$

$$= (1.00 - 1) \tan [1.4(0)]$$

$$= 0$$

Influence of water table

Because zw is less than the base width, gamma will be a combined unit weight:

$$\gamma = \gamma_{sub} + \frac{zw}{B}(\gamma_m - \gamma_{sub})$$

$$= (120 - 62.4) + \frac{10}{20}[120 - (120 - 62.4)]$$

$$= 88.8 \text{ pcf}$$

Effective foundation dimensions

Since there is an eccentric load, the base dimensions must be adjusted:

$$B' = B - 2e_x$$

$$= 20 - 2(3)$$

$$= 14 \text{ ft}$$

$$L = L - 2e_z$$

$$= 20 - 2(0)$$

$$= 20 \text{ ft}$$

Shape factors

Shape factors are used to account for other geometrical configurations:

$$\delta_c = 1 + 0.2N_\phi \frac{B'}{L'}$$
$$= 1 + 0.2(1.0)\left(\frac{14}{20}\right)$$
$$= 1.140$$

For $\phi = 0 \quad \delta_q = \delta_\gamma = 1.0$

Effective overburden pressure

This is the pressure due to the soil and/or surface loads above the base of the footing:

$$q_o = D\gamma'_m$$
$$= 10(120.0)$$
$$= 1200 \text{ psf}$$

Nonhomogeneous soil conditions

Since there is a subsoil present, shear strengths of both the soil and the subsoil should be checked to see if they vary by more than 50 percent.

Shear strength of the soil:

$$S = N \tan \phi + C$$
$$= N \tan (0) + C$$
$$= 0 + 800$$
$$= 800$$

Shear strength of the subsoil:

$$S = N \tan \phi + C$$
$$= N \tan (0) + C$$
$$= 0 + C$$
$$= 2500$$

Since the shear strengths do vary by more than 50 percent and both soils are clays, because their angles are equal to zero, the bearing capacity will be found using a method dealing with clays. The technique used will involve a soft clay over a stiff clay. This is because the soil cohesion is less than the subsoil cohesion:

$$N^*_c = \delta_c N_c$$
$$= 1.14(5.14)$$
$$= 5.860$$

$$N_m = \frac{3.125(5.86)(5.86 + 0.4118 - 1)\{(3.125 + 1)(5.86)^2 + [1 + 3.125(0.4118)]5.86 + 0.4118 - 1\}}{[3.125(3.125 + 1)5.86 + 3.125 + 0.4118 - 1][(5.86 + 0.4118)5.86 + 0.4118 - 1] - [3.125(5.86) + 0.4118 - 1](5.86 + 1)}$$

$$= \frac{96.54(141.65 + 12.81)}{78.076(36.164) - 121.589}$$

$$= \frac{14{,}911.57}{2701.95}$$

$$= 5.519$$

$$Q = c_1 N_m + q_o$$

The overburden will be ignored because the bearing capacity is net:

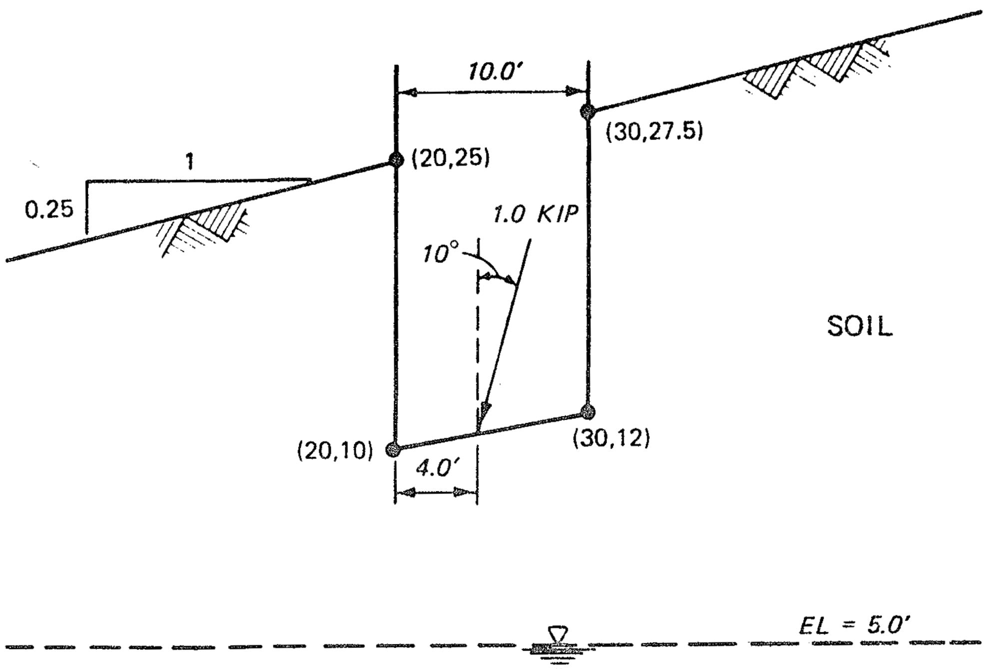
$$Q = c_1 N_m$$

$$= 800(5.519)$$

$$= 4415 \text{ psf}$$

$$= 4.415 \text{ ksf}$$

Example 3: Footings with One Layer, Sloping Ground Surface, Sloping Base, and Eccentric, Inclined Load



Soil Properties

	Cohesion c , psf	Angle of Internal Friction ϕ , deg	Unit Weight, pcf Moist	Unit Weight, pcf Saturated
Soil	500.0	28.0	120.0	120.0

<u>Input Data File BCP3</u>

```
100 NAME TEST RUN 3 (Data List 'NAME' - Title)
110 CONTINUOUS GROSS (Footing Type)
120 BASE 20 10 30 12 (Data List 'BASE' - X1 Y1 X2 Y2 LENGTH)
130 SOIL 0 20 40 30 120 120 28 500 (Data List 'SOIL' - XS1 YS1 XS2 YS2 SOILGM SOILGS PHI C)
140 LOAD 1 24 .5 10 (Data List 'LOAD' - P XP ZP ALPHA)
150 WATR 5 62.4 (Data List 'WATR' - YWATER WTRWGT)
160 END  ('END' - End of Data Entry)

*
```

```
        08/10/81    16.516


    PROGRAM CBEAR - BEARING CAPACITY ANALYSIS

    TIME: 16:31: 7                         DATE:  8/10/81

IS INPUT FROM TERMINAL OR A FILE?
ENTER T OR F
=F

ENTER DATA FILE NAME
=BCP3

WILL OUTPUT GO TO THE TERMINAL, FILE,OR BOTH?
ENTER T, F, OR B
=T


***** INPUT COMPLETE *****

DO YOU WANT AN ECHOPRINT OF THE INPUT? YES OR NO.
=Y
```

PROGRAM CBEAR - BEARING CAPACITY ANALYSIS

TIME: 16:32:42 DATE: 8/10/81

I.--INPUT DATA

1.--HEADING

TEST RUN 3

2.--BASE DESCRIPTION

2.A--BASELINE

LEFT SIDE POINT NO.	ELEVATION (FT)	X-COORD (FT)	RIGHT SIDE POINT NO.	ELEVATION (FT)	X-COORD (FT)
1	10.0	20.0	1	12.0	30.0

2.B--BASE CONFIGURATION

CONTINUOUS

FOUNDATION BASE WIDTH = 10.0
FOUNDATION BASE LENGTH = 1.0

3.--SOIL DESCRIPTION

3.A--SOIL PROFILE

LAYER NO. 1

LEFT SIDE POINT NO.	ELEVATION (FT)	X-COORD (FT)	RIGHT SIDE POINT NO.	ELEVATION (FT)	X-COORD (FT)
1	20.0	0.	1	30.0	40.0

3.B--SOIL PROPERTIES

LAYER NO.	INTERNAL FRICTION ANGLE (DEG)	COHESION (PSF)	UNIT WEIGHT MOIST (PCF)	UNIT WEIGHT SATURATED (PCF)
1	28.0	500.0	120.0	120.0

5.--WATER TABLE DESCRIPTION

ELEVATION OF WATER TABLE = 5.0 (FT)
UNIT WEIGHT OF WATER = 62.4 (PCF)

6.--LOAD DESCRIPTION

APPLIED LOAD = 1.0 (KIPS)
X-COORD OF APPLIED LOAD = 24.0 (FT)
Z-COORD OF APPLIED LOAD = 0.5 (FT)
ANGLE INCLINATION OF APPLIED LOAD = 10.0 (DEG)

DO YOU WANT TO EDIT YOUR DATA? YES OR NO.
=N

DO YOU WANT A PLOT OF THE INPUT? YES OR NO.
=Y

TABLE SOIL PROPERTIES

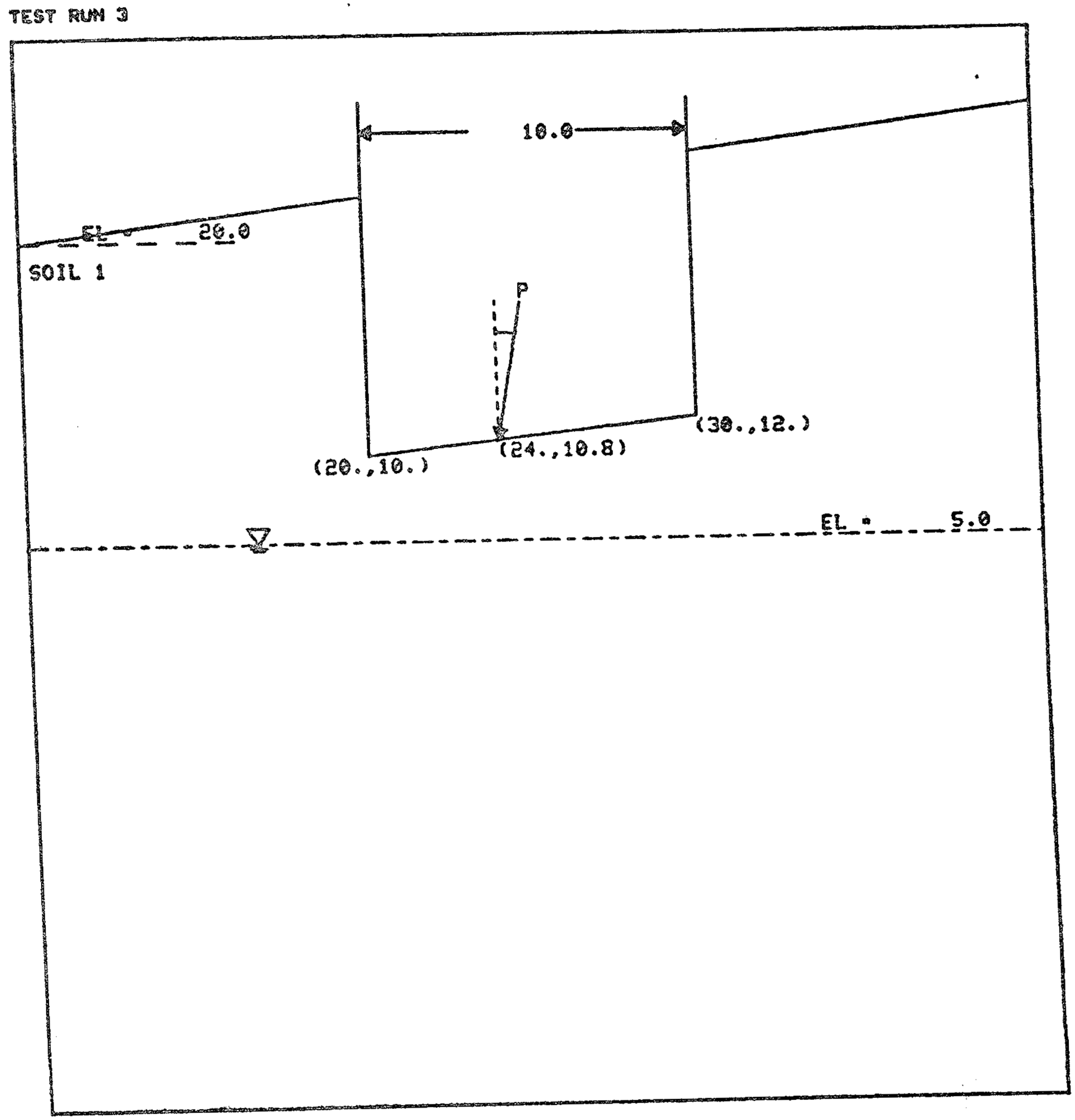
LAYER	C (PSF)	PHI (DEG)	UNIT WEIGHT MOIST (PCF)	UNIT WEIGHT SAT. (PCF)
SOIL 1	500.0	28.0	120.0	120.0

LOAD DATA

P = 1.0 KIPS AT 10.0 DEGREES

ALL MEASUREMENTS ON PLOT ARE IN FEET.
THIS PLOT IS NOT DRAWN TO SCALE.

TEST RUN 3



PROGRAM CBEAR - BEARING CAPACITY ANALYSIS

TIME: 9:50:32 DATE: 4/16/82

II.--RESULTS

1.--HEADING

TEST RUN 3

2.--SUMMARY OF RESULTS

2.A--EFFECTIVE BASE DIMENSION

EFFECTIVE BASE WIDTH = 8.0 (FT)
EFFECTIVE BASE LENGTH = 1.0 (FT)

2.B--SUMMARY OF BEARING CAPACITY FACTORS

FACTORS	C	Q	G	UBC - GROSS (KIPS/FT**2)
BEARING CAP.	25.80	14.72	11.19	45.156
SHAPE - CONC	1.00000	1.00000	1.00000	45.156
SHAPE - ECC.	1.00000	1.00000	1.00000	44.093
*INCLINATION	0.79012	0.79012	0.41327	33.236
*BASE TILT	0.78660	0.80110	0.80110	26.477
*GROUND SLOPE	0.53061	0.56250	0.56250	14.199
*EMBEDMENT	1.49928	1.24964	1.24964	18.806

	FNC +	FNQ +	FNG =	Q
COMBINE EFFECTS OF FACTORS	6.379	11.437	0.990	18.806

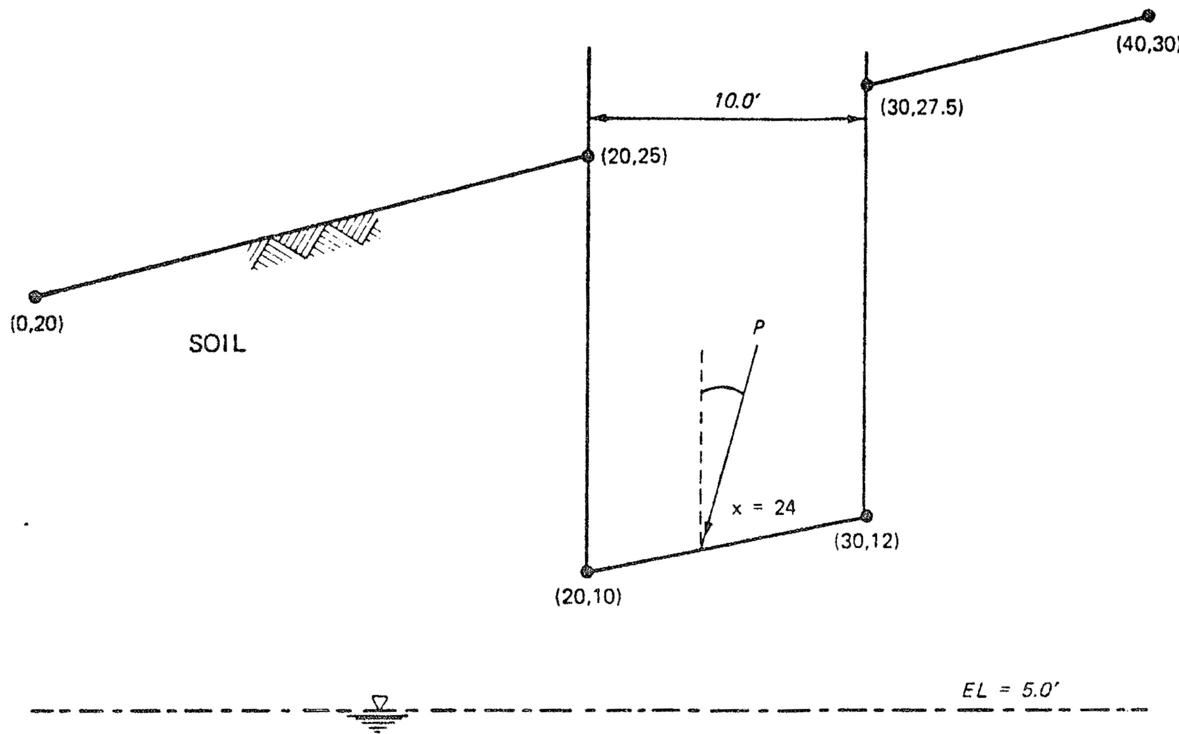
THE FACTOR OF SAFETY FOR BEARING CAPACITY = 152.77

* FOR THE APPLICATION OF THESE FACTORS TO YOUR PROBLEM SEE APPENDIX B IN THE PROGRAM DOCUMENTATION.

DO YOU WANT YOUR OWN COMBINATION OF FACTORS? YES OR NO.
=

```
DO YOU WANT YOUR OWN COMBINATION OF FACTORS? YES OR NO.
=Y

       SUMMARY OF BEARING CAPACITY FACTORS

      FACTORS          C             Q              G
   ------------ ------------ ------------ ------------

   BEARING CAP.     NC           NQ             NG

   SHAPE - ECC.     FC           FQ             FG

   EMBEDMENT        FCD          FQD            FGD

   INCLINATION      FCI          FQI            FGI

   BASE TILT        FCT          FQT            FGT

   GROUND SLOPE     FCG          FQG            FGG

ENTER BEARING CAPACITY FACTORS TO BE USED IN
COMPUTATION.(MAX. 6 TO A LINE)
=NC NQ NG FCI FQI FGI
=FCG FQG FGG
=

    COMBINED EFFECTS
    ----------------
    Q = FNC + FNQ + FNG =          17.046 (KIPS/FT**2)

DO YOU WANT YOUR OWN COMBINATION OF FACTORS? YES OR NO.
=N


DO YOU WANT TO MODIFY CURRENT DATA AND RERUN
THE PROBLEM? YES OR NO.
=N

DO YOU WANT TO MAKE ANOTHER RUN? YES OR NO.
=N
```

Example 3: Hand Verification



Soil Properties

	Cohesion c , psf	Angle of Internal Friction ϕ , deg	Unit Weight, pcf Moist	Unit Weight, pcf Saturated
Soil	500.0	28.0	120.0	120.0

Load Data

P = 1 kip at 10.0 deg

Bearing capacity factors

The following are the theoretical bearing capacity factors for a shallow horizontal footing under a vertical load:

$$N_\phi = \tan^2\left(\frac{\pi}{4} + \frac{\phi}{2}\right)$$

$$= \tan^2\left(45 + \frac{28}{2}\right)$$

$$= 2.770$$

$$N_q = e^{\pi \tan(\phi)} N_\phi$$

$$= e^{\pi \tan(28)} (2.770)$$

$$= 14.721$$

$$N_c = (N_q - 1) \cot \phi$$

$$= (14.721 - 1) \cot (28)$$

$$= 25.805$$

$$N_\gamma = (N_q - 1) \tan (1.4\phi)$$

$$= (14.721 - 1) \tan [1.4(28)]$$

$$= 11.191$$

Effective foundation dimensions

Since there is an eccentric load, the base dimensions must be adjusted:

$$B' = B - 2e_x$$

$$= 10 - 2(1)$$

$$= 8 \text{ ft}$$

$$L' = L - 2e_z$$

$$= 1 - 2(0)$$

$$= 1 \text{ ft}$$

Shape factors

These factors are used to account for other geometrical configurations:

$$\delta_c = 1 + 0.2 N_\phi \frac{B'}{L'}$$

$$= 1 + 0.2(2.770)(0)$$

$$= 1.000$$

For $\phi > 10°$ $\delta_q = \delta_\gamma = 1$

Embedment factors

These factors are calculated when the structure is embedded:

$$\delta_{cd} = 1 + 0.2\,\frac{D}{B}\tan\left(45 + \frac{\phi}{2}\right)$$

$$= 1 + 0.2\left(\frac{15}{10}\right)\tan\left(45 + \frac{28}{2}\right)$$

$$= 1.499$$

$$\delta_{qd} = \delta_{\gamma d} = 1 + 0.1\,\frac{D}{B}\tan\left(45 + \frac{\phi}{2}\right) \quad \text{for} \quad \phi > 10°$$

$$= 1 + 0.1\left(\frac{15}{10}\right)\tan\left(45 + \frac{28}{2}\right)$$

$$= 1.250$$

Inclination factors

These factors will account for load inclination for a concentrically loaded foundation:

$$\delta_{ci} = \delta_{qi} = \left(1 - \frac{\delta}{90}\right)^2$$

$$= \left(1 - \frac{10}{90}\right)^2$$

$$= 0.790$$

$$\delta_{\gamma i} = \left(1 - \frac{\delta}{\phi}\right)^2$$

$$= \left(1 - \frac{10}{28}\right)^2$$

$$= 0.413$$

Base tilt factors

These factors are used to account for a sloping base of a shallow footing:

$$\delta_{qt} = \delta_{\gamma t} = (1 - \alpha \tan\phi)^2$$

$$= [1 - 0.197(\tan 28)]^2$$

$$= 0.801$$

$$\delta_{ct} = \delta_{qt} - (1 - \delta_{qt})/(N_c \tan\phi) \quad \text{for} \quad \phi > 0$$

$$= 0.801 - (1 - 0.801)/[25.805(\tan 28)]$$

$$= 0.786$$

Ground slope factors

These factors are utilized to correct the bearing capacity for a sloping ground surface:

$$\delta_{qg} = \delta_{\gamma g} = [1 - \tan(w)]^2$$

$$= [1 - \tan(14.036)]^2$$

$$= (1 - 0.25)^2$$

$$= (0.75)^2$$

$$= 0.563$$

$$\delta_{cg} = \delta_{qg} - (1 - \delta_{qg})/(N_c \tan\phi) \quad \text{for} \quad \phi > 0$$

$$= 0.563 - (1 - 0.563)/[25.805(\tan 28)]$$

$$= 0.531$$

Effective overburden pressure

$$q_o = D\gamma$$

$$= 15.25(120)$$

$$= 1830 \text{ psf}$$

Influence of water table

Since zw is less than the base width of the footing, gamma will be a combined unit weight:

$$\gamma = \gamma_{sub} + \left(\frac{zw}{B}\right)(\gamma_m - \gamma_{sub})$$

$$= (120 - 62.4) + \frac{6}{10}[120 - (120 - 62.4)]$$

$$= 95.04$$

Bearing capacity--gross

Each bearing capacity will be calculated starting with the bearing capacity factors and adding one set of factors at a time. The bearing capacity using just the bearing capacity factors will not include any adjustments of foundation dimensions:

$$Q = cN_c + q_oN_q + \gamma \frac{B}{2} N_\gamma$$

$$= 500(25.805) + 1830(14.721) + 95.04\left(\frac{10}{2}\right)(11.191)$$

$$= 45{,}160 \text{ psf}$$

$$= 45.160 \text{ ksf}$$

The shape factors with a concentric load is calculated, no adjustment is made for eccentric loading

$$Q = \delta_c c N_c + \delta_q q_o N_q + \delta_\gamma \gamma \frac{B}{2} N_\gamma$$

$$= 1(500)(25.81) + 1(1830)(14.72) + 1(95.04)(5)(11.19)$$

$$= 45.160 \text{ ksf}$$

The shape factors and the remaining factors will include the effective foundation dimensions:

$$Q = \delta_c c N_c + \delta_q q_o N_q + \delta_\gamma \gamma \frac{B'}{2} N_\gamma$$

$$= 1(500)(25.81) + 1(1830)(14.72) + 1(95.04)\left(\frac{8}{2}\right)(11.19)$$

$$= 44{,}097 \text{ psf}$$

$$= 44.097 \text{ ksf}$$

$$Q = \delta_{cd}\delta_c c N_c + \delta_{qd}\delta_q q_o N_q + \delta_{\gamma d}\delta_\gamma \gamma \frac{B'}{2} N_\gamma$$

$$= 1.499(1)(500)(25.81) + 1.25(1)(1830)(14.72) + 1.25(1)(95.04)(4)(11.19)$$

$$= 58{,}334 \text{ psf}$$

$$= 58.334 \text{ ksf}$$

$$Q = \delta_{ci}\delta_{cd}\delta_c c N_c + \delta_{qi}\delta_{qd}\delta_q q_o N_q + \delta_{\gamma i}\delta_{\gamma d}\delta_\gamma \gamma \frac{B'}{2} N_\gamma$$

$$= 0.790(1.499)(1)(500)(25.81) + 0.790(1.25)(1)(1830)(14.72) + 0.413(1.25)(1)(95.04)(4)(11.19)$$

$$= 44{,}079 \text{ psf}$$

$$= 44.079 \text{ ksf}$$

$$Q = \delta_{ct}\delta_{ci}\delta_{cd}\delta_c c N_c + \delta_{qt}\delta_{qi}\delta_{qd}\delta_q q_o N_q + \delta_{\gamma t}\delta_{\gamma i}\delta_{\gamma d}\delta_\gamma \gamma \frac{B'}{2} N_\gamma$$

$$= 0.786(0.790)(1.499)(1)(500)(25.81) + 0.801(0.790)(1.25)(1)(1830)(14.72) + 0.801(0.413)(1.25)(1)(95.04)(4)(11.19)$$

$$= 35{,}078 \text{ psf}$$

$$= 35.078 \text{ ksf}$$

For the bearing capacity calculated with the ground slope factors, the overburden must also be adjusted to account for a sloping ground surface:

$$q_o = \gamma D \cos \omega$$
$$= 120(15) \cos (14.036)$$
$$= 1746 \text{ psf}$$
$$Q = \delta_{cg}\delta_{ct}\delta_{ci}\delta_{cd}\delta_c c N_c + \delta_{qg}\delta_{qt}\delta_{qi}\delta_{qd}\delta_q q_o N_q + \delta_{\gamma g}\delta_{\gamma t}\delta_{\gamma i}\delta_{\gamma d}\delta_\gamma \gamma \frac{B'}{2} N_\gamma$$
$$= 0.531(0.786)(0.790)(1.499)(1)(500)(25.81)$$
$$+ 0.563(0.801)(0.790)(1.25)(1)(1746)(14.72)$$
$$+ 0.563(0.801)(0.413)(1.25)(1)(95.04)(4)(11.19)$$
$$= 18{,}814 \text{ psf}$$
$$= 18.814 \text{ ksf}$$

APPENDIX B: BEARING CAPACITY OF SHALLOW FOUNDATIONS*

Purpose and Scope

1. This appendix outlines a procedure for calculating the bearing capacity of shallow foundations for various loading geometries and soil conditions. The procedure is intended to form the basis of a computer program that will compute the factor of safety against bearing capacity failure. A shallow foundation as considered herein is one whose width is greater than its depth of embedment.

2. Two basic procedures were considered for adoption: one proposed by Meyerhof (1963) and the other by Vesic (1975). Meyerhof's method was chosen as the basis for the procedure described herein because for many cases it is more conservative than Vesic's method and because some of Vesic's shape factors do not vary in a consistent manner with the parameters ϕ (the angle of internal friction) and c (cohesion). Some of Vesic's procedures are included, however, where Meyerhof makes no recommendation regarding some special cases.

3. The related problems of soil compressibility, local shear, and punching shear are not considered here. However, since they are important factors in some bearing capacity failures, due consideration should be given them before completing a final design. In all situations, it will be necessary to consult a geotechnical engineer regarding the appropriateness of the analytical method chosen and of the input parameters.

Generalized Bearing Capacity Equation

4. The generalized bearing capacity equation can be written as:

$$q = \frac{Q}{B'L'} = \zeta_c \zeta_{cd} \zeta_{ci} \zeta_{ct} \zeta_{cg} c N_{cstrip} + \zeta_q \zeta_{qd} \zeta_{qi} \zeta_{qt} \zeta_{qg} q_o N_{qstrip} + \frac{\zeta_\gamma \zeta_{\gamma d} \zeta_{\gamma i} \zeta_{\gamma t} \zeta_{\gamma g} B' \gamma N_{\gamma strip}}{2}$$

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* By Dana Humphrey, St. Louis District. Edited by Reed Mosher, WES.

where

q = vertical component of the ultimate unit bearing capacity of the foundation

Q = vertical component of the ultimate bearing capacity of the foundation

B', L' = effective foundation dimensions

$N_{cstrip}, N_{qstrip}, N_{\gamma strip}$ = bearing capacity factors for a strip load

c = cohesion parameter

γ = unit weight of soil

$\zeta_c, \zeta_q, \zeta_\gamma$ = shape factors

$\zeta_{cd}, \zeta_{qd}, \zeta_{\gamma d}$ = embedment factors

$\zeta_{ci}, \zeta_{qi}, \zeta_{\gamma i}$ = inclination factors

$\zeta_{ct}, \zeta_{qt}, \zeta_{\gamma t}$ = base tilt factors

$\zeta_{cg}, \zeta_{qg}, \zeta_{\gamma g}$ = ground slope factors

q_o = effective overburden pressure on the plane passing through the base of the footing

Bearing capacity factors

5. The theoretical bearing capacity factors for a shallow horizontal strip footing under a vertical load can be defined as (Meyerhof 1963):

For $\phi > 0$

$$N_{cstrip} = (N_{qstrip} - 1) \cot \phi$$

$$N_{qstrip} = e^{(\pi \tan\phi)} N_\phi$$

$$N_{\gamma strip} = (N_{qstrip} - 1) \tan 1.4\phi$$

For $\phi = 0$

$$N_c = 5.14$$

where

$$N_\phi = \tan^2\left(\frac{\pi}{4} + \frac{\phi}{2}\right)$$

ϕ = angle of internal friction

If ϕ is obtained by triaxial testing, it should be corrected before input to the program by:

$$\phi_r = \left(1.1 - 0.1\,\frac{B'}{L'}\right)\phi_t$$

where

ϕ_t = angle of internal friction obtained from a triaxial test

ϕ_r = angle of internal friction to be used in calculating the bearing capacity factors

Shape factors

6. Shape factors are used to adjust the theoretical bearing capacity for a shallow horizontal strip footing to account for the influence of other geometrical configurations. The shape factors are (Meyerhof 1963):

$$\zeta_c = 1 + 0.2N_\phi \frac{B'}{L'}$$

and for $\phi = 0°$,

$$\zeta_q = \zeta_\gamma = 1$$

For $\phi > 10°$,

$$\zeta_q = \zeta_\gamma = 1 + 0.1N_\phi \frac{B'}{L'}$$

An approximate method for computing ζ_q and ζ_γ when $0° < \phi \leq 10°$ is a linear interpolation between 1 for $\phi = 0°$, and $1 + 0.1N_\phi(B'/L')$ for $\phi = 10°$. For strip footings,

$$\frac{B'}{L'} \approx 0$$

For square and circular footings,

$$\frac{B'}{L'} = 1$$

Embedment factors

7. Embedment factors take into consideration the shearing resistance on the failure plane passing through soil above the base of the footing, indicated by segment AB in Figure B1.

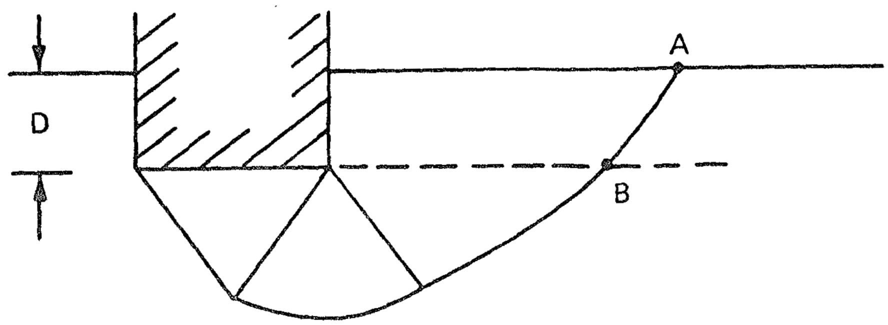


Figure B1. Embedment of footing

The embedment factors can be computed as (Meyerhof 1963):

$$\zeta_{cd} = 1 + 0.2 \frac{D}{B} \tan\left(45 + \frac{\phi}{2}\right)$$

and for $\phi = 0°$,

$$\zeta_{qd} = \zeta_{\gamma d} = 1$$

For $\phi > 10°$,

$$\zeta_{qd} = \zeta_{\gamma d} = 1 + 0.1 \frac{D}{B} \tan\left(45 + \frac{\phi}{2}\right)$$

An approximate method for computing ζ_{qd} and $\zeta_{\gamma d}$ when $0° < \phi \leq 10°$ is a linear interpolation between 1 for $\phi = 0°$, and $1 + 0.1(D/B) \tan [45 + (10/2)]$ for $\phi = 10°$.

8. These embedment factors should be used with caution because, as Vesic (1975) states: "There exists good evidence that this effect is practically nonexistent, if the foundations are drilled in or buried and backfilled or if the overburden strata are relatively compressible. For

this reason, it is advised not to introduce depth factors in the design of shallow foundations." Therefore,

$$\zeta_c = \zeta_q = \zeta_\gamma = 1$$

Inclination factors

9. The inclination factors account for the effect of load inclination for concentrically loaded foundations with a "rough" base (Figure B2). These are computed as (Meyerhof 1963):

$$\zeta_{ci} = \zeta_{qi} = \left(1 - \frac{\delta}{90}\right)^2$$

and for $\delta \leq \phi$,

$$\zeta_{\gamma i} = \left(1 - \frac{\delta}{\phi}\right)^2$$

For $\delta > \phi$,

$$\zeta_{\gamma i} = 0$$

where δ is the angle of inclination of the load from the vertical. Meyerhof makes no specific recommendation for an inclined load with a component parallel to the long axis of the footing. However, a

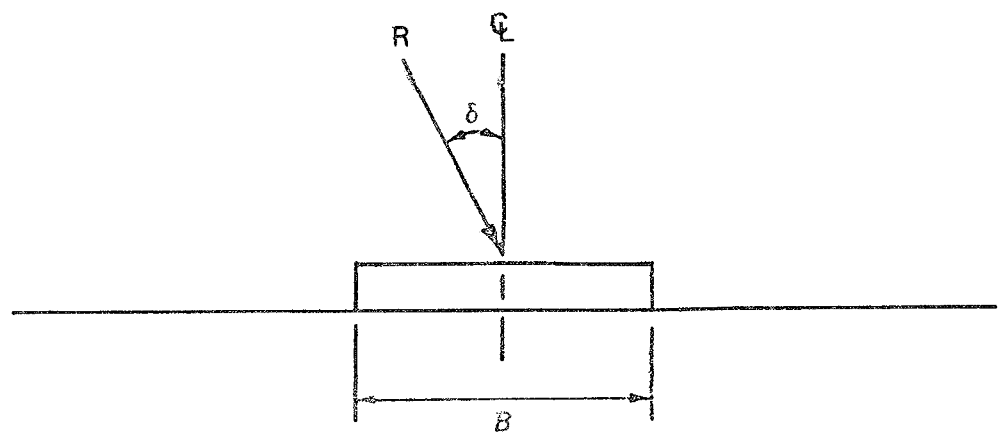


Figure B2. Footing with an inclined load reasonable approach would seem to be taking δ as the inclination of the resultant with the vertical, irrespective of the axes of the footing, and computing the bearing capacity assuming that failure will be in the "p" direction.

Base tilt factors

10. Base tilt factors are employed to account for the effects of a sloping base of a shallow footing. They can be computed as (Vesic 1975):

$$\zeta_{qt} = \zeta_{\gamma t} = (1 - \alpha \tan \phi)^2$$

and for $\phi = 0°$,

$$\zeta_{ct} = 1 - \left(2 \frac{\alpha}{\pi + 2}\right)$$

For $\phi > 0°$,

$$\zeta_{ct} = \zeta_{qt} - \frac{1 - \zeta_{qt}}{N_c \tan \phi} \quad \text{For } \phi > 0$$

where α is the slope of the base of the footing, as shown in Figure B3.

11. The base tilt factors are valid only for long rectangular footings with the main axis parallel to the slope and α less than

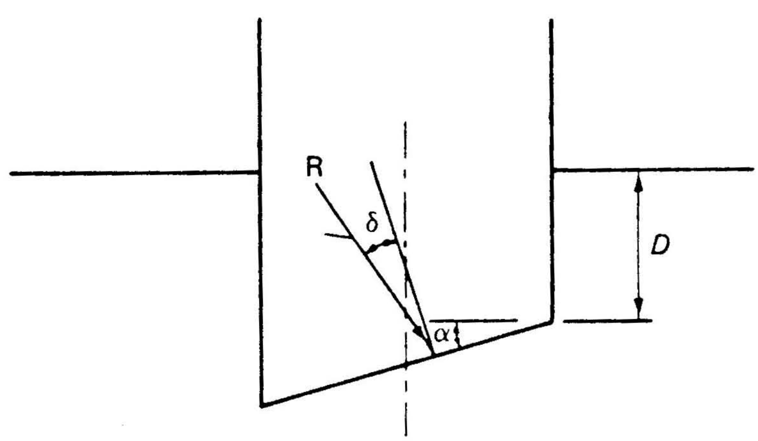


Figure B3. Footing with a tilted base

45 degrees. Vesic suggests that shape factors presented previously are valid for base tilt, but there is no experimental evidence to support this conclusion. Although Vesic does not say so, these factors may only be used when the inclination of the load, its eccentricity, the ground slope, and the tilt all tend to produce failure in the same direction.

12. The above equation for $\zeta_{\gamma t}$ is quite accurate. It is on the safe side.

Ground slope factors

13. Ground slope factors are used to correct the bearing capacity factors for a sloping ground surface, as illustrated in Figure B4. The ground slope factors can be computed as (Vesic 1975):

$$\zeta_{qg} = \zeta_{\gamma g} = (1 - \tan \beta)^2$$

and for $\phi = 0°$,

$$\zeta_{cg} = 1 - \left(2 \frac{\beta}{\pi + 2}\right)$$

Also the N_γ term should be included for $\phi = 0$. where:

$$N_\gamma = -2 \sin \beta$$

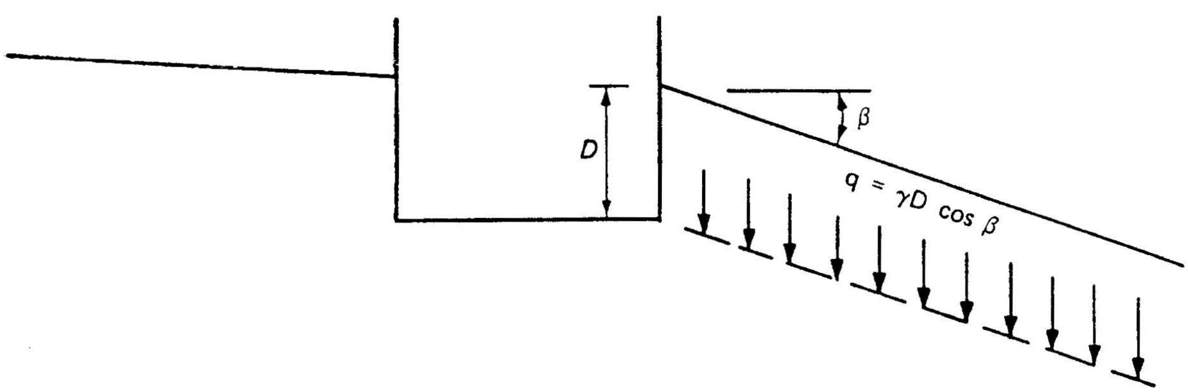


Figure B4. Footing with a sloped surface

For $\phi > 0°$,

$$\zeta_{cg} = \zeta_{qg} - \frac{1 - \zeta_{qg}}{N_c \tan \phi}$$

14. The ground slope factors are valid only for long rectangular footings with the main axis parallel to the ground slope, ground slope (β) less than 45°, and ϕ . Vesic suggests that shape factors presented previously are valid when used with ground slope, but there is no experimental evidence to support this conclusion. A slope stability analysis should also be performed for slopes greater than $\phi/2$ to ensure the stability of the footing. Although Vesic does not say so, these factors should only be used when all factors tend to produce failure in the same direction.

Effective foundation dimensions

15. An approximate method for accounting for eccentric loading of strip footings (Figure B5) is (Meyerhof 1963):

$$B' = B - 2e_x$$

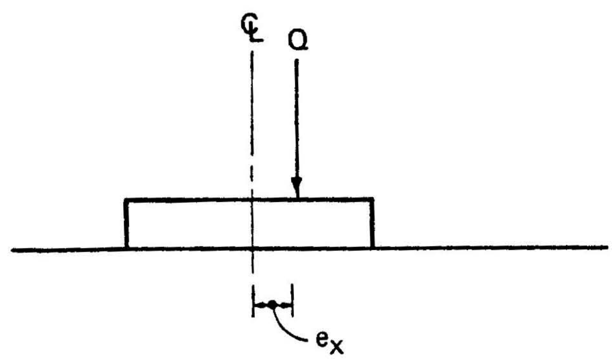


Figure B5. Strip footing with an eccentric loading

For rectangular footings (Figure B6),

$$B' = B - 2e_x$$

$$L' = L - 2e_z$$

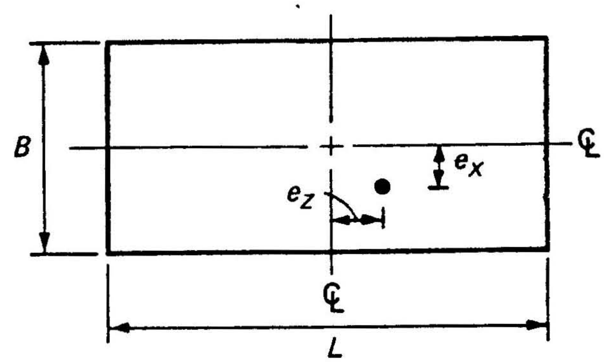


Figure B6. Rectangular footing with an eccentric loading

16. For other shapes, Vesic (1975) says "Effective foundation area may be determined as that of an equivalent rectangle, constructed so that its geometric center coincides with the load center and that it follows as closely as possible the adjacent contour of the actual base area." (In all cases, $e_x \leq (B/6)$ and $e_z \leq (L/6)$.) In general, B and L are chosen such that $L' > B'$. However, for the case of several monoliths in a row (Figure B7), B should be chosen as:

For monoliths 2, 3, 4,...,

$$B = A$$

For an end monolith (e.g., 1),

$$\text{if } A > C, \quad B = C$$

$$\text{if } A < C, \quad B = A$$

Effective overburden pressure

17. q_o, as illustrated in Figure B8, is the pressure due to the

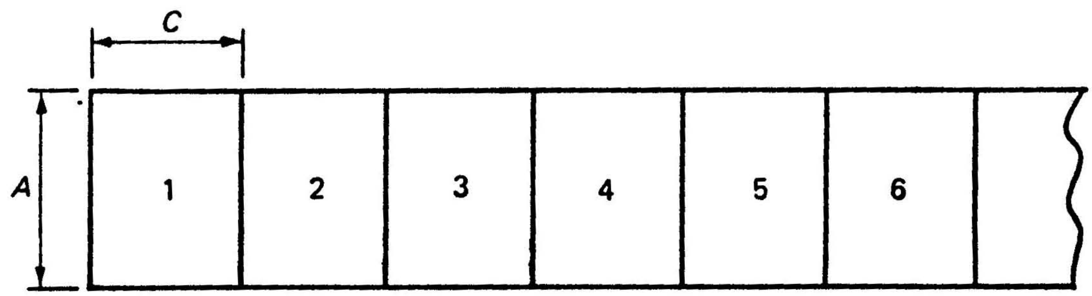


Figure B7. Base dimensions for monoliths

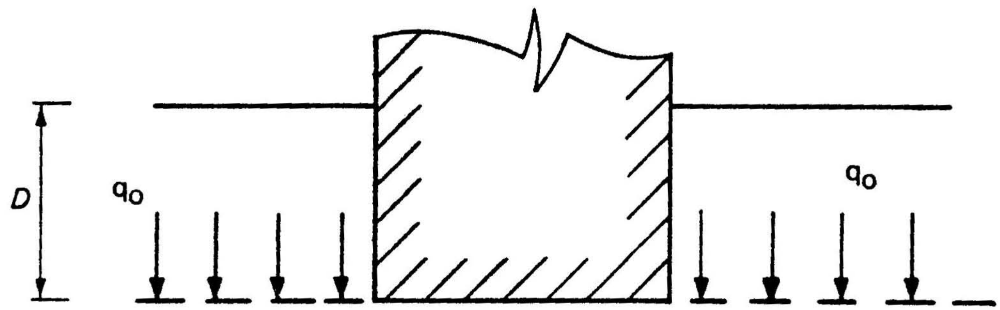


Figure B8. Overburden pressure for one layer above the base

soil and/or surface loads above the base of the footing; i.e.,

$$q_o = D\gamma'_m$$

where γ'_m is the effective unit weight of the overlying soil. Now, if γ'_m is not constant (Figure B9),

$$q_o = \sum_{i=1}^{n} d_i \gamma'_{mi}$$

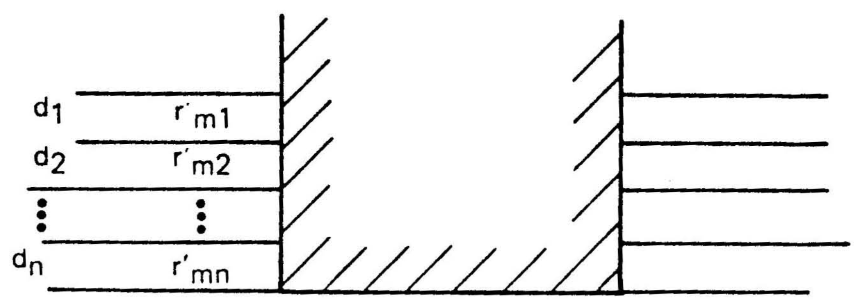


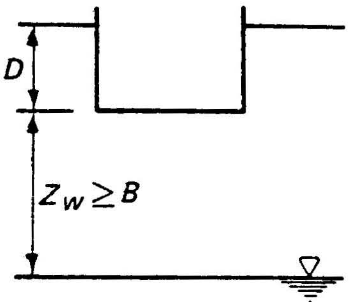
Figure B9. Overburden pressure for multiple layers above the base

For the special case of sloping ground surface, q_o should be calculated as shown in Figure B4.

Influence of groundwater table

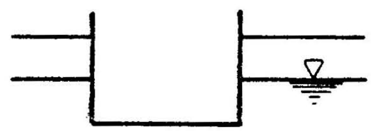
18. The three cases in Figure B10 show the influence on the groundwater table on the unit weight of the soil to be used in the bear-capacity calculation.

Use mass unit weight γ_m



a. Case I

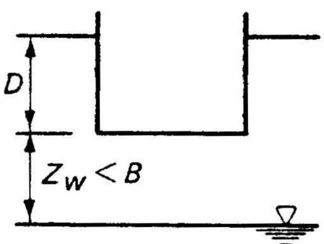
Use sumberged unit weight γ_{sub}



b. Case II

Use combined unit weight γ , where

$$\gamma = \gamma_{sub} + \left(\frac{Zw}{B}\right)(\gamma_m - \gamma_{sub})$$



c. Case III

Figure B10. Influence of groundwater

Nonhomogeneous Soil Conditions

Method I (clays)

19. This method (Sowers 1962) is applicable where soil strengths

do not vary more than 50 percent throughout the depth of the shear zone, which is obtained using Figure B11, where b is base width and d is the depth of the shear (failure) zone (Figure B12). The weighted average of the soil properties within the depth d would be used in the analysis.

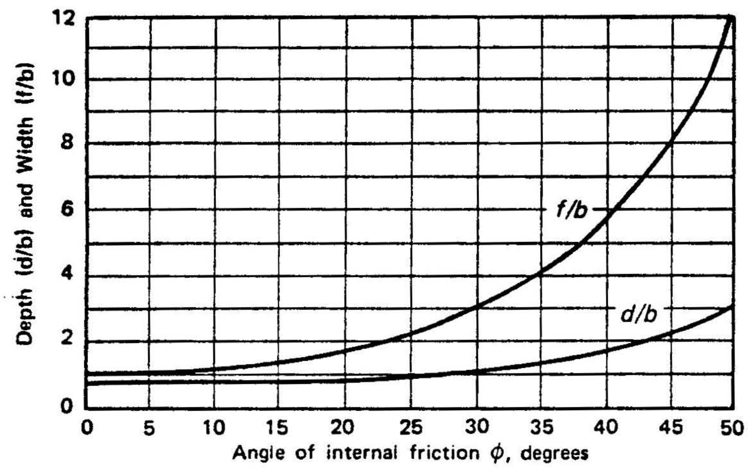


Figure B11. Depth and width of the shear zone in bearing capacity failure of a cohesionless sand (after Sowers (1962))

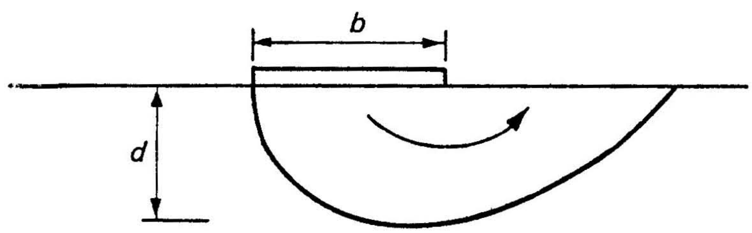


Figure B12. Failure zone

Method II (soft clay over stiff clay)

20. This method (Vesic 1975) is applicable for a soft clay layer over a stiff clay layer, as shown in Figure B13. The bearing capacity equation is:

$$q = c_1 N_m + q_o$$

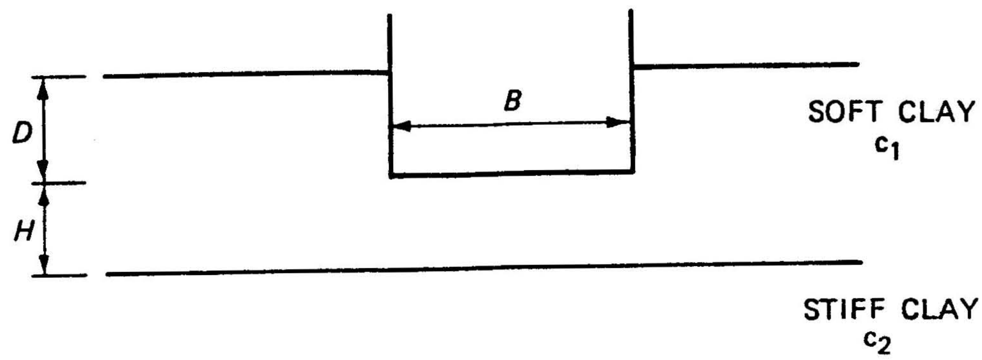


Figure B13. Soft clay layer over a stiff clay layer

where

$$N_m = \frac{KN_c^*(N_c^* + \beta - 1)\left[(K + 1)N_c^{*2} + (1 + K\beta)N_c^* + \beta - 1\right]}{[K(K + 1)N_c^* + K + \beta - 1][(N_c^* + \beta)N_c^* + \beta - 1] - (KN_c^* + \beta - 1)(N_c^* + 1)}$$

$\beta = BL/[2(B + L)H]$

$K = c_2/c_1$

$N_c^* = \zeta_c N_c$

c_2 = cohesion of layer 2

c_1 = cohesion of layer 1

For $(B/H) \leq 4$,

$N_m = 6.17$ (square footing)

For $(B/H) \leq 2$,

$N_m = 5.14$ (strip footing)

} The stiff layer has no effect

21. The failure of the footing occurs, at least in part, because of lateral plastic flow similar to that occurring in a solid squeezed between two rough parallel plates. Vesic states that "For absolutely rigid footings they are probably on the safe side. However, caution is advised in applying these factors to very flexible footings."

Method III (stiff
clay over soft clay

22. This method (Vesic (1975) is applicable for a stiff clay over a soft clay layer (Figure B14). The failure is caused by punching

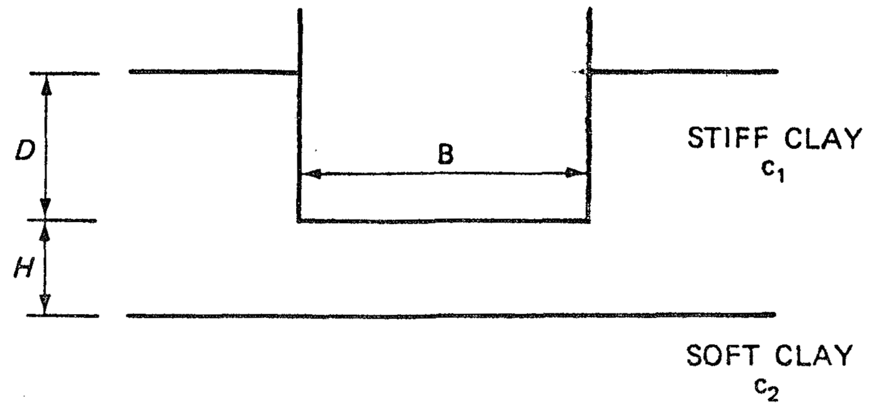


Figure B14. Stiff clay layer over a soft clay layer

through the stiff clay around the footing perimeter. The equations given by Vesic may be rearranged to form

$$q = c_1 \frac{[2(B + L)H]}{BL} + c_2 \zeta_c N_c + q_o$$

$$\begin{pmatrix}\text{shearing resistance}\\ \text{due to punching}\\ \text{through stiff clay}\end{pmatrix} \quad \begin{pmatrix}\text{bearing capacity}\\ \text{of soft clay}\end{pmatrix} \quad \begin{pmatrix}\text{overburden}\\ \text{stress at}\\ \text{depth } D\end{pmatrix}$$

The c_1 used in the above equation should be reduced by an appropriate factor to account for progressive failure in stiff clay in some situations (Brown and Meyerhof (1969) used 0.75 for clay with sensitivity of 2). It is felt that the shearing resistance in punching through the stiff clay should be neglected in computing the ultimate bearing capacity.

Sand over a weak layer

23. This method is the same as Method I, paragraph 19 of this appendix, for clays.

Method I (Perloff and Baron 1976)

24. This method is applicable for the conditions shown in

Figure B15. The procedure is as follows:

> The stronger material upon which the foundation rests is assumed to extend to an infinite depth. The bearing capacity of the material (q) is computed on this basis.
>
> The average vertical stress transmitted from the foundation to the surface of the weaker material is determined by an approximate method as shown in Figure B16a. The surface of the underlying material is then considered to be the base of an equivalent foundation with dimensions determined as shown in Figure B16b and carrying a unit pressure equal to that transmitted from the foundation in addition to the weight of the overburden material above the equivalent foundation.

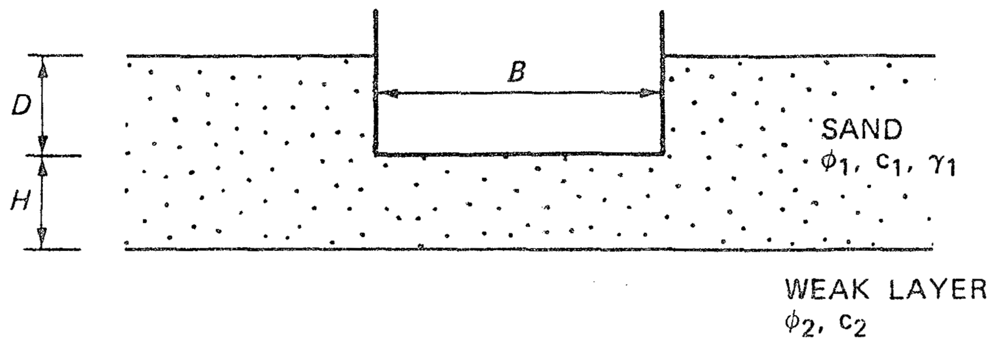


Figure B15. Sand over a weak layer

The bearing capacity used is the smaller of the two.

25. To compute the ultimate bearing capacity of the footing, the ultimate bearing pressure of the weak layer q'' must be transmitted from the weak layer to the footing and the weight of the overburden material above footing must be subtracted.

26. The relationships between the ultimate bearing capacity of the footing q and the ultimate bearing capacity of the weak layer q'' are:

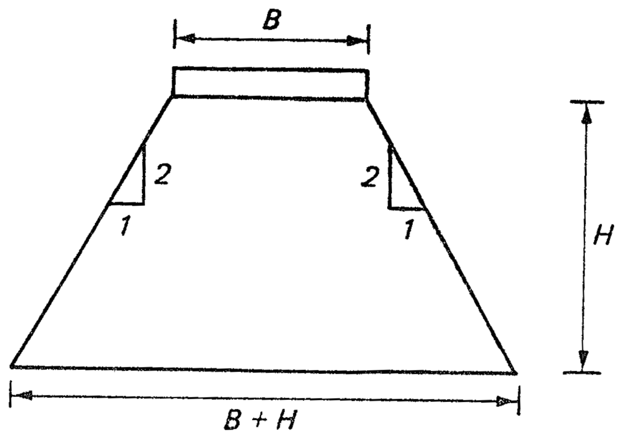
For a strip footing,

$$q'' = \frac{qB}{B + Z}$$

q = ultimate bearing capacity of footing

q' = ultimate bearing capacity of footing <u>neglecting</u> weak layer

q" = ultimate bearing capacity of weak layer



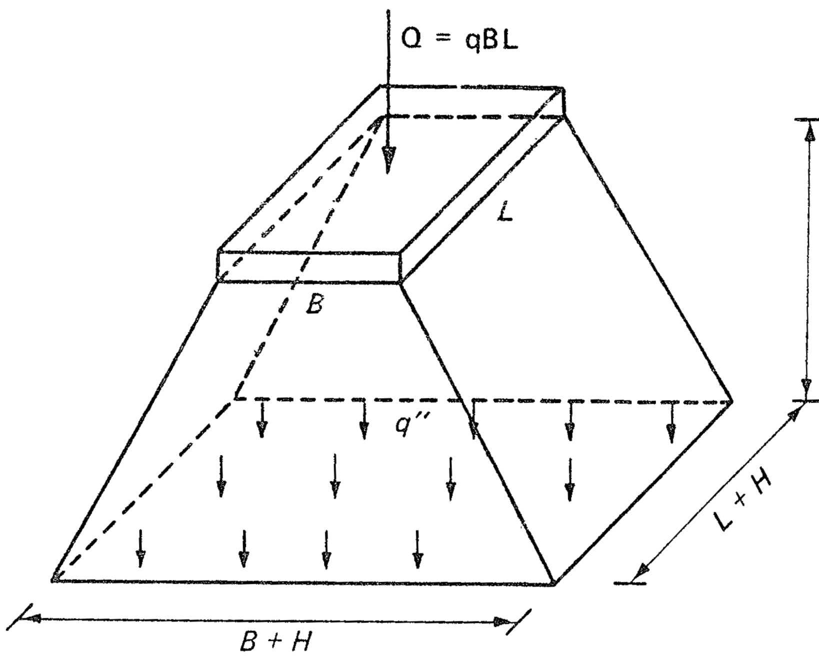


Figure B16. Approximate distribution of vertical stress due to a surface load

For a rectangular footing,

$$q'' = \frac{qBL}{(B + Z)(L + Z)}$$

27. Rearranging the equations to solve for the ultimate bearing capacity of the footing q the resulting equations are:

For a strip footing,

$$q = (q'' - \gamma_1 H) \frac{(B + H)}{B} , \text{ but } \leq q'$$

For a rectangular footing,

$$q = (q'' - \gamma_1 H) \frac{(B + H)(L + H)}{BL} , \text{ but } \leq q'$$

28. The $\gamma_1 H$ term should take into account the location of the water table. The unit pressure on the surface of the underlying material q'' should be computed using B or an equivalent footing and an embedment depth of $D + H$. It should be noted that q is independent of c_1 and ϕ_1.

The Proper Combination of the Factors Tending to Cause Failure

Eccentric and inclined loading

29. A controversy exists in the literature (Perloff and Baron 1976, Meyerhof 1963, Vesic 1975) as to whether in case A or case B (Figure B17) the inclination and the eccentricity combine to produce the

Figure B17. Footing with an eccentric and inclined load

most critical case. It is therefore felt prudent to assume that in both cases the inclination and eccentricity combine to produce the most critical case.

Eccentric loading of a
strong layer over a weak layer

30. It is found that for $e \leq (B/6)$, the eccentricity may be neglected when calculating the bearing capacity of the weak layer, if $(B/H) \leq 2$ (see Figure B18).

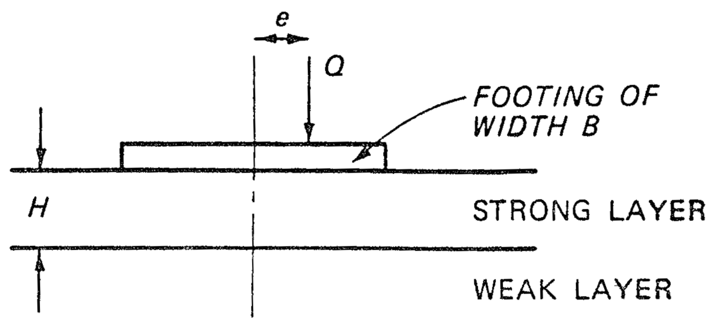


Figure B18. Two-layer system with eccentric loading

Factors tending to cause
failure in different directions

31. The recommendations given in this appendix cannot be blindly applied in cases such as in Figure B19. Judgment will be required.

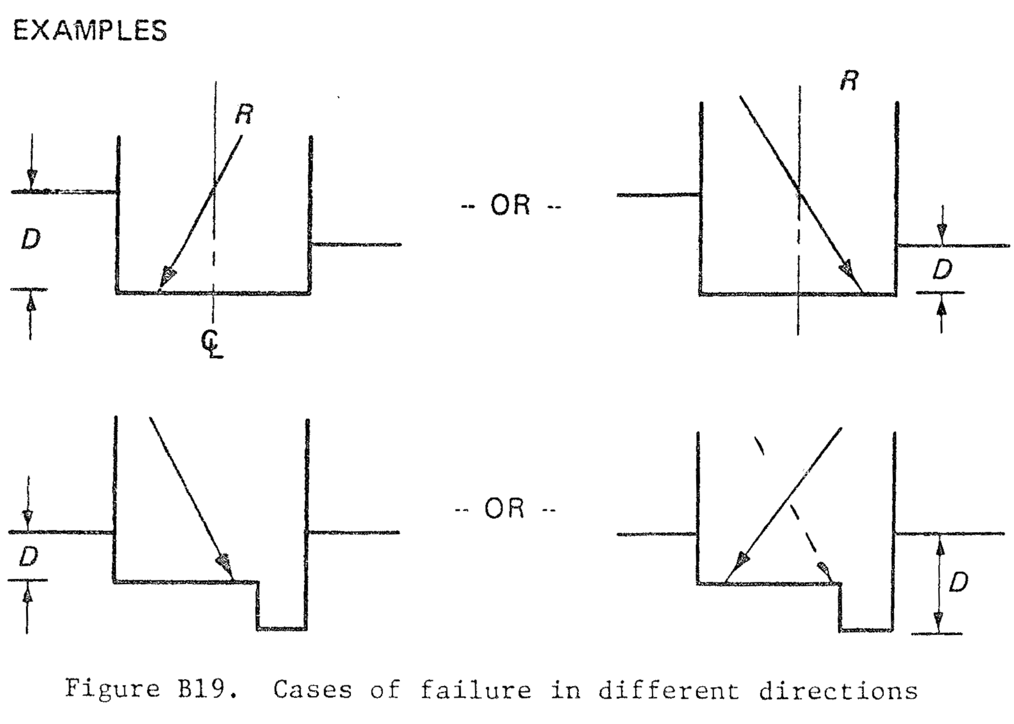


Figure B19. Cases of failure in different directions

APPENDIX C: COMPARISON OF BEARING CAPACITY PROCEDURES*

Bearing Capacity Factors

1. The values for bearing capacity factors presented by Meyerhof (1963) and Vesic (1975) are approximately the same for the cohesion term N_c and the surcharge term N_q. Meyerhof's values for the friction term N_γ are smaller than Vesic's when ϕ is less than 35 degrees (Figure C1).

Shape Factors

2. Meyerhof and Vesic's recommendations are presented in Table C1. The table compares shape factors computed by their methods for various values of B/L and N_c ratios. For the cohesion term ζ_c, the two methods give practically the same results (Figure C2a). For the surcharge term ζ_q, Meyerhof's values are more conservative than Vesic's (Figures C2b). The values for the friction term ζ_γ for the two methods do not correct in the same direction (Figure C2c); Vesic's values are more conservative.

Embedment Factors

3. Meyerhof and Vesic's recommended embedment factors for various values of ϕ and D/B are compared in Table C2. Vesic's values for the cohesion term ζ_{cd} are more conservative than Meyerhof's. However, they exhibit an unusual behavior of decreasing in value when ϕ is greater than 25 (Figure C3a). This behavior is also present in Vesic's values for the surcharge term $\zeta_{\gamma d}$, but his values are on the unconservative side (Figure C3b). Vesic's values for the friction term $\zeta_{\gamma d}$ are more conservative (Figure C3c).

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* By Dana Humphrey, St. Louis District. Edited by Reed Mosher, WES.

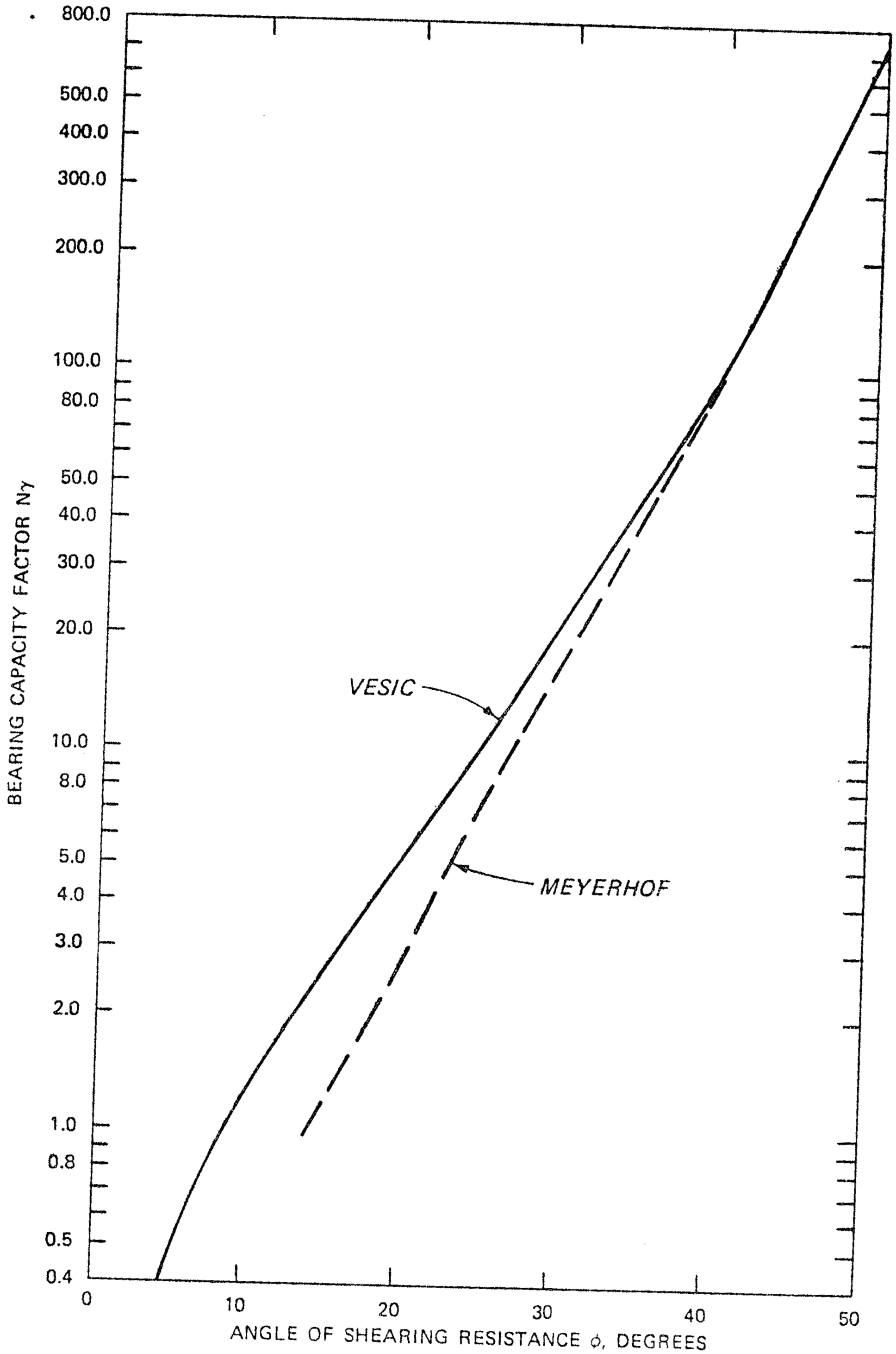


Figure C1. Comparison of bearing capacity factors determined using the methods of Meyerhof (1963) and Vesic (1975)

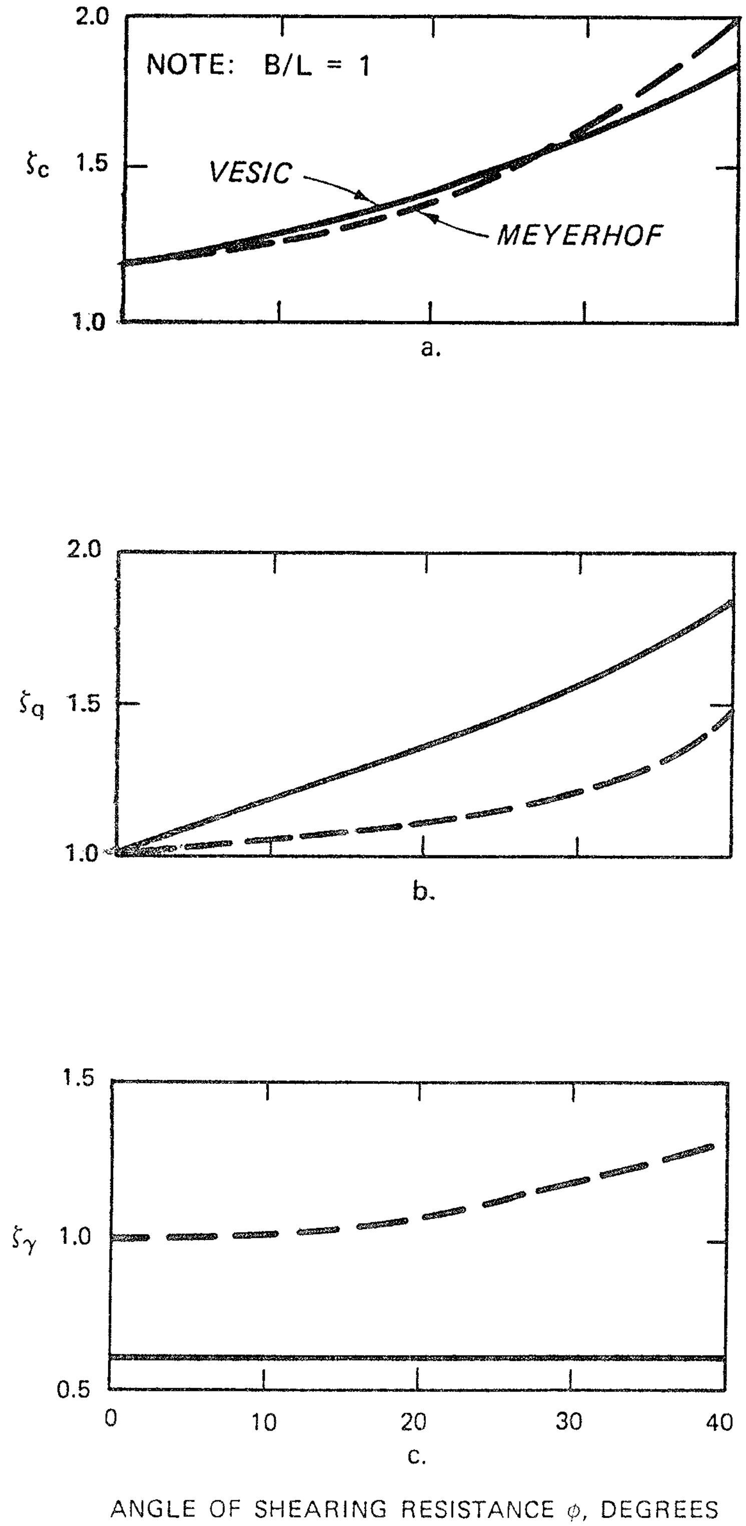


Figure C2. Comparisons of shape factors determined using the methods of Meyerhof (1963) and Vesic (1975)

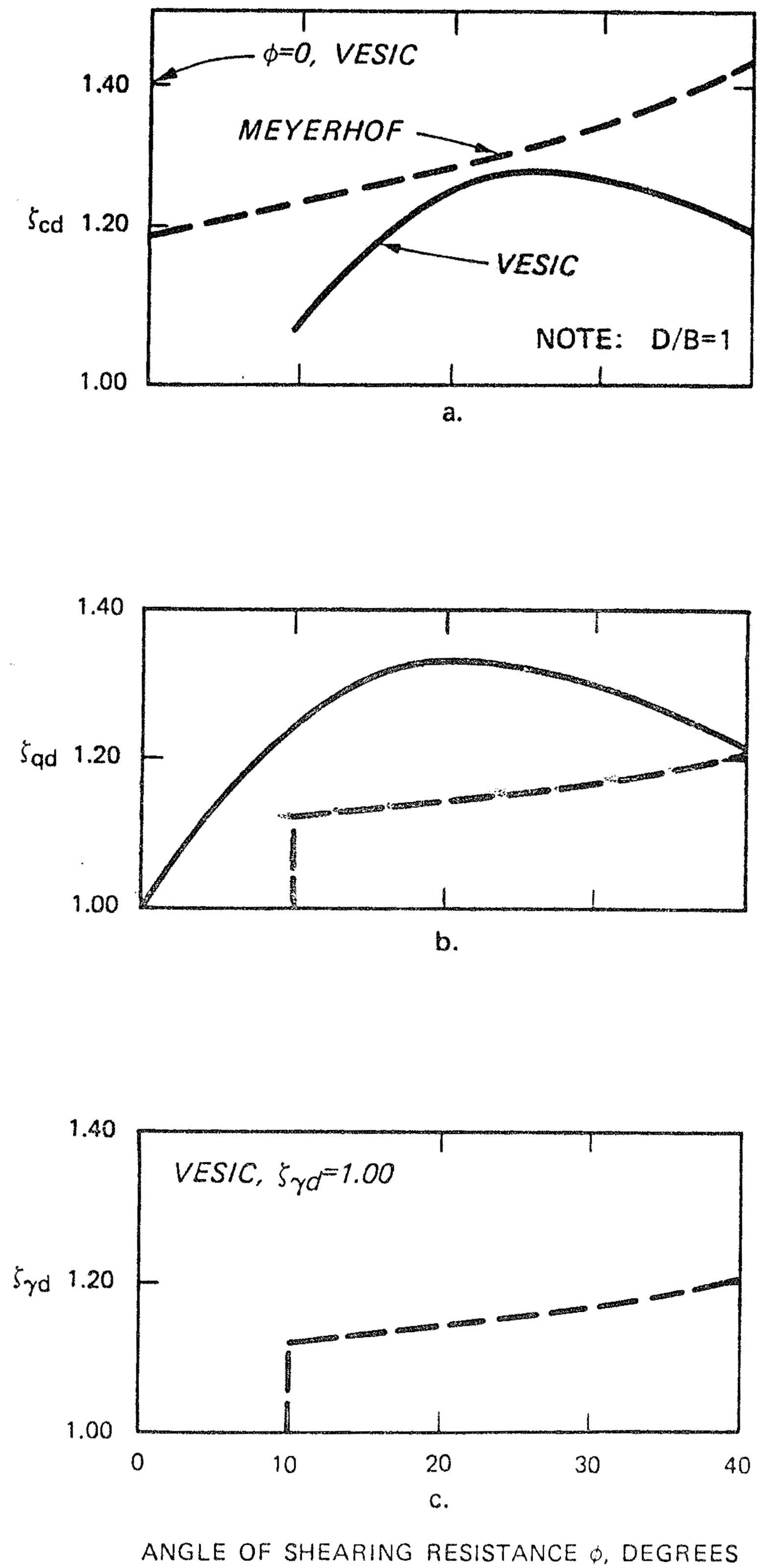


Figure C3. Comparisons of embedment factors determined using the methods of Meyerhof (1963) and Vesic (1975)

Inclination Factors

4. The values proposed by Vesic and Meyerhof are presented in Table C3 along with typical computations. The inclination factors for the special case of $c = 0$ are evaluated to show the relationship between the inclination factors in the surcharge $\zeta_{\gamma i}$ and friction ζ_{qi} terms. For the values in the surcharge term, Meyerhof's values are more conservative (Figure C4), except for the case of $\phi > 40°$. Vesic's values for the friction term are more conservative (Figure C5). Vesic's values show that for $c \neq 0$, as ϕ increases, ζ_{ci} and ζ_{qi} decrease.

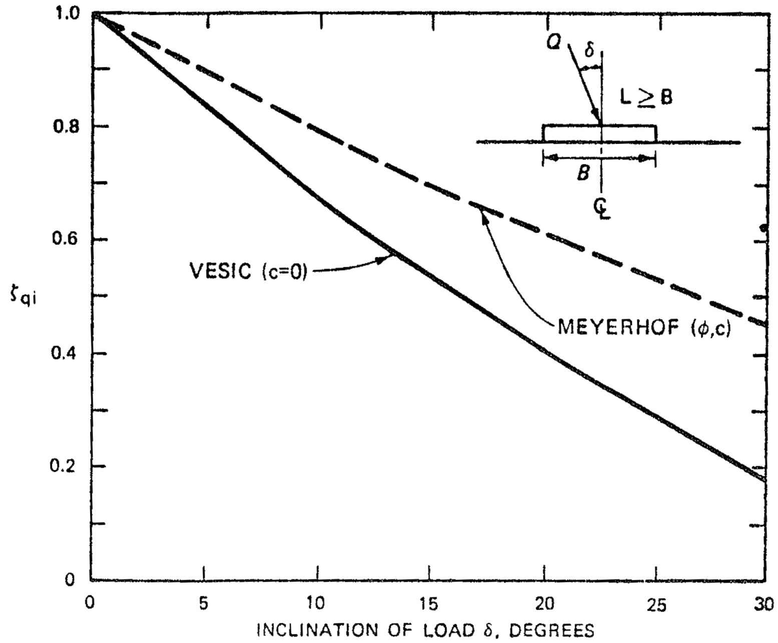


Figure C4. Comparison of inclination factors (surcharge term) determined using the methods of Meyerhof (1963) and Vesic (1975)

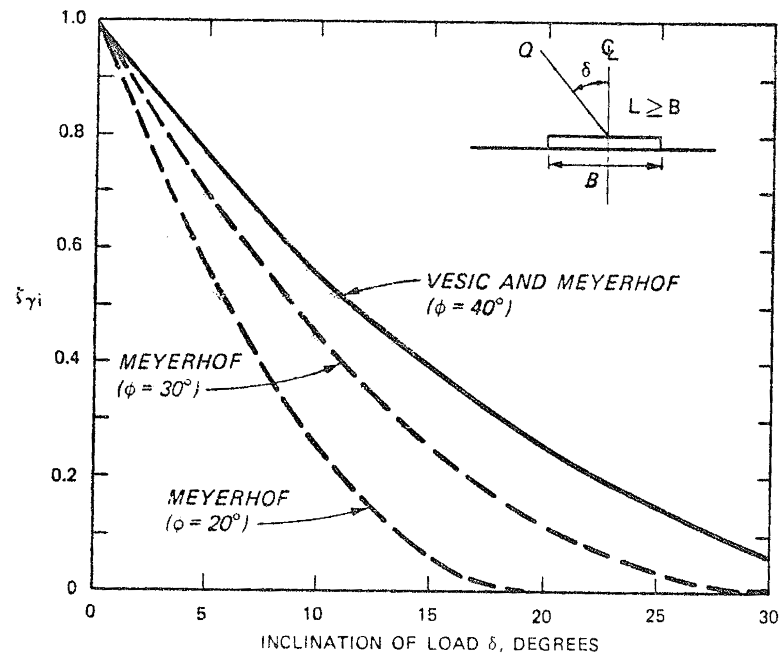


Figure C5. Comparison of inclination factors (friction term) determined using the methods of Meyerhof (1963) and Vesic (1975)

Table C1

Comparison of Shape Factors

Vesic	Meyerhof
$\zeta_c = 1 + \frac{B}{L}\left(\frac{N_q}{N_c}\right)$	$\zeta_c = 1 + \frac{B}{L}\left(\frac{N_{csquare}}{N_{cstrip}} - 1\right)$
$\zeta_q = 1 + \frac{B}{L}\tan\phi$	$\zeta_q = 1 + \frac{B}{L}\left(\frac{N_{qsquare}}{N_{qstrip}} - 1\right)$
$\zeta_y = 1 - 0.40\frac{B}{L}$	$\zeta_y = 1 + \frac{B}{L}\left(\frac{N_{\gamma square}}{N_{\gamma strip}} - 1\right)$

Recommended ζ_c

ϕ	$\frac{N_q}{N_c}$	B/L 0.5	B/L 1.0	ϕ	$\frac{N_{csquare}}{N_{cstrip}}$	B/L 0.5	B/L 1.0
0	0.195	1.098	1.195	0	1.20	1.10	1.20
10	0.296	1.148	1.296	10	1.27	1.14	1.27
20	0.432	1.216	1.432	20	1.35	1.18	1.35
30	0.610	1.305	1.610	30	1.66	1.33	1.66
40	0.852	1.426	1.852	40	2.07	1.54	2.07

Recommended ζ_q

ϕ	B/L 0.5	B/L 1.0	ϕ	$\frac{N_{qsquare}}{N_{qstrip}}$	B/L 0.5	B/L 1.0
0	1.00	1.00	0	1.00	1.00	1.00
10	1.09	1.18	10	1.04	1.02	1.04
20	1.18	1.36	20	1.13	1.07	1.13
30	1.29	1.58	30	1.17	1.09	1.17
40	1.42	1.84	40	1.48	1.24	1.48

Recommended ζ_γ

ϕ	B/L 0.5	B/L 1.0	ϕ	$\frac{N_{\gamma square}}{N_{\gamma strip}}$	B/L 0.5	B/L 1.0
0	0.80	0.60	0	—	1.00	1.00
10	0.80	0.60	10	1.00	1.00	1.00
20	0.80	0.60	20	1.07	1.04	1.07
30	0.80	0.60	30	1.19	1.10	1.19
40	0.80	0.60	40	1.32	1.16	1.32

Table C2

Comparison of Embedment Factors

Vesic	Meyerhof: For $\phi = 0$	Meyerhof: For $\phi > 10°$
$\zeta_{qd} = 1 + 2 \tan \phi (1 - \sin \phi)^2 \frac{D}{B}$	$\zeta_{qd} = 1$	$\zeta_{qd} = 1 + 0.1 \frac{D}{B} \tan \left(45 + \frac{\phi}{2}\right)$
$\zeta_{\gamma d} = 1$	$\zeta_{\gamma d} = 1$	$\zeta_{\gamma d} = 1 + 0.1 \frac{D}{B} \tan \left(45 + \frac{\phi}{2}\right)$
$\zeta_{cd} = 1 + 0.4 \frac{D}{B}$ *		$\zeta_{cd} = 1 + 0.2 \frac{D}{B} \tan \left(45 + \frac{\phi}{2}\right)$
$\zeta_{cd} = \zeta_{qd} - \frac{1 - \zeta_{qd}}{N_c \tan \phi}$ **		

Recommended $\zeta_{\gamma d}$

ϕ	D/B 0.5	D/B 1.0	ϕ	D/B 0.5	D/B 1.0
0	1.00	1.00	0	1.00	1.00
10	1.12	1.24	10	1.00	1.00
20	1.16	1.32	20	1.07	1.14
30	1.14	1.29	30	1.09	1.17
40	1.11	1.21	40	1.11	1.21

Recommended $\zeta_{\gamma d}$

ϕ	D/B 0.5	D/B 1.0	ϕ	D/B 0.5	D/B 1.0
0	1.00	1.00	0	1.00	1.00
10	1.00	1.00	10	1.00	1.00
20	1.00	1.00	20	1.07	1.14
30	1.00	1.00	30	1.09	1.17
40	1.00	1.00	40	1.11	1.21

Recommended ζ_{cd}

ϕ	N_c	D/B 0.5	D/B 1.0	ϕ	D/B 0.5	D/B 1.0
0	5.14	1.20	1.40	0	1.10	1.20
10	8.35	1.04	1.08	10	1.12	1.24
20	14.83	1.13	1.26	20	1.14	1.29
30	30.14	1.13	1.27	30	1.17	1.35
40	75.31	1.11	1.21	40	1.21	1.43

* For $\phi = 0$.
** For $\phi \neq 0$.

Table C3

Comparison of Inclination Factors

Vesic	Meyerhof
$\zeta_{qi} = \left(1 - \frac{P}{Q + B'L'C \cot \phi}\right)^m$	$\zeta_{qi} = \left(1 - \frac{\delta}{90}\right)^2$
$\zeta_{ii} = \zeta_{qi} - \frac{1 - \zeta_{qi}}{N_c \tan \phi}$	$\zeta_{ii} = \left(1 - \frac{\delta}{90}\right)^2$
$\zeta_{\gamma i} = \left(1 - \frac{P}{Q + B'L'C \cot \phi}\right)^{m+1}$	$\zeta_{\gamma i} = \left(1 - \frac{\delta}{\phi}\right)^2$

where

$$m_B = \frac{2 + \frac{B}{L}}{1 + \frac{B}{L}}$$ (for inclination in the base width B direction)

$$m_L = \frac{2 + \frac{L}{B}}{1 + \frac{L}{B}}$$ (for inclination in the base length L direction)

The comparison is for the special case of a load inclined in the B direction and c = 0 :

Therefore,

$$m_B = \frac{2}{1} = 1$$

$$\zeta_{qi} = \left(1 - \frac{P}{Q}\right)^2 = (1 - \tan \delta)^2$$

ζ_{ii} is irrelevant

$$\zeta_{\gamma i} = \left(1 - \frac{P}{Q}\right)^3 = (1 - \tan \delta)^3$$

(Continued)

Vesic	Meyerhof

The factors are:

δ	ζ_{qi}	$\zeta_{\gamma i}$	$\zeta_{\gamma i}$	δ	$\zeta_{\gamma i}$ $\phi = 20$	$\zeta_{\gamma i}$ $\phi = 30°$	$\zeta_{\gamma i}$ $\phi = 40°$
0°	1.00	1.00	1.00	0°	1.00	1.00	1.00
5	0.833	0.760	0.892	5°	0.563	0.694	0.766
10	0.678	0.559	0.790	10°	0.250	0.444	0.563
15	0.536	0.392	0.694	15°	0.063	0.250	0.391
20	0.405	0.257	0.605	20°	0.000	0.111	0.250
25	0.285	0.152	0.522	25°	--	0.028	0.141
30	0.179	0.075	0.444	30°	--	--	0.063

$$\zeta_{qi} = \left(1 - \frac{P}{Q + B'L'C \cot \phi}\right)^2$$

Say $c = 0.10$ tsf

$\phi = 15°, 30°$

$$\zeta_{qi} = \left(1 - \frac{P}{Q + B'L'0.10} 1/\tan 15\right)^2 = 1 - \frac{P}{Q + B'L'(0.37)}$$

$$\zeta_{qi} = \left(1 - \frac{P}{Q + B'L'0.10} 1/\tan 30°\right)^2$$

$$= 1 - \frac{P}{Q + B'L'(0.17)}$$

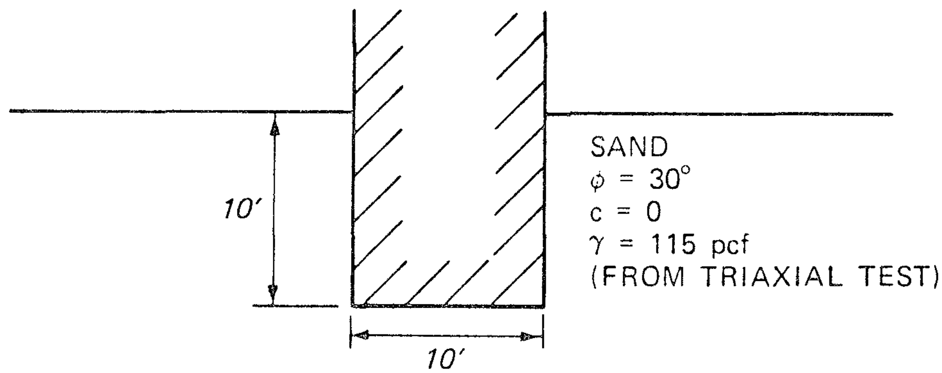
Thus, for $c \neq 0$, as ϕ increases, ζ_{qi} decreases.

APPENDIX D: COMPARISON OF BEARING CAPACITY CALCULATIONS*

Homogeneous Soil Profiles

1. Simple examples of bearing capacity calculations for cohesionless and cohesive soils are shown in the following pages. For the particular examples, Meyerhof's (1963) procedure gives more conservative values than Vesic's (1975) although the two sets of values are not very different.

Example 1: cohesionless soil



APPLIED LOAD IS VERTICAL AND CONCENTRIC

$$q_o = \Psi_q \Psi_{qd} q N_q + \frac{1}{2} \Psi_\gamma \Psi_{\gamma d} B \gamma N_\gamma$$

Vesic

$$\Psi_q = 1 + \left(\frac{B}{L}\right) \tan \phi = 1 + \left(\frac{10}{10}\right) \tan 30 = 1.58$$

$$\Psi_{qd} = 1 + 2 \tan \phi (1 - \sin \phi)^2 \frac{D}{B}$$

$$= 1 + 2 \tan 30 (1 - \sin 30)^2 \left(\frac{10}{10}\right)$$

$$= 1.29$$

$$q = 10 \times 115 = 1150 \text{ psf}$$

N_q = 18.40 (from Table 3.1, Vesic (1975))

* By Dana Humphrey, St. Louis District. Edited by Reed Mosher, WES.

Vesic (Continued)

$$\Psi_\gamma = 1 - 0.4\left(\frac{B}{L}\right) = 1 - 0.4\left(\frac{10}{10}\right) = 0.60$$

$$\Psi_{\gamma d} = 1$$

N_γ = 22.40 (from Table 3.1, Vesic (1975))

$$q_o = (1.58)(1.29)(1150)(18.40) + \frac{1}{2}(0.60)(1.0)(10)(115)(22.4)$$

= 50,900 psf = 50.9 ksf

Meyerhof

$$\Psi_q = 1 + \frac{B}{L}\left(\frac{N_{qsquare}}{N_{qstrip}} - 1\right) = 1 + \frac{10}{10}(1.17 - 1) = 1.17$$

$$\Psi_{qd} = 1 + 0.1\,\frac{D}{B}\tan\left(45 + \frac{\phi}{2}\right)$$

$$= 1 + 0.1\left(\frac{10}{10}\right)\tan\left(45 + \frac{30}{2}\right) = 1.17$$

q = 1150 psf

N_q = 18.70

$$\Psi_\gamma = 1 + \frac{B}{L}\left(\frac{N_{\gamma square}}{N_{\gamma strip}} - 1\right) = 1 + \frac{10}{10}(1.19 - 1) = 1.19$$

$$\Psi_{\gamma d} = \Psi_{qd} = 1.17$$

N_γ = 18.00

$$q_o = (1.17)(1.17)(1150)(18.70) + \frac{1}{2}(1.19)(1.17)(10)(115)(18.00)$$

= 43,800 psf = 43.8 ksf

Example 2: cohesive soil

Same as example 1 but c = 1.0 ksf and $\phi = 0$

$$q_o = \Psi_c\Psi_{cd}cN_c + \Psi_q\Psi_{qd}qN_q$$

Vesic

$$\Psi_c = 1 + \left(\frac{B}{L}\right)\left(\frac{N_q}{N_c}\right) = 1 + \left(\frac{10}{10}\right)\left(\frac{1.00}{5.14}\right) = 1.19$$

$$\Psi_{cd} = 1 + 0.4\,\frac{D}{B} = 1 + 0.4\,\frac{10}{10} = 1.40$$

Vesic (Continued)

$$N_c = 5.14 \text{ (from Table 3.1, Vesic (1975))}$$

$$\Psi_q = 1 + \left(\frac{B}{L}\right) \tan \phi = 1 + \frac{10}{10} (\tan 0) = 1.00$$

$$\Psi_{qd} = 1 + 2 \tan \phi (1 - \sin \phi)^2 \frac{D}{B} = 1.00$$

$$q = 1150 \text{ psf}$$

$$N_q = 1.00$$

$$q_o = (1.19)(1.40)(1.0)(5.14) + (1.00)(1.00)\left(\frac{1150}{1000}\right)(1.00)$$

$$= 9.7 \text{ ksf}$$

Meyerhof

$$\Psi_c = 1 + \frac{B}{L}\left(\frac{N_{csquare}}{N_{cstrip}} - 1\right) = 1 + \frac{10}{10}\left(\frac{6.16}{5.14} - 1\right) = 1.20$$

$$\Psi_{cd} = 1 + 0.2 \frac{D_\gamma}{B} \tan\left(45 + \frac{\phi}{2}\right) = 1 + 0.2\left(\frac{10}{10}\right) \tan (45 + 0) = 1.20$$

$$N_c = 5.14$$

$$\Psi_q = 1 + \frac{B}{L}\left(\frac{N_{qsquare}}{N_{qstrip}} - 1\right) = 1 + \frac{10}{10}\left(\frac{1.0}{1.0} - 1\right) = 1.00$$

$$\Psi_{qd} = 1.00 \quad \text{for} \quad \phi = 0$$

$$N_q = 1.00$$

$$q_o = (1.20)(1.20)(1.0)(5.14) + (1.00)(1.00)\left(\frac{1150}{1000}\right)(1.00)$$

$$= 8.6 \text{ ksf}$$

Nonhomogeneous Soil Conditions

2. A search of the literature revealed many different methods and procedures for evaluating the bearing capacity for nonhomogenous soil conditions. The procedures are dependent on the type of nonhomogeneous soil profile; i.e., soft clay over stiff clay, or strong layer over weak layer, etc. Several of the methods were examined and compared. From these comparisons, the most reliable methods were recommended for the program criteria.

Button's (1953) method

3. This method assumes that a general shear failure occurs along a cylindrical slip surface starting at the edge of the foundation. Brown and Meyerhof (1969) showed that this assumed failure mode was unrealistic and resulted in bearing factors on the unsafe side for a soft clay over a stiff clay and a stiff clay over a soft clay. Figure D1 compares Button's values with those of Vesic (1975) which were described earlier in Appendix B.

Sand of finite thickness over clay layer

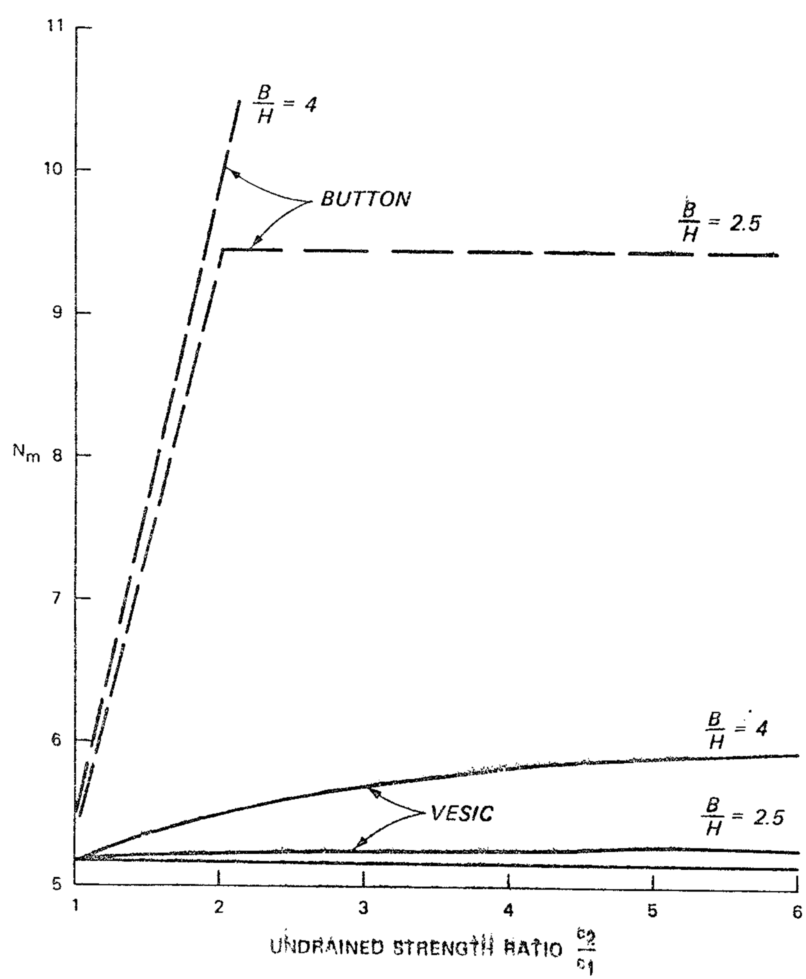
4. Experimental studies (Tcheng 1957, Vesic 1970) have shown that failure for this condition is by punching along essentially vertical slip lines forming at the foundation perimeter.

5. Tcheng's (1957) analysis proposed relating the bearing capacity of the underlying clay layer q''_o to the bearing capacity of a long rectangular footing on a sand layer over clay (with shear parameters of $c = 0$ and ϕ) by the expression

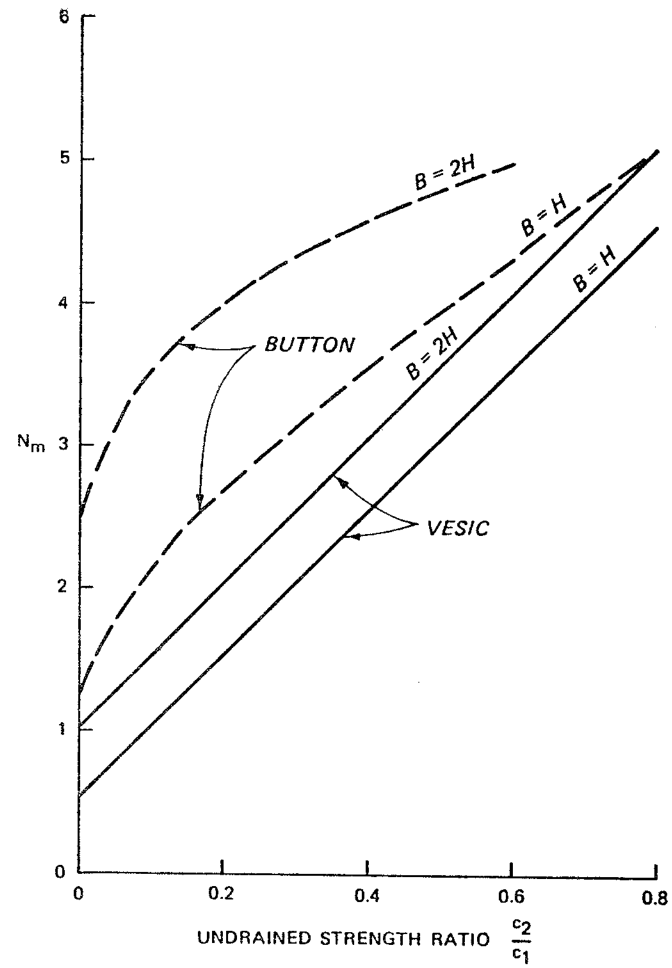
$$q_o = \frac{q''_o}{1 - 2\left(\frac{H}{B}\right) \tan\phi \,(1 + \sin\phi)} e^{-(\pi/4-\phi/2)\tan\phi}$$

Tcheng reported that the above expression showed reasonable agreement with his test results when $H \leq 1.5B$, and for greater depths he proposed semiempirical formulas for depths up to $H \leq 3.5B$, after which the influence of the soft clay layer is negligible. This method was found to give unrealistically high bearing capacity values even for small thicknesses of the sand stratum, a result that is shown in the comparison later in this appendix. It is therefore recommended that this method not be used.

6. Vesic (1970) proposed a more general analysis (valid for rectangular footings of any shape on a stronger layer with shear strength parameters c_1 , ϕ_1 and underlain by a weaker layer with shear strength parameters c_2 , ϕ_2) based on the assumption of vertical slip surfaces.



a. Soft clay over stiff clay



b. Stiff clay over soft clay

Figure D1. Comparison of Vesic and Button's (1953) modified bearing capacity factors

This approach yielded the expression

$$q_o = \left[q_o'' + \left(\frac{1}{K}\right) c_1 \cot \phi_1\right] e^{2[1+(B/L)]K\tan\phi_1 (H/B)} - \left(\frac{1}{K}\right) c_1 \cot \phi_1$$

where

$$K \doteq \frac{1 - \sin^2 \phi_1}{1 + \sin^2 \phi_1}$$

The bearing capacity value q_o'' is for a fictitious footing of the same size and shape as the actual footing but resting on the lower layer and evaluated with the shear strength parameters c_2 , ϕ_2 . When $c_1 = 0$ and $25 \leq \phi \leq 50$, the above expression can be reduced to

$$q_o = q_o'' e^{0.67[1+(B/L)](H/B)}$$

This expression can be used to find the critical depth of the upper layer, after which the bearing capacity of underlying weaker layer will have little influence:

$$\frac{H}{B}_{crit} = \frac{3 \ln \left(\frac{q_o'}{q_o''}\right)}{2\left[1 + \left(\frac{B}{L}\right)\right]}$$

where q_o' is the bearing capacity of the upper layer as an infinite mass. For $\phi_1 = 0$, the bearing capacity q_o goes to negative infinity.

7. A special problem with this method is determining the bearing capacity of the weaker layer q'' . In an example given by Vesic (1975), embedment is taken as the depth to the top of the weaker layer, but when the bearing capacity of the actual footing is computed, no account is taken of the weight of soil between the base of the footing and the soft layer. On the basis of the procedure given by Perloff and Baron (1976) in Appendix B, paragraph 24, this assumption seems incorrect. It is therefore recommended that Vesic's method not be used until this is resolved.

8. Perloff and Baron (1976) proposed a procedure which was presented earlier (Appendix B, paragraph 30) for a strong layer over a weak layer. It was found to give reasonable results as shown in the following comparison.

9. A comparison of the three methods described above was performed using $c_1 = 0$ and four different angle of internal friction (15°, 25°, 35°, 50°). In these calculations and comparisons, it is assumed that the bearing capacity of the lower layer is calculated in a consistent manner regardless of the method being used.

a. For a rectangular footing (Figure D2),*

(1) Tcheng's (1957) method:

$$q_o = \frac{q_o''}{1 - 2\left(\frac{H}{B}\right) \tan\phi \; (1 + \sin\phi)} e^{-(\pi/4-\phi/2)\tan\phi}$$

Therefore,

$$M = \frac{1}{1 - 2\left(\frac{H}{B}\right) \tan\phi \; (1 + \sin\phi)} e^{-(\pi/4-\phi/2)\tan\phi}$$

and for

$$\phi = 15° \; , \quad M = \frac{1}{1 - 0.566(H/B)}$$

$$\phi = 25° \; , \quad M = \frac{1}{1 - 1.018(H/B)}$$

$$\phi = 35° \; , \quad M = \frac{1}{1 - 1.575(H/B)}$$

$$\phi = 50° \; , \quad M = \frac{1}{1 - 2.777(H/B)}$$

(2) Vesic's (1970) method:

For $c_1 = 0$ and $B/L = 0$, the expression reduces to:

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* Note: For all three methods, q_o' (base length of sand extending to infinite depth) is the limiting value of q_o.

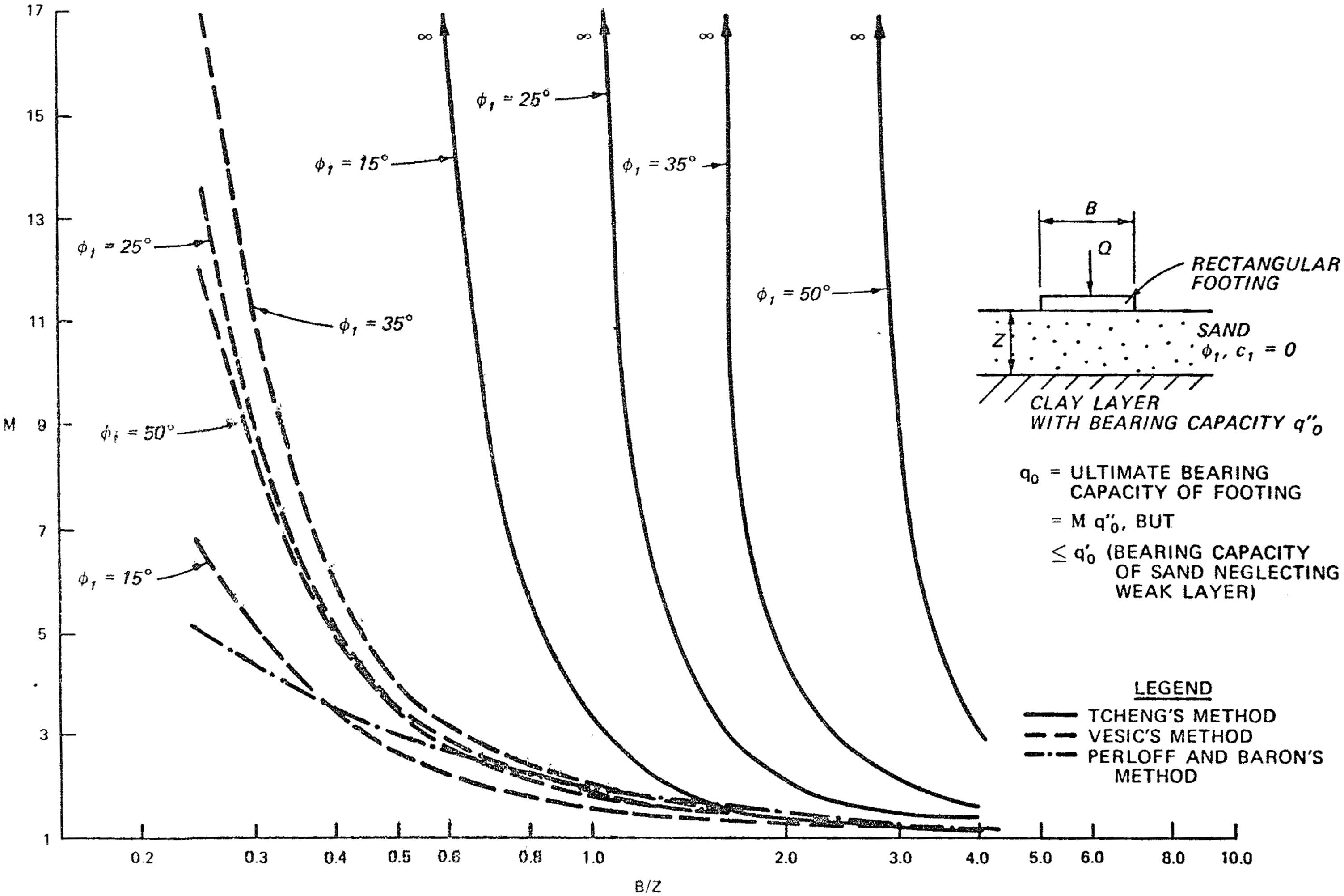

Figure D2. Comparison of Tcheng (1957), Vesic (1970), and Perloff and Baron's (1976) methods for a rectangular footing

$$q_o = q_o'' \frac{e^{2K\tan\phi_1 (H/B)}}{M}$$

Thus, for

$$\phi = 25° \ , \quad M = e^{0.650(H/B)}$$

$$\phi = 35° \ , \quad M = e^{0.707(H/B)}$$

$$\phi = 50° \ , \quad M = e^{0.621(H/B)}$$

$$\phi = 15° \ , \quad M = e^{0.469(H/B)}$$

(3) Perloff and Baron's (1976) method:

$$q_o'' = q_o \frac{\frac{B}{Z}}{\left(\frac{B}{Z + 1}\right)}$$

(not a function of ϕ)

Therefore,

$$q_o = q_o'' \frac{\left[\frac{\left(\frac{B}{Z+1}\right)}{\frac{B}{Z}}\right]}{M}$$

The bearing capacity factors are:

$\frac{B}{Z}\left(\frac{1}{H/B}\right)$	Tcheng ϕ = 15°	Tcheng ϕ = 25°	Tcheng ϕ = 35°	Tcheng ϕ = 50°	Vesic ϕ = 15°	Vesic ϕ = 25°	Vesic ϕ = 35°	Vesic ϕ = 50°	Perloff and Baron
4	1.16	1.34	1.65	3.27	1.12	1.18	1.19	1.17	1.25
2	1.39	2.04	4.71	--	1.26	1.38	1.42	1.36	1.50
1	2.30	--	--	--	1.60	1.92	2.03	1.86	2.00
0.5	--	--	--	--	2.55	3.67	4.11	3.46	3.00
0.25	--	--	--	--	6.53	13.46	16.91	11.99	5.00

b. For a square footing (Figure D3),

(1) Vesic's (1970) method:

$$M = e^{2[1+(B/L)]K\tan\phi(H/B)}$$

For this case, B/L = 1 . Therefore,

$$M = e^{4K\tan\phi_1(H/B)}$$

and for

$$\phi = 15^\circ \;,\quad M = e^{0.938(H/B)}$$

$$\phi = 25^\circ \;,\quad M = e^{1.300(H/B)}$$

$$\phi = 35^\circ \;,\quad M = e^{1.414(H/B)}$$

$$\phi = 50^\circ \;,\quad M = e^{1.242(H/B)}$$

(2) Perloff and Baron's (1976) method:

$$q_o'' = q_o \left[\frac{B^2}{(B+Z)^2}\right]$$

Therefore,

$$q_o = q_o'' \frac{(B+Z)^2}{B^2}\left(\frac{\frac{1}{Z^2}}{\frac{1}{Z^2}}\right)$$

$$= q_o'' \frac{\left(\frac{B}{Z}+1\right)^2}{\left(\frac{B}{Z}\right)^2}$$

(independent of ϕ)

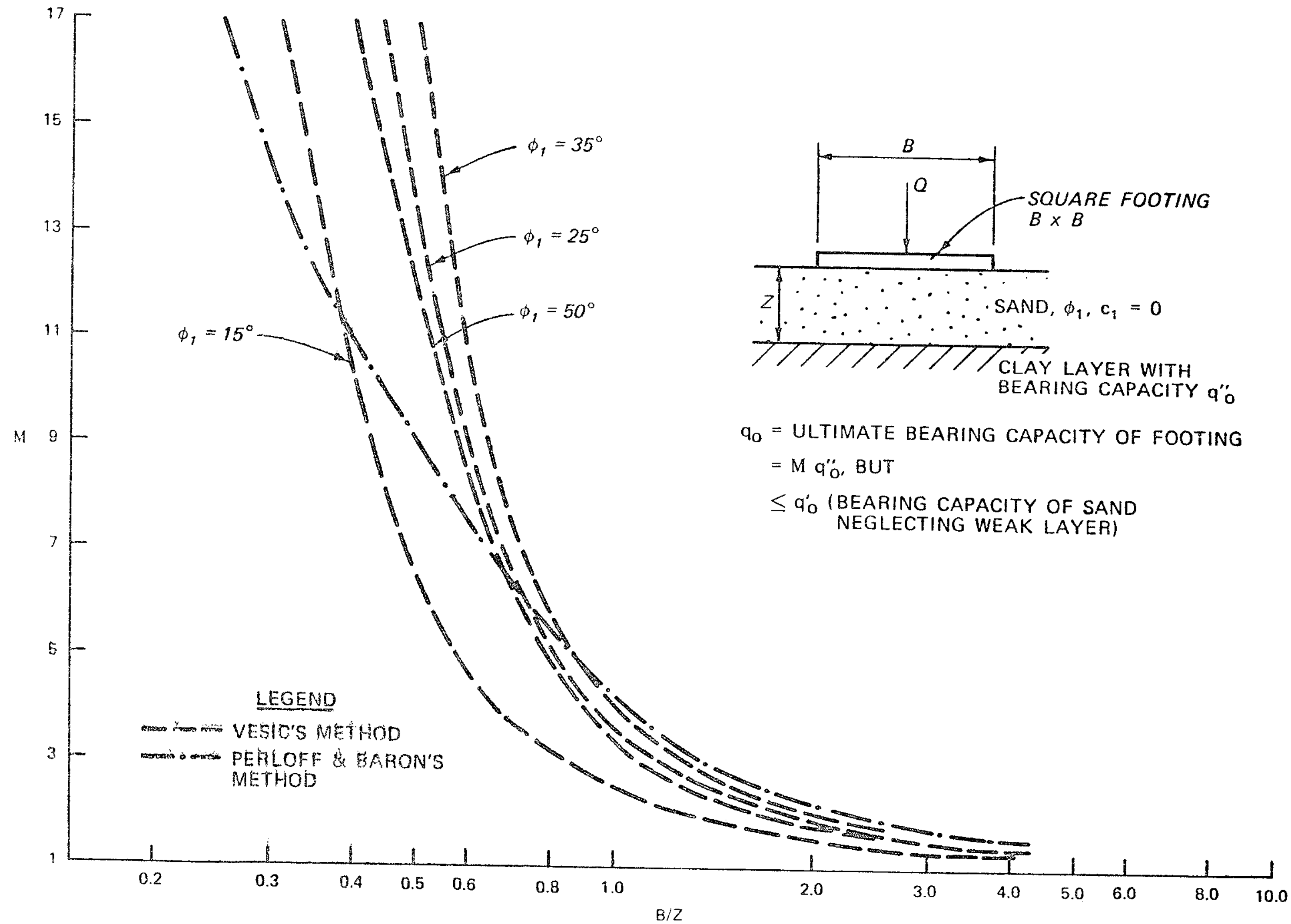

Figure D3. Comparison of Vesic (1970) and Perloff and Baron's (1976) methods for a square footing

The bearing capacity factors are:

$\frac{B}{Z}\left(\frac{1}{H/B}\right)$	Vesic $\phi = 15°$	Vesic $\phi = 25°$	Vesic $\phi = 35°$	Vesic $\phi = 50°$	Perloff and Baron
4	1.26	1.38	1.42	1.36	1.56
2	1.60	1.92	2.03	1.86	2.25
1	2.55	3.67	4.11	3.46	4.00
0.5	6.53	13.46	16.91	11.99	9.00
0.25	42.61	181.27	286.00	143.74	25.00

For critical (H/B),

$$q_o' = \frac{1}{2}\gamma B N\gamma = q_o''\left[\frac{(B/Z)_{crit} + 1}{(B/Z)_{crit}}\right]^{C_2 N_c}$$

$$\frac{(B/Z)_{crit} + 1}{(B/Z)_{crit}} = \frac{1\gamma B N\gamma}{2C_2 N_c}$$

$$1 + \frac{1}{(B/Z)_{crit}} = \frac{\gamma B N\gamma}{2C_2 N_c} - 1$$

$$(B/Z)_{crit} = \frac{1}{\frac{\gamma B N\gamma}{2C_2 N_c} - 1}$$

For a typical case ($\phi = 35°$, $B = 15$, $\gamma = 115$ pcf),

$$C_2 = 0.10,\ 0.25,\ 0.50,\ 1.0 \text{ tcf}$$

$$(B/Z)_{crit} = \frac{1}{\frac{(115)(15)(45)}{2(C_2)(5.14)(2000)} - 1}$$

$$= \frac{1}{\left(\frac{3.78}{C_2} - 1\right)}$$

γ_2	$(B/Z)_{crit}$	z
0.10	0.027	551'
0.25	0.071	212'
0.50	0.153	98.3'
1.00	0.360	41.6'

The effect of $c_1 \neq 0$

(a) Recall that the Perloff and Baron method is independent of ϕ_1 and c_1)

(b) Vesic's method may be rewritten:

$$q_o = q_o'' \cdot e^{2[1+(B/L)]K\tan\phi_1 (H/B)} + c_1 \cdot \frac{\frac{1}{K}\cot\phi_1 \left\{e^{2[1+(B/L)]K\tan\phi_1 (H/B)-1}\right\}}{M_c}$$

Therefore, $q_o = Mq_o'' + M_c c_1$

For a strip footing, for

$$\phi_1 = 15^\circ, \quad M_c = 4.27[e^{0.469(H/B)} - 1]$$

$$\phi_1 = 25^\circ, \quad M_c = 3.08[e^{0.650(H/B)} - 1]$$

$$\phi_1 = 35^\circ, \quad M_c = 2.83[e^{0.707(H/B)} - 1]$$

$$\phi_1 = 50^\circ, \quad M_c = 3.22[e^{0.621(H/B)} - 1]$$