

this document downloaded from

vulcanhammer.info

the website about
Vulcan Iron Works
Inc. and the pile
driving equipment it
manufactured

Visit our companion site
<http://www.vulcanhammer.org>

Terms and Conditions of Use:

All of the information, data and computer software ("information") presented on this web site is for general information only. While every effort will be made to insure its accuracy, this information should not be used or relied on for any specific application without independent, competent professional examination and verification of its accuracy, suitability and applicability by a licensed professional. Anyone making use of this information does so at his or her own risk and assumes any and all liability resulting from such use. The entire risk as to quality or usability of the information contained within is with the reader. In no event will this web page or webmaster be held liable, nor does this web page or its webmaster provide insurance against liability, for any damages including lost profits, lost savings or any other incidental or consequential damages arising from the use or inability to use the information contained within.

This site is not an official site of Prentice-Hall, Pile Buck, or Vulcan Foundation Equipment. All references to sources of software, equipment, parts, service or repairs do not constitute an endorsement.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM LMNDPILE - Rigid Cap 2- and 3-D Pile Analysis (X0034) ^{X0035} _{X0036}		PROGRAM NO. 713-11-R0026					
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				
Deborah Kaufman		December 1976	<table border="1"> <tr> <td>PHASE</td> <td>STAGE</td> </tr> <tr> <td>INIT</td> <td>OP</td> </tr> </table>	PHASE	STAGE	INIT	OP
PHASE	STAGE						
INIT	OP						
A. PURPOSE OF PROGRAM							
This program is a general method of analysis by direct stiffness of two- and three-dimensional pile foundations. The pile foundation consists of a group of piling placed into the soil topped with a rigid cap. Loads to the cap are transmitted by the piling to the soil. Determinations of deflections and individual pile loads are computed as required by the designer. Adequate representation of the soil-pile interaction is necessary.							
B. PROGRAM SPECIFICATIONS							
G-635 FORTRAN 24K Core							
C. METHODS							
The base is assumed rigid. Piles in a three-dimensional analysis are represented by a 6x6 stiffness matrix as proposed by Hrennikoff. In a two-dimensional analysis the piles are represented by a 3x3 stiffness matrix. The subgrade modulus may be constant or linearly varying. The solution is by a direct stiffness method.							
D. EQUIPMENT DETAILS							
Interactive T/S Terminal Honeywell G-635							
E. INPUT - OUTPUT							
Input generally consists of pile geometric, material and fixity properties and the applied loads. Data may be input interactively or saved in a file prior to the run. (Detailed guide available from WES ADP Center). Outputs structure, and pile deflections, pile forces along pile axis and along structure axis. Output may be directed to the terminal or saved in a file. Pile forces along the structure axis may be saved in a file.							
F. ADDITIONAL REMARKS							

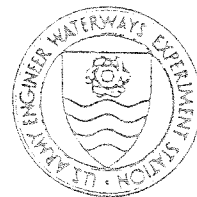
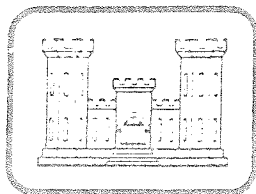
✧ ✧ ✧ ✧ ✧ ✧ ✧ ✧ ✧

C O N D I T I O N S O F U S E

THE FOLLOWING CONDITIONS REGULATE THE USE OF COMPUTER PROGRAMS DEVELOPED BY THE CORPS OF ENGINEERS, DEPARTMENT OF THE ARMY:

1. THE COMPUTER PROGRAMS ARE FURNISHED BY THE GOVERNMENT AND MAKES NO WARRANTIES, EXPRESS OR IMPLIED, CONCERNING THE ACCURACY, COMPLETENESS, RELIABILITY, USABILITY, OR SUITABILITY FOR ANY PARTICULAR PURPOSE OF THE INFORMATION OR DATA CONTAINED IN THE PROGRAMS, OR FURNISHED IN CONNECTION THEREWITH, AND THE UNITED STATES SHALL BE UNDER NO LIABILITY WHATSOEVER TO ANY SUCH INDIVIDUAL OR GROUP ENTITY BY REASON OF ANY USE MADE THEREOF.
2. THE PROGRAMS BELONG TO THE FEDERAL GOVERNMENT. THEREFORE, THE RECIPIENT AGREES NOT TO ASSERT ANY PROPRIETARY RIGHTS IN THE PROGRAMS AND ALL DOCUMENTS RELATED HERETO, INCLUDING ALL COPIES AND VERSIONS IN POSSESSION THEREOF, WILL BE DISCONTINUED FROM USE OR DESTROYED UPON REQUEST BY THE GOVERNMENT.
3. THE PROGRAMS ARE TO BE USED ONLY IN THE PUBLIC INTEREST AND/OR THE ADVANCEMENT OF SCIENCE AND WILL NOT BE USED BY THE RECIPIENT TO GAIN UNFAIR ADVANTAGE OVER ANY CLIENT OR COMPETITOR. WHEREAS THE RECIPIENT MAY CHARGE CLIENTS FOR ORDINARY COSTS OF APPLYING THESE PROGRAMS, THE RECIPIENT AGREES NOT TO LEVY A CHARGE, ROYALTY OR PROPRIETARY USAGE FEE UPON ANY CLIENT FOR THE DEVELOPMENT OR USE OF ANY PROGRAM RECEIVED, OR FOR ANY MODIFICATION OF SUCH PROGRAM BY THE RECIPIENT, OR MINOR OR TEMPORARY MODIFICATIONS WILL BE MADE TO THE PROGRAMS (E.G., NECESSARY CORRECTIONS OR CHANGES IN THE FORMAT OF INPUT OR OUTPUT) WITHOUT WRITTEN APPROVAL FROM THE GOVERNMENT. THE PROGRAMS WILL NOT BE FURNISHED BY THE RECIPIENT TO ANY THIRD PARTY UNDER ANY CIRCUMSTANCE. HOWEVER, INFORMATION ON THE SOURCE OF THE PROGRAMS WILL BE FURNISHED TO ANYONE REQUESTING SUCH INFORMATION.
4. ALL DOCUMENTS AND REPORTS CONVEYING INFORMATION OBTAINED AS A RESULT OF THE USE OF THE PROGRAM(S) BY THE RECIPIENT WILL ACKNOWLEDGE THE CORPS OF ENGINEERS, DEPARTMENT OF THE ARMY, AS THE ORIGIN OF THE PROGRAM(S) AND FOR ANY ASSISTANCE RECEIVED IN THEIR APPLICATION.

CATEGORY B
713-F5-R0026



TECHNICAL REPORT K-80-3

DOCUMENTATION FOR LMVDP PILE PROGRAM

by

Deborah K. Martin, H. Wayne Jones, N. Radhakrishnan

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

June 1980

Final Report

Approved For Public Release; Distribution Unlimited



Prepared for U. S. Army Engineer Division, Lower Mississippi Valley
P. O. Box 80, Vicksburg, Miss. 39180

Destroy this report when no longer needed. Do not return
it to the originator.

The findings in this report are not to be construed as an official
Department of the Army position unless so designated
by other authorized documents.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report H-11-3	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) DOCUMENTATION FOR LMVDFILE PROGRAM		5. TYPE OF REPORT & PERIOD COVERED Final report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Deborah K. Martin N. Radhakrishnan H. Wayne Jones		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Automatic Data Processing Center P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Engineer Division, Lower Mississippi Valley P. O. Box 60, Vicksburg, Miss. 39180		12. REPORT DATE June 1980
		13. NUMBER OF PAGES 182
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Computer programs LMVDFILE (Computer program) Computerized simulation File caps Documentation Pile foundations Matrix analysis		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The primary work reported here consists of consolidating the rigid cap pile analysis programs of the U. S. Army Engineer Districts, St. Louis and New Orleans. The new program, LMVDFILE, is documented with example problems in this report. The work was performed at the request of the Lower Mississippi Valley Division and provides the capability of analyzing two-dimensional or three-dimensional pile foundations according to Division guidelines. The report includes discussions of factors influencing pile group behavior and of the		

(Continued)

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

22. ABSTRACT (Continued).

analytical procedure, a user's guide, and several example problems for the pile analysis program LMDPILE. Also included are two appendices. Appendix A describes the computer program PILESTF which computes the pile head stiffness coefficients for piles in soils with varying moduli. Appendix B describes the computer program PDRAW which is an interactive graphics post-processor. Each appendix includes a general introduction, a user's guide, and example problems.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

PREFACE

The study reported herein was performed at the U. S. Army Engineer Waterways Experiment Station (WES) as part of the support provided by the Computer-Aided Design Group (CADG) of the Automatic Data Processing (ADP) Center to the U. S. Army Engineer Division, Lower Mississippi Valley (LMVD).

The work involved consolidation of two existing pile analysis programs, one from the St. Louis District and the other from the New Orleans District. This work was performed by Ms. Deborah K. Martin, formerly of CADG. The computer program PILESTF which is described in Appendix A was coded and documented by Dr. William P. Dawkins, Consultant, Oklahoma State University, Stillwater, Okla. PILESTF computes the pile head stiffness coefficients for piles in soils with varying moduli. The computer program FDRAW which is described in Appendix B was coded and documented by Mr. John Jobst of the St. Louis District. FDRAW is an interactive graphics post-processor program that can display pile geometry, resultant axial forces, pile loading factors, and elastic center diagrams. The authors thank Dr. Dawkins and Mr. Jobst for their contributions to this work.

This report was written by Ms. Martin, Mr. H. Wayne Jones, CADG, and Dr. N. Radhakrishnan, Special Technical Assistant, ADP Center. Technical contact at the St. Louis District was Mr. Thomas J. Mudd and at the New Orleans District was Mr. C. W. Ruckstuhl. The authors thank Mr. Mudd, Mr. Ruckstuhl, and several of their co-workers for their technical guidance.

The study was monitored at LMVD by Mr. Victor Agostinelli, Technical Engineering Branch. The work was done under the general supervision of Mr. D. L. Neumann, Chief of the ADP Center.

COL J. L. Cannon, CE, and COL N. P. Conover, CE, were Directors and Mr. F. B. Brown was Technical Director of WES during the performance of the work and the preparation of the report.

CONTENTS

	<u>Page</u>
PREFACE	1
CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)	
UNITS OF MEASUREMENT	4
PART I: INTRODUCTION	5
Background	5
Scope	5
PART II: FACTORS INFLUENCING PILE GROUP BEHAVIOR	6
Factors that Influence Capacity of Pile Foundations	6
Conclusion	9
PART III: PROCEDURE FOR THE ANALYSIS OF PILE FOUNDATIONS	10
The General Model	10
Analysis	11
Failure Criteria	25
PART IV: USER'S GUIDE FOR PROGRAM LMVDPFILE	28
General Introduction	28
Flow Charts	29
Data Input for LMVDPFILE	29
PART V: EXAMPLE PROBLEMS	41
Example Problem 1 - Two-dimensional problem, 2 pinned piles with constant soil modulus	41
Example Problem 2 - Two-dimensional problem, 1 fixed vertical pile	53
Example Problem 3 - Two-dimensional problem, Hrennikoff's example case 2a	58
Example Problem 4 - Two-dimensional problem, Hrennikoff's example case 4a	63
Example Problem 5 - Two-dimensional problem, Hrennikoff's example case 6a	68
Example Problem 6 - Two-dimensional problem, 16 piles with linearly varying soil moduli	73
Example Problem 7 - Three-dimensional problem, 4 pinned piles and constant soil modulus	83
Example Problem 8 - Three-dimensional problem, 1 fixed vertical pile	96
Example Problem 9 - Three-dimensional problem, 27 piles with constant soil modulus	101
Example Problem 10 - Three-dimensional problem, 9 piles and linearly varying soil moduli	110
Example Problem 11 - Three-dimensional problem, 60 piles with linearly varying soil moduli	117
REFERENCES	132

	<u>Page</u>
APPENDIX A: USER'S GUIDE FOR PROGRAM PILESTF	A1
General Introduction	A1
Background	A1
Previous Pile Head Stiffness Evaluation	A3
Alternate Derivation	A7
General Pile Head Stiffness Analysis Introduction	A10
Pile-Soil Model	A10
Soil Springs	A11
Element Force-Displacement Relations	A12
Nodal Equilibrium	A13
Special Conditions at Node m (Bottom of Pile)	A14
Special Conditions at Node o (Pile Head)	A14
Guide to Data Input	A18
Example Solutions	A19
Discussion of Results	A21
Conclusions	A21
APPENDIX B: USER'S GUIDE FOR PROGRAM FDRAW	B1
General Introduction	B1
Guide for Data Input	B3
Example Problems	B5

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
feet	0.3048	metres
inches	2.54	centimetres
kips (1000 lb force)	4.448222	kilonewtons
kips (force) per square foot	47.88026	kilopascals
pounds (mass)	0.45359237	kilograms
pounds (force) per square inch	6.894757	kilopascals
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per cubic inch	0.02768	kilograms per cubic centimetre
square inches	6.4516	square centimetres

DOCUMENTATION FOR LMVDPILE PROGRAM

PART I: INTRODUCTION

Background

1. Many Corps of Engineers offices use the Hrennikoff (1950) method to analyze pile foundations. This method was originally proposed for analyzing two-dimensional pile foundations but has been refined and extended by Saul (1968) for three-dimensional foundations.

2. The U. S. Army Engineer Districts, St. Louis and New Orleans, each use a different version of a pile analysis computer program, but both use the Hrennikoff method. The Technical Engineering Branch of the Lower Mississippi Valley Division (LMVD) was interested in standardizing the two Districts' programs into one program, LMVDPILE, that would include all options from both programs. The work described herein was performed at the request of LMVD. The result of this work provides the capability of analyzing two-dimensional or three-dimensional pile foundations according to the LMVD guidelines.

Scope

3. Factors influencing pile group behavior, the analytical procedure, a user's guide, and several example problems for the pile analysis program LMVDPILE are presented herein. User's guides for a pre-processor routine called PILESTF that can compute the pile head stiffness matrix for a pile in a layered soil mass and for an interactive graphics post-processor program, FDRAW, are also included.

PART II: FACTORS INFLUENCING PILE GROUP BEHAVIOR*

4. Foundation piles are supporting structural members which transfer loads from the structure to the subsoil. Adequate design will insure that excessive deflections and stresses in the "structure-pile-soil system" will not occur. Generally, it is not a difficult task to determine the loads acting on the pile foundation from the structure. However, the distribution of the loads from the piles to the soil is a highly indeterminate and sometimes nonlinear problem. This leads to complex solutions of the pile-soil interaction problem. Many conditions affect the resistance of the pile foundation to movement and the transfer of loads from the structure to the pile-soil medium (Mudd 1969).

Factors that Influence Capacity of Pile Foundations

5. The capacity of a pile foundation can be defined as its ability to resist applied loads without exceeding certain allowable deflections or stresses. The following variables should be considered during analysis of the load-carrying capacity of the soil-pile medium.

Subgrade modulus

6. A subgrade modulus can be employed to relate the lateral, axial, and rotational resistance of the pile-soil medium to displacements. The subgrade modulus is a function of the nature of the loading, the elasticity of the pile, and the stress-strain characteristics of the surrounding soil. Therefore, the determination of the subgrade modulus depends on the nonlinear and nonelastic, pile-soil stress-strain relationship characteristics. The load-carrying capacity of the foundation is dependent on these nonlinear and nonelastic characteristics.

Fixity

7. The fixity of the pile head into the pile cap influences the load-carrying capacity of a pile foundation. Generally, fixing the pile heads completely rather than pinning them into the pile cap will double

* Major portions of Part II are extracted from Mudd (1969).

the lateral stiffness of the foundation. Thus the fixed pile can carry twice the lateral load with the equivalent deflection as the pinned pile foundation.

Batter

8. The direction and slope of batter affect the subgrade modulus. Murthy (1964) has shown with model pile tests that piles battered upstream are more resistant to lateral loads than piles battered downstream. A pile battered upstream is defined as having its tip further upstream than its top, and a pile battered downstream as having its tip further downstream than its top.

Group effect

9. Close spacing of piles will affect the lateral and vertical resistance of adjacent piles within a pile group. Prakash (1962) has shown that piles spaced from three to eight pile diameters apart (normal to the load) cause a reduction in the lateral capacity of the group. A pile spacing of less than three diameters decreases the stiffness of the pile group by about one half of the sum of the same number of isolated piles. The group effect can be accounted for by reducing the subgrade modulus by an appropriate factor. Similar effects have been noted for the axial capacity of group friction piles.

Position in group

10. Prakash has also shown that the position of the pile in a group affects its individual stiffness influence coefficients. He has shown that a pile in the interior of the group would be more flexible than one on the perimeter. This is due to the interference of the zone of influence of the pile by adjacent piles when these zones overlap.

Stiffness of pile cap

11. The stiffness of the pile cap will influence the distribution of the structural loads to the individual piles. A multicolumn bent can be approximated as having a rigid top if the cap is 10 or more times stiffer than the columns. Therefore a rigid pile cap can generally be assumed for gravity-type hydraulic structures. If the cap is less than rigid, then the problem becomes one of achieving compatibility between pile-head displacements and the structure deformation. The program

SAPIV has been modified to include a pile element (Jones and Radhakrishnan 1975). This will allow the analysis of flexible pile caps if necessary.

Nature of loading

12. The different conditions of static, cyclic, dynamic, and transient loadings affect the ability of the pile foundation to resist applied forces.

13. Cyclic loading (repeated application of a static load) causes a greater deflection than the application of a sustained static load of the same magnitude. In some pile tests the application of cyclic loading doubles the deflection over that of the application of a single static load for a given level of loading (U. S. Army Engineer District, Little Rock 1964).

14. Piles subjected to vibratory loads may produce greater pile displacements than piles subjected to static loads. At present, little is known of the quantitative effect vibrations may have on the load-carrying capacity of pile-founded structures.

15. If tension and compression piles are present in a foundation, the tension pile may have a reduced load-carrying capacity from that of the compression pile for equivalent deflections. Also, the tension pile may have less lateral stiffness than an equivalent compression pile.

Pile driving

16. Driving piles in a group increases the density of the soil within and around a pile group. Consequently the stiffness of the soil may increase by driving piles in closely spaced groups. Although tests on a single pile within a group may indicate an increased stiffness due to pile driving, the pile group as a whole may not reflect this increased stiffness. A larger zone of stressed soil may not be favorably affected by pile driving. Thus deflections larger than anticipated may result. Therefore, lateral load tests on a single pile in a large group of piles may indicate liberal stiffness coefficients.

Water table and seepage pressures

17. The position of the water table affects the lateral subgrade modulus. Effects of submergence have been accounted for by some

designers by reducing the lateral subgrade modulus by the ratio of submerged unit weight of the soil to its dry unit weight. An additional load on the pile foundation can be caused by seepage pressures under structures that support unbalanced water loads. These seepage pressures also may affect the subgrade modulus of the soil.

Sheet pile cutoffs

18. Sheet pile cutoffs inclosing the pile group may change the distribution of stress in the soil, affecting the load-carrying capacity of the foundation.

Length of pile

19. The length of a pile will affect the lateral and axial subgrade modulus. The lateral subgrade modulus is different for short rigid piles that act as poles and long flexible piles that act in flexural bending. Piles can be considered to act in the flexural mode if the nondimensional length L/T is greater than 5, as defined by Reese and Matlock (1960).

Conclusion

20. All these factors must be considered if a valid analysis of pile foundations is to be accomplished. The effects of most of these variables can be accounted for in the analysis by appropriate changes in the value of the subgrade modulus obtained from pile test data of a single free pile.

PART III: PROCEDURE FOR THE ANALYSIS OF PILE FOUNDATIONS*

21. A general direct stiffness analysis method for three-dimensional pile foundations has been presented by Saul (1968), which expands the Hrennikoff (1950) method from two dimensions to three. This method appears to be general, provided the designer has an understanding of matrix methods and structure-soil-pile interactions and an electronic computer available to perform the computations. The method uses exact numerical analysis solutions for solving the assumed soil-pile model. However, the designer must have an adequate representation of soil-pile interaction for input to the method. Various factors that influence the soil-pile interaction have been discussed in Part II.

The General Model

22. A generalized model of the structure-pile system can be described as a rigid body supported by sets of springs which represent the actions of the pile forces on the structure when the structure undergoes unit displacements. It is assumed that the pile head loading for any single pile in a batter group may be resolved into a combination of axial load, bending moment, shear, and torque. Also, each of these components can be represented by a proper spring constant and results added vectorially to obtain the total movement of the pile head. This method of analysis only considers the effect the piles have on the pile cap at the top of the pile; i.e., each pile can be replaced by the proper elastic spring restraints at the pile cap. The assumptions required by this method are:

- a. A rigid piling cap.
- b. Elastic behavior of the system.
- c. Effects of displacement for six degrees of freedom in a three-dimensional analysis or for three degrees of freedom in a two-dimensional analysis can be superimposed.

* Major portions of Part III are extracted from Mudd (1969).

23. This method can also account for:

- a. Any degree of fixity of any pile with the pile cap.
- b. Piles with different bending stiffness about their principal axes.
- c. Any degree of linear (elastic) torsional, axial, or lateral resistance of any pile in the foundation.
- d. Any position and batter of piles in the foundation.
- e. Piles of different sizes or materials in the foundation.

24. If the restrictions as stated in paragraph 22 are not allowed, then the response of the system is nonlinear, and a closed form solution cannot be achieved. However, it is possible to include these in some type of iterative procedure.

Analysis

Elastic pile constants, three-dimensional system

25. Each pile has six degrees of freedom in a three-dimensional system: two lateral, one axial, two moment, and one torsional. The forces and displacements along the pile axes are shown in Figure 1 in which axes U_1 and U_2 are principal axes of inertia and axis U_3 coincides with the longitudinal axis of the piling. In a two-dimensional system, each pile has three degrees of freedom: one lateral, one axial, and one moment. Figure 2 shows the forces and displacements along the pile axes. The pile forces can be equated to the pile displacements by the expression

$$\{F\}_i = \{b\}_i \{X\}_i \quad (1)$$

such that b_i are the individual pile stiffness influence coefficients called the elastic pile constants. The $\{b\}_i$ matrix for a three-dimensional system can be defined for the i^{th} pile as

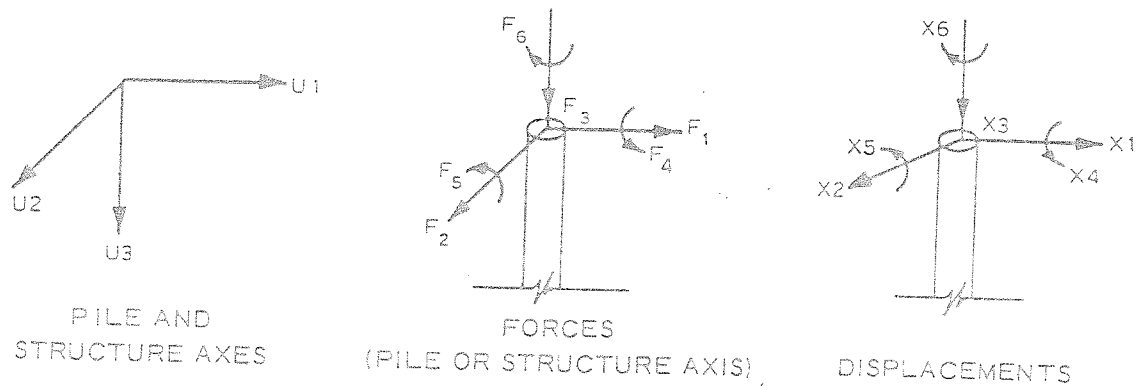


Figure 1. Coordinate system for three-dimensional system

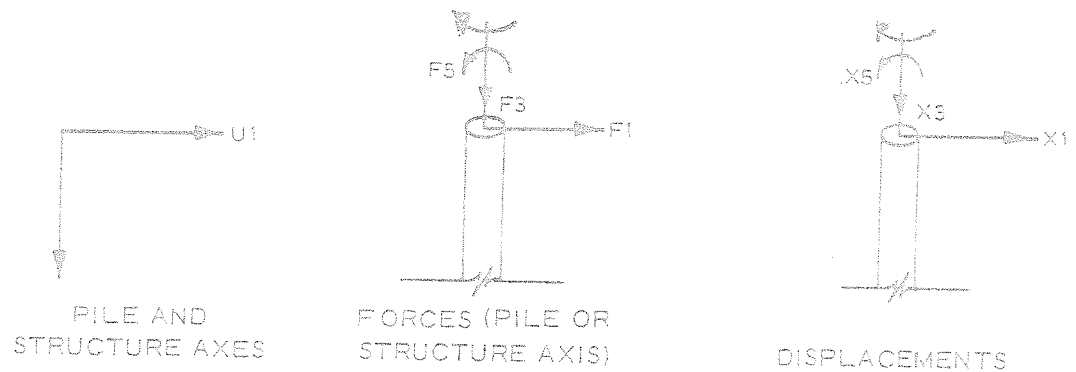


Figure 2. Coordinate system for two-dimensional system

$$\{b\}_1 = \begin{Bmatrix} b_{11} & 0 & 0 & 0 & b_{15} & 0 \\ 0 & b_{22} & 0 & b_{24} & 0 & 0 \\ 0 & 0 & b_{33} & 0 & 0 & 0 \\ 0 & b_{42} & 0 & b_{44} & 0 & 0 \\ b_{51} & 0 & 0 & 0 & b_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & b_{66} \end{Bmatrix} \quad (2)$$

26. The elastic pile constants are defined as follows:

b_{11} is the force required to displace the pile head a unit distance along the U_1 -axis, FORCE/LENGTH

b_{22} is the force required to displace the pile head a unit distance along the U_2 -axis, FORCE/LENGTH

b_{31} is the moment around the U_2 -axis caused by a unit displacement of the pile head² along the U_1 -axis,
FORCE-LENGTH/LENGTH

29. The elements for the $\{b\}_i$ matrix are symmetric. That is:

$$b_{15} = b_{51}$$

$$b_{24} = b_{42}$$

for a three-dimensional system. For a two-dimensional system,

$$b_{13} = b_{31}$$

Constant soil modulus

30. If it is assumed that the lateral subgrade modulus is constant with depth, then the pile constants for a three-dimensional system can be derived as follows. If

$$\beta_1 = \sqrt[4]{\frac{E_s}{4EI_2}}, \quad \beta_2 = \sqrt[4]{\frac{E_s}{4EI_1}} \quad (4)$$

then

$$b_{11} = (1 + DF) \left(\frac{E_s}{2\beta_1} \right) \quad (5)$$

$$b_{22} = (1 + DF) \left(\frac{E_s}{2\beta_2} \right) \quad (6)$$

$$b_{33} = K_2 \left(\frac{AE}{L} \right) \quad (7)$$

$$b_{44} = DF \left(\frac{E_s}{2\beta_2^3} \right) \quad (8)$$

- b_{33} is the force required to displace the pile head a unit distance along the U_3 -axis, FORCE/LENGTH
- b_{44} is the moment required to displace the pile head a unit rotation around the U_1 -axis, FORCE-LENGTH/RADIAN
- b_{55} is the moment required to displace the pile head a unit rotation around the U_2 -axis, FORCE-LENGTH/RADIAN
- b_{66} is the torque required to displace the pile head a unit rotation around the U_3 -axis, FORCE/RADIAN
- b_{15} is the force along the U_1 -axis caused by a unit rotation of the pile head around the U_2 -axis, FORCE/RADIAN
- $-b_{24}$ is the force along the U_2 -axis caused by a unit rotation of the pile head around the U_1 -axis, FORCE/RADIAN
(Note: The sign is negative.)
- b_{51} is the moment around the U_2 -axis caused by a unit of displacement of the pile head along the U_1 -axis, FORCE-LENGTH/LENGTH
- $-b_{42}$ is the moment around the U_1 -axis caused by a unit displacement of the pile head along the U_2 -axis, FORCE-LENGTH/LENGTH (Note: The sign is negative.)

Elastic pile constants,
two-dimensional system

27. The $\{b\}_i$ matrix for a two-dimensional system can be defined for the i^{th} pile as

$$\{b\}_i = \begin{Bmatrix} b_{11} & 0 & b_{13} \\ 0 & b_{22} & 0 \\ b_{31} & 0 & b_{33} \end{Bmatrix} \quad (3)$$

28. The elastic pile constants are defined as follows:

- b_{11} is the force required to displace the pile head a unit distance along the U_1 -axis, FORCE/LENGTH = Translational Spring
- b_{22} is the force required to displace the pile head a unit distance along the U_3 -axis, FORCE/LENGTH = Axial Spring
- b_{33} is the moment required to displace the pile head a unit rotation around the U_2 -axis, FORCE-LENGTH/RADIAN = Rotational Spring
- b_{13} is the force along the U_1 -axis caused by a unit rotation of the pile head around the U_2 -axis, FORCE/RADIAN

$$b_{55} = DF \left(\frac{E_s}{2\beta_1^3} \right) \quad (9)$$

$$b_{66} = K_4 \quad (10)$$

$$b_{15} = DF \left(\frac{E_s}{2\beta_1^2} \right) \quad (11)$$

$$b_{24} = DF \left(\frac{E_s}{2\beta_2^2} \right) \quad (12)$$

$$b_{51} = b_{15} \quad (13)$$

$$b_{42} = b_{24} \quad (14)$$

where

E_s = lateral subgrade modulus, FORCE/LENGTH²*

E = modulus of elasticity, FORCE/LENGTH²

I_1, I_2 = moment of inertia, LENGTH⁴, about the U_1 and U_2 axes, respectively

DF = degree of fixity (fraction)

Constants K_2 and K_4 = degrees of pile rigidity under axial and torsional behavior, respectively. K_2 is normally assumed to be 1.0 for bearing piles and 2.0 for friction piles. K_4 is normally assumed to be zero as the torsional behavior of the pile is not well known.

* The lateral subgrade modulus E_s required in the program input should include width effect of the pile, group effect, cyclic load effect, etc. There are no provisions in the program to internally calculate these effects.

A = cross-sectional area of pile, LENGTH²

L = length of pile, LENGTH

31. For a two-dimensional system, if

$$\beta_1 = \sqrt[4]{\frac{E_s}{4EI_2}} \quad (15)$$

then

$$b_{11} = (1 + DF) \left(\frac{E_s}{2\beta_1} \right) \quad (16)$$

$$b_{22} = K_2 \left(\frac{AE}{L} \right) \quad (17)$$

$$b_{33} = DF \left(\frac{E_s}{2\beta_1^3} \right) \quad (18)$$

$$b_{13} = DF \left(\frac{E_s}{2\beta_1^2} \right) \quad (19)$$

$$b_{31} = b_{13} \quad (20)$$

Linearly varying subgrade moduli

32. If it is assumed that the lateral subgrade modulus varies linearly with depth, $E_s = K_s(X_2)$, then the pile constants for a three-dimensional system can be derived as follows. If

$$T_1 = \sqrt[5]{\frac{EI_2}{K_s}}, \quad T_2 = \sqrt[5]{\frac{EI_1}{K_s}} \quad (21)$$

then

$$b_{11} = K_1 \left(\frac{EI_2}{T_1^3} \right) \quad (22)$$

$$b_{22} = K_1 \left(\frac{EI_1}{T_2^3} \right) \quad (23)$$

$$b_{33} = K_2 \left(\frac{AE}{L} \right) \quad (24)$$

$$b_{44} = K_3 \left(\frac{EI_1}{T_2} \right) \quad (25)$$

$$b_{55} = K_3 \left(\frac{EI_2}{T_1} \right) \quad (26)$$

$$b_{66} = K_4 \left(\frac{JG}{L} \right) \quad (27)$$

$$b_{15} = K_5 \left(\frac{EI_2}{T_1^2} \right) \quad (28)$$

$$b_{24} = K_5 \left(\frac{EI_1}{T_2^2} \right) \quad (29)$$

$$b_{51} = K_6 \left(\frac{EI_2}{T_1^2} \right) \quad (30)$$

$$b_{42} = -K_6 \left(\frac{EI_1}{T_2^2} \right) \quad (31)$$

Where

E = modulus of elasticity, FORCE/LENGTH²

I_1, I_2 = moments of inertia, LENGTH⁴, about U_1 and U_2 axes, respectively

K_s = coefficient of subgrade modulus, FORCE/LENGTH³

A = cross-sectional area of pile, LENGTH²

L = length of pile, LENGTH

J = polar moment of inertia, LENGTH⁴

G = torsion modulus, FORCE/LENGTH²

K_1 = lateral fixity coefficient

K_2 = pile axial resistance coefficient

K_3 = rotational fixity coefficient

K_4 = coefficient for torsion

K_5 = fixity coefficient

K_6 = fixity coefficient

33. For a two-dimensional system, if

$$T = \sqrt[5]{\frac{EI}{K_s}} \quad (32)$$

then

$$b_{11} = K_1 \left(\frac{EI}{T^3} \right) \quad (33)$$

$$b_{22} = K_2 \left(\frac{AE}{L} \right) \quad (34)$$

$$b_{33} = K_3 \left(\frac{EI}{T} \right) \quad (35)$$

$$b_{13} = K_5 \left(\frac{EI}{T^2} \right) \quad (36)$$

$$b_{31} = K_6 \left(\frac{EI}{T^2} \right) \quad (37)$$

Fixity coefficients

34. The constants K_1 through K_6 depend on such variables as the pile head fixity and the distribution of load from the pile to the soil axially and torsionally. Values of K_1 through K_6 can be derived for various degrees of fixity.

35. Knowing the degree of fixity, the following values of K_1 through K_6 can be derived for a lateral subgrade modulus that varies linearly with depth:

Degree of Fixity (DF)	Fixity Coefficients for Linear Subgrade Modulus					
	K_1	K_2	K_3	K_4	K_5	K_6
1.0	1.0756	1.0 for bear-	1.4988	Torsion (as- sumed 0.0 by some designers)	0.9990	0.9990
0.9	0.9263	ing or 2.0	1.3489		0.8991	0.7736
0.8	0.8129	for fric-	1.1990		0.7992	0.6035
0.7	0.7242	tion piles	1.0491		0.6993	0.4704
0.6	0.6530	in compres-	0.8993		0.5994	0.3636
0.5	0.5945	sion. For	0.7494		0.4995	0.2759
0.4	0.5457	piles in	0.5995		0.3996	0.2025
0.3	0.5042	tension	0.4496		0.2997	0.1404
0.2	0.4687	the value	0.2998		0.1998	0.0870
0.1	0.4370	should be	0.1499		0.0999	0.0406
0.0	0.4107	reduced. Suggest 1/2 of value for com- pression piles.	0.0		0.0	0.0

36. The value of DF, degree of fixity of a pile into the cap (expressed as a fraction), must be selected with a full understanding of the conditions that must be met for a pile, which is assumed to be fixed, to actually be fixed.

37. The fixity of the pile, DF, depends to a great extent on the pile's embedment into the pile cap. A pretensioned prestressed concrete pile is not fully fixed unless the extension of the pile concrete into the cap is at least as long as the bond development length of the prestressing strands. Further, the pile cannot develop the full moment capacity at the bottom of the cap. Any strand extension distance beyond the end of the pile does not contribute to the bond development distance because the strand elongation needed to develop the strand prestress will cause excessive cracking and loss of rigidity of the concrete. However, a posttensioned concrete pile can be considered fully fixed with less embedment than a pretensioned pile if the tendon(s) are tensioned to the cap after the cap is placed. A nonprestressed concrete pile may be considered fully fixed by a bar extension equal to the bond development length.

Orientation of the
pile to the foundation

38. In a three-dimensional system the pile may be located at a position rotated to the foundation axis and may be battered. Its position in the pile cap is fully defined by the clockwise angle α_i to the direction of batter and the batter slope h_i , as shown in Figure 3. The major principal axis of a pile i , where $I_1 \neq I_2$, should coincide with the angle α_i . The components of force and displacement of the rotated pile axis to the foundation axis are found by the transformation matrix $\{a\}_i$ for pile i where

h_i = batter (h_i Vertical on 1 Horizontal)

α_i = clockwise angle to the batter and/or major principal axis

γ_i = arc cot h_i

In a three-dimensional system

$$\{a'\}_i = \begin{Bmatrix} (\cos\gamma \cos\alpha) & -\sin\alpha & (\sin\gamma \cos\alpha) \\ (\cos\gamma \sin\alpha) & \cos\alpha & (\sin\gamma \sin\alpha) \\ -\sin\gamma & 0 & \cos\gamma \end{Bmatrix} \quad (38)$$

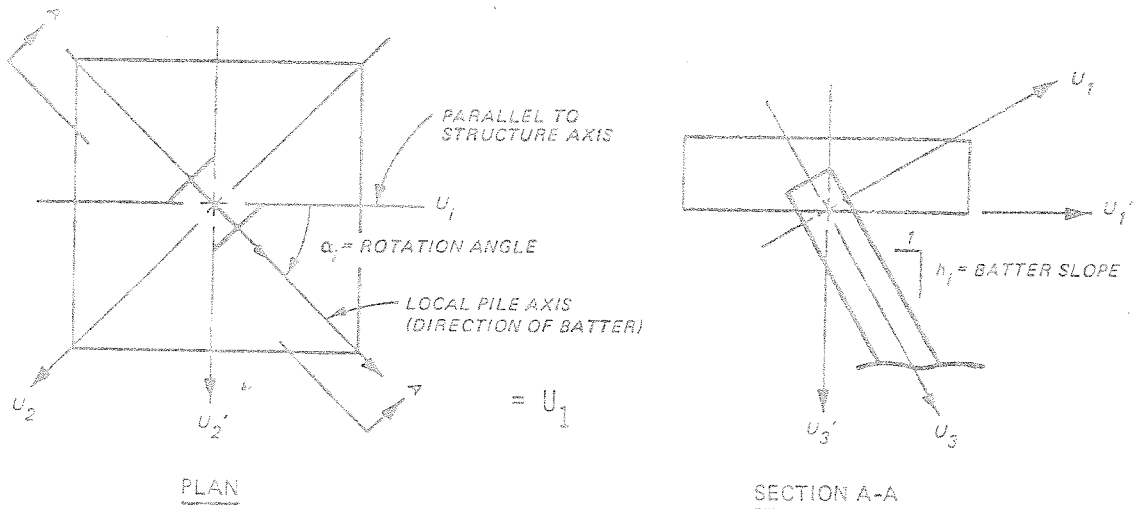


Figure 3. Orientation of local pile axis and global foundation axis

and

$$\{a\}_i = \begin{Bmatrix} a' & 0 \\ 0 & a' \end{Bmatrix} \quad (39)$$

In a two-dimensional system

$$\{a\}_i = \begin{Bmatrix} (\cos\gamma \cos\alpha) & (\sin\gamma \cos\alpha) & 0 \\ -\sin\gamma & \cos\gamma & 0 \\ 0 & 0 & \cos\alpha \end{Bmatrix} \quad (40)$$

39. By the use of the transformation matrix the pile forces can be rotated into forces parallel to the foundation axis by

$$\{F'\}_i = \{a\}_i \{F\}_i \quad (41)$$

and

$$\{x\}_i = \{a\}_i^T \{x'\}_i \quad (42)$$

By substitution

$$\{F'\}_i = \{a\}_i \{b\}_i \{a\}_i^T \{x'\}_i \quad (43)$$

which is the relationship of the pile forces to their deflections in an orthogonal coordinate system parallel to the foundation axes.

Coordinate location of
the pile in the foundation

40. Pile i may be located in the foundation with axes through its origin parallel to the foundation axes. The foundation loads $\{Q\}$ and displacements $\{\Delta\}$ are located with respect to the foundation axes.

41. The forces $\{F'\}_i$ due to the pile on the pile cap are in equilibrium with a set of forces $\{q\}_i$ at the coordinate center of the pile cap.

Equilibrium yields

$$\{q\}_i = \{c\}_i \{F'\}_i \quad (44)$$

in which $\{c\}_i$, the statics matrix for a three-dimensional system, is

$$\{c\}_i = \begin{Bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & -u_3 & u_2 & 1 & 0 & 0 \\ u_3 & 0 & -u_1 & 0 & 1 & 0 \\ -u_2 & u_1 & 0 & 0 & 0 & 1 \end{Bmatrix} \quad (45)$$

The statics matrix $\{c\}_i$ for a two-dimensional system is

$$\{c\}_i = \begin{Bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ u_3 & -u_1 & 1 \end{Bmatrix} \quad (46)$$

where

$u_1 = U_1$ coordinate of the pile, LENGTH

$u_2 = U_2$ coordinate of the pile, LENGTH

$u_3 = U_3$ coordinate of the pile, LENGTH

Foundation stiffness analysis

42. If the pile cap is assumed rigid, then the deflection of the pile cap can be related to the deflection of the piling in the foundation axis coordinates by

$$\{x'\}_i = \{c\}_i^T \{\Delta\} \quad (47)$$

43. The foundation load $\{Q\}$ is distributed to each pile so that

$$\{Q\} = \sum_{i=1}^n \{q\}_i \quad (48)$$

where n = number of piles. The relationships between the foundation load and the pile cap deflections are

$$\{Q\} = \{S\}\{\Delta\} \quad (49)$$

in which $\{S\}$ is the stiffness influence coefficients matrix for the foundation as a whole. The $\{S\}$ matrix is found by introducing the contribution of each individual pile toward the stiffness of the pile cap. This yields

$$\{q\}_i = \{S'\}_i \{\Delta\} \quad (50)$$

in which

$$\{S'\}_i = \{c\}_i \{a\}_i \{b\}_i \{a\}_i^T \{c\}_i^T \quad (51)$$

and finally

$$\{S\} = \sum_{i=1}^n \{S'\}_i \quad (52)$$

Once the stiffness matrix is known for the total foundation, the problem is essentially solved and only requires back substitution to find the distribution of loads to the individual pile. It can be noted that the foundation stiffness matrix $\{S\}$ is independent of the external loads.

Loads and displacements

44. The displacements of the pile cap can be found by inverting the foundation stiffness matrix $\{S\}$ and multiplying it by the

external load matrix $\{Q\}$ or

$$\{\Delta\} = \{S\}^{-1}\{Q\} \quad (53)$$

Once the foundation deflections are known the deflection of pile i about its own axes can be found by

$$\{x\}_i = \{a\}_i^T \{c\}_i^T \{\Delta\} \quad (54)$$

Finally, the forces allotted to each pile about its axes can be found from Equation 1 where

$$\{F\}_i = \{b\}_i \{x\}_i \quad (55)$$

It may be desirable to resolve the forces along the pile axes to forces parallel to the structure coordinate axes. These can be found by

$$\{F'\}_i = \{a\}_i \{b\}_i \{a\}_i^T \{c\}_i^T \{\Delta\} \quad (56)$$

Failure Criteria

Allowable loads

45. The allowable axial loads for combined bending (ACB), the allowable moment about the minor principal axis (AMIN), and the allowable moment about the major principal axis (AMAJ) differ in prestressed concrete piles depending on whether the pile is in tension or compression. Therefore, the program allows the user to input two sets of values for the above-mentioned variables, one set for piles in tension and one set for piles in compression. The program checks whether the value of the axial force in the pile is positive (compression) or negative (tension) to determine which set of allowables will be used

for checking failure. The program also allows the user to input an allowable compressive load and an allowable tensile load.

Combined bending factor

46. The combined bending factor for a three-dimensional case is computed as (a) the absolute value of the vertical pile force divided by the allowable axial load plus (b) the absolute value of the moment about the U_1 axis divided by the allowable moment about the minor axis plus (c) the absolute value of the moment about the U_2 axis divided by the allowable moment about the major axis. The pile is considered to fail if the combined bending factor is greater than one.

Buckling

47. The program calculates a buckling factor for a constant soil modulus or a linearly varying soil modulus. For a constant soil modulus the buckling factor is

$$PBUCK = (7 \times DF \times \frac{(1 + PR)}{56.0} \times E \times AMIN1 \left((I_1 \times E_s), (I_2 \times E_s) \right)) \quad (57)$$

where

DF = degree of fixity (0 = not fixed; 1 = fixed; 0.5 = partial)

PR = pile resistance (end bearing or friction) (1 = end brg.; 2 = friction)

E = modulus of elasticity of pile material

AMIN1 = minimum of two values in parentheses

X = pile dimension parallel to U_1 -axis of the pile

48. For a linearly varying soil modulus the buckling factor is

$$PBUCK = \left(7 \times DF \times \frac{(1 + PR)}{56.0} \times 1.57 \times \frac{E_s}{X} \right)^{2.0} \times E^{3.0} \times AMIN1 \left(X^{2.0} \times I_1^{3.0}, X^{2.0} \times I_2^{3.0} \right)^{0.2} \quad (58)$$

49. A pile fails in buckling if the buckling factor, PBUCK, is greater than zero and less than the axial force in the pile.

Compression and tension

50. If a pile is in compression, it fails when the allowable compressive load is exceeded by the axial force in the pile. If a pile is in tension, it fails when the allowable tensile load is exceeded by the absolute value of the axial force in the pile.

$2\sqrt{EIK}$ hinged end constant soil modulus

PART IV: USER'S GUIDE FOR PROGRAM LMVDPFILE

General Introduction

51. Documentation for the computer program LMVDPFILE (analysis of two- and three-dimensional pile foundations) is presented herein and includes a general introduction, program listing, flow charts, guide for data input, and input-output data for several example problems.

52. LMVDPFILE is a general direct stiffness analysis computer program that can be used to determine structure deflections, pile deflections, and forces acting on a group of piles placed in soil and topped with a rigid cap.

53. In the analysis used in LMVDPFILE, the base (pile cap) is assumed to be rigid, and the structure and soil are considered to behave in a linear-elastic manner. Each pile behavior in a three-dimensional problem is represented by a 6 by 6 stiffness matrix and in a two-dimensional problem by a 3 by 3 stiffness matrix (Hrennikoff 1950, Saul 1968). The elastic pile constants b_{ij} are dependent on many factors, as shown in Part III, and can be obtained by using the sets of equations given. The direct stiffness method is then used to analyze the problem.

54. Two companion programs are available for use with LMVDPFILE. One is a preprocessor routine (PILESTF) which will calculate the pile-head stiffness matrix b_{ij} for a pile in layered soil with a lateral subgrade modulus E_s varying with depth as follows:

$$E_s = K_1 + K_2 z^n \quad (59)$$

where

z = depth

K_1, K_2, n = soil parameters

When K_2 equals zero, E_s is a constant (such as for clays). When K_1 equals zero and n equals 1.0, E_s is linearly varying (such as for sands). The pile-head stiffness can be used as input to the LMVDPFILE program. Documentation for PILESTF is presented in Appendix A.

55. The second program is an interactive graphics postprocessor display program (FDRAW). Program LMVDPILE writes an output file which is used by FDRAW to display geometry, batter, pile loads, and load factors as calculated by program LMVDPILE. Documentation for FDRAW is presented in Appendix B. A pile optimization program that can help in designing pile layouts is also being developed.

56. LMVDPILE can be run on the WES G-635, Macon H6000, and Boeing CDC computers in the time-sharing mode. The program is part of the CORPS (Conversationally Oriented Real-Time Program-Generating System) library. It is identified by the program number X0034. To execute the program, issue the appropriate run command given below:

a. On the WES or Macon computer

RUN WESLIB/CORPS/X0034,R

b. On the Boeing computer

OLD,CORPS/UN=CECELB

CALL,CORPS,X0034

Data may be input interactively at execute time or may be input as a prepared data file. Output may be directed to an output file or come directly back to the terminal.

Flow Charts

57. A flow chart for the program is shown in Figure 4. The sequence of operations for subroutine BMAT, a subroutine to calculate elastic pile constants, is diagrammed in Figure 5.

Data Input for LMVDPILE

58. Data input to program LMVDPILE is basically the same for a two- or three-dimensional analysis. However, for the user's convenience, the data input guide for a two-dimensional analysis is given first. Then the data input guide for a three-dimensional analysis is given.

Guide for two-dimensional data input

59. Data for a two-dimensional analysis should be input to program

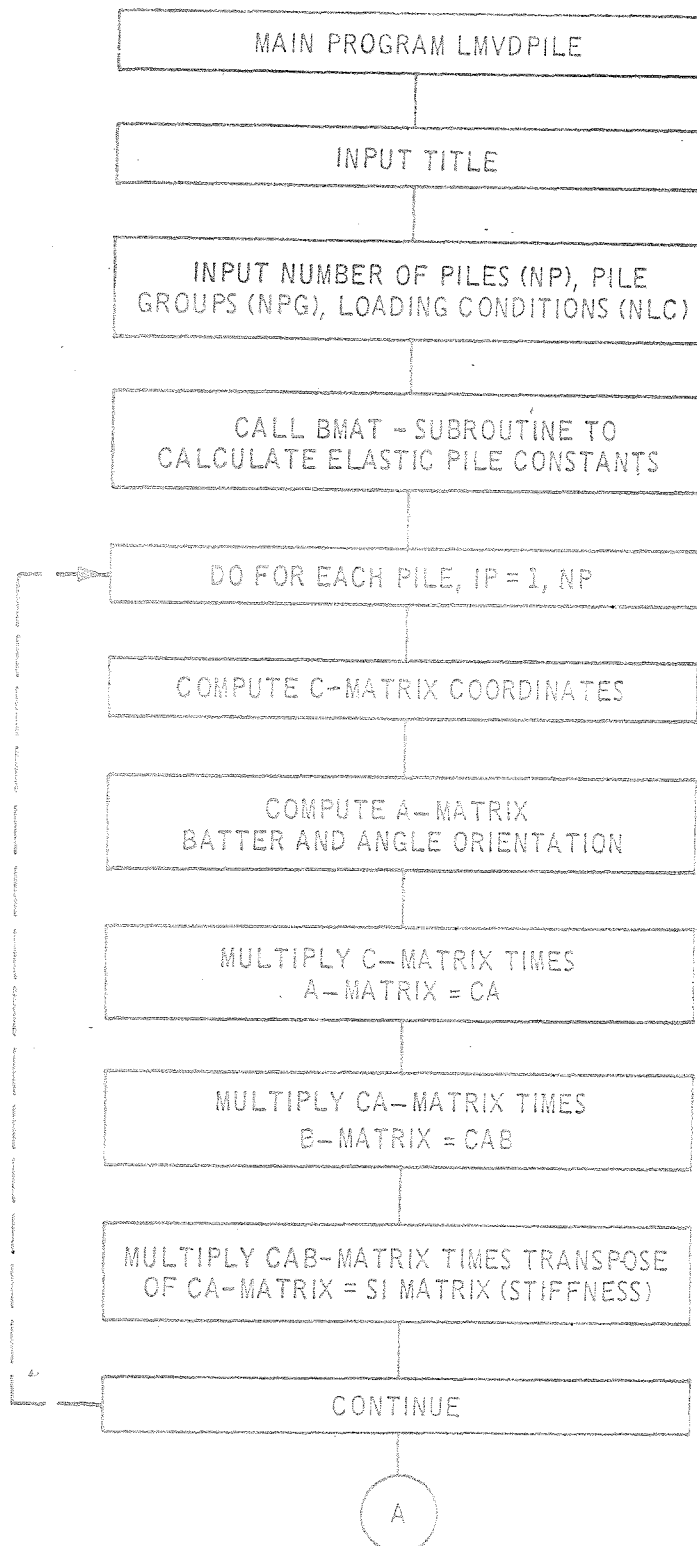


Figure 4. Flow chart for LMVDPILE (sheet 1 of 2)

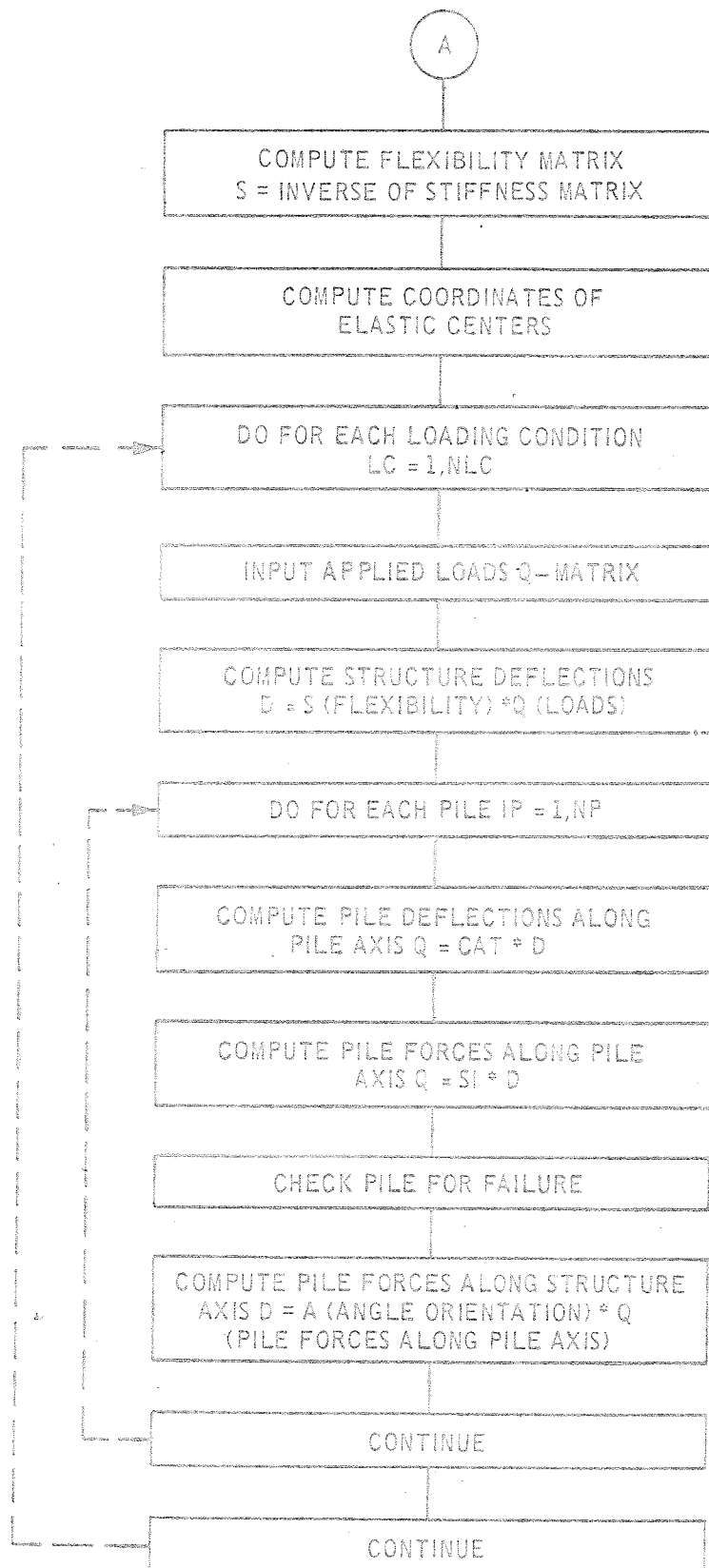
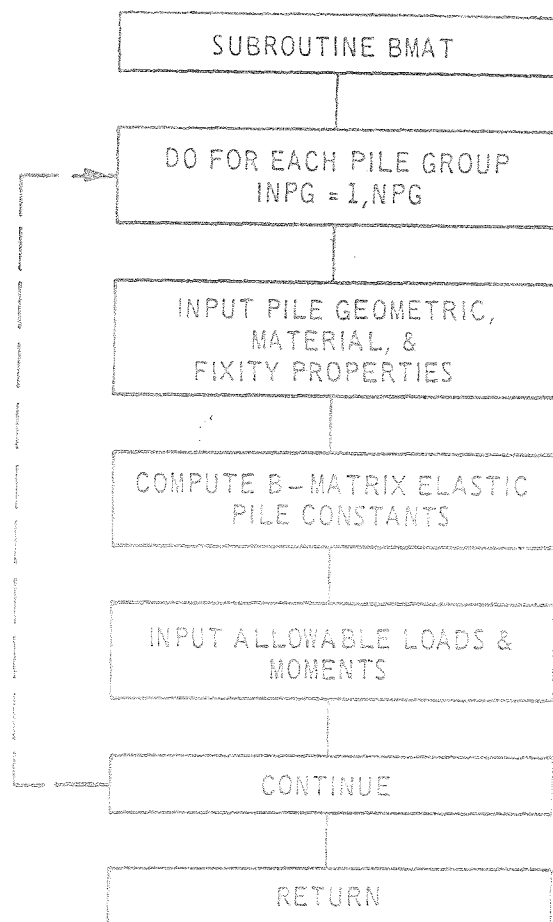


Figure 4 (sheet 2 of 2)

Figure 5. Flow chart of sub-
routine BMAT for LMVDPIL



LMVDPIL according to the following guide. All input is in free field (a comma or at least one blank should separate data items). Data can be input either interactively or from a data file. If a data file is created, use line numbers for each data line.

Group 1 - Title

- A.
TITLE = 66-character problem heading
- B.
TITLE1 = second 66-character problem heading

Group 2 - Control Data for Piles and Loads

- A.
ITYPE = code for type of analysis
2 --- two dimensional
- B.
NP = number of pile rows

NPG = number of pile groups-- one group = 1 pile length, 1 fixity
NLC = number of loading conditions cap

Group 3 - Control and Data for Soil Properties

MV, ES

(See pages 8 & 15 footnote)

MV = type of soil modulus variance

1 --- constant soil modulus (see p. 16 for constant modulus)

2 --- linearly varying soil modulus (see pp. 18 & 19 for linear

ES = subgrade modulus (units are in psi) for MV = 1 varying

ES = KS = coefficient of subgrade modulus (pci) for MV = 2 modulus

Group 4 - Control and Data for Elastic Pile Constants

See also par.
p. 28 for PILE

Note: Groups 4-8 should be repeated NPG (number of pile groups)
number of times.

A. NPA, NPB, SLEN, NPS

NPA = identification number of first pile in pile group

NPB = identification number of last pile in pile group

SLEN = length of pile (feet)

NPS = code for type of input to compute elastic pile constants (B-matrix terms)

1 --- input B-matrix terms directly

2 --- any shape pile

3 --- round pile

B. Note: Necessary only if NPS = 1

B11, B22, B33, B31

BIJ = elastic pile constant for row I, column J

C. Note: Necessary only if NPS = 2

AIX, AIY, AREA, X, Y

AIX = I_1 , moment of inertia about local U_1 axis (in.⁴)

AIY = I_2 , moment of inertia about local U_2 axis (in.⁴)

AREA = cross-sectional area of pile (in.²)

X = pile dimension parallel to U_1 axis (in.)

Y = pile dimension parallel to U_2 axis (in.)

D. Note: Necessary only if NPS = 3

D

D = average diameter of piles in the groups (in.)

Group 5 - Control and Data for Pile Material

A. MP

MP = type of material

1 --- concrete (E calculated from US&W input in item 5B)

- 2 --- timber (E set to 1,760,000 psi*)
- 3 --- steel (E set to 29,000,000 psi)
- 4 --- special (E input in item 5C)

B. Note: Necessary only if MP = 1

US, W

US = ultimate strength of concrete (psi)
W = weight of concrete (pcf)

C. Note: Necessary only if MP = 4

E

E = modulus of elasticity (psi)

Group 6 - Control and Data for Fixity Coefficients to Describe Pile

A. NF

NF = code for input of fixities

- 1 --- input degree of fixity and all coefficients
- 2 --- input degree of fixity

B. Note: Necessary only if NF = 1. See paragraph 35 on page 19.

DF, K1, K2, K3, K4, K5, K6

DF = degree of fixity of pile head-to-base (values between 0 and 1)

K1 = lateral fixity coefficient

K2 = pile axial resistance coefficient

1.0 --- end bearing pile in compression

2.0 --- friction pile in compression

For piles in tension the value should be reduced.

Suggest one half of value for compression piles. (amplify discuss predict T or use different G)

K3 = rotational fixity coefficient

K4 = coefficient for torsion

K5 = fixity constant

K6 = fixity constant

C. Note: Necessary only if NF = 2

DF, PR, PFT, G

DF = degree of fixity of pile head-to-base (one of the three values given below)

0.0 --- hinged pile head

0.5 --- partially fixed pile head

1.0 --- fixed pile head -- if enough embedment

-- see strength of PS Conc. pile par. 27 p. 20

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

PR = pile axial resistance coefficient, K_2
1.0 --- end bearing pile in compression
2.0 --- friction pile in compression

For piles in tension the value should be reduced.
Suggest one half of value for compression piles.

PFT = participation factor for torsion, K_4 (values between 0 and 1) (equals zero for 2-D problem)

G = torsion modulus (psi) (equals zero for 2-D problem)

Group 7 - Data for 2-D Analysis (ITYPE = 2)

NROW

NROW = number of similar rows

Group 8 - Data for Allowable Pile Loads and Moments

ACL, ATL, ACB, AMAJ

ACL = allowable compressive load (kips)

ATL = allowable tensile load (kips)

ACB = allowable compressive load in bending (kips)

AMAJ = allowable moment (kip-ft)

Note: Repeat groups 4-8 data NPG (number of pile groups) number of times.

Group 9 - Control and Data for Pile Orientation

A. IB

IB = code for input of batter and angle

0 --- input batter and angle for each pile

>0 --- number of subgroups of piles in the group with the same batter and angle orientation

B. Note: Necessary only if IB (number of subgroups) > 0 .
Repeat IB number of times.

NFP, NLP, BATT

NFP = identification number of first pile in subgroup

NLP = identification number of last pile in subgroup

BATT = batter "BATT" vertical on 1 horizontal

<0 --- pile slopes from top right to lower left

=0 --- vertical pile

>0 --- pile slopes from top left to lower right

Group 10 - Pile Data for 2-D Pile Groups (ITYPE=2)

Note: Necessary only if IB > 0

U1(1) , U1(2) , U1(3) U1(NP)

* U_1 = distance from origin to pile along U_1 -axis.

Group 11 - Data for Pile Orientation

Note: Necessary only if $IB = 0$ and $ITYPE = 2$ (2-D pile groups). Repeat NP (number of pile rows) number of times

H, U_1

H = batter H vertical on 1 horizontal
<0 --- pile slopes from top right to lower left
0 --- vertical pile
>0 --- pile slopes from top left to lower right
 U_1 = distance from origin to pile along U_1 axis (feet)

Group 12 - Data for applied Loads and Moments

Note: Repeat NLC (number of loading conditions) number of times.

Q_1 , Q_3 , Q_5

Q_1 = horizontal load along U_1 axis (kips)
 Q_3 = vertical load along U_3 axis (kips)
 Q_5 = moment about U_2 axis (kip-ft)

Guide for three-dimensional data input

58. Data for a three-dimensional analysis should be input to program LMVDPILE according to the following guide. All input is in free field (a comma or at least one blank should separate data items). Data can be input either interactively or from a data file. If a data file is created, use line numbers for each data line.

Group 1 - Title

A. TITLE

TITLE = 66-character problem heading

B. TITLE1

TITLE1 = second 66-character problem heading

Group 2 - Control Data for Piles and Loads

A. ITYPE

* Successive piles with the same coordinate may be input in the form

$$N * U$$

where N = the number of piles with the same coordinates
U = the value of the coordinate in feet

ITYPE = code for type of analysis

3 --- three dimensional

B. NP, NPG, NLC

NP = total number of piles

NPG = number of pile groups

NLC = number of loading conditions

Group 3 - Control and Data for Soil Properties

MV, ES

MV = type of soil modulus variance

1 --- constant soil modulus

2 --- linearly varying soil modulus

ES = subgrade modulus (psi) for MV = 1

ES = KS = coefficient of subgrade modulus (pci) for MV = 2

Group 4 - Control and Data for Elastic Pile Constants

Note: Groups 4-7 should be repeated NPG (number of pile groups) number of times.

A. NPA, NPB, SLEN, NPS

NPA = identification number of first pile in pile group

NPB = identification number of last pile in pile group

SLEN = length of pile (feet)

NPS = code for type of input to compute elastic pile constants (B-matrix terms)

1 --- input B-matrix terms directly

2 --- any shape pile

3 --- round pile

B. Note: Necessary only if NPS = 1

B11, B22, B33, B44, B55, B66, B42, B51

B11, etc = elastic pile constants

C. Note: Necessary only if NPS = 2

AIX, AIY, AREA, X, Y

AIX = I_1 , moment of inertia about local U_1 axis (in.⁴)

AIY = I_2 , moment of inertia about local U_2 axis (in.⁴)

AREA = cross-sectional area of pile (in.²)

X = pile dimension parallel to U_1 axis (in.)

Y = pile dimension parallel to U_2 axis (in.)

D. Note: Necessary only if NPS = 3

D

D = average diameter of piles in the groups (in.)

Groups 4-7 repeated NPG times

Group 5 - Control and Data for Pile Material

A. MP

MP = type of material

- 1 --- concrete (E calculated from US input in item 5C)
- 2 --- timber (E set to 1,760,000 psi)
- 3 --- steel (E set to 29,000,000 psi)
- 4 --- special (E input in item 5C)

B. Note: Necessary only if MP = 1

US, W

US = ultimate strength of concrete (psi)
W = weight of concrete (pcf)

C. Note: Necessary only if MP = 4

E

E = modulus of elasticity (psi)

Group 6 - Control and Data for Fixity Coefficients to Describe Pile

A. NF

NF = code for input of fixities

- 1 --- input degree of fixity and all coefficients
- 2 --- input degree of fixity

B. Note: Necessary only if NF = 1. See paragraph 35. c.

DF, K1, K2, K3, K4, K5, K6

DF = degree of fixity of pile head-to-base (values between 0 and 1)

K1 = lateral fixity coefficient

K2 = pile axial resistance coefficient

1.0 --- end bearing pile in compression

2.0 --- friction pile in compression

For piles in tension the value should be reduced.
Suggest one half of value for compression piles.

K3 = rotational fixity coefficient

K4 = coefficient for torsion

K5 = fixity constant

K6 = fixity constant

C. Note: Necessary only if NF = 2

DF, PR, PFT, G

DF = degree of fixity of pile head-to-base (one of the values given below)

0.0 --- hinged pile head

0.5 --- partially fixed pile head

1.0 --- fixed pile head

if enough embolus strength of PS Core

combined bending factor (Appendix B)

$$= \frac{F_3}{ACBT_c} + \frac{F_4}{AMINT_c} + \frac{F_5}{AMAJT_c}$$

PR = pile axial resistance coefficient, K_2
 1.0 --- end bearing pile in compression
 2.0 --- friction pile in compression

For piles in tension the value should be reduced.
 Suggest one half of value for compression piles.

PFT = participation factor for torsion (values between 0 and 1), K_4

G = torsion modulus (psi) = $\frac{E}{2(1+\nu)}$

Group 7 - Data for Allowable Pile Loads and Moments

ACBT, AMINT, AMAJT, ACBC, AMINC, AMAJC, ACL, ATL

ACBT = allowable axial load used in combined bending equation for pile in tension (kips)

AMINT = allowable moment about minor principal axis for pile in tension (kip-ft)

AMAJT = allowable moment about major principal axis for pile in tension (kip-ft)

ACBC = allowable axial load used in combined bending equation for pile in compression (kips)

AMINC = allowable moment about minor principal axis for pile in compression (kip-ft)

AMAJC = allowable moment about major principal axis for pile in compression (kip-ft)

ACL = allowable compressive load (kips)

ATL = allowable tensile load (kips)

Note: Repeat groups 4-7 data NPG (number of pile groups) number of times

Group 8 - Control and Data for Pile Orientation

A. IB

IB = code for input of batter and angle

0 --- input batter and angle for each pile

>0 --- number of subgroups of piles in the group with the same batter and angle orientation (use Group 9)

B. Note: Necessary only if IB (number of subgroups) > 0.

NFP, NLP, BATT, ANGL

NFP = identification number of first pile in subgroup

NLP = identification number of last pile in subgroup

BATT = batter "BATT" vertical on 1 horizontal

0 --- vertical pile

ANGL = clockwise angle between the positive U_1' axis of the structure and the U_1 axis (direction of batter) of the pile (degrees)

Group 9 - Pile Data for 3-D Pile Groups (ITYPE = 3)

Note: Necessary only if $IB > 0$.

A. $U1(1), U1(2), U1(3), \dots, U1(NP)$

* $U1$ = distance from origin to pile along U_1 axis (feet)

★ B. $U2(1), U2(2), U2(3), \dots, U2(NP)$

* $U2$ = distance from origin to pile along U_2 axis (feet)

★ C. $U3(1), U3(2), U3(3), \dots, U3(NP)$

* $U3$ = distance from origin to pile along U_3 axis (feet)

★ Group 10 - Data for Pile Orientation 3-D Pile Group (ITYPE = 3)

Note: Necessary only if $IB = 0$. Repeat NP (number of piles) number of times.

H, ANG, $U1$, $U2$, $U3$

H = batter H vertical on 1 horizontal

0 --- vertical pile

ANG = clockwise angle between the positive U_1 axis of the structure and the U_1 axis (direction of batter) of the pile (degrees)

$U1$ = distance from origin to pile along U_1 -axis (feet)

$U2$ = distance from origin to pile along U_2 -axis (feet)

$U3$ = distance from origin to pile along U_3 -axis (feet)

Group 11 - Data for Applied Loads and Moments

Note: Repeat NLC (number of loading conditions) number of times.

Q1, Q2, Q3, Q4, Q5, Q6

Q1 = horizontal load along U_1 axis (kips)

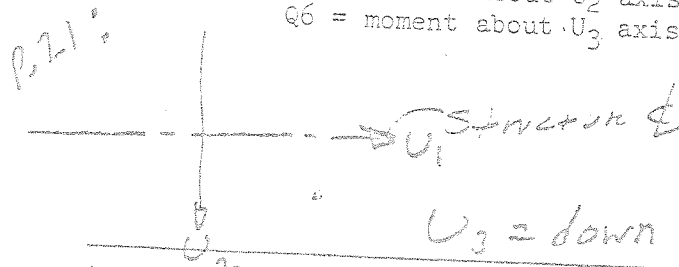
Q2 = horizontal load along U_2 axis (kips)

Q3 = vertical load along U_3 axis (kips)

Q4 = moment about U_1 axis (kip-ft)

Q5 = moment about U_2 axis (kip-ft)

Q6 = moment about U_3 axis (kip-ft)



* Successive piles with the same coordinate may be input in the form:

$N * U$

where N = the number of piles with the same coordinates
U = the value of the coordinate in feet

PART V: EXAMPLE PROBLEMS

Example Problem 1

Two-dimensional problem, 2 pinned
piles with constant soil modulus

59. This example problem illustrates the use of LMVDPILE for a two-dimensional system supported by four vertical piles. The physical problem is shown in Figure 6. (Example problem 7, is the three-dimensional run of this same problem; Figure 16, page 83, shows the plan view of the system.) Figure 7 shows the properties and loading conditions for this example. Input data are saved in a file and listed in Table 2. The computer output is presented in Table 3.

60. This example serves as a means to verify the computer output by comparison with manual calculations.

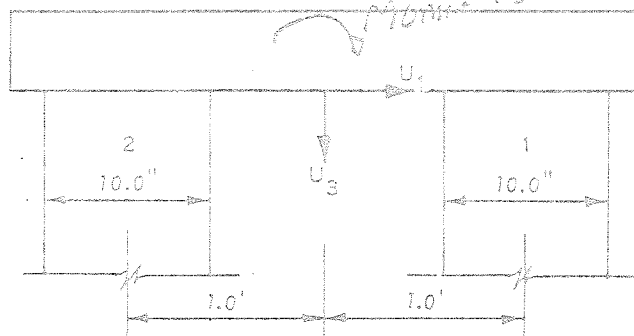


Figure 6. Physical problem for example problem 1

Results and calculations

61. The pile forces can be calculated by satisfying equilibrium $\sum F = 0$. These were found to agree with the program output shown in Table 3. For example, in loading case 2 there are two rows of piles each having 2 piles subjected to a 1-kip vertical load. The force on each pile is

$$F_H = 1/4 (\text{applied vertical load}) = 1/4 (1 \text{ kip}) = 0.25 \text{ kip}$$

The displacement in each pile is equal to

Properties	
Ult. str. of concrete = 5000.0 psi	Vertical (h = 0.0)
ES = 10.0 psi	Degree of fixity = 0.0
$I_1 = 833.333 \text{ in.}^4$	File resistance (K2) = 1.0
$I_2 = 833.333 \text{ in.}^4$	Participation factor for torsion (K4) = 0.0
Area = 100 in. ²	Torsion modulus = 0.0
Length = 100 ft	

	$F \rightarrow$ U1 axis	$F \downarrow$ U2 axis	(Moment) U3 axis
Loading Case	Q_1 (kips)	Q_2 (kips)	Q_3 (kip-ft)
1	1.0	0.0	0.0
2	0.0	1.0	0.0
3	0.0	0.0	1.0
4	1.0	1.0	1.0

Figure 7. Properties and loading conditions for example problem 1

2 D

Table 1
Interactively Input Data for Example Problem 1

INPUT DATA FILE NAME IN 8 CHARACTERS OR LESS. HIT A
CARRIAGE RETURN IF INPUT DATA WILL COME FROM TERMINAL.
?

INPUT A FILE NAME FOR DATA. HIT A CARRIAGE RETURN
IF YOU DO NOT WANT TO SAVE DATA FILE.
? DATA1

INPUT TWO LINES OF PROJECT IDENTIFICATION NOT
TO EXCEED 66 CHARACTERS EACH

INPUT FIRST LINE
? EXAMPLE PROBLEM NO. 1
INPUT SECOND LINE
? VERTICAL PILES WITH UNIT LOADS

DO YOU WANT TO RUN A 2-D OR 3-D ANALYSIS?
ENTER 2 OR 3 ? 2

INPUT TOTAL NUMBER OF PILE ROWS IN FOUNDATION
NUMBER OF PILE GROUPS AND LOADING CONDITIONS
? 2,1,4

INPUT SOIL PROPERTY DATA - MV AND ES:
MV=1=CONSTANT SOIL OR MV=2=LINEARLY VARYING SOIL
ES=SUBGRADE MODULUS (PSI IF MV=1 OR PCF IF MV=2)
? 1,18.0

DATA FOR PILE GROUP NO. - 1

INPUT PILE SHAPE DATA:
NPA=IDENTIFICATION NUMBER OF FIRST PILE ROW IN GROUP
NPS=IDENTIFICATION NUMBER OF LAST PILE ROW IN GROUP
SLEN=LENGTH OF PILES (FEET)
NPS=CODE FOR TYPE OF INPUT TO COMPUTE ELASTIC PILE CONSTANTS
1=INPUT PILE B MATRIX TERMS DIRECTLY
2=ANY SHAPE PILE
3=ROUND PILE
? 1,2,102.0,2

INPUT AX & AYY-MOMENTS OF INERTIA (IN**4)
AREA - CROSS SECTIONAL AREA (IN**2)
A & Y - PILE DIMENSIONS ALONG X & Y AXES (INCHES)
? 833.333,833.333,102.0,18.0,12.0

INPUT PILE MATERIAL DATA-MP (1=CONCRETE, 2=TIMBER, 3=STEEL, 4=SPECIAL)
? 1

INPUT US=ULTIMATE STRENGTH OF CONCRETE (PSI)
W=WEIGHT OF CONCRETE (PCF)
? 5000.0,152.0

INPUT FIXITY DATA - NF (1=INPUT ALL FIXITY COEFFICIENTS
OR 2=INPUT DEGREE OF FIXITY
? 2

INPUT DP - DEGREE OF FIXITY (2.2,2.5,1.0)
PF - PILE RESISTANCE (1=FAIRING OR 2.5=FRICITION)
PFT - PARTICIPATION FACTOR FOR TORSION
G - TORSION MODULUS (PSI)
? 2.0,1.2,2.2,2.2

(Continued)

Table 1 (Concluded)

INPUT NUMBER OF SIMILAR ROWS IN GROUP 1 2

INPUT ALLOWABLE LOADS:
 ACL = ALLOWABLE COMPRESSIVE LOAD (KIPS)
 ATL = ALLOWABLE TENSILE LOAD (KIPS)
 ACS = ALLOWABLE COMPRESSIVE LOAD IN BENDING (KIPS)
 AMAJ = ALLOWABLE MOMENT (KIP-FT)
 7 100.0,100.0,100.0,100.0

INPUT IB: 2=INPUT BATTER FOR EACH PILE OR
 THE NUMBER OF SUBGROUPS WITH THE SAME BATTER
 7 2

INPUT PILE ORIENTATION DATA
 B=BATTER=0 VERTICAL OR 1 HORIZONTAL
 POSITIVE IF BATTERED TO RIGHT & NEGATIVE IF TO LEFT
 U1=DISTANCE FROM ORIGIN TO PILE ROW(FEET)
 1 7 0.0,1.0
 2 7 0.0,-1.0

INPUT APPLIED LOADS AND MOMENT:
 Q1-HORIZONTAL LOAD ALONG U1-AXIS (KIPS)
 Q3-VERTICAL LOAD ALONG U3-AXIS (KIPS)
 Q5-MOMENT ABOUT U2-AXIS (KIP-FT)

FOR LOADING CONDITION - 1 7 1.0,0.0

FOR LOADING CONDITION - 2 7 0.0,1.0,0

FOR LOADING CONDITION - 3 7 0.0,0.0,1.0

FOR LOADING CONDITION - 4 7 1.0,1.0,1.0

THIS PROGRAM GENERATES THE FOLLOWING TABLES:

TABLE NO.	CONTENTS
1	PILE AND SOIL DATA
2	PILE COORDINATES AND BATTER
3	STIFFNESS AND FLEXIBILITY MATRICES FOR THE STRUCTURE AND COORDINATES OF ELASTIC CENTER
4	APPLIED LOADS
5	STRUCTURE DEFLECTIONS
6	PILE DEFLECTIONS ALONG PILE AXIS
7	PILE FORCES ALONG PILE AXIS
8	PILE FORCES ALONG STRUCTURE AXIS

INPUT THE NUMBERS OF THE TABLES FOR WHICH YOU WANT THE OUTPUT.
 SEPARATE THE NUMBERS WITH COMMAS. 7 1,2,3,4,5,6,7,8

INPUT A FILENAME FOR TABLE 6 IN 8 CHARACTERS OR LESS
 IF YOU WANT TO USE THIS INFORMATION FOR A NEW RUN
 HIT A CARRIAGE RETURN IF YOU DO NOT WANT THIS FILE.
 7

INPUT A FILE NAME FOR OUTPUT IN 8 CHARACTERS OR LESS.
 HIT A CARRIAGE RETURN IF OUTPUT IS TO BE PRINTED ON TERMINAL.
 7

INPUT A FILE NAME IN 8 CHARACTERS OR LESS FOR PLOT DATA NECESSARY
 FOR PROGRAM FDRAW. HIT A CARRIAGE RETURN IF YOU DO NOT WANT TO
 SAVE THIS FILE
 7

Table 2
Input Data for Example Problem 1

Group	1A	10000	EXAMPLE PROBLEM NO. 1							
	1B	10010	VERTICAL PILES WITH UNIT LOADS				TITLE			
	2A	10020	2	2-D ANALYSIS						
	2B	10030	2	1	4	NUMBER OF PILES, PILE GROUPS, LOADING CONDITIONS				
	2C	10040	1	10.000	SOIL PROPERTIES					
	2A	10050	1	2	100.000	2	PILE GEOMETRY			
	2C	10060	833.333	833.333	100.000	10.000	10.000			
	5A	10070	1							
	5B	10080	5000.000	150.000	PILE MATERIAL					
	6A	10090	2							
	6B	10100	0.	1.000	0.	0.	PILE FIXITY			
	7	10110	2	NUMBER OF ROWS						
	8	10120	100.000	100.000	100.000	100.000	ALLOWABLE LOADS			
	9A	10130	0							
	11	10140	0.	1.000	PILE BAYIER AND LOCATION					
		10150	0.	-1.000						
		10160	1.000	0.	0.					
	12	10170	0.	1.000	0.	APPLIED LOADINGS				
		10180	0.	0.	1.000					
		10190	1.000	1.000	1.000					

Table 3
Output Data for Example Problem 1

EXAMPLE PROBLEM NO. 1
VERTICAL PILES WITH UNIT LOADS

NO. OF PILE ROWS = 2 B MATRIX IS CALCULATED FOR EACH ROW

1. TABLE OF PILE AND SOIL DATA

PILE NUMBERS

1	2	E = 0.43E 07 PSI	IX = 833.33 IN**4	IY = 833.33 IN**4
		AREA = 100.0 IN**2	I = 10.00 IN	J = 10.00 IN
		LENGTH = 100.0 FEET	ES = 10.000	
		K1 = 0.4107	K2 = 1.0000	K3 = 0.
		K4 = 0.	K5 = 0.	K6 = 0.

ALLOWABLES: COMPRESSIVE LOAD = 100.000 KIPS
TENSILE LOAD = 100.000 KIPS
BENDING = 100.000 KIPS
MOMENT = 100.000 KIP-FT

THE B MATRIX FOR PILES 1 THROUGH 2 IS

0.972E 03	0.	0.
0.	0.357E 00	0.
0.	0.	0.

2. TABLE OF PILE COORDINATES AND BATTER

PILE ROW	BATTER	U1 (FT)
1	VERTICAL	1.000
2	VERTICAL	-1.000

3. STIFFNESS MATRIX S FOR THE STRUCTURE

0.369E 04	0.	0.
0.	0.143E 07	0.
0.	0.	0.206E 00

3A FLEXIBILITY MATRIX Y FOR THE STRUCTURE

0.257E-03	0.	0.
0.	0.700E-00	0.
0.	0.	0.486E-00

F = inverse of S

COORDINATES OF ELASTIC CENTER
EC1 = 0. EC2 = 0.

(Continued)

(Sheet 1 of 5)

Table 3 (Continued)

***** LOADING CONDITION 1 *****

4. MATRIX OF APPLIED LOADS Q (KIPS & FEET)

Q1	Q3	Q5
1.288	0.	0.

5. STRUCTURE DEFLECTIONS (INCHES)

D1	D3	D5
0.257E 00	0.	0.

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1	X3	X5
1	0.257E 00	0.	0.
2	0.257E 00	0.	0.

7. PILE FORCES ALONG PILE AXIS (KIPS & FT)

PILE	F1	F3	F5	FAILURE BU CO TE
1	0.258	0.	0.	
2	0.258	0.	0.	

TOTAL NO. FAILURES = 0 LOAD CASE 1

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	F1	F3	F5
1	0.258	0.	0.
2	0.258	0.	0.
SUM	1.288	0.	0.

(Continued)

(Sheet 1 of 5)

Table 3 (Continued)

***** LOADING CONDITION 2 *****

4. MATRIX OF APPLIED LOADS C (KIPS & FEET)

	C1	C2	C3
1.	0.	1.200	0.

5. STRUCTURE DEFLECTIONS (INCHES)

	D1	D2	D3
1.	0.	0.700E-03	0.

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1	X2	X3
1	0.	0.700E-03	0.
2	0.	0.700E-03	0.

7. PILE FORCES ALONG PILE AXIS (KIPS & FT)

PILE	F1	F2	F3	FAILURE
1	0.	0.250	0.	PU TO T2
2	0.	0.250	0.	

TOTAL NO. FAILURES = 0 LOAD CASE 2

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	F1	F2	F3
1	0.	0.250	0.
2	0.	0.250	0.
SUM	0.	1.200	-0.200

(Continued)

(Sheet 3 of 5)

Table 3 (Continued)

***** LOADING CONDITION 3 *****

4. MATRIX OF APPLIED LOADS Q (KIPS & FEET)

Q1	Q3	Q5
2.	0.	1.200

5. STRUCTURE DEFLECTIONS (INCHES)

D1	D3	D5
0.	0.	0.5831E-74

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1	X3	X5
1	0.	-0.7888E-23	0.5831E-74
2	0.	3.7900E-23	0.5831E-74

7. PILE FORCES ALONG PILE AXIS (KIPS & FT)

PILE	F1	F3	F5	FAILURE
1	2.	-0.25%	0.	PU 20 TB
2	0.	0.25%	0.	

TOTAL NO. FAILURES = 0 LOAD CASE 3

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	F1	F3	F5
1	2.	-0.25%	0.
2	0.	0.25%	0.
SUM	2.	0.	1.200

(Continued)

(Sheet - of 5)

Table 3 (Concluded)

***** LOADING CONDITION 4 *****

4. MATRIX OF APPLIED LOADS Q (KIPS & FEET)

Q1	Q3	Q5
1.200	1.200	1.200

5. STRUCTURE DEFLECTIONS (INCHES)

D1	D3	D5
0.257E-08	0.730E-03	0.593E-04

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1	X3	X5
1	0.257E-08	-0.364E-11	0.593E-04
2	0.257E-08	0.140E-02	0.593E-04

7. PILE FORCES ALONG PILE AXIS (KIPS & FT)

PILE	F1	F3	F5	FAILURE PU TO TE
1	0.252	-0.000	0.	
2	0.252	0.500	0.	

TOTAL NO. FAILURES = 0 LOAD CASE 4

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	F1	F3	F5
1	0.250	-0.000	0.
2	0.250	0.500	0.
SUM	1.200	1.200	1.200

$$\delta = \frac{PL}{AE} = \frac{\frac{1}{2} \times 1 \times 100 \times 12}{4300 \times 144 \times \frac{100}{144}} = 0.7 \times 10^{-3} \text{ in.}$$

This result also agrees with the computer program results (page 48, item 6).

62. In loading case 3, a 1 kip-ft moment is applied about the U_2 -axis. The pile forces can be calculated by satisfying equilibrium $\Sigma M_{U_2} = 0$.

$$\Sigma M_{U_2} = F_{3_1} \times N \times U_{1_1} + F_{3_2} \times N \times U_{1_2} + Q_5$$

where

F_{3_m} = vertical force for pile row m , $m = 1, 2$

N = number of piles in rows

U_1 = distance from origin to pile

$$\therefore \Sigma M_{U_2} = 2F_{3_1} + 2F_{3_2} + 1 \text{ kip-ft}$$

From symmetry $F_{3_1} = F_{3_2}$

$$\therefore |F_3| = 0.25 \text{ kip}$$

This result also agrees with the computer program results (page 49, item 8).

63. Load case 4 can be obtained as a superposition of load cases 1 through 3. The deflections of the pile and the load on each pile can be obtained by superimposing the respective results for load cases 1 through 3. The following computations verify these results.

File No.	Load Case	Deflections		
		X_1 (in.)	X_3 (in.)	X_5 (rad.)
1	1	0.257	0.	0.
	2	0.	0.7×10^{-3}	0.
	3	0.	-0.7×10^{-3}	0.583×10^{-4}
	4	0.257	0.	0.583×10^{-4} (page 50, item 6)
2	1	0.257	0.	0.
	2	0.	0.7×10^{-3}	0.
	3	0.	0.7×10^{-3}	0.583×10^{-4}
	4	0.257	0.14×10^{-2}	0.583×10^{-4} (page 50, item 6)

		Loads		
		F_1 (kips)	F_3 (kips)	F_5 (kip-ft)
1	1	0.25	0.	0.
	2	0.	0.25	0.
	3	0.	-0.25	0.
	4	0.25	0.	0. (page 50, item 7)
2	1	0.25	0.	0.
	2	0.	0.25	0.
	3	0.	0.25	0.
	4	0.25	0.50	0. (page 50, item 7)

These results also agree with the computer program results.

Example Problem 2

Two-dimensional prob-
lem. 1 fixed vertical pile

64. This example problem has only one vertical pile completely fixed into the rigid cap. Figure 8 shows the physical problem. (Example problem 8 is the three-dimensional run of this same problem; Figure 19, page 96, shows the plan view for this example.) Figure 9 shows the loading and properties. The input data are stored in a file and are presented in Table 4. The computer output is shown in Table 5.

65. This example is also a means to verify output by comparison with manual calculations and output from example problem 8.

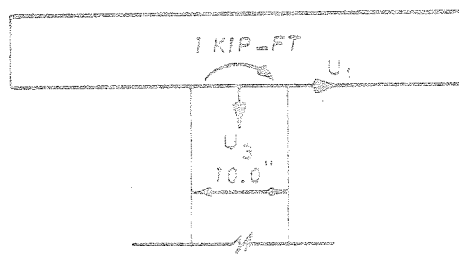


Figure 8. Physical problem for example problem 2

Properties		
Ult. str. of concrete = 5000.0 psi	$K_1 = 1.0756$	
KS = 10.0 pci	DF = 1.0	$K_2 = 1.0$
$I_1 = 833.333 \text{ in.}^4$	PR = 1.0	$K_3 = 1.4988$
$I_2 = 833.333 \text{ in.}^4$	PFT = 0.0	$K_4 = 0.0$
Area = 100.0 in. ²	G = 0.0	$K_5 = 0.9990$
Length = 100.0 ft		$K_6 = 0.9990$
Vertical (h = 0.0)		

Loading Case	P_1 (kips)	P_3 (kips)	M_3 (kip-ft)
1	0.0	0.0	1.0

Figure 9. Properties and loading for example problem 2

Table 4
Input Data for Example Problem 2

Group								
1A	10000	EXAMPLE PROBLEM NO. 2						
1B	10010	ONE FIXED VERTICAL PILE WITH UNIT MOMENT APPLIED						
2A	10020	2						
2B	10030	1	1	1				
3	10040	2		10.000				
4A	10050	1	1	100.000	2			
4C	10060	833.333	833.333	100.000	10.000	10.000		
5A	10070	1						
5B	10080	5000.000	150.000					
6A	10090	2						
6C	10100	1.000	1.000	0.	0.			
7	10110	1						
8	10120	100.000	100.000	100.000	100.000			
9A	10130	0						
11	10140	0.	0.					
12	10150	0.	0.	1.000				

Table 5
Output Data for Example Problem 2

EXAMPLE PROBLEM NO. 2
0.2 FIRED VERTICAL PILE WITH UNIT MOMENT APPLIED

NO. OF PILE ROWS = 1 E MATRIX IS CALCULATED FOR EACH ROW

1. TABLE OF PILE AND SOIL DATA

PILE NUMBERS

1	2	E = 3.43E+07 PSI	IX = 933.33 IN ⁴	IY = 933.33 IN ⁴
		AREA = 100.2 IN ²	X = 10.00 IN	Y = 10.00 IN
		LENGTH = 120.0 FEET	ES = 10.000	
		K1 = 1.0756	K2 = 1.0000	K3 = 1.4938
		K4 = 0.	K5 = 0.9990	K6 = 0.9990

ALLOWABLES: COMPRESSIVE LOAD = 120.000 KIPS
TENSILE LOAD = 100.000 KIPS
BENDING = 100.000 KIPS
MOMENT = 100.000 KIP-FT

THE E MATRIX FOR PILES 1 THROUGH 1 IS

0.254E+05	0.	0.135E+07
0.	0.357E+06	0.
0.135E+07	0.	0.104E+09

2. TABLE OF PILE COORDINATES AND BATTER

PILE ROW	BATTER	X1 (FT)
1	VERTICAL	0.

3. STIFFNESS MATRIX S FOR THE STRUCTURE

0.254E+05	0.	0.135E+07
0.	0.357E+06	0.
0.135E+07	0.	0.104E+09

4A FLEXIBILITY MATRIX F FOR THE STRUCTURE

0.000E+00	0.	-0.100E-05
0.	0.000E+00	0.
-0.100E-05	0.	0.000E+00

COORDINATES OF ELASTIC CENTER

EX1 = 0.	EX2 = 7.213
----------	-------------

(Continued)

Table 5 (Concluded)

***** LOADING CONDITION 1 *****

4. MATRIX OF APPLIED LOADS : (KIPS & FEET)

	1	3	5
1	2.	2.	1.222

5. STRUCTURE DEFLECTIONS (INCHES)

	1	3	5
1	-2.144E-21	2.	2.322E-23

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	1	3	5
1	-2.144E-21	2.	2.322E-23

7. PILE FORCES ALONG PILE AXIS (KIPS & FT)

PILE	1	3	5	FAILURE
1	2.222	2.	1.222	BU CO 71

TOTAL NO. FAILURES = 0 LOAD CASE 1

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	1	3	5
1	2.222	2.	1.222
3	2.222	2.	1.222

Results and calculations

66. A 1 kip-ft moment was applied about the U_2 axis at the center of the structure where the pile is located. The pile is completely fixed into the rigid cap. Therefore, the resulting moment about the U_2 axis is equal to 1 kip-ft. This result agrees with the computer output shown in Table 5 (item 8).

Example Problem 3

Two-dimensional problem,
Hrennikoff's example
case 2a (very weak soil)

67. This example problem is taken from Hrennikoff's (1950) paper, case 2a. This example is for very weak soil with hinged piles. The physical problem is shown in Figure 10. The properties and loading conditions are shown in Figure 11. The input data are stored in a file prior to the run and are presented in Table 6. The computer output is shown in Table 7.

68. This example serves as a means to verify the computer output with the classical method.

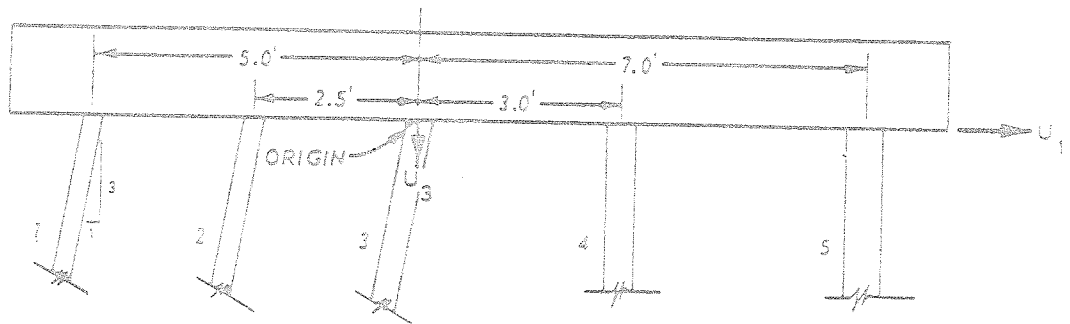


Figure 10. Physical problem for examples 3, 4, and 5

Results and calculations

69. In Hrennikoff's paper manual calculations for this problem are presented. The computer results shown in Table 7 agree closely with his results. A comparison of the two results is presented below. For pile 1,

$$F_1 = 0.442 \text{ kips} \quad F_3 = 27.395 \text{ kips}$$

as compared with

$$F_1 = 0.44 \text{ kips} \quad F_3 = 27.4 \text{ kips}$$

Properties	
$E = 0.15 \times 10^7$ psi	Degree of fixity = 0.0
$ES = 3.123$ psi	Pile resistance (K2) = 0.5
$I_1 = 322.06$ in. ⁴	Participation factor for torsion (K4) = 0.0
$I_2 = 322.06$ in. ⁴	Torsion modulus = 0.0
Area = 63.5 in. ²	
Length = 30 ft	

Loading Case	Q_1 (kips)	Q_3 (kips)	Q_5 (kip-ft)
1	-39.375	113.1	173.4

Figure 11. Properties and loading conditions for example problem 3

from case 2a in Hrennikoff's paper. Pile forces along the pile axis for piles 2-5 also agree closely as tabulated below.

File No.	Computer Output		Hrennikoff's Example	
	F_1 (kips)	F_3 (kips)	F_1 (kips)	F_3 (kips)
1	0.442	27.395	0.44	27.5
2	0.435	39.282	0.43	39.3
3	0.427	51.170	0.43	51.0
4	0.436	-9.167	0.43	-9.0
5	0.436	10.681	0.43	10.9

Table 6

Input Data for Example Problem 3

Group						
1A	10000	EXAMPLE PROBLEM NO. 3				
1B	10010	HRENNIKOFF'S EXAMPLE - CASE 2A				
2A	10020	2				
2B	10030	5	1	1		
3	10040	1	3.123			
4A	10050	1	5	30.000	3	
4D	10060	9.000				
5A	10070	4				
5C	10080	1500000.000				
6A	10090	2				
6C	10100	0.	0.500	0.	0.	
7	10110	1				
8	10120	82.000	40.000	100.000	100.000	
9A	10130	2				
9B	10140	1	5	-3.000		
	10150	4	5	0.		
10	10160	-5.000	-2.500	0.	3.000	7.000
12	10170	-39.375	113.1		173.4	

Table 7 Output Data for Example Problem 3

EXAMPLE PROBLEM NO. 3
BRENNEICOFF'S EXAMPLE - CASE 24

NO. OF PILE ROWS = 5 * MATRIX IS CALCULATED FOR EACH ROW

1. TABLE OF PILE AND SOIL DATA

PILE NUMBERS

1 E = 0.151 07 PSI I1 = 322.00 IN⁴ IY = 322.00 IN⁴
 AREA = 63.6 IN² Y = 5.00 IN Y = 9.00 IN
 LENGTH = 30.0 FEET ES = 3.123
 K1 = 0.4107 K2 = 0.0000 K3 = 0.
 K4 = 0. K5 = 0. K6 = 0.

LENGTH OF PILES (30.00 FEET) IS INSUFFICIENT
 FOR PILE GROUP - 1 MINIMUM ACCEPTABLE LENGTH IS 37.17 FEET
 FOR SEMI-INFINITE BEAM ON ELASTIC FOUNDATION

ALLOWABLES: COMPRESSIVE LOAD = 82.000 KIPS
 TENSILE LOAD = -40.000 KIPS

THE K MATRIX FOR PILES 1 THROUGH 5 IS

0.246E 03 0. 0.
 0. 0.133E 06 0.
 0. 0. 0.

2. TABLE OF PILE COORDINATES AND BATTER

PILE ROW	BATTER	UL (FT)
1	-3.00	-0.000
2	-3.00	-2.000
3	-3.00	0.
4	VERTICAL	3.000
5	VERTICAL	7.000

3. STIFFNESS MATRIX S FOR THE STRUCTURE

0.409E 05 -0.110E 06 -0.337E 07
 -0.110E 06 0.023E 06 -0.517E 07
 -0.337E 07 -0.517E 07 0.160E 10

3A. FLEXIBILITY MATRIX F FOR THE STRUCTURE

0.193E-01 0.414E-04 0.550E-06
 0.414E-04 0.183E-04 0.123E-06
 0.550E-06 0.123E-06 0.219E-08

COORDINATES OF ELASTIC CENTER
 EC1 = 0.000 EC2 = -0.002

(Continued)

Table 7 (Concluded)

LOADING CONDITION 1

4. MATRIX OF APPLIED LOCALS Q (KIPS & FEET)

Q1	Q3	Q5
-39.375	113.180	173.400

5. STRUCTURE DEFLECTIONS (INCHES)

D1	D3	D5
-0.1771	-0.1031	-0.3151

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1	X3	X5	Radians
1	-0.1805	0.2871	-0.3151	-0.2
2	-0.1771	0.2962	-0.3151	-0.2
3	-0.1741	0.3061	-0.3151	-0.2
4	-0.1771	-0.0941	-0.3151	-0.2
5	-0.1771	0.0211	-0.3151	-0.2

7. PILE FORCES ALONG PILE AXIS (KIPS & FT)

PILE	F1	F3	F5	FAILURE
1	-0.442	27.395	0.	BU
2	-0.405	39.282	0.	CO
3	-0.427	51.178	0.	TE
4	-0.436	-3.167	0.	TE
5	-0.436	10.081	0.	TE

TOTAL NO. FAILURES = 3 LOAD CASE 1

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	F1	F3	F5
1	-9.602	25.049	0.
2	-12.833	37.123	0.
3	-10.587	48.488	0.
4	-0.436	-3.167	0.
5	-0.436	10.081	0.
SUM	-39.375	113.180	173.400

Example Problem 4

Two-dimensional problem, Hrennikoff's example case 4a (weak soil)

70. This example is also from Hrennikoff's paper, case 4a (weak soil). Figure 10 shows the physical problem. The properties and loading conditions are shown in Figure 12. The input data are presented in Table 8. The computer output is shown in Table 9.

71. This example serves as a means to verify that output agrees with the classical method.

Properties	
$E = 0.15 \times 10^7$ psi	Degree of fixity = 0.0
$ES = 31.230$ psi	Pile resistance (K_2) = 1.0
$I_1 = 322.06$ in. ⁴	Participation factor for torsion (K_4) = 0.0
$I_2 = 322.06$ in. ⁴	
Area = 63.5 in. ²	Torsion modulus = 0.0
Length = 30 ft	

Loading Case	Q_1 (kips)	Q_3 (kips)	Q_5 (kip-ft)
1	-39.375	113.1	173.4

Figure 12. Properties and loading conditions for example problem 4

Results and calculations

72. The pile forces along pile axis in the computer output presented in Table 9 agree closely with the results in Hrennikoff's (1950) paper, case 4a. For example, for pile 1 from the computer output

Input Data for Example Problem 4

Table 8

Group		EXAMPLE PROBLEM NO. 4					BRENNIKOFF'S EXAMPLE - CASE 4A				
1A	1000	10020	2	1	1	1					
2B	10030	10030	5	1	1	1					
3	10040	10040	1	31.23							
4A	10050	10050	1	5	30.000	3					
4D	10060	10060	9.000								
5A	10070	10070	4								
5C	10080	10080	1500000.000								
6A	10090	10090	2								
6C	10100	10100	0.	1.000	0.	0.					
7	10110	10110	1								
8	10120	82.000	40.000	100.000	100.000	100.000					
9A	10130	2									
9B	10140	1	3	-3.000							
10	10160	4	5	0.							
10	10160	-5.000	-2.500	0.	3.000	7.000					
12	10170	-39.375	113.1			173.4					

Table 9
Output Data for Example Problem 4

EXAMPLE PROBLEM NO. 4
HRENNIKOFF'S EXAMPLE - CASE 4A

NO. OF PILE ROWS = 5 B MATRIX IS CALCULATED FOR EACH ROW

1. TABLE OF PILE AND SOIL DATA

PILE NUMBERS

1	5	E = 0.15E 07 PSI	IX = 322.06 IN**4	IV = 322.06 IN**4
		AREA = 63.6 IN**2	X = 9.00 IN	Y = 9.00 IN
		LENGTH = 30.0 FEET	ES = 31.230	
		K1 = 0.4107	K2 = 1.0000	K3 = 0.
		K4 = 0.	K5 = 0.	K6 = 0.

ALLOWABLES: COMPRESSIVE LOAD = 82.000 KIPS
TENSILE LOAD = 40.000 KIPS
BENDING = 100.000 KIPS
MOMENT = 100.000 KIP-FT

THE B MATRIX FOR PILES 1 THROUGH 5 IS

0.138E 04	0.	0.
0.	2.265E 06	0.
0.	0.	0.

2. TABLE OF PILE COORDINATES AND BATTER

PILE ROW	BATTER	U1 (FT)
1	-3.00	-5.000
2	-3.00	-2.500
3	-3.00	0.
4	VERTICAL	3.000
5	VERTICAL	7.000

3. STIFFNESS MATRIX S FOR THE STRUCTURE

0.060E 05	-0.237E 06	-0.712E 07
-0.237E 06	0.125E 07	-0.103E 08
-0.712E 07	-0.103E 08	0.329E 10

3A FLEXIBILITY MATRIX F FOR THE STRUCTURE

0.664E-04	0.142E-04	0.188E-06
0.142E-04	0.386E-05	0.429E-07
0.188E-06	0.429E-07	0.647E-09

COORDINATES OF ELASTIC CENTER

EC1 = 2.003 EC2 = -0.002

(Continued)

Table 9 (Concluded)

***** LOADING CONDITION 1 *****

4. MATRIX OF APPLIED LOADS Q (KIPS & FEET)

Q1	Q3	Q5
-39.375	113.100	173.400

5. STRUCTURE DEFLECTIONS (INCHES)

D1	D3	D5
-0.616E-00	-0.332E-01	-0.805E-03

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1			
1	-0.910E-02	0.117E-01	0.111E-03	
2	-0.027E-00	0.140E-02	-0.805E-03	
3	-0.595E-00	0.163E-00	-0.805E-03	
4	-0.616E-00	-0.421E-02	-0.805E-03	
5	-0.616E-00	0.344E-01	-0.805E-03	

7. PILE FORCES ALONG PILE AXIS (KIPS & FT)

PILE	F1	F3	F5	FAILURE BU CO TE
1	-0.845	31.130	0.	F
2	-0.834	37.204	0.	F
3	-0.824	43.276	0.	F
4	-0.853	-1.117	0.	
5	-0.853	9.124	0.	

TOTAL NO. FAILURES = 3 LOAD CASE 1

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	F1	F3	F5
1	-10.646	29.267	0.
2	-12.556	35.031	0.
3	-14.467	40.795	0.
4	-0.853	-1.117	0.
5	-0.853	9.124	0.

SUM	-39.375	113.100	173.400
-----	---------	---------	---------

$$F_1 = 0.845 \text{ kips} \quad \text{and} \quad F_3 = 31.13 \text{ kips} \quad F_5 = 0 \text{ kip-ft}$$

in comparison with

$$F_1 = 0.84 \text{ kips} \quad \text{and} \quad F_3 = 31.2 \text{ kips} \quad F_5 = 0 \text{ kip-ft}$$

from Hrennikoff's paper. The pile forces along the pile axis for piles 2-5 also agree closely. The computer results and Hrennikoff's results are presented below.

Pile No.	Computer Output		Hrennikoff's Example	
	F_1 (kips)	F_3 (kips)	F_1 (kips)	F_3 (kips)
1	0.845	31.132	0.84	31.2
2	0.834	37.204	0.83	37.2
3	0.824	43.276	0.82	43.2
4	0.853	-1.117	0.85	-1.0
5	0.853	9.124	0.85	9.1

Example Problem 5

Two-dimensional problem,
Hrennikoff's example
case 6a (medium soil)

73. This example is case 6a (medium soil) from Hrennikoff's paper. The physical problem is shown in Figure 10. The properties and loading conditions are shown in Figure 13. The input data are stored in a file prior to the run and are shown in Table 10. The computer output is presented in Table 11.

74. This example also serves as a means to verify that output agrees with the classical method results.

Properties	
$E = 0.15 \times 10^7$ psi	Degree of fixity = 0.0
$ES = 312.30$ psi	Pile resistance (K2)
$I_1 = 322.06$ in. ⁴	= 1.0
$I_2 = 322.06$ in. ⁴	Participation factor
Area = 63.5 in. ²	for torsion (K4)
Length = 30 ft	= 0.0
	Torsion modulus = 0.0

Loading Case	Q_1 (kips)	Q_3 (kips)	Q_5 (kip-ft)
1	-39.375	113.1	173.4

Figure 13. Properties and loading conditions for example problem 5

Results and calculations

75. Manual calculations for this example are presented in Hrennikoff's paper, case 6a. The computer results shown in Table 11 agree closely with the classical method results. For example, a comparison of the horizontal forces in each pile is shown below:

Table 10
Input Data for Example Problem 5

Group							
1A	10000	EXAMPLE PROBLEM NO. 5					
1B	10010	HRENNIKOFF'S EXAMPLE - CASE 6A					
2A	10020	2					
2B	10030	5	1	1			
3	10040	1	312.300				
4A	10050	1	5	30.000	3		
4D	10060	9.000					
5A	10070	4					
5C	10080	1500000.000					
6A	10090	2					
6C	10100	0.	1.000	0.	0.		
7	10110	1					
8	10120	82.000	40.000	100.000	100.000		
9A	10130	2					
9B	10140	1	3	-3.000			
	10150	4	5	0.			
10	10160	-5.000	-2.500	0.	3.000	7.000	
12	10170	-39.375	113.1		173.4		

Table 11
Output Data for Example Problem 5

EXAMPLE PROBLEM NO. 5
HRENNIKOFF'S EXAMPLE - CASE 6A

NO. OF PILE ROWS = 5 B MATRIX IS CALCULATED FOR EACH ROW

1. TABLE OF PILE AND SOIL DATA

PILE NUMBERS

1 5 F = 0.15E 07 PSI IX = 322.06 IN**4 IY = 322.06 IN**4
 AREA = 67.6 IN**2 X = 9.00 IN Y = 9.00 IN
 LENGTH = 30.0 FEET ES = 312.300
 K1 = 0.4107 K2 = 1.0000 K3 = 0.
 K4 = 0. K5 = 0. K6 = 0.

ALLOWABLES: COMPRESSIVE LOAD = 82.000 KIPS
 TENSILE LOAD = 40.000 KIPS
 PENDING = 100.000 KIPS
 MOMENT = 100.000 KIP-FT

THE B MATRIX FOR PILES 1 THROUGH 5 IS

0.779E 04 0. 0.
 0. 0.265E 06 0.
 0. 0. 0.

2. TABLE OF PILE COORDINATES AND BATTER

PILE ROW	BATTER	U1 (FT)
1	-3.00	-5.000
2	-3.00	-2.500
3	-3.00	0.
4	VERTICAL	3.000
5	VERTICAL	7.000

3. STIFFNESS MATRIX S FOR THE STRUCTURE

0.116E 06 -0.232E 06 -0.695E 07
 -0.232E 06 0.125E 07 -0.103E 08
 -0.695E 07 -0.103E 08 0.329E 10

3A FLEXIBILITY MATRIX F FOR THE STRUCTURE

0.205E-04 0.427E-05 0.566E-07
 0.427E-05 0.171E-05 0.144E-07
 0.566E-07 0.144E-07 0.468E-09

COORDINATES OF ELASTIC CENTER
 EC1 = 0.003 EC2 = -0.002

(Continued)

Pile No.	F_1 (kips) from	
	Computer Output	Hrennikoff's Example
1	1.338	1.34
2	1.365	1.37
3	1.392	1.39
4	1.611	1.61
5	1.611	1.61

76. The vertical pile forces also agree closely and are shown below:

Pile No.	F_3 (kips) from	
	Computer Output	Hrennikoff's Example
1	36.790	36.8
2	34.014	34.0
3	31.237	31.2
4	11.137	11.1
5	6.454	6.5

Table 11 (Concluded)

***** LOADING CONDITION 1 *****

4. MATRIX OF APPLIED LOADS Q (KIPS & FEET)

Q1	Q3	Q5
-39.375	113.100	173.400

5. STRUCTURE DEFLECTIONS (INCHES)

D1	D3	D5
-0.207E 00	0.553E-01	0.368E-03

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1	X3	X5
1	-0.172E 00	0.139E 00	0.368E-03
2	-0.175E 00	0.128E 00	0.368E-03
3	-0.179E 00	0.118E 00	0.368E-03
4	-0.207E 00	0.420E-01	0.368E-03
5	-0.207E 00	0.243E-01	0.368E-03

7. PILE FORCES ALONG PILE AXIS (KIPS & FT)

PILE	F1	F3	F5	FAILURE BU CO TE
1	-1.338	36.790	0.	
2	-1.365	34.014	0.	
3	-1.392	31.237	0.	
4	-1.611	11.137	0.	
5	-1.611	6.454	0.	

TOTAL NO. FAILURES = 0 LOAD CASE 1

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	F1	F3	F5
1	-12.903	34.479	0.
2	-12.051	31.836	0.
3	-11.199	29.194	0.
4	-1.611	11.137	0.
5	-1.611	6.454	0.

SUM	-39.375	113.100	173.400
-----	---------	---------	---------

Example Problem 6

Two-dimensional problem, 16 piles with linearly varying soil moduli

77. To further illustrate the use of program LMVDPILE for two-dimensional systems, a sixth example problem was run. The B-matrix terms are input directly. The physical problem is shown in Figure 14. The properties and loading conditions are shown in Figure 15. The input data are stored in a file that is listed in Table 12. The computer output is presented in Table 13.

78. This two-dimensional example was run to verify that the computer results agree with the St. Louis District's program output.

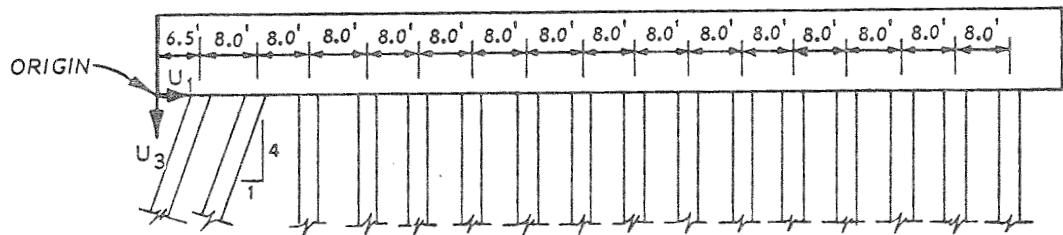


Figure 14. Physical problem for example problem 6

Properties	
$b_{11} = 5.6$	$E = 30,000.0 \text{ psi}$
$b_{22} = 448.0$	$KS = 0.001 \text{ pci}$
$b_{33} = 0.001$	
$b_{31} = 0$	

Loading Case	Q_1 (kips)	Q_3 (kips)	Q_5 (kip-ft)
1	-0.11	2.678	-177.5
2	-0.11	3.110	-206.67
3	-0.11	0.028	-1.233

Figure 15. Properties and loading conditions for example problem 6

Input Data for Example Problem 6

Group	1A	12020	EXAMPLE PROBLEM NO. 6							
	1B	12010	JOHN H. CARTON LOCK AND DAM UFRAME ADJACENT							
	2A	12020	2							
	2B	12030	15	1	3					
	3	12040	2	0.001						
	4A	12050	1	16	50.222	1				
	4B	12060	5.620	443.220	2.001	2.				
	5A	12070	4							
	5C	12050	30000.000							
	6A	12030	1							
	6B	12120	1.000	1.000	1.000	1.220	1.000	1.220	1.200	
	7	12110	1							
	8	12120	2.365	0.050	0.1	2.1				
	9A	12130	2							
	9B	12140	1	2	-4.202					
		12150	3	16	2.					
10		12160	6.5, 14.5, 22.5, 30.5, 38.5, 46.5, 54.5, 62.5, 70.5, 78.5, 86.5, 94.5,							
		12170	102.5, 110.5, 118.5, 126.5							
12		12130	-0.110	2.673	-177.520					
		12150	-2.110	3.110	-206.657					
		12200	-2.110	0.025	-1.233					

Table 13
Output Data for Example Problem 6

EXAMPLE PROBLEM NO. 1
JOHN H. OVERTON LOCK AND DAM UFRAME ADJACENT

NO. OF PILE ROWS = 16 B MATRIX IS CALCULATED FOR EACH ROW

1. TABLE OF PILE AND SOIL DATA

PILE NUMBERS

1 16E = 0.30E 25 PSI ES = 2.201
K1 = 1.0000 K2 = 1.0000 K3 = 1.0000
K4 = 1.0000 K5 = 1.0000 K6 = 1.0000

ALLOWABLES: COMPRESSIVE LOAD = 2.365 KIPS
TENSILE LOAD = 0.252 KIPS
BENDING = 0.102 KIPS
MOMENT = 0.102 KIP-FT

B MATRIX INPUT DIRECTLY AND THEN MODIFIED BY FIXITIES

THE B MATRIX FOR PILES 1 THROUGH 16 IS

0.560E 01 0. 0.
0. 0.446E 03 0.
0. 0. 2.100E-02

2. TABLE OF PILE COORDINATES AND BATTER

FILE ROW	BATTER	U1 (FT)
1	-4.00	6.500
2	-4.00	14.500
3	VERTICAL	22.500
4	VERTICAL	30.500
5	VERTICAL	38.500
6	VERTICAL	46.500
7	VERTICAL	54.500
8	VERTICAL	62.500
9	VERTICAL	70.500
10	VERTICAL	78.500
11	VERTICAL	86.500
12	VERTICAL	94.500
13	VERTICAL	102.500
14	VERTICAL	110.500
15	VERTICAL	118.500
16	VERTICAL	126.500

3. STIFFNESS MATRIX S FOR THE STRUCTURE

2.142E 03 -2.203E 03 2.202E 05
-0.203E 03 0.712E 04 -0.271E 07
0.202E 05 -2.571E 07 0.597E 12

3A FLEXIBILITY MATRIX F FOR THE STRUCTURE

0.525E-02 0.513E-03 0.543E-06
0.513E-03 0.710E-03 0.276E-06
0.543E-06 0.276E-06 0.511E-09

COORDINATES OF ELASTIC CENTER
LC1 = 2.201 LC2 = 0.002

(Continued)

(Sheet 1 of 7)

Table 13 (Continued)

***** LOADING CONDITION 1 *****

4. MATRIX OF APPLIED LOADS Q (KIPS & FEET)

D1	D3	D5
-0.110	2.678	-177.520

5. STRUCTURE DEFLECTIONS (INCHES)

D1	D3	D5
-2.244E-20	2.361E-20	-2.103E-24

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1	X3	X5
1	-2.149E-20	2.410E-20	-0.103E-24
2	-2.149E-20	2.411E-20	-0.103E-24
3	-2.244E-20	2.364E-20	-0.103E-24
4	-2.244E-20	2.365E-20	-0.103E-24
5	-2.244E-20	2.366E-20	-0.103E-24
6	-2.244E-20	2.367E-20	-0.103E-24
7	-2.244E-20	2.368E-20	-0.103E-24
8	-2.244E-20	2.369E-20	-0.103E-24
9	-2.244E-20	2.370E-20	-0.103E-24
10	-2.244E-20	2.371E-20	-0.103E-24
11	-2.244E-20	2.372E-20	-0.103E-24
12	-2.244E-20	2.373E-20	-0.103E-24
13	-2.244E-20	2.374E-20	-0.103E-24
14	-2.244E-20	2.375E-20	-0.103E-24
15	-2.244E-20	2.376E-20	-0.103E-24
16	-2.244E-20	2.377E-20	-0.103E-24

(Continued)

(Sheet 2 of 7)

Table 13 (Continued)

7. PILE FORCES ALONG PILE AXIS (KIPS & FT)

PILE	F1	F3	F5	FAILURE SUCCES
1	-2.221	2.154	-2.200	F
2	-2.201	2.154	-2.200	F
3	-2.221	2.163	-2.200	F
4	-2.201	2.163	-2.200	F
5	-2.201	2.154	-2.200	F
6	-2.221	2.164	-2.200	F
7	-2.221	2.165	-2.200	F
8	-2.201	2.165	-2.202	F
9	-2.201	2.166	-2.200	F
10	-2.221	2.166	-2.200	F
11	-2.201	2.166	-2.200	F
12	-2.201	2.167	-2.200	F
13	-2.221	2.167	-2.200	F
14	-2.201	2.165	-2.202	F
15	-2.201	2.163	-2.200	F
16	-2.201	2.169	-2.200	F

TOTAL NO. FAILURES = 16 LOAD CASE 1

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

FILE	F1	F3	F5
1	-2.245	2.178	-2.200
2	-2.245	2.178	-2.200
3	-2.221	2.163	-2.200
4	-2.221	2.163	-2.200
5	-2.201	2.154	-2.200
6	-2.201	2.154	-2.200
7	-2.221	2.165	-2.200
8	-2.221	2.165	-2.200
9	-2.201	2.166	-2.200
10	-2.201	2.166	-2.200
11	-2.221	2.166	-2.200
12	-2.221	2.167	-2.200
13	-2.201	2.167	-2.200
14	-2.221	2.163	-2.200
15	-2.201	2.163	-2.200
16	-2.201	2.159	-2.200
SUM	-2.110	2.678	-177.500

(Continued)

(Sheet 3 of 7)

Table 13 (Continued)

***** LOADING CONDITION 2 *****

4. MATRIX OF APPLIED LOADS 2 (KIPS & FEET)

X1	X3	X5
-0.110	3.110	-225.667

5. STRUCTURE DEFLECTIONS (INCHES)

X1	X3	X5
-0.143E-00	0.431E-00	-0.219E-25

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1	X3	X5
1	-2.337E-21	2.453E-00	-0.219E-25
2	-2.336E-21	0.453E-00	-0.219E-25
3	-0.143E-00	0.432E-00	-0.219E-25
4	-0.143E-00	0.432E-00	-0.219E-25
5	-0.143E-00	0.432E-00	-0.219E-25
6	-0.143E-00	0.432E-00	-0.219E-25
7	-0.143E-00	0.433E-00	-0.219E-25
8	-0.143E-00	0.433E-00	-0.219E-25
9	-0.143E-00	0.433E-00	-0.219E-25
10	-0.143E-00	0.433E-00	-0.219E-25
11	-0.143E-00	0.433E-00	-0.219E-25
12	-0.143E-00	0.434E-00	-0.219E-25
13	-0.143E-00	0.434E-00	-0.219E-25
14	-0.143E-00	0.434E-00	-0.219E-25
15	-0.143E-00	0.434E-00	-0.219E-25
16	-0.143E-00	0.434E-00	-0.219E-25

(Continued)

(Sheet 4 of 7)

Table 13 (Continued)

7. PILE FORCES ALONG PILE AXIS (KIPS & FT)

PILE	F1	F3	F5	FAILURE BY CODE
1	-2.222	2.223	-2.222	F
2	-2.222	2.223	-2.222	F
3	-2.221	2.153	-2.222	F
4	-2.221	2.153	-2.222	F
5	-2.221	2.154	-2.222	F
6	-2.221	2.154	-2.222	F
7	-2.221	2.154	-2.222	F
8	-2.221	2.154	-2.222	F
9	-2.221	2.154	-2.222	F
10	-2.221	2.154	-2.222	F
11	-2.221	2.154	-2.222	F
12	-2.221	2.154	-2.222	F
13	-2.221	2.154	-2.222	F
14	-2.221	2.154	-2.222	F
15	-2.221	2.155	-2.222	F
16	-2.221	2.155	-2.222	F

TOTAL NO. FAILURES = 16 LOAD CASE 2

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	F1	F3	F5
1	-2.249	2.197	-2.222
2	-2.249	2.197	-2.222
3	-2.221	2.153	-2.222
4	-2.221	2.153	-2.222
5	-2.221	2.154	-2.222
6	-2.221	2.154	-2.222
7	-2.221	2.154	-2.222
8	-2.221	2.154	-2.222
9	-2.221	2.154	-2.222
10	-2.221	2.154	-2.222
11	-2.221	2.154	-2.222
12	-2.221	2.154	-2.222
13	-2.221	2.154	-2.222
14	-2.221	2.154	-2.222
15	-2.221	2.155	-2.222
16	-2.221	2.155	-2.222
SUM	-2.112	3.110	-205.667

(Continued)

(Sheet 5 of 7)

Table 13 (Continued)

***** LOADING CONDITION 3 *****

4. MATRIX OF APPLIED LOADS Q (KIPS & FEET)

Q1	Q3	Q5
-0.110	0.028	-1.233

5. STRUCTURE DEFLECTIONS (INCHES)

D1	D3	D5
-0.099E-02	-0.011E-01	-0.508E-04

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1	X3	X5
1	-0.000E+00	0.135E+00	-0.000E+00
2	-0.000E+00	0.143E+00	-0.000E+00
3	-0.000E+00	-0.000E+00	-0.000E+00
4	-0.000E+00	-0.000E+00	-0.000E+00
5	-0.000E+00	-0.000E+00	-0.000E+00
6	-0.000E+00	-0.000E+00	-0.000E+00
7	-0.000E+00	-0.000E+00	-0.000E+00
8	-0.000E+00	-0.000E+00	-0.000E+00
9	-0.000E+00	-0.000E+00	-0.000E+00
10	-0.000E+00	-0.000E+00	-0.000E+00
11	-0.000E+00	-0.000E+00	-0.000E+00
12	-0.000E+00	0.000E+00	-0.000E+00
13	-0.000E+00	0.000E+00	-0.000E+00
14	-0.000E+00	0.000E+00	-0.000E+00
15	-0.000E+00	0.000E+00	-0.000E+00
16	-0.000E+00	0.000E+00	-0.000E+00

(Continued)

(Sheet 6 of 7)

Table 13 (Concluded)

7. PILE FORCES ALONG PILE AXIS (KIPS & FT)

PILE	F1	F3	F5	FAILURE BU CC TE
1	-2.225	0.261	-2.222	
2	-2.225	0.264	-2.222	
3	-2.225	-2.232	-2.222	
4	-2.225	-2.227	-2.222	
5	-2.225	-2.223	-2.222	
6	-2.225	-2.219	-2.222	
7	-2.225	-2.216	-2.222	
8	-2.225	-2.212	-2.222	
9	-2.225	-2.208	-2.222	
10	-2.225	-2.205	-2.222	
11	-2.225	-2.201	-2.222	
12	-2.225	0.203	-2.222	
13	-2.225	0.206	-2.222	
14	-2.225	0.210	-2.222	
15	-2.225	0.214	-2.222	
16	-2.225	0.218	-2.222	

TOTAL NO. FAILURES = 0 LOAD CASE 3

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	F1	F3	F5
1	-2.222	0.257	-2.222
2	-2.222	0.261	-2.222
3	-2.225	-2.232	-2.222
4	-2.225	-2.227	-2.222
5	-2.225	-2.223	-2.222
6	-2.225	-2.219	-2.222
7	-2.225	-2.216	-2.222
8	-2.225	-2.212	-2.222
9	-2.225	-2.208	-2.222
10	-2.225	-2.205	-2.222
11	-2.225	-2.201	-2.222
12	-2.225	0.203	-2.222
13	-2.225	0.206	-2.222
14	-2.225	0.210	-2.222
15	-2.225	0.214	-2.222
16	-2.225	0.218	-2.222

SUM	-2.112	2.228	-1.233

ready

*

Results and calculations

79. The computer results presented in Table 13 agree closely with answers from St. Louis program output. For example, for pile 1 and loading case 1, the pile forces along the structure axis from Table 13 are

$$F_1 = -0.045 \text{ kip}$$

$$F_3 = 0.178 \text{ kip}$$

$$F_5 = 0.0$$

as compared with

$$F_1 = -45.4 \text{ lb}$$

$$F_3 = 178.1 \text{ lb}$$

$$F_5 = 0$$

from the St. Louis program. The results for all piles agree very closely.

Example Problem 7

Three-dimensional
problem, 4 pinned piles
and constant soil modulus

80. This example problem illustrates the use of program LMVDPILE, given four vertical piles (similar to example problem 1 for 2-D system). Figures 16 and 17 show the physical problem. There are six loading conditions: a unit load applied along each axis, a unit moment about the U_1 and U_2 axes and a combination of all loads. Figure 18 shows the loading conditions and properties. The input data are stored in a data file prior to running the program and are shown in Table 14. The computer output is presented in Table 15.

81. This example illustrates how a three-dimensional problem with linearly varying soil modulus is coded. It also serves as a means to verify the computer output by comparison with manual calculations.

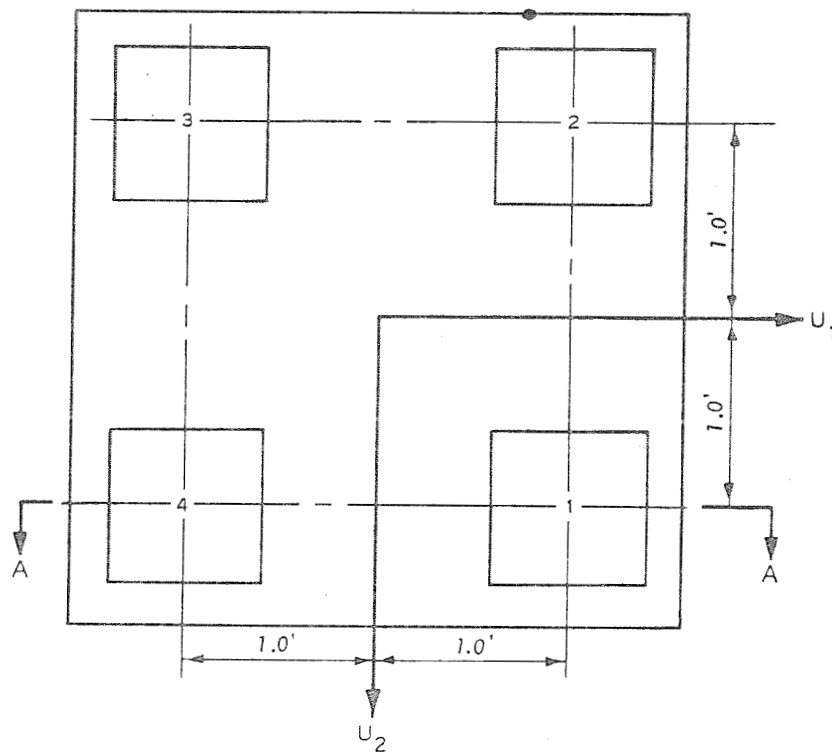


Figure 16. Plan view of example problem 7

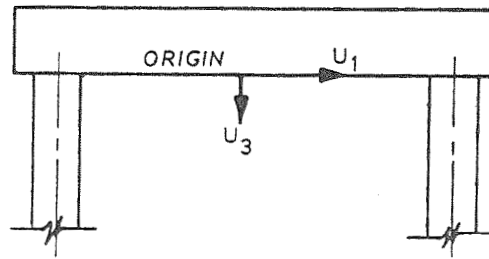


Figure 17. Section A-A for example problem 7

Properties	
Ult. str. of concrete = 5000 psi	Vertical (h = 0.0)
KS = 10.000 pci	
$I_1 = 833.333 \text{ in.}^4$	Degree of fixity = 0.0
$I_2 = 833.333 \text{ in.}^4$	Pile resistance (K2) = 1.0
Area = 100.0 in. ²	Participation factor for torsion (K4) = 0.0
Length = 100.0 ft	Torsion modulus = 0.0

Loading Case	Q_1 (kips)	Q_2 (kips)	Q_3 (kips)	Q_4 (kip-ft)	Q_5 (kip-ft)	Q_6 (kip-ft)
1	1.0	0.0	0.0	0.0	0.0	0.0
2	0.0	1.0	0.0	0.0	0.0	0.0
3	0.0	0.0	1.0	0.0	0.0	0.0
4	0.0	0.0	0.0	1.0	0.0	0.0
5	0.0	0.0	0.0	0.0	1.0	0.0
6	1.0	1.0	1.0	1.0	1.0	0.0

Figure 18. Properties and loading conditions for example problem 7

Table 14
Input Data for Example Problem 7

Group													
1A	10020	EXAMLE PROBLEM NO. 7								TITLE			
1B	10010	VERTICAL PILES WITH UNIT LOADS											
2A	10020	3	TYPE OF ANALYSIS 3-D										
2B	10030	4	1	6	NUMBER OF PILES, PILE GROUPS, LOADING CONDITIONS								
3	10040	2	10.000 SOIL PROPERTIES										
4A	10050	1	4	100.000	2								
4C	10060	833.333	833.333	100.000	10.000	10.000	10.000	PILE GEOMETRY					
5A	10070	1											
5B	10080	5000.000	150.000	PILE MATERIAL									
6A	10090	2											
6C	10100	0.	1.000	0.	0.	PILE FIXITIES							
7	10110	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	ALLOWABLE LOAD & MOMENTS			
8A	10120	1											
8B	10130	1	4	0.	0.	BATTER AND ANGLE ORIENTATION							
9A	10140	2*1.000, 2*-1.000				U1 COORDINATES							
9B	10150	1.000, 2*-1.000				U2 COORDINATES							
9C	10160	4*0.0				U3 COORDINATES							
11	10180	1.000	0.	0.	0.	0.	0.	0.	APPLIED LOADS AND MOMENTS				
	10190	0.	1.000	0.	0.	0.	0.	0.					
	10200	0.	0.	1.000	0.	0.	0.	0.					
	10210	0.	0.	0.	1.000	0.	0.	0.					
	10220	0.	0.	0.	0.	1.000	0.	0.					
	10230	1.000	1.000	1.000	1.000	1.000	1.000	1.000					

Table 15
Output Data for Example Problem 7

EXAMPLE PROBLEM NO. 7
VERTICAL PILES WITH UNIT LOADS

NO. OF PILES = 4 B MATRIX IS CALCULATED FOR EACH PILE

1. TABLE OF PILE AND SOIL DATA

PILE NUMBERS

1 4 E = 0.43E 07 PSI IX = 833.33 IN**4 IY = 833.33 IN**4
AREA = 100.0 IN**2 X = 10.00 IN Y = 10.00 IN
LENGTH = 100.0 FEET ES = 10.000
K1 = 0.4107 K2 = 1.0000 K3 = 0.
K4 = 0. K5 = 0. K6 = 0.

ALLOWABLES: COMBINED BENDING FOR TENSION = 100.000 KIPS
MOMENT ABOUT MINOR AXIS FOR TENSION = 100.000 KIP-FT
MOMENT ABOUT MAJOR AXIS FOR TENSION = 100.000 KIP-FT
COMBINED BENDING FOR COMPRESSION = 100.000 KIPS
MOMENT ABOUT MINOR AXIS FOR COMPRESSION = 100.000 KIP-FT
MOMENT ABOUT MAJOR AXIS FOR COMPRESSION = 100.000 KIP-FT
COMPRESSIVE LOAD = 100.000 KIPS
TENSILE LOAD = 100.000 KIPS

THE B MATRIX FOR PILES 1 THROUGH 4 IS

0.108E 05	0.	0.	0.	0.	0.
0.	0.108E 05	0.	0.	0.	0.
0.	0.	0.357E 06	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.

2. TABLE OF PILE COORDINATES AND BATTER

PILE NO.	BATTER	ANGLE	U1(FT)	U2(FT)	U3(FT)
1	VERTICAL	0.	1.000	1.000	0.
2	VERTICAL	0.	1.000	-1.000	0.
3	VERTICAL	0.	-1.000	-1.000	0.
4	VERTICAL	0.	-1.000	1.000	0.

3. STIFFNESS MATRIX S FOR THE STRUCTURE

0.433E 05	0.	0.	0.	0.	0.
0.	0.433E 05	0.	0.	0.	0.
0.	0.	0.143E 07	0.	0.	0.
0.	0.	0.	0.206E 09	0.	0.
0.	0.	0.	0.	0.206E 09	0.
0.	0.	0.	0.	0.	0.125E 08

3A FLEXIBILITY MATRIX F FOR THE STRUCTURE

0.231E-04	0.	0.	0.	0.	0.
0.	0.231E-04	0.	0.	0.	0.
0.	0.	0.700E-06	0.	0.	0.
0.	0.	0.	0.486E-08	0.	0.
0.	0.	0.	0.	0.486E-08	0.
0.	0.	0.	0.	0.	0.801E-07

(Continued)

(Sheet 1 of 7)

Table 15 (Continued)

***** LOADING CONDITION 1 *****

4. MATRIX OF APPLIED LOADS Q (KIPS & FEET)

Q1	Q2	Q3	Q4	Q5	Q6
1.000	0.	0.	0.	0.	0.

5. STRUCTURE DEFLECTIONS (INCHES)

D1	D2	D3	D4	D5	D6
0.231E-01	0.	0.	0.	0.	0.

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1	X2	X3	X4	X5	X6
1	0.231E-01	0.	0.	0.	0.	0.
2	0.231E-01	0.	0.	0.	0.	0.
3	0.231E-01	0.	0.	0.	0.	0.
4	0.231E-01	0.	0.	0.	0.	0.

7. PILE FORCES ALONG PILE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6	CBPTR	FAILURE
								CB BU CO TE
1	0.250	0.	0.	0.	0.	0.	0.	
2	0.250	0.	0.	0.	0.	0.	0.	
3	0.250	0.	0.	0.	0.	0.	0.	
4	0.250	0.	0.	0.	0.	0.	0.	

TOTAL NO. FAILURES = 0 LOAD CASE 1

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6
1	0.250	0.	0.	0.	0.	0.
2	0.250	0.	0.	0.	0.	0.
3	0.250	0.	0.	0.	0.	0.
4	0.250	0.	0.	0.	0.	0.
SUM	1.000	0.	0.	0.	0.	0.000

(Continued)

(Sheet 2 of 7)

Table 15 (Continued)

***** LOADING CONDITION 2 *****

4. MATRIX OF APPLIED LOADS Q (KIPS & FEET)

Q1	Q2	Q3	Q4	Q5	Q6
0.	1.000	0.	0.	0.	0.

5. STRUCTURE DEFLECTIONS (INCHES)

D1	D2	D3	D4	D5	D6
0.	0.231E-01	0.	0.	0.	0.

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1	X2	X3	X4	X5	X6
1	0.	0.231E-01	0.	0.	0.	0.
2	0.	0.231E-01	0.	0.	0.	0.
3	0.	0.231E-01	0.	0.	0.	0.
4	0.	0.231E-01	0.	0.	0.	0.

7. PILE FORCES ALONG PILE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6	CBFTR	FAILURE
								CB BU CO TE
1	0.	0.250	0.	0.	0.	0.	0.	
2	0.	0.250	0.	0.	0.	0.	0.	
3	0.	0.250	0.	0.	0.	0.	0.	
4	0.	0.250	0.	0.	0.	0.	0.	

TOTAL NO. FAILURES = 0 LOAD CASE 2

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6
1	0.	0.250	0.	0.	0.	0.
2	0.	0.250	0.	0.	0.	0.
3	0.	0.250	0.	0.	0.	0.
4	0.	0.250	0.	0.	0.	0.
SUM	0.	1.000	0.	0.	0.	0.000

(Continued)

(Sheet 3 of 7)

Table 15 (Continued)

***** LOADING CONDITION 3 *****

4. MATRIX OF APPLIED LOADS Q (KIPS & FEET)

Q1	Q2	Q3	Q4	Q5	Q6
0.	0.	1.000	0.	0.	0.

5. STRUCTURE DEFLECTIONS (INCHES)

D1	D2	D3	D4	D5	D6
0.	0.	0.700E-03	0.	0.	0.

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1	X2	X3	X4	X5	X6
1	0.	0.	0.700E-03	0.	0.	0.
2	0.	0.	0.700E-03	0.	0.	0.
3	0.	0.	0.700E-03	0.	0.	0.
4	0.	0.	0.700E-03	0.	0.	0.

7. PILE FORCES ALONG PILE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6	CBFTR	FAILURE
							CB	BU CO TE
1	0.	0.	0.250	0.	0.	0.	0.00	
2	0.	0.	0.250	0.	0.	0.	0.00	
3	0.	0.	0.250	0.	0.	0.	0.00	
4	0.	0.	0.250	0.	0.	0.	0.00	

TOTAL NO. FAILURES = 0 LOAD CASE 3

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6
1	0.	0.	0.250	0.	0.	0.
2	0.	0.	0.250	0.	0.	0.
3	0.	0.	0.250	0.	0.	0.
4	0.	0.	0.250	0.	0.	0.
SUM	0.	0.	1.000	-0.000	-0.000	0.

(Continued)

(Sheet 4 of 7)

Table 15 (Continued)

***** LOADING CONDITION 4 *****

4. MATRIX OF APPLIED LOADS Q (KIPS & FEET)

Q1	Q2	Q3	Q4	Q5	Q6
0.	0.	0.	1.000	0.	0.

5. STRUCTURE DEFLECTIONS (INCHES)

D1	D2	D3	D4	D5	D6
0.	0.	0.	0.583E-04	0.	0.

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1	X2	X3	X4	X5	X6
1	0.	0.	0.700E-03	0.583E-04	0.	0.
2	0.	0.	-0.700E-03	0.583E-04	0.	0.
3	0.	0.	-0.700E-03	0.583E-04	0.	0.
4	0.	0.	0.700E-03	0.583E-04	0.	0.

7. PILE FORCES ALONG PILE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6	CBFTR	FAILURE
								CP BJ CO TE
1	0.	0.	0.250	0.	0.	0.	0.00	
2	0.	0.	-0.250	0.	0.	0.	0.00	
3	0.	0.	-0.250	0.	0.	0.	0.00	
4	0.	0.	0.250	0.	0.	0.	0.00	

TOTAL NO. FAILURES = 0 LOAD CASE 4

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6
1	0.	0.	0.250	0.	0.	0.
2	0.	0.	-0.250	0.	0.	0.
3	0.	0.	-0.250	0.	0.	0.
4	0.	0.	0.250	0.	0.	0.
SUM	0.	0.	-0.000	1.000	-0.000	0.

(Continued)

(Sheet 5 of 7)

Table 15 (Continued)

***** LOADING CONDITION 5 *****

4. MATRIX OF APPLIED LOADS Q (KIPS & FEET)

Q1	Q2	Q3	Q4	Q5	Q6
0.	0.	0.	0.	1.000	0.

5. STRUCTURE DEFLECTIONS (INCHES)

D1	D2	D3	D4	D5	D6
0.	0.	0.	0.	0.583E-04	0.

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1	X2	X3	X4	X5	X6
1	0.	0.	-0.700E-03	0.	0.583E-04	0.
2	0.	0.	-0.700E-03	0.	0.583E-04	0.
3	0.	0.	0.700E-03	0.	0.583E-04	0.
4	0.	0.	0.700E-03	0.	0.583E-04	0.

7. PILE FORCES ALONG PILE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6	CBFTR	FAILURE
		0						CB BU CO TE
1	0.	0.	-0.250	0.	0.	0.	0.00	
2	0.	0.	-0.250	0.	0.	0.	0.00	
3	0.	0.	0.250	0.	0.	0.	0.00	
4	0.	0.	0.250	0.	0.	0.	0.00	

TOTAL NO. FAILURES = 0 LOAD CASE 5

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6
1	0.	0.	-0.250	0.	0.	0.
2	0.	0.	-0.250	0.	0.	0.
3	0.	0.	0.250	0.	0.	0.
4	0.	0.	0.250	0.	0.	0.
SUM	0.	0.	-0.000	-0.000	1.000	0.

(Continued)

(Sheet 6 of 7)

Table 15 (Concluded)

***** LOADING CONDITION 6 *****

4. MATRIX OF APPLIED LOADS Q (KIPS & FEET)

Q1	Q2	Q3	Q4	Q5	Q6
1.000	1.000	1.000	1.000	1.000	0.

5. STRUCTURE DEFLECTIONS (INCHES)

D1	D2	D3	D4	D5	D6
0.231E-01	0.231E-01	0.700E-03	0.583E-04	0.583E-04	0.

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1	X2	X3	X4	X5	X6
1	0.231E-01	0.231E-01	0.700E-03	0.583E-04	0.583E-04	0.
2	0.231E-01	0.231E-01	-0.700E-03	0.583E-04	0.583E-04	0.
3	0.231E-01	0.231E-01	0.700E-03	0.583E-04	0.583E-04	0.
4	0.231E-01	0.231E-01	0.210E-02	0.583E-04	0.583E-04	0.

7. PILE FORCES ALONG PILE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6	CBFTR	FAILURE
								CB BU CO TE
1	0.250	0.250	0.250	0.	0.	0.	0.20	
2	0.250	0.250	-0.250	0.	0.	0.	0.00	
3	0.250	0.250	0.250	0.	0.	0.	0.20	
4	0.250	0.250	0.750	0.	0.	0.	0.01	

TOTAL NO. FAILURES = 0 LOAD CASE 6

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6
1	0.250	0.250	0.250	0.	0.	0.
2	0.250	0.250	-0.250	0.	0.	0.
3	0.250	0.250	0.250	0.	0.	0.
4	0.250	0.250	0.750	0.	0.	0.
SUM	1.000	1.000	1.000	1.000	1.000	0.000

(Sheet 7 of 7)

Results and calculations

82. The pile forces can be calculated by satisfying equilibrium $\Sigma F = 0$. These were found to agree with the program output shown in Table 15. For example, in loading case 3 with a 1-kip vertical load, the force in each pile is 0.25 kip. The force on each pile is

$$F_H = 1/4 \text{ (applied vertical load)} = 1/4 \text{ (1 kip)} = 0.25 \text{ kip}$$

The displacement in each pile is equal to

$$\delta = \frac{PL}{AE} = \frac{\frac{1}{4} \times 1 \times 100 \times 12}{4300 \times 144 \times \frac{100}{144}} = 0.7 \times 10^{-3} \text{ in.}$$

This result also agrees with the computer program results.

83. In loading case 4, a 1 kip-ft moment is applied about the U_1 -axis. The pile forces can be calculated by satisfying equilibrium $M_{U_1} = 0$.

$$\Sigma M_{U_1} = F_{3_1} U_1(1) - F_{3_2} U_1(2) - F_{3_3} U_1(2) + F_{3_4} U_1(1) + Q_4$$

where

F_{3_n} = vertical force in pile n , $n = 1 - 4$

Q_4 = applied moment = 1 kip-ft

U_1 = horizontal distance along the U_1 -axis

$$U_1(1) = 1.0 \text{ ft}$$

$$U_1(2) = 1.0 \text{ ft}$$

$$\therefore \Sigma M_{U_1} = F_{3_1} - F_{3_2} - F_{3_3} + F_{3_4} + 1.0 = 0$$

From symmetry $F_{3_1} = F_{3_4}$ and $F_{3_2} = F_{3_3}$

$$\therefore |F_{3_n}| = 0.25 \text{ kip}$$

This result agrees with the computer output.

84. Load case 6 can be obtained as a superposition of load cases 1 through 5. The deflections of the piles and the load on each pile can also be obtained by superimposing the respective results for load cases 1 through 5. The following computations verify the computer results in item 6 (deflections) and item 8 (loads).

File No.	Load Case	Deflections				
		X_1 (in.)	X_2 (in.)	X_3 (in.)	X_4 (rad)	X_5 (rad)
1	1	0.0231	0.	0.	0.	0.
	2	0.	0.0231	0.	0.	0.
	3	0.	0.	0.7×10^{-3}	0.	0.
	4	0.	0.	0.7×10^{-3}	0.583×10^{-4}	0.
	5	0.	0.	-0.7×10^{-3}	0.	0.583×10^{-4}
	6	0.0231	0.0231	0.7×10^{-3}	0.583×10^{-4}	0.583×10^{-4}
2	1	0.0231	0.	0.	0.	0.
	2	0.	0.0231	0.	0.	0.
	3	0.	0.	0.7×10^{-3}	0.	0.
	4	0.	0.	-0.7×10^{-3}	0.583×10^{-4}	0.
	5	0.	0.	-0.7×10^{-3}	0.	0.583×10^{-4}
	6	0.0231	0.0231	-0.7×10^{-3}	0.583×10^{-4}	0.583×10^{-4}
3	1	0.0231	0.	0.	0.	0.
	2	0.	0.0231	0.	0.	0.
	3	0.	0.	0.7×10^{-3}	0.	0.
	4	0.	0.	-0.7×10^{-3}	0.583×10^{-4}	0.
	5	0.	0.	0.7×10^{-3}	0.	0.583×10^{-4}
	6	0.0231	0.0231	0.7×10^{-3}	0.583×10^{-4}	0.583×10^{-4}
4	1	0.0231	0.	0.	0.	0.
	2	0.	0.0231	0.	0.	0.
	3	0.	0.	0.7×10^{-3}	0.	0.
	4	0.	0.	0.7×10^{-3}	0.583×10^{-4}	0.
	5	0.	0.	0.7×10^{-3}	0.	0.583×10^{-4}
	6	0.0231	0.0231	0.21×10^{-2}	0.583×10^{-4}	0.583×10^{-4}

(Continued)

Pile No.	Load Case	Loads				
		F ₁ (kips)	F ₂ (kips)	F ₃ (kips)	F ₄ (kip-ft)	F ₅ (kip-ft)
1	1	0.25	0.	0.	0.	0.
	2	0.	0.25	0.	0.	0.
	3	0.	0.	0.25	0.	0.
	4	0.	0.	0.25	0.	0.
	5	<u>0.</u>	<u>0.</u>	<u>-0.25</u>	<u>0.</u>	<u>0.</u>
	6	0.25	0.25	0.25	0.	0.
2	1	0.25	0.	0.	0.	0.
	2	0.	0.25	0.	0.	0.
	3	0.	0.	0.25	0.	0.
	4	0.	0.	-0.25	0.	0.
	5	<u>0.</u>	<u>0.</u>	<u>-0.25</u>	<u>0.</u>	<u>0.</u>
	6	0.25	0.25	-0.25	0.	0.
3	1	0.25	0.	0.	0.	0.
	2	0.	0.25	0.	0.	0.
	3	0.	0.	0.25	0.	0.
	4	0.	0.	-0.25	0.	0.
	5	<u>0.</u>	<u>0.</u>	<u>0.25</u>	<u>0.</u>	<u>0.</u>
	6	0.25	0.25	0.25	0.	0.
4	1	0.25	0.	0.	0.	0.
	2	0.	0.25	0.	0.	0.
	3	0.	0.	0.25	0.	0.
	4	0.	0.	0.25	0.	0.
	5	<u>0.</u>	<u>0.</u>	<u>0.25</u>	<u>0.</u>	<u>0.</u>
	6	0.25	0.25	0.75	0.	0.

These results also agree with the computer program results.

Example Problem 8

Three-dimensional problem, 1 fixed vertical pile

85. This example problem has only one vertical pile completely fixed into the rigid cap. It is similar to example 2 except the analysis now is three-dimensional. Figure 19 shows the physical problem. A 1 kip-ft moment is applied about the U_1 , U_2 , and U_3 axes. Figure 20 shows the loading conditions and properties. The input data are stored in a file prior to running the program and are presented in Table 16. The computer output is presented in Table 17.

86. This example serves as a means to verify the computer output by comparison with manual calculations.

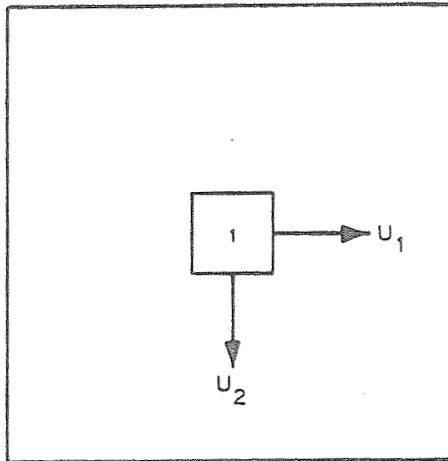


Figure 19. Plan view for example problem 8

Results and calculations

87. In this example, 1 kip-ft moments about the U_1 , U_2 , and U_3 axes were applied at the center of the structure where the pile is located. The pile is completely fixed into the rigid cap. Therefore, the resulting moments about the U_1 , U_2 , and U_3 axes are 1 kip-ft. These results agree with the program output presented in Table 17.

Properties	
Ult. str. of concrete = 5000 psi	$K_1 = 1.0756$
KS = 10.000 pci	$K_2 = 1.0$
$I_1 = 833.333 \text{ in.}^4$	$K_3 = 1.4988$
$I_2 = 833.333 \text{ in.}^4$	$K_4 = 1.000$
Area = 100.0 in. ²	$K_5 = 0.9990$
Length = 100.0 ft	$K_6 = 0.9990$
Vertical = (h = 0.0)	

Loading Case	Q_1 (kips)	Q_2 (kips)	Q_3 (kips)	Q_4 (kip-ft)	Q_5 (kip-ft)	Q_6 (kip-ft)
1	0.0	0.0	0.0	1.0	1.0	1.0

Figure 20. Properties and loading conditions for example problem 8

Table 16
Input Data for Example Problem 8

Group									
1A	12020	EXAMPLE PROBLEM NO. 8							
1B	12010	ONE FIXED VERTICAL PILE WITH UNIT MOMENTS APPLIED							
2A	12020	3							
2B	12030	1	1	1					
3	12040	2	10.000						
4A	12050	1	1	120.200	2				
4C	12060	333.333	333.333	120.000	12.000	12.000			
5A	12070	1							
5B	12080	5200.000	150.200						
6A	12090	1							
6B	12100	1.200	1.2756	1.000	1.4938	1.200	2.999	2.999	
7	12110	120.20	120.20	100.00	100.20	120.00	120.20	120.00	120.20
8A	12120	2							
10	12130	2.	2.	2.	2.	2.			
11	12140	2.	2.	2.	2.	1.200	1.200	1.200	

ready

*

Table 17
Output Data for Example Problem 8

EXAMPLE PROBLEM NO. 8
ONE FIXED VERTICAL PILE WITH UNIT MOMENTS APPLIED

NO. OF FILES = 1 B MATRIX IS CALCULATED FOR EACH PILE

1. TABLE OF PILE AND SOIL DATA

PILE NUMBERS

1 1 E = 2.43E 27 PSI IX = 833.33 IN**4 IY = 833.33 IN**4
AREA = 122.0 IN**2 X = 12.00 IN Y = 12.00 IN
LENGTH = 122.0 FEET ES = 12.222
K1 = 1.2756 K2 = 1.2222 K3 = 1.4958
K4 = 1.2222 K5 = 2.2222 K6 = 2.2222

ALLOWABLES: COMBINED BENDING FOR TENSION = 122.222 KIPS
MOMENT ABOUT MINOR AXIS FOR TENSION = 122.222 KIP-FT
MOMENT ABOUT MAJOR AXIS FOR TENSION = 122.222 KIP-FT
COMBINED BENDING FOR COMPRESSION = 122.222 KIPS
MOMENT ABOUT MINOR AXIS FOR COMPRESSION = 122.222 KIP-FT
MOMENT ABOUT MAJOR AXIS FOR COMPRESSION = 122.222 KIP-FT
COMPRESSIVE LOAD = 122.222 KIPS
TENSILE LOAD = 122.222 KIPS

THE B MATRIX FOR PILES 1 THROUGH 1 IS

2.254E 25	2.	2.	2.	2.135E 27	2.
2.	2.254E 25	0.	-2.135E 27	2.	2.
2.	2.	2.357E 26	2.	2.	2.
2.	-2.135E 27	2.	2.124E 29	2.	2.
2.135E 27	2.	2.	2.	2.124E 29	2.
2.	2.	2.	2.	2.	2.122E 24

2. TABLE OF PILE COORDINATES AND BATTER

PILE NO.	BATTER	ANGLE	U1(FT)	U2(FT)	U3(FT)
1	VERTICAL	2.	2.	0.	2.

3. STIFFNESS MATRIX S FOR THE STRUCTURE

2.254E 25	2.	2.	2.	2.135E 27	2.
2.	2.254E 25	2.	-2.135E 27	2.	2.
2.	2.	2.357E 26	2.	2.	2.
2.	-2.135E 27	2.	2.124E 29	2.	2.
2.135E 27	2.	2.	2.	2.124E 29	2.
2.	2.	2.	2.	2.	2.122E 24

3A FLEXIBILITY MATRIX F FOR THE STRUCTURE

3.925E-24	2.	2.	2.	-2.122E-25	2.
2.	3.925E-24	2.	2.122E-25	2.	2.
2.	2.	2.252E-25	2.	2.	2.
2.	2.122E-25	2.	2.252E-27	2.	2.
-2.122E-25	2.	2.	2.	2.252E-27	2.
2.	2.	2.	2.	2.	2.122E-22

(Continued)

Table 17 (Concluded)

***** LOADING CONDITION 1 *****

4. MATRIX OF APPLIED LOADS Q (KIPS & FEET)

D1	D2	D3	D4	D5	D6
0.	0.	0.	1.000	1.000	1.000

5. STRUCTURE DEFLECTIONS (INCHES)

D1	D2	D3	D4	D5	D6
-2.144E-21	0.144E-21	0.	2.302E-23	0.302E-23	0.120E-22

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1	X2	X3	X4	X5	X6
1	-2.144E-21	0.144E-21	0.	2.302E-23	0.302E-23	0.120E-22

7. PILE FORCES ALONG PILE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6	CEFR	FAILURE
1	0.000	-0.000	0.	1.000	1.000	1.000	0.22	CB BU CO TE

TOTAL NO. FAILURES = 0 LOAD CASE 1

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

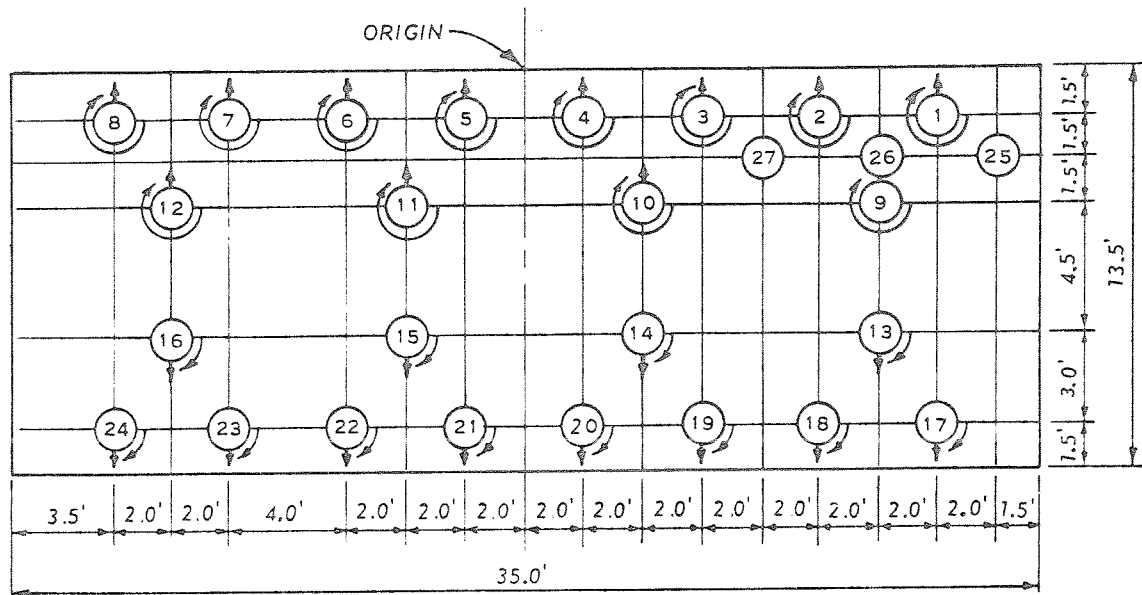
PILE	F1	F2	F3	F4	F5	F6
1	0.000	-0.000	0.	1.000	1.000	1.000
SUM	0.000	-0.000	0.	1.000	1.000	1.000

Example Problem 9

Three-dimensional
problem, 27 piles
with constant soil modulus

88. To demonstrate further the use of program LMVDPFILE an example problem with a constant soil modulus is given. Figure 21 shows the physical problem for this example. The properties and loading conditions are presented in Figure 22. The input data are input interactively and are shown in Table 18. These data are saved in a file and are listed in Table 19. The computer output is presented in Table 20.

89. This example illustrates the option of inputting data interactively for a three-dimensional problem with 27 piles (vertical and battered) and a constant soil modulus. It also shows how the batter can be input in groups.



NOTE: PILINGS NUMBERED 1-12 ROTATE
AT 270° IN DIRECTION SHOWN.

PILINGS NUMBERED 13-24 ROTATE
AT 90° IN DIRECTION SHOWN.

Figure 21. Physical problem for example
problem 9

Properties	
Ult. str. of concrete = 5000 psi	$K_1 = 0.4107$
ES = 200.0 psi	$K_2 = 1.0$
$I_1 = 1728.0 \text{ in.}^4$	DF = 0.0
$I_2 = 1728.0 \text{ in.}^4$	PR = 1.0
Area = 144.0 in. ²	PFT = 0.0
Length = 70.0 ft	G = 0.0
	$K_3-K_6 = 0.0$

Loading Case	Q_1 (kips)	Q_2 (kips)	Q_3 (kips)	Q_4 (kip-ft)	Q_5 (kip-ft)	Q_6 (kip-ft)
1	0.0	276.961	344.9	5287.422	0.0	0.0

Figure 22. Properties and loading conditions for example problem 9

Results and calculations

90. The program output is shown in Table 20. From statics,
 $\Sigma F = 0$.

$$\Sigma F_1 = Q_1$$

where

F_1 = horizontal pile forces along the structure axis (kips)

Q_1 = applied horizontal load in the U_1 direction (kips)

$$\Sigma F_1 = 8(-0.015) + 4(0.006) + 4(0.008) + 8(0.018) + 3(-0.0011) = 0$$

Similarly

$$\Sigma F_2 = Q_2$$

Table 18
Interactively Input Data for Example Problem 9

INPUT DATA FILE NAME IN 8 CHARACTERS OR LESS. HIT A
CARRIAGE RETURN IF INPUT DATA WILL COME FROM TERMINAL.
?

INPUT A FILE NAME FOR DATA. HIT A CARRIAGE RETURN
IF YOU DO NOT WANT TO SAVE DATA FILE.
? DEBS

INPUT TWO LINES OF PROJECT IDENTIFICATION NOT
TO EXCEED 66 CHARACTERS EACH

INPUT FIRST LINE
? EXAMPLT PROCELFM NO. 9
INPUT SECOND LINE
? ACC EXAMPLT PROBLEM - CONSTANT SOIL MODULUS

DO YOU WANT TO RUN A 2-D OR 3-D ANALYSIS?
ENTER 2 OR 3 ? 3

INPUT NUMBER OF PILLS, PILE GROUPS, AND LOADING CONDITIONS
? 27,1,1

INPUT SOIL PROPERTY DATA - MV AND FS:
MV=1=CONSTANT SOIL OR MV=2=LINEARLY VARYING SOIL
FS=SUBGRADE MODULUS (PSI IF MV=1 OR PCF IF MV=2)
? 1,222.2

DATA FOR PILE GROUP NO. - 1

INPUT PILE SHAPE DATA:
NPA=IDENTIFICATION NUMBER OF FIRST PILE IN GROUP
NPB=IDENTIFICATION NUMBER OF LAST PILE IN GROUP
SLEN=LENGTH OF PILE (FEET)
NPS=CODE FOR TYPE OF INPUT TO COMPUTE ELASTIC PILE CONSTANTS
1=INPUT PILE B MATRIX TERMS DIRECTLY
2=ANY SHAPE PILE
3=ROUND PILE
? 1,27,72.2,2

INPUT AIX & AIY-MOMENTS OF INERTIA (IN**4)
APFA - CROSS SECTIONAL AREA (IN**2)
X & Y - PILE DIMENSIONS ALONG X & Y AXES (INCHES)
? 1726.2,1726.2,144.2,12.2,12.2

INPUT PILE MATERIAL DATA-MP (1=CONCRETE, 2=TIMBER, 3=STEEL, 4=SOIL)
? 1

INPUT US=ULTIMATE STRENGTH OF CONCRETE (PSI)
W=WEIGHT OF CONCRETE (PCF)
? 5222.2,152.2

INPUT FIXITY DATA - NF (1=INPUT ALL FIXITY COEFFICIENTS
OR 2=INPUT DEGREE OF FIXITY
? 2

INPUT DF - DEGREE OF FIXITY (2.0,2.5,1.0)
PF - PILE RESISTANCE (1=PEARLING OR 2.5=EFFICIENCY)
PFT - PARTICIPATION FACTOR FOR TORSION
G - TORSION MODULUS (PSI)
? 2.2,1.2,2.2,2.2

(Continued)

Table 18 (Concluded)

```

INPUT ALLOWABLE LOADS AND MOMENTS:
ACBT=ALLOWABLE AXIAL LOAD USED IN COMBINED BENDING
      FOR PILE IN TENSION (KIPS)
AMINT=ALLOWABLE MOMENT ABOUT MINOR PRINCIPLE AXIS
      FOR PILE IN TENSION (KIP-FT)
AMAJT=ALLOWABLE MOMENT ABOUT MAJOR PRINCIPLE AXIS
      FOR PILE IN TENSION (KIP-FT)
ACBC=ALLOWABLE AXIAL LOAD USED IN COMBINED BENDING
      FOR PILE IN COMPRESSION (KIPS)
AMINC=ALLOWABLE MOMENT ABOUT MINOR PRINCIPLE AXIS
      FOR PILE IN COMPRESSION (KIP-FT)
AMAJC=ALLOWABLE MOMENT ABOUT MAJOR PRINCIPLE AXIS
      FOR PILE IN COMPRESSION (KIP-FT)
ACL=ALLOWABLE COMPRESSIVE LOAD (KIPS)
ATL=ALLOWABLE TENSILE LOAD (KIPS)
? 1000.0,1000.0,1000.0,1000.0,1000.0,1000.0,1000.0,1000.0

INPUT IB: IB=INPUT BATTER FOR EACH PILE OR
      THE NUMBER OF SUBGROUPS WITH THE SAME BATTER
? 3

INPUT NFP-NO. OF FIRST PILE NLP-NO. OF LAST PILE
BATT=BATTER=BATT VERTICAL OR 1 HORIZONTAL
ANG=CLOCKWISE ANGLE BETWEEN POSITIVE Y-AXIS OF THE
      STRUCTURE AND X-AXIS (DIRECTION OF BATTER) OF PILE (DEG)

FOR PILE SUBGROUP - 1 ? 1,12,3,270
FOR PILE SUBGROUP - 2 ? 13,24,3,90
FOR PILE SUBGROUP - 3 ? 25,27,2,0

THIS PROGRAM GENERATES THE FOLLOWING TABLES:

TABLE NO.      CONTENTS
1              FILE AND SOIL DATA
2              PILE COORDINATES AND BATTER
3              STIFFNESS AND FLEXIBILITY MATRICES FOR THE
              STRUCTURE AND COORDINATES OF ELASTIC CENTER
4              APPLIED LOADS
5              STRUCTURE DEFLECTIONS
6              PILE DEFLECTIONS ALONG PILE AXIS
7              PILE FORCES ALONG PILE AXIS
8              PILE FORCES ALONG STRUCTURE AXIS

INPUT THE NUMBERS OF THE TABLES FOR WHICH YOU WANT THE OUTPUT.
SEPARATE THE NUMBERS WITH COMMAS. ? 1,2,3,4,5,6,7,8

INPUT A FILENAME FOR TABLE 8 IN 8 CHARACTERS OR LESS
IF YOU WANT TO USE THIS INFORMATION FOR A NEW RUN
HIT A CARRIAGE RETURN IF YOU DO NOT WANT THIS FILE.
?

INPUT A FILE NAME FOR OUTPUT IN 8 CHARACTERS OR LESS.
HIT A CARRIAGE RETURN IF OUTPUT IS TO BE PRINTED ON TERMINAL.
?

INPUT U1'S - DISTANCES FOR ORIGIN TO PILE
      ALONG U1 AXIS
? 14,10,6,2,-2,-6,-10,-14,12,4,-4,-12,12,4,-4,-12,14,10,6,2.
? -2,-6,-10,-14,16,12,8

INPUT U2'S - DISTANCES FROM ORIGIN TO PILE
      ALONG U2 AXIS
? 8*1.5,4*4.5,4*9.0,8*12.0,3*3.0

INPUT U3'S - DISTANCES FROM ORIGIN TO PILE
      ALONG U3 AXIS
? 27*0.2

INPUT APPLIED LOADS AND MOMENTS:
Q1 & Q2 - HORIZONTAL LOADS ALONG U1 & U2 AXES (KIPS)
Q3 - VERTICAL LOAD ALONG U3 AXIS (KIPS)
Q4,Q5,Q6 - MOMENTS ABOUT U1,U2,U3 AXES (KIP-FT)

FOR LOADING CONDITION - 1 ? 0.0 270.001,314.9 220.002 0.0 0.

```

Table 19
Input Data for Example Problem 9

Group										
1A	10000 EXAMPLE PROBLEM NO. 9									
1B	10010 NOD EXAMPLE PROBLEM - CONSTANT SOIL MODULUS									
2A	10020	3								
2B	10030	27	1	1						
3	10040	1	200.000							
4A	10050	1	27	70.000	2					
4C	10060	1728.000	1728.000	144.00	12.000	12.000				
5A	10070	1								
5B	10080	5000.000	150.000							
6A	10090	2								
6C	10100	0.	1.200	0.	0.					
7	10110	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00
8A	10120	2								
10	10130	3.00	270.00	14.00	1.50	0.				
	10140	3.00	270.00	10.00	1.50	0.				
	10150	3.00	270.00	6.00	1.50	0.				
	10160	3.00	270.00	2.00	1.50	0.				
	10170	3.00	270.00	-2.00	1.50	0.				
	10180	3.00	270.00	-6.00	1.50	0.				
	10190	3.00	270.00	-10.00	1.50	0.				
	10200	3.00	270.00	-14.00	1.50	0.				
	10210	3.00	270.00	12.00	4.50	0.				
	10220	3.00	270.00	4.00	4.50	0.				
	10230	3.00	270.00	-4.00	4.50	0.				
	10240	3.00	270.00	-12.00	4.50	0.				
	10250	3.00	90.00	12.00	9.00	0.				
	10260	3.00	90.00	4.00	9.00	0.				
	10270	3.00	90.00	-4.00	9.00	0.				
	10280	3.00	90.00	-12.00	9.00	0.				
	10290	3.00	90.00	14.00	12.00	0.				
	10300	3.00	90.00	10.00	12.00	0.				
	10310	3.00	90.00	6.00	12.00	0.				
	10320	3.00	90.00	2.00	12.00	0.				
	10330	3.00	90.00	-2.00	12.00	0.				
	10340	3.00	90.00	-6.00	12.00	0.				
	10350	3.00	90.00	-10.00	12.00	0.				
	10360	3.00	90.00	-14.00	12.00	0.				
	10370	0.	0.	16.00	3.00	0.				
	10380	0.	0.	12.00	3.00	0.				
	10390	0.	0.	8.00	3.00	0.				
11	10400	0.	275.961	344.900	5287.422	0.	0.			

Table 20
Output Data for Example Problem 9

EXAMPLE PROBLEM NO. 9
MOD EXAMPLE PROBLEM - CONSTANT SOIL MODULUS

NO. OF PILES = 27 B MATRIX IS CALCULATED FOR EACH PILE

1. TABLE OF PILE AND SOIL DATA

PILE NUMBERS

1 27 F = 0.43E 47 PSI IX = 1729.00 IN**4 IY = 1728.00 IN**4
 AREA = 144.0 IN**2 X = 12.00 IN Y = 12.00 IN
 LENGTH = 70.0 FEET ES = 200.00E 6
 K1 = 0.4127 K2 = 1.0000 K3 = 0.
 K4 = 0. K5 = 0. K6 = 0.

ALLOWABLES: COMBINED BENDING FOR TENSION = 1000.000 KIPS
 MOMENT ABOUT MINOR AXIS FOR TENSION = 1000.000 KIP-FT
 MOMENT ABOUT MAJOR AXIS FOR TENSION = 1000.000 KIP-FT
 COMBINED BENDING FOR COMPRESSION = 1000.000 KIPS
 MOMENT ABOUT MINOR AXIS FOR COMPRESSION = 1000.000 KIP-FT
 MOMENT ABOUT MAJOR AXIS FOR COMPRESSION = 1000.000 KIP-FT
 COMPRESSIVE LOAD = 1000.000 KIPS
 TENSILE LOAD = 1000.000 KIPS

THE B MATRIX FOR PILES 1 THROUGH 27 IS

0.110E 05	0.	0.	0.	0.	0.
0.	0.110E 05	0.	0.	0.	0.
0.	0.	0.735E 06	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.

2. TABLE OF PILE COORDINATES AND BATTER

PILE NO.	BATTER	ANGLE	U1(FT)	U2(FT)	U3(FT)
1	3.00	270.	14.000	1.500	0.
2	3.00	270.	10.000	1.500	0.
3	3.00	270.	6.000	1.500	0.
4	3.00	270.	2.000	1.500	0.
5	3.00	270.	-2.000	1.500	0.
6	3.00	270.	-6.000	1.500	0.
7	3.00	270.	-10.000	1.500	0.
8	3.00	270.	-14.000	1.500	0.
9	3.00	270.	-18.000	1.500	0.
10	3.00	270.	-14.000	4.500	0.
11	3.00	270.	-10.000	4.500	0.
12	3.00	270.	-6.000	4.500	0.
13	3.00	270.	-2.000	4.500	0.
14	3.00	90.	12.000	9.000	0.
15	3.00	90.	8.000	9.000	0.
16	3.00	90.	4.000	9.000	0.
17	3.00	90.	0.000	9.000	0.
18	3.00	90.	-4.000	9.000	0.
19	3.00	90.	-8.000	9.000	0.
20	3.00	90.	-12.000	9.000	0.
21	3.00	90.	-8.000	12.000	0.
22	3.00	90.	-4.000	12.000	0.
23	3.00	90.	0.000	12.000	0.
24	3.00	90.	4.000	12.000	0.
25	VERTICAL	0.	10.000	3.000	0.
26	VERTICAL	0.	12.000	3.000	0.
27	VERTICAL	0.	8.000	3.000	0.

(Continued)

(Sheet 1 of 3)

Table 20 (Continued)

3. STIFFNESS MATRIX S FOR THE STRUCTURE

```

0.298E 06 -0.549E-22 0.337E-01 0.127E 01 0.931E-09 -0.222E 23
-0.949E-22 0.204E 07 -0.234E-01 0.266E 09 0.150E 01 0.477E 27
0.337E-21 -0.234E-01 0.181E 08 0.137E 10 -0.317E 29 0.521E 20
0.127E 01 0.266E 09 0.137E 10 0.153E 12 -0.114E 11 0.256E 23
0.466E-09 0.520E 02 -0.317E 09 -0.114E 11 0.238E 12 0.641E 23
-0.226E 28 0.477E 27 0. 0.256E 23 0.641E 23 0.271E 11

```

3A FLEXIBILITY MATRIX F FOR THE STRUCTURE

```

0.358E-05 -0.239E-27 -0.986E-08 0.129E-09 -0.695E-11 0.370E-20
-0.239E-27 0.157E-25 0.691E-06 -0.904E-09 0.487E-09 -0.314E-29
-0.986E-08 0.691E-06 0.461E-06 -0.529E-09 0.361E-09 -0.130E-29
0.129E-09 -0.904E-09 -0.529E-09 0.692E-10 -0.373E-11 0.170E-11
-0.695E-11 0.487E-09 0.361E-09 -0.373E-11 0.450E-11 -0.915E-13
0.302E-08 -0.314E-29 -0.130E-09 0.170E-11 -0.915E-13 0.394E-10

```

***** LOADING CONDITION 1 *****

4. MATRIX OF APPLIED LOADS Q (KIPS & FEET)

```

      Q1      Q2      Q3      Q4      Q5      Q6
      0.      276.951  344.902  5287.422  0.      0.

```

5. STRUCTURE DEFLECTIONS (INCHES)

```

      D1      D2      D3      D4      D5      D6
-0.183E-22 0.128E 00 0.148E-21 0.614E-04 0.227E-04 -0.246E-24

```

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

```

PILE  X1      X2      X3      X4      X5      X6
1 -0.122E 00 -0.139E-02 -0.278E-01 -0.139E-04 0.614E-04 -0.702E-24
2 -0.123E 00 -0.139E-02 -0.271E-01 -0.139E-04 0.614E-04 -0.300E-24
3 -0.124E 00 -0.139E-02 -0.264E-01 -0.139E-04 0.614E-04 -0.300E-24
4 -0.126E 00 -0.139E-02 -0.258E-01 -0.139E-04 0.614E-04 -0.300E-24
5 -0.127E 00 -0.139E-02 -0.251E-01 -0.139E-04 0.614E-04 -0.300E-24
6 -0.129E 00 -0.139E-02 -0.244E-01 -0.139E-04 0.614E-04 -0.300E-24
7 -0.132E 00 -0.139E-02 -0.238E-01 -0.139E-04 0.614E-04 -0.300E-24
8 -0.132E 00 -0.139E-02 -0.231E-01 -0.139E-04 0.614E-04 -0.300E-24
9 -0.133E 00 -0.529E-03 -0.253E-01 -0.139E-04 0.614E-04 -0.300E-24
10 -0.126E 00 -0.529E-03 -0.240E-01 -0.139E-04 0.614E-04 -0.300E-24
11 -0.129E 00 -0.529E-03 -0.227E-01 -0.139E-04 0.614E-04 -0.300E-24
12 -0.132E 00 -0.529E-03 -0.213E-01 -0.139E-04 0.614E-04 -0.300E-24
13 0.113E 00 -0.770E-03 0.567E-01 0.291E-04 -0.614E-04 -0.156E-24
14 0.114E 00 -0.770E-03 0.595E-01 0.291E-04 -0.614E-04 -0.156E-24
15 0.116E 00 -0.770E-03 0.623E-01 0.291E-04 -0.614E-04 -0.156E-24
16 0.117E 00 -0.770E-03 0.651E-01 0.291E-04 -0.614E-04 -0.156E-24
17 0.111E 00 -0.164E-02 0.581E-01 0.291E-04 -0.614E-04 -0.156E-24
18 0.112E 00 -0.164E-02 0.595E-01 0.291E-04 -0.614E-04 -0.156E-24
19 0.113E 00 -0.164E-02 0.609E-01 0.291E-04 -0.614E-04 -0.156E-24
20 0.114E 00 -0.164E-02 0.623E-01 0.291E-04 -0.614E-04 -0.156E-24
21 0.114E 00 -0.164E-02 0.637E-01 0.291E-04 -0.614E-04 -0.156E-24
22 0.115E 00 -0.164E-02 0.651E-01 0.291E-04 -0.614E-04 -0.156E-24
23 0.116E 00 -0.164E-02 0.665E-01 0.291E-04 -0.614E-04 -0.156E-24
24 0.117E 00 -0.164E-02 0.679E-01 0.291E-04 -0.614E-04 -0.156E-24
25 -0.962E-23 0.124E 00 0.127E-21 0.614E-04 0.227E-04 -0.240E-24
26 -0.962E-23 0.125E 00 0.138E-21 0.614E-04 0.227E-04 -0.240E-24
27 -0.962E-23 0.126E 00 0.148E-21 0.614E-04 0.227E-04 -0.240E-24

```

(Continued)

(Sheet 2 of 3)

Table 20 (Concluded)

7. PILE FORCES ALONG PILE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6	CBFTR	FAILURE
								CS BJ CC TE
1	-1.341	-0.015	-22.396	0.	0.	0.	0.22	
2	-1.357	-0.015	-19.905	0.	0.	0.	0.22	
3	-1.373	-0.015	-19.415	0.	0.	0.	0.22	
4	-1.389	-0.015	-18.925	0.	0.	0.	0.22	
5	-1.404	-0.015	-18.435	0.	0.	0.	0.22	
6	-1.420	-0.015	-17.944	0.	0.	0.	0.22	
7	-1.436	-0.015	-17.454	0.	0.	0.	0.22	
8	-1.452	-0.015	-16.964	0.	0.	0.	0.22	
9	-1.457	-0.006	-16.509	0.	0.	0.	0.22	
10	-1.388	-0.006	-17.528	0.	0.	0.	0.22	
11	-1.420	-0.006	-16.648	0.	0.	0.	0.22	
12	-1.452	-0.006	-15.667	0.	0.	0.	0.22	
13	1.241	-0.008	41.544	0.	0.	0.	0.24	
14	1.258	-0.008	43.697	0.	0.	0.	0.24	
15	1.274	-0.008	45.751	0.	0.	0.	0.25	
16	1.291	-0.008	47.805	0.	0.	0.	0.25	
17	1.229	-0.018	42.872	0.	0.	0.	0.24	
18	1.238	-0.018	43.699	0.	0.	0.	0.24	
19	1.246	-0.018	44.725	0.	0.	0.	0.24	
20	1.254	-0.018	45.753	0.	0.	0.	0.25	
21	1.263	-0.018	46.782	0.	0.	0.	0.25	
22	1.271	-0.015	47.805	0.	0.	0.	0.25	
23	1.279	-0.018	48.833	0.	0.	0.	0.25	
24	1.287	-0.018	49.860	0.	0.	0.	0.25	
25	-0.011	1.363	9.309	0.	0.	0.	0.21	
26	-0.011	1.375	10.109	0.	0.	0.	0.21	
27	-0.011	1.358	10.909	0.	0.	0.	0.21	

TOTAL NO. FAILURES = 0 LOAD CASE 1

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6
1	-0.015	7.722	-18.925	0.	0.	0.
2	-0.015	7.582	-18.455	0.	0.	0.
3	-0.015	7.442	-17.985	0.	0.	0.
4	-0.015	7.302	-17.515	0.	0.	0.
5	-0.015	7.162	-17.044	0.	0.	0.
6	-0.015	7.022	-16.574	0.	0.	0.
7	-0.015	6.882	-16.104	0.	0.	0.
8	-0.015	6.742	-15.634	0.	0.	0.
9	-0.006	7.172	-17.225	0.	0.	0.
10	-0.006	6.892	-16.285	0.	0.	0.
11	-0.006	6.612	-15.344	0.	0.	0.
12	-0.006	6.332	-14.404	0.	0.	0.
13	0.008	14.347	39.114	0.	0.	0.
14	0.008	15.012	41.057	0.	0.	0.
15	0.008	15.677	43.000	0.	0.	0.
16	0.008	16.342	44.943	0.	0.	0.
17	0.018	14.661	40.094	0.	0.	0.
18	0.018	14.993	41.065	0.	0.	0.
19	0.018	15.326	42.037	0.	0.	0.
20	0.018	15.659	43.008	0.	0.	0.
21	0.018	15.991	43.980	0.	0.	0.
22	0.018	16.323	44.951	0.	0.	0.
23	0.018	16.656	45.923	0.	0.	0.
24	0.018	16.988	46.894	0.	0.	0.
25	-0.011	1.363	9.309	0.	0.	0.
26	-0.011	1.375	10.109	0.	0.	0.
27	-0.011	1.358	10.909	0.	0.	0.
SUM	-0.000	276.961	344.920	5287.422	0.000	-2.220

$$\begin{aligned}
\Sigma F_2 &= 7.722 + 7.582 + 7.442 + 7.302 + 7.162 + 7.022 \\
&\quad + 6.882 + 6.742 + 7.172 + 6.892 + 6.612 + 6.332 \\
&\quad + 14.347 + 15.012 + 15.677 + 16.342 + 14.661 \\
&\quad + 14.993 + 15.326 + 15.658 + 15.991 + 16.323 \\
&\quad + 16.656 + 16.988 + 1.363 + 1.375 + 1.388 \\
\Sigma F_2 &= 277
\end{aligned}$$

and

$$\Sigma F_3 = Q_3$$

$$\begin{aligned}
\Sigma F_3 &= -18.925 - 18.455 - 17.985 - 17.515 - 17.044 \\
&\quad - 16.574 - 16.104 - 15.634 - 17.225 - 16.285 \\
&\quad - 15.344 - 14.404 + 39.114 + 41.057 + 43.0 \\
&\quad + 44.943 + 40.094 + 41.065 + 42.037 + 43.008 \\
&\quad + 43.980 + 44.951 + 45.923 + 46.894 + 9.309 \\
&\quad + 10.109 + 10.909 \\
\Sigma F_3 &= 345
\end{aligned}$$

These results agree closely with the computer results (item 8).

Example Problem 10

Three-dimensional problem, 9 piles and linearly varying soil moduli

91. The tenth example problem illustrating the use of program LMVDPILE has linearly varying soil moduli and is taken from Saul (1968). Figures 23 and 24 show the physical problem. Figure 25 shows the properties and loading conditions. The input data are stored in a data file prior to running the program and are shown in Table 21. The computer output is presented in Table 22. This example illustrates how a three-dimensional problem with linearly varying soil moduli is coded. It also shows how battered piles are coded.

Results and calculations

92. From statics $\Sigma F = 0$. From the program output in Table 22

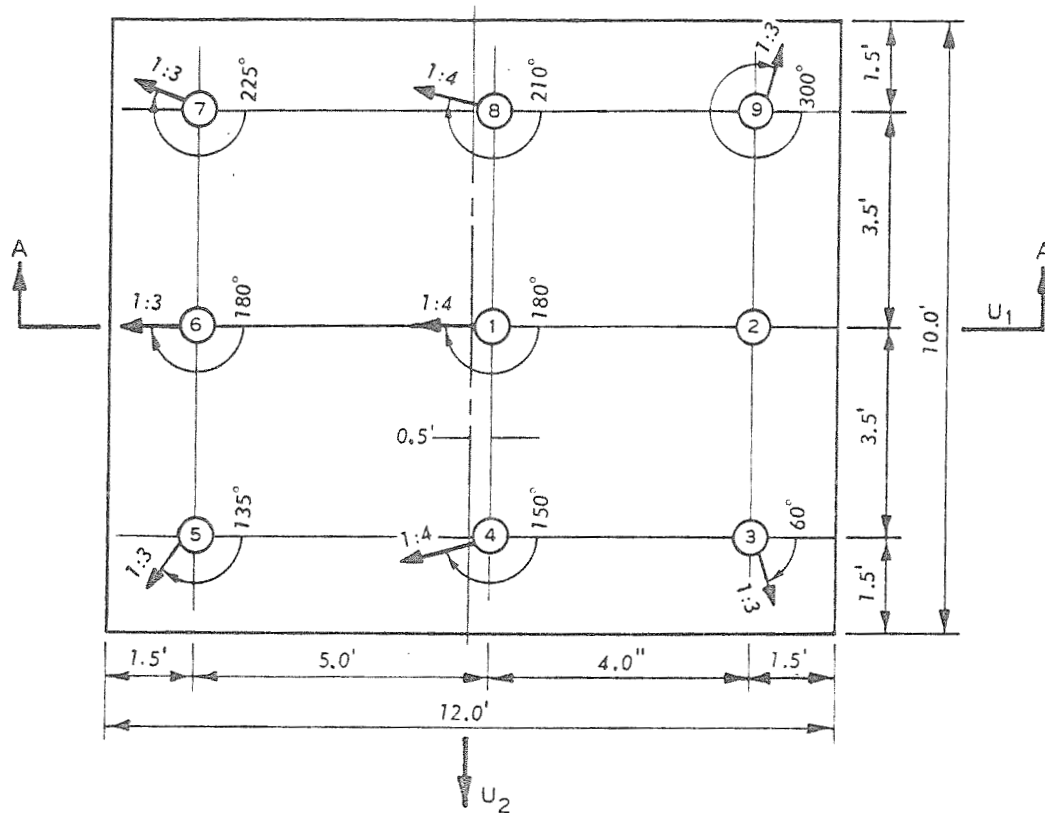


Figure 23. Plan view of example problem 10

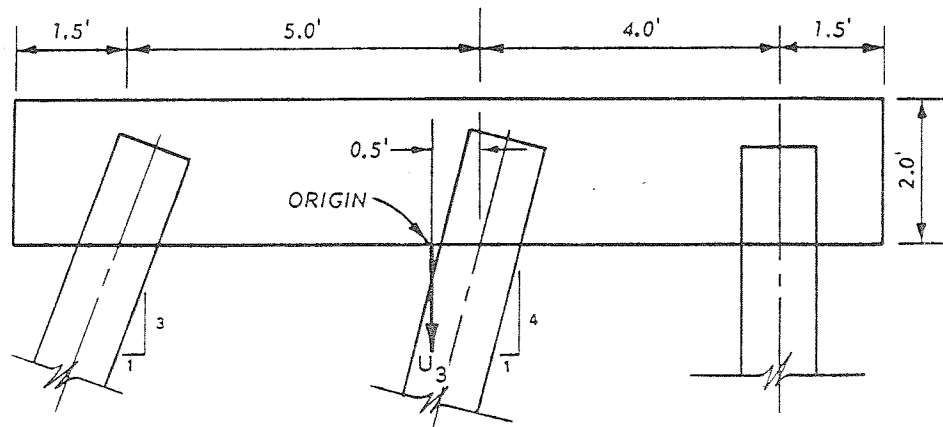


Figure 24. Section A-A for example problem 10

USE: full pile head fixity
piles are, n $\square$

Properties	
$E = 0.3 \times 10^8$ psi	$K_1 = 0.576$
$KS = 100.0$ pci	$K_2 = 2.0$
$I_1 = 211.9$ in. ⁴	$K_3 = 1.043$
$I_2 = 211.9$ in. ⁴	$K_4 = 7063.3$
Area = 16.1 in. ²	$K_5 = 0.544$
Length = 120.0 ft	$K_6 = 0.544$

Loading Case	Q_1 (kips)	Q_2 (kips)	Q_3 (kips)	Q_4 (kip-ft)	Q_5 (kip-ft)	Q_6 (kip-ft)
1	200.0	100.0	1500.0	1000.0	4000.0	416.667

Figure 25. Properties and loading conditions
for example problem 10

Table 21
Input Data for Example Problem 10

Group														
1A	10000	EXAMPLE PROBLEM NO. 10												
1B	10010	SLD CHECK PROBLEM NO. 2 - SAUL												
2A	10020	3												
2B	10030	9	1	1										
3A	10040	2	100.000											
4A	10050	1	9	120.000	2									
4C	10060	211.900	211.900	18.100	1.000	1.000								
5A	10070	4												
5C	10080	30000000.000												
6A	10090	1												
6B	10100	1.000	2.567	2.000	1.043	7063.300	2.544	2.544						
7	10110	500.00	333.33	333.33	500.00	333.33	333.33	500.00	100.00					
8A	10120	2												
10	10130	4.000	150.000	0.500	0.	0.								
	10140	0.	0.	4.500	0.	0.								
	10150	3.000	60.000	4.500	3.500	0.								
	10160	4.000	150.000	0.500	3.500	0.								
	10170	3.000	135.000	-4.500	3.500	0.								
	10180	3.000	150.000	-4.500	0.	0.								
	10190	3.000	225.000	-4.500	-3.500	0.								
	10200	4.000	210.000	0.500	-3.500	0.								
	10210	3.000	300.000	4.500	-3.500	0.								
	10220	200.000	100.000	1500.000	1000.000	4000.000	418.607							

Table 22
Output Data for Example Problem 10

EXAMPLE PROBLEM NO. 10
SLD CHECK PROBLEM NO. 2 - SAUL

NO. OF PILES = 9 P MATRIX IS CALCULATED FOR EACH PILE

1. TABLE OF PILE AND SOIL DATA

PILE NUMBERS

```

1  9  E = 0.30E 08 PSI  IX = 211.90 IN**4  IY = 211.90 IN**4
    AREA = 15.1 IN**2  X = 1.00 IN  Y = 1.00 IN
    LENGTH = 120.0 FEET  ES = 100.000
    K1 = 0.5670 K2 = 2.0000 K3 = 1.0430
    K4 = 7063.3000 K5 = 0.5440 K6 = 0.5440
  
```

```

ALLOWABLES:  COMBINED BENDING FOR TENSION = 500.000 KIPS
              MOMENT ABOUT MINOR AXIS FOR TENSION = 333.330 KIP-FT
              MOMENT ABOUT MAJOR AXIS FOR TENSION = 333.330 KIP-FT
              COMBINED BENDING FOR COMPRESSION = 500.000 KIPS
              MOMENT ABOUT MINOR AXIS FOR COMPRESSION = 333.330 KIP-FT
              MOMENT ABOUT MAJOR AXIS FOR COMPRESSION = 333.330 KIP-FT
              COMPRESSIVE LOAD = 500.000 KIPS
              TENSILE LOAD = 100.000 KIPS
  
```

THE P MATRIX FOR PILES 1 THROUGH 9 IS

```

0.750E 05  0.      0.      0.      0.262E 07  0.
0.      2.750E 05  0.      -0.262E 07  0.      0.
0.      0.      0.671E 06  0.      0.      0.
0.      -0.262E 07  0.      0.182E 09  0.      0.
0.262E 07  0.      0.      0.      0.182E 09  0.
0.      0.      0.      0.      0.      0.706E 07
  
```

2. TABLE OF PILE COORDINATES AND BATTER

PILE NO.	BATTER	ANGLE	U1(FT)	U2(FT)	U3(FT)
1	4.00	180.	0.500	0.	0.
2	VERTICAL	0.	4.500	0.	0.
3	3.00	60.	4.500	3.500	0.
4	4.00	150.	0.500	3.500	0.
5	3.00	135.	-4.500	3.500	0.
6	3.00	180.	-4.500	0.	0.
7	3.00	225.	-4.500	-3.500	0.
8	4.00	210.	0.500	-3.500	0.
9	3.00	300.	4.500	-3.500	0.

3. STIFFNESS MATRIX S FOR THE STRUCTURE

```

0.911E 06  0.732E 03 -0.656E 06  0.313E 00 -0.803E 07  0.625E 01
0.977E 03  0.841E 05  0.195E 02  0.688E 07  0.250E 00  0.177E 07
-0.656E 06  0.391E 02  0.563E 07  0.500E 00 -0.118E 08 -0.375E 00
0.250E 00  0.688E 07  0.500E 00  0.840E 10  0.      0.857E 09
-0.803E 07  0.188E 00 -0.118E 08  0.160E 02  0.120E 11  0.280E 02
0.156E 00  0.177E 07 -0.563E 07  0.857E 09  0.320E 02  0.305E 10
  
```

3A FLEXIBILITY MATRIX P FOR THE STRUCTURE

```

0.120E-05 -0.144E-14  0.137E-06 -0.534E-16  0.878E-09  0.513E-19
-0.158E-14  0.120E-05 -0.604E-15 -0.936E-09 -0.238E-16 -0.432E-09
0.137E-06 -0.975E-15  0.104E-06 -0.188E-16  0.764E-09  0.244E-16
-0.392E-16 -0.936E-09 -0.183E-16  0.123E-09  0.622E-19 -0.341E-10
0.878E-09 -0.172E-16  0.764E-09 -0.116E-18  0.788E-10 -0.667E-18
-0.335E-16 -0.432E-09  0.314E-16 -0.341E-10 -0.828E-18  0.338E-09
  
```

(Continued)

Table 22 (Concluded)

***** LOADING CONDITION 1 *****

4. MATRIX OF APPLIED LOADS Q (KIPS & FEET)

Q1	Q2	Q3	Q4	Q5	Q6
200.000	100.000	1500.000	1000.000	4000.000	416.667

5. STRUCTURE DEFLECTIONS (INCHES)

D1	D2	D3	D4	D5	D6
0.498E 00	0.106E 00	0.330E 00	0.122E-02	0.436E-02	0.124E-02

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1	X2	X3	X4	X5	X6
1	-0.540E 00	-0.114E 00	0.177E 00	-0.148E-02	-0.436E-02	0.900E-03
2	0.480E 00	0.173E 00	0.052E-01	0.122E-02	0.436E-02	0.124E-02
3	0.303E 00	-0.001E 00	0.255E 00	0.376E-02	0.113E-02	0.256E-02
4	-0.190E 00	-0.317E 00	0.267E 00	0.792E-03	-0.438E-02	0.147E-02
5	-0.461E 00	-0.137E 00	0.496E 00	0.172E-02	-0.394E-02	0.188E-02
6	-0.642E 00	-0.395E-01	0.382E 00	-0.154E-02	-0.436E-02	0.789E-03
7	-0.552E 00	0.354E 00	0.358E 00	-0.413E-02	-0.222E-02	-0.722E-04
8	-2.571E 00	0.172E 00	0.118E 00	-0.343E-02	-0.316E-02	0.417E-03
9	0.100E 00	0.554E 00	0.799E-01	-0.130E-02	0.323E-02	0.175E-03

7. PILE FORCES ALONG PILE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6	CBPTR	FAILURE
							CB	BU CO TE
1	-52.443	-4.660	118.577	2.319-185.527	0.533	0.80		
2	48.223	0.821	63.888	-19.266	172.620	0.728	0.70	
3	25.657	-31.588	171.191	120.696	83.134	1.506	0.95	
4	-41.267	-25.815	179.317	81.059-153.219	0.867	1.06	F	
5	-44.890	-29.717	332.913	99.416-160.382	1.104	1.45	F	
6	-59.533	1.274	256.359	-14.844-206.142	0.464	1.18	F	
7	-47.167	17.343	240.492-139.903-153.992	-0.043	1.36	F		
8	-51.049	21.848	79.427	-89.585-172.434	0.245	0.94		
9	15.951	50.443	53.626-172.409	70.896	0.102	0.84		

TOTAL NO. FAILURES = 4 LOAD CASE 1

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6
1	22.118	4.660	127.756	-2.379	185.527	-0.046
2	48.223	0.821	63.888	-19.266	172.620	0.728
3	66.631	52.110	154.292	-14.507	141.141	-36.739
4	9.977	24.049	183.681	8.324	172.116	-18.819
5	-23.322	65.349	330.021	46.470	180.344	-32.391
6	-74.589	-1.074	262.029	13.936	206.142	5.135
7	4.271	-48.549	243.366	-15.023	232.741	44.231
8	37.131	-1.701	89.437	-11.022	102.758	21.965
9	59.731	-2.572	45.833	-20.367	177.068	54.617
SUM	200.000	100.000	1500.000	1000.000	4000.000	416.667

this can be shown. For example, for a 200-kip applied horizontal load in the U_1 direction

$$\Sigma F_1 = Q_1$$

where

F_1 = horizontal pile force along the structure axis

Q_1 = applied horizontal load in the U_1 direction

$$\Sigma F_1 = 22.12 + 48.00 + 66.7 + 9.98 - 23.32 - 24.59 + 4.27 + 37.13 + 59.73$$

$$\Sigma F_1 = 200.0 \text{ kips}$$

Similarly

$$\Sigma F_2 = Q_2$$

where

Q_2 = applied horizontal load in the U_2 direction

$$\Sigma F_2 = 100.0 \text{ kips}$$

$$\Sigma F_3 = Q_3$$

where

F_3 = vertical pile force along the structure axis

Q_3 = applied vertical load in the U_3 direction

$$\Sigma F_3 = 1500.0 \text{ kips}$$

These results agree with the computer program results.

93. Manual calculations for this example are presented in Saul's (1968) paper. The computer results presented in Table 22 agree closely with the classical method results. For example, a comparison of the moments about the U_1 -axis (M_1 's) is shown below:

Pile No.	M_1 from	
	Computer Output (kip-ft)	Saul's Example (kip-ft)
1	2.319	2.31
2	-19.266	-19.25
3	120.696	120.68

(Continued)

Pile No.	F ₄ from	
	Computer Output (kip-ft)	Saul's Example (kip-ft)
4	81.059	81.03
5	99.416	99.38
6	-14.844	-14.85
7	-139.903	-139.88
8	-89.585	-89.58
9	-172.408	-172.36

Example Problem 11

Three-dimensional problem, 60 piles
with linearly varying soil moduli

94. This example problem is a three-dimensional system with 60 piles. The physical problem for this example is shown in Figure 26. The properties and loading conditions are shown in Figure 27. Table 23 shows the data file saved prior to the run. The computer output is presented in Table 24.

95. This example was run to verify that the computer results agree with the St. Louis District's program.

Results and calculations

96. The computer results shown in Table 24 agree closely with those from the St. Louis program output. For example, for pile 1 for load case 1, the pile forces along the structure axis from Table 24 are

$$F_1 = 42.305 \text{ kips}$$

$$F_2 = 0.0 \text{ kips}$$

$$F_3 = 120.806 \text{ kips}$$

$$F_4 = 0 \text{ kip-ft}$$

$$F_5 = 0 \text{ kip-ft}$$

$$F_6 = 0 \text{ kip-ft}$$

The St. Louis program produced

$$F_1 = 42.3 \text{ kips}$$

$$F_2 = 0.0 \text{ kips}$$

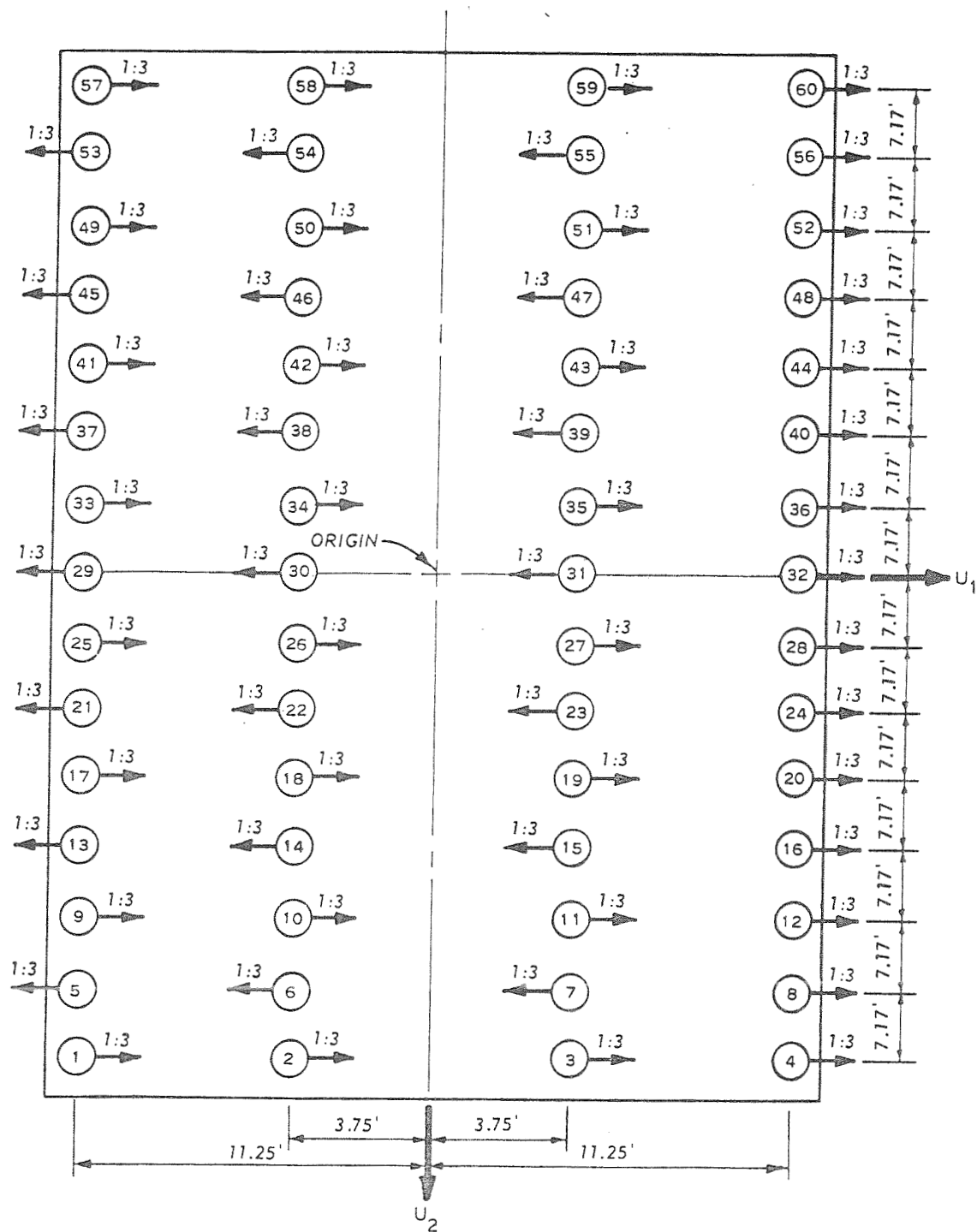


Figure 26. Physical problem for example problem 11

Properties	
$E = 0.3 \times 10^7$ psi	$K_1 = 0.411$
$KS = 2.000$ pci	$K_2 = 0.5$
$I_1 = 5461.333$ in. ⁴	$K_3-K_6 = 0.0$
$I_2 = 5461.333$ in. ⁴	
Area = 256.000 in. ²	
Length = 60.0 ft	

Loading Case	Q_1 (kips)	Q_2 (kips)	Q_3 (kips)	Q_4 (kip-ft)	Q_5 (kip-ft)	Q_6 (kip-ft)
1	1207.5	0.0	3113.25	0.0	4825.5875	0.0
2	1454.25	0.0	1683.15	0.0	-2743.5342	0.0
3	1825.95	0.0	875.5	0.0	-5779.62	0.0

Figure 27. Properties and loading conditions for example problem 11

$$F_3 = 120.8 \text{ kips}$$

$$F_4 = 0.0 \text{ kip-ft}$$

$$F_5 = 0.0 \text{ kip-ft}$$

$$F_6 = 0.0 \text{ kip-ft}$$

These results agree very closely.

Table 23
Input Data for Example Problem 11

Group 100000 EXAMPLE PROBLEM NO. 11									
1A	10010	TECHN-VERMILION OUTLET STRUCTURE 7.17 FT SPACING							
2A	10020	3							
2B	10030	60	1	3					
3	10040	2	2.000						
4A	10050	1	60	50	2				
4C	10060	5461.333	5461.333	256.000	16.000	16.000			
5A	10070	4							
5C	10080	300000.000							
6A	10090	1							
6B	10100	0.	0.411	0.500	0.			0.	0.
7	10110	268.80	59.70	59.70	268.80	59.70	59.70	150.00	100.00
8A	10120	0							
10	10130	3.000	0.	-11.250	50.170	0.			
	10140	3.000	0.	-3.750	50.170	0.			
	10150	3.000	0.	3.750	50.170	0.			
	10160	3.000	0.	11.250	50.170	0.			
	10170	3.000	180.000	-11.250	43.000	0.			
	10180	3.000	180.000	-3.750	43.000	0.			
	10190	3.000	180.000	3.750	43.000	0.			
	10200	3.000	0.	11.250	43.000	0.			
	10210	3.000	0.	-11.250	35.833	0.			
	10220	3.000	0.	-3.750	35.833	0.			
	10230	3.000	0.	3.750	35.833	0.			
	10240	3.000	0.	11.250	35.833	0.			
	10250	3.000	180.000	-11.250	28.667	0.			
	10260	3.000	180.000	-3.750	28.667	0.			
	10270	3.000	180.000	3.750	28.667	0.			
	10280	3.000	0.	11.250	28.667	0.			
	10290	3.000	0.	-11.250	21.500	0.			
	10300	3.000	0.	-3.750	21.500	0.			
	10310	3.000	0.	3.750	21.500	0.			
	10320	3.000	0.	11.250	21.500	0.			
	10330	3.000	180.000	-11.250	14.333	0.			
	10340	3.000	180.000	-3.750	14.333	0.			
	10350	3.000	180.000	3.750	14.333	0.			
	10360	3.000	0.	11.250	14.333	0.			
	10370	3.000	0.	-11.250	7.170	0.			
	10380	3.000	0.	-3.750	7.170	0.			
	10390	3.000	0.	3.750	7.170	0.			
	10400	3.000	0.	11.250	7.170	0.			
	10410	3.000	180.000	-11.250	0.	0.			
	10420	3.000	180.000	-3.750	0.	0.			
	10430	3.000	180.000	3.750	0.	0.			
	10440	3.000	0.	11.250	0.	0.			
	10450	3.000	0.	-11.250	-7.170	0.			
	10460	3.000	0.	-3.750	-7.170	0.			
	10470	3.000	0.	3.750	-7.170	0.			
	10480	3.000	0.	11.250	-7.170	0.			
	10490	3.000	180.000	-11.250	-14.333	0.			
	10500	3.000	180.000	-3.750	-14.333	0.			
	10510	3.000	180.000	3.750	-14.333	0.			
	10520	3.000	0.	11.250	-14.333	0.			
	10530	3.000	0.	-11.250	-21.500	0.			
	10540	3.000	0.	-3.750	-21.500	0.			
	10550	3.000	0.	3.750	-21.500	0.			
	10560	3.000	0.	11.250	-21.500	0.			
	10570	3.000	180.000	-11.250	-28.667	0.			
	10580	3.000	180.000	-3.750	-28.667	0.			
	10590	3.000	180.000	3.750	-28.667	0.			
	10600	3.000	0.	11.250	-28.667	0.			
	10610	3.000	0.	-11.250	-35.833	0.			
	10620	3.000	0.	-3.750	-35.833	0.			
	10630	3.000	0.	3.750	-35.833	0.			
	10640	3.000	0.	11.250	-35.833	0.			
	10650	3.000	180.000	-11.250	-43.000	0.			
	10660	3.000	180.000	-3.750	-43.000	0.			
	10670	3.000	180.000	3.750	-43.000	0.			
	10680	3.000	0.	11.250	-43.000	0.			
	10690	3.000	0.	-11.250	-50.170	0.			
	10700	3.000	0.	-3.750	-50.170	0.			
	10710	3.000	0.	3.750	-50.170	0.			
	10720	3.000	0.	11.250	-50.170	0.			
11	10730	1207.500	0.	3113.250	0.	4825.5675	0.		
	10740	1454.250	0.	1683.150	0.	-2743.5342	0.		
	10750	1825.350	0.	875.500	0.	-5779.620	0.		

Table 24
Output Data for Example Problem 11

EXAMPLE PROBLEM NO. 11
TECHE-VERMILION OUTLET STRUCTURE 7.17 FT SPACING

NO. OF PILES = 60 B MATRIX IS CALCULATED FOR EACH PILE

1. TABLE OF PILE AND SOIL DATA

PILE NUMBERS

1 60 E = 0.30E 07 PSI IX = 5461.33 IN**4 IY = 5461.33 IN**4
AREA = 256.0 IN**2 X = 16.00 IN Y = 16.00 IN
LENGTH = 30.0 FEET ES = 2.000
K1 = 0.4110 K2 = 0.5000 K3 = 0.
K4 = 0. K5 = 0. K6 = 0.

ALLOWABLES: COMBINED BENDING FOR TENSION = 268.800 KIPS
MOMENT ABOUT MINOR AXIS FOR TENSION = 59.700 KIP-FT
MOMENT ABOUT MAJOR AXIS FOR TENSION = 59.700 KIP-FT
COMBINED BENDING FOR COMPRESSION = 268.800 KIPS
MOMENT ABOUT MINOR AXIS FOR COMPRESSION = 59.700 KIP-FT
MOMENT ABOUT MAJOR AXIS FOR COMPRESSION = 59.700 KIP-FT
COMPRESSIVE LOAD = 150.000 KIPS
TENSILE LOAD = 100.000 KIPS

THE B MATRIX FOR PILES 1 THROUGH 60 IS

0.759E 04	0.	0.	0.	0.	0.
0.	0.759E 04	0.	0.	0.	0.
0.	0.	0.533E 06	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.

(Continued)

(Sheet 1 of 11)

Table 24 (Continued)

2. TABLE OF PILE COORDINATES AND BATTER

PILE NO.	BATTER	ANGLE	U1(FT)	U2(FT)	U3(FT)
1	3.00	0.	-11.250	50.170	0.
2	3.00	0.	-3.750	50.170	0.
3	3.00	0.	3.750	50.170	0.
4	3.00	0.	11.250	50.170	0.
5	3.00	180.	-11.250	43.000	0.
6	3.00	180.	-3.750	43.000	0.
7	3.00	180.	3.750	43.000	0.
8	3.00	0.	11.250	43.000	0.
9	3.00	0.	-11.250	35.833	0.
10	3.00	0.	-3.750	35.833	0.
11	3.00	0.	3.750	35.833	0.
12	3.00	0.	11.250	35.833	0.
13	3.00	180.	-11.250	28.667	0.
14	3.00	180.	-3.750	28.667	0.
15	3.00	180.	3.750	28.667	0.
16	3.00	0.	11.250	28.667	0.
17	3.00	0.	-11.250	21.500	0.
18	3.00	0.	-3.750	21.500	0.
19	3.00	0.	3.750	21.500	0.
20	3.00	0.	11.250	21.500	0.
21	3.00	180.	-11.250	14.333	0.
22	3.00	180.	-3.750	14.333	0.
23	3.00	180.	3.750	14.333	0.
24	3.00	0.	11.250	14.333	0.
25	3.00	0.	-11.250	7.170	0.
26	3.00	0.	-3.750	7.170	0.
27	3.00	0.	3.750	7.170	0.
28	3.00	0.	11.250	7.170	0.
29	3.00	180.	-11.250	0.	0.
30	3.00	180.	-3.750	0.	0.
31	3.00	180.	3.750	0.	0.
32	3.00	0.	11.250	0.	0.
33	3.00	0.	-11.250	-7.170	0.
34	3.00	0.	-3.750	-7.170	0.
35	3.00	0.	3.750	-7.170	0.
36	3.00	0.	11.250	-7.170	0.
37	3.00	180.	-11.250	-14.333	0.
38	3.00	180.	-3.750	-14.333	0.
39	3.00	180.	3.750	-14.333	0.
40	3.00	0.	11.250	-14.333	0.
41	3.00	0.	-11.250	-21.500	0.
42	3.00	0.	-3.750	-21.500	0.
43	3.00	0.	3.750	-21.500	0.
44	3.00	0.	11.250	-21.500	0.
45	3.00	180.	-11.250	-28.667	0.
46	3.00	180.	-3.750	-28.667	0.
47	3.00	180.	3.750	-28.667	0.
48	3.00	0.	11.250	-28.667	0.
49	3.00	0.	-11.250	-35.833	0.
50	3.00	0.	-3.750	-35.833	0.
51	3.00	0.	3.750	-35.833	0.
52	3.00	0.	11.250	-35.833	0.
53	3.00	180.	-11.250	-43.000	0.
54	3.00	180.	-3.750	-43.000	0.
55	3.00	180.	3.750	-43.000	0.
56	3.00	0.	11.250	-43.000	0.
57	3.00	0.	-11.250	-50.170	0.
58	3.00	0.	-3.750	-50.170	0.
59	3.00	0.	3.750	-50.170	0.
60	3.00	0.	11.250	-50.170	0.

3. STIFFNESS MATRIX S FOR THE STRUCTURE

0.361E 07	-0.219E -02	0.204E 07	0.100E 02	-0.298E 09	0.700E 01
-0.219E -02	0.455E 00	0.607E -02	0.180E -07	0.206E 00	0.547E -01
0.204E 07	0.607E -02	0.208E 00	0.320E 02	0.500E 00	0.000E 01
0.100E 02	0.180E -07	0.320E 02	0.090E 13	0.512E 03	-0.523E 12
-0.298E 09	0.206E 00	0.	0.102E 04	0.202E 12	0.120E 04
0.	0.000E -01	0.000E 01	-0.523E 12	0.040E 03	0.503E 12

3A FLEXIBILITY MATRIX F FOR THE STRUCTURE

0.330E -06	0.100E -14	-0.320E -07	-0.200E -17	0.037E -09	-0.711E -17
0.100E -14	0.220E -05	-0.001E -15	-0.003E -19	-0.046E -10	-0.070E -10
-0.320E -07	-0.001E -15	0.000E -07	-0.001E -10	-0.332E -10	-0.074E -10
-0.200E -17	-0.003E -19	-0.001E -10	0.000E -12	-0.047E -20	0.302E -12
0.037E -09	-0.046E -10	-0.332E -10	-0.047E -20	0.077E -11	-0.104E -19
-0.123E -17	-0.074E -10	-0.000E -10	0.302E -12	-0.046E -20	0.230E -11

(Continued)

(Sheet 2 of 11)

Table 24 (Continued)

***** LOADING CONDITION 1 *****

4. MATRIX OF APPLIED LOADS Q (KIPS & FEET)

Q1	Q2	Q3	Q4	Q5	Q6
1207.500	0.	3113.250	0.	4625.588	0.

5. STRUCTURAL DEFLECTIONS (INCHES)

D1	D2	D3	D4	D5	D6
0.317E-00	0.804E-10	0.707E-01	-0.340E-11	0.522E-03	-0.105E-10

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1	X2	X3	X4	X5	X6
1	0.254E-00	0.150E-08	0.240E-00	0.919E-13	0.522E-03	-0.110E-10
2	0.269E-00	0.553E-09	0.195E-00	0.919E-13	0.522E-03	-0.110E-10
3	0.284E-00	-0.392E-09	0.151E-00	0.919E-13	0.522E-03	-0.110E-10
4	0.299E-00	-0.134E-08	0.106E-00	0.919E-13	0.522E-03	-0.110E-10
5	-0.346E-00	-0.213E-08	0.393E-01	0.753E-11	-0.522E-03	-0.856E-11
6	-0.333E-00	-0.118E-08	-0.528E-02	0.753E-11	-0.522E-03	-0.856E-11
7	-0.318E-00	-0.238E-09	-0.499E-01	0.753E-11	-0.522E-03	-0.856E-11
8	0.299E-00	-0.134E-08	0.106E-00	0.919E-13	0.522E-03	-0.110E-10
9	0.254E-00	0.150E-08	0.240E-00	0.919E-13	0.522E-03	-0.110E-10
10	0.269E-00	0.553E-09	0.195E-00	0.919E-13	0.522E-03	-0.110E-10
11	0.284E-00	-0.392E-09	0.151E-00	0.919E-13	0.522E-03	-0.110E-10
12	0.299E-00	-0.134E-08	0.106E-00	0.919E-13	0.522E-03	-0.110E-10
13	-0.346E-00	-0.213E-08	0.393E-01	0.753E-11	-0.522E-03	-0.856E-11
14	-0.333E-00	-0.118E-08	-0.528E-02	0.753E-11	-0.522E-03	-0.856E-11
15	-0.318E-00	-0.238E-09	-0.499E-01	0.753E-11	-0.522E-03	-0.856E-11
16	0.299E-00	-0.134E-08	0.106E-00	0.919E-13	0.522E-03	-0.110E-10
17	0.254E-00	0.150E-08	0.240E-00	0.919E-13	0.522E-03	-0.110E-10
18	0.269E-00	0.553E-09	0.195E-00	0.919E-13	0.522E-03	-0.110E-10
19	0.284E-00	-0.392E-09	0.151E-00	0.919E-13	0.522E-03	-0.110E-10
20	0.299E-00	-0.134E-08	0.106E-00	0.919E-13	0.522E-03	-0.110E-10
21	-0.346E-00	-0.213E-08	0.393E-01	0.753E-11	-0.522E-03	-0.856E-11
22	-0.333E-00	-0.118E-08	-0.528E-02	0.753E-11	-0.522E-03	-0.856E-11
23	-0.318E-00	-0.238E-09	-0.499E-01	0.753E-11	-0.522E-03	-0.856E-11
24	0.299E-00	-0.134E-08	0.106E-00	0.919E-13	0.522E-03	-0.110E-10
25	0.254E-00	0.150E-08	0.240E-00	0.919E-13	0.522E-03	-0.110E-10
26	0.269E-00	0.553E-09	0.195E-00	0.919E-13	0.522E-03	-0.110E-10
27	0.284E-00	-0.392E-09	0.151E-00	0.919E-13	0.522E-03	-0.110E-10
28	0.299E-00	-0.134E-08	0.106E-00	0.919E-13	0.522E-03	-0.110E-10
29	-0.346E-00	-0.213E-08	0.393E-01	0.753E-11	-0.522E-03	-0.856E-11
30	-0.333E-00	-0.118E-08	-0.528E-02	0.753E-11	-0.522E-03	-0.856E-11
31	-0.318E-00	-0.238E-09	-0.499E-01	0.753E-11	-0.522E-03	-0.856E-11
32	0.299E-00	-0.134E-08	0.106E-00	0.919E-13	0.522E-03	-0.110E-10
33	0.254E-00	0.150E-08	0.240E-00	0.919E-13	0.522E-03	-0.110E-10
34	0.269E-00	0.553E-09	0.195E-00	0.919E-13	0.522E-03	-0.110E-10
35	0.284E-00	-0.392E-09	0.151E-00	0.919E-13	0.522E-03	-0.110E-10
36	0.299E-00	-0.134E-08	0.106E-00	0.919E-13	0.522E-03	-0.110E-10
37	-0.346E-00	-0.213E-08	0.393E-01	0.753E-11	-0.522E-03	-0.856E-11
38	-0.333E-00	-0.118E-08	-0.528E-02	0.753E-11	-0.522E-03	-0.856E-11
39	-0.318E-00	-0.238E-09	-0.499E-01	0.753E-11	-0.522E-03	-0.856E-11
40	0.299E-00	-0.134E-08	0.106E-00	0.919E-13	0.522E-03	-0.110E-10
41	0.254E-00	0.150E-08	0.240E-00	0.919E-13	0.522E-03	-0.110E-10
42	0.269E-00	0.553E-09	0.195E-00	0.919E-13	0.522E-03	-0.110E-10
43	0.284E-00	-0.392E-09	0.151E-00	0.919E-13	0.522E-03	-0.110E-10
44	0.299E-00	-0.134E-08	0.106E-00	0.919E-13	0.522E-03	-0.110E-10
45	-0.346E-00	-0.213E-08	0.393E-01	0.753E-11	-0.522E-03	-0.856E-11
46	-0.333E-00	-0.118E-08	-0.528E-02	0.753E-11	-0.522E-03	-0.856E-11
47	-0.318E-00	-0.238E-09	-0.499E-01	0.753E-11	-0.522E-03	-0.856E-11
48	0.299E-00	-0.134E-08	0.106E-00	0.919E-13	0.522E-03	-0.110E-10
49	0.254E-00	0.150E-08	0.240E-00	0.919E-13	0.522E-03	-0.110E-10
50	0.269E-00	0.553E-09	0.195E-00	0.919E-13	0.522E-03	-0.110E-10
51	0.284E-00	-0.392E-09	0.151E-00	0.919E-13	0.522E-03	-0.110E-10
52	0.299E-00	-0.134E-08	0.106E-00	0.919E-13	0.522E-03	-0.110E-10
53	-0.346E-00	-0.213E-08	0.393E-01	0.753E-11	-0.522E-03	-0.856E-11
54	-0.333E-00	-0.118E-08	-0.528E-02	0.753E-11	-0.522E-03	-0.856E-11
55	-0.318E-00	-0.238E-09	-0.499E-01	0.753E-11	-0.522E-03	-0.856E-11
56	0.299E-00	-0.134E-08	0.106E-00	0.919E-13	0.522E-03	-0.110E-10
57	0.254E-00	0.150E-08	0.240E-00	0.919E-13	0.522E-03	-0.110E-10
58	0.269E-00	0.553E-09	0.195E-00	0.919E-13	0.522E-03	-0.110E-10
59	0.284E-00	-0.392E-09	0.151E-00	0.919E-13	0.522E-03	-0.110E-10
60	0.299E-00	-0.134E-08	0.106E-00	0.919E-13	0.522E-03	-0.110E-10

(Continued)

(Sheet 3 of 11)

Table 24 (Continued)

7. PILE FORCES ALONG PILE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6	CASTR	FAILURE
								CB BU CO TE
1	1.931	0.000	127.985	0.	0.	0.	0.48	
2	2.044	0.000	104.209	0.	0.	0.	0.39	
3	2.157	-0.000	80.433	0.	0.	0.	0.30	
4	2.270	-0.000	56.657	0.	0.	0.	0.21	
5	-2.638	-0.000	20.957	0.	0.	0.	0.08	
6	-2.525	-0.000	-2.818	0.	0.	0.	0.01	
7	-2.412	-0.000	-26.594	0.	0.	0.	0.10	
8	2.270	-0.000	56.657	0.	0.	0.	0.21	
9	1.931	0.000	127.985	0.	0.	0.	0.48	
10	2.044	0.000	104.209	0.	0.	0.	0.39	
11	2.157	-0.000	80.433	0.	0.	0.	0.30	
12	2.270	-0.000	56.657	0.	0.	0.	0.21	
13	-2.638	-0.000	20.957	0.	0.	0.	0.08	
14	-2.525	-0.000	-2.818	0.	0.	0.	0.01	
15	-2.412	-0.000	-26.594	0.	0.	0.	0.10	
16	2.270	-0.000	56.657	0.	0.	0.	0.21	
17	1.931	0.000	127.985	0.	0.	0.	0.48	
18	2.044	0.000	104.209	0.	0.	0.	0.39	
19	2.157	-0.000	80.433	0.	0.	0.	0.30	
20	2.270	-0.000	56.657	0.	0.	0.	0.21	
21	-2.638	-0.000	20.957	0.	0.	0.	0.08	
22	-2.525	-0.000	-2.818	0.	0.	0.	0.01	
23	-2.412	-0.000	-26.594	0.	0.	0.	0.10	
24	2.270	-0.000	56.657	0.	0.	0.	0.21	
25	1.931	0.000	127.985	0.	0.	0.	0.48	
26	2.044	0.000	104.209	0.	0.	0.	0.39	
27	2.157	-0.000	80.433	0.	0.	0.	0.30	
28	2.270	-0.000	56.657	0.	0.	0.	0.21	
29	-2.638	-0.000	20.957	0.	0.	0.	0.08	
30	-2.525	-0.000	-2.818	0.	0.	0.	0.01	
31	-2.412	-0.000	-26.594	0.	0.	0.	0.10	
32	2.270	-0.000	56.657	0.	0.	0.	0.21	
33	1.931	0.000	127.985	0.	0.	0.	0.48	
34	2.044	0.000	104.209	0.	0.	0.	0.39	
35	2.157	-0.000	80.433	0.	0.	0.	0.30	
36	2.270	-0.000	56.657	0.	0.	0.	0.21	
37	-2.638	-0.000	20.957	0.	0.	0.	0.08	
38	-2.525	-0.000	-2.818	0.	0.	0.	0.01	
39	-2.412	-0.000	-26.594	0.	0.	0.	0.10	
40	2.270	-0.000	56.657	0.	0.	0.	0.21	
41	1.931	0.000	127.985	0.	0.	0.	0.48	
42	2.044	0.000	104.209	0.	0.	0.	0.39	
43	2.157	-0.000	80.433	0.	0.	0.	0.30	
44	2.270	-0.000	56.657	0.	0.	0.	0.21	
45	-2.638	-0.000	20.957	0.	0.	0.	0.08	
46	-2.525	-0.000	-2.818	0.	0.	0.	0.01	
47	-2.412	-0.000	-26.594	0.	0.	0.	0.10	
48	2.270	-0.000	56.657	0.	0.	0.	0.21	
49	1.931	0.000	127.985	0.	0.	0.	0.48	
50	2.044	0.000	104.209	0.	0.	0.	0.39	
51	2.157	-0.000	80.433	0.	0.	0.	0.30	
52	2.270	-0.000	56.657	0.	0.	0.	0.21	
53	-2.638	-0.000	20.957	0.	0.	0.	0.08	
54	-2.525	-0.000	-2.818	0.	0.	0.	0.01	
55	-2.412	-0.000	-26.594	0.	0.	0.	0.10	
56	2.270	-0.000	56.657	0.	0.	0.	0.21	
57	1.931	0.000	127.985	0.	0.	0.	0.48	
58	2.044	0.000	104.209	0.	0.	0.	0.39	
59	2.157	-0.000	80.433	0.	0.	0.	0.30	
60	2.270	-0.000	56.657	0.	0.	0.	0.21	

TOTAL NO. FAILURES = 0 LOAD CASE 1

(Continued)

(Sheet 4 of 11)

Table 24 (Continued)

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6
1	42.305	0.000	120.806	0.	0.	0.
2	34.893	0.000	98.215	0.	0.	0.
3	27.481	-0.000	75.623	0.	0.	0.
4	20.070	-0.000	53.032	0.	0.	0.
5	-4.125	0.000	20.716	0.	0.	0.
6	3.287	0.000	-1.875	0.	0.	0.
7	10.698	-0.000	-24.467	0.	0.	0.
8	20.070	-0.000	53.032	0.	0.	0.
9	42.305	0.000	120.806	0.	0.	0.
10	34.893	0.000	98.215	0.	0.	0.
11	27.481	-0.000	75.623	0.	0.	0.
12	20.070	-0.000	53.032	0.	0.	0.
13	-4.125	0.000	20.716	0.	0.	0.
14	3.287	0.000	-1.875	0.	0.	0.
15	10.698	-0.000	-24.467	0.	0.	0.
16	20.070	-0.000	53.032	0.	0.	0.
17	42.305	0.000	120.806	0.	0.	0.
18	34.893	0.000	98.215	0.	0.	0.
19	27.481	-0.000	75.623	0.	0.	0.
20	20.070	-0.000	53.032	0.	0.	0.
21	-4.125	0.000	20.716	0.	0.	0.
22	3.287	0.000	-1.875	0.	0.	0.
23	10.698	-0.000	-24.467	0.	0.	0.
24	20.070	-0.000	53.032	0.	0.	0.
25	42.305	0.000	120.806	0.	0.	0.
26	34.893	0.000	98.215	0.	0.	0.
27	27.481	-0.000	75.623	0.	0.	0.
28	20.070	-0.000	53.032	0.	0.	0.
29	-4.125	0.000	20.716	0.	0.	0.
30	3.287	0.000	-1.875	0.	0.	0.
31	10.698	-0.000	-24.467	0.	0.	0.
32	20.070	-0.000	53.032	0.	0.	0.
33	42.305	0.000	120.806	0.	0.	0.
34	34.893	0.000	98.215	0.	0.	0.
35	27.481	-0.000	75.623	0.	0.	0.
36	20.070	-0.000	53.032	0.	0.	0.
37	-4.125	0.000	20.716	0.	0.	0.
38	3.287	0.000	-1.875	0.	0.	0.
39	10.698	-0.000	-24.467	0.	0.	0.
40	20.070	-0.000	53.032	0.	0.	0.
41	42.305	0.000	120.806	0.	0.	0.
42	34.893	0.000	98.215	0.	0.	0.
43	27.481	-0.000	75.623	0.	0.	0.
44	20.070	-0.000	53.032	0.	0.	0.
45	-4.125	0.000	20.716	0.	0.	0.
46	3.287	0.000	-1.875	0.	0.	0.
47	10.698	-0.000	-24.467	0.	0.	0.
48	20.070	-0.000	53.032	0.	0.	0.
49	42.305	0.000	120.806	0.	0.	0.
50	34.893	0.000	98.215	0.	0.	0.
51	27.481	-0.000	75.623	0.	0.	0.
52	20.070	-0.000	53.032	0.	0.	0.
53	-4.125	0.000	20.716	0.	0.	0.
54	3.287	0.000	-1.875	0.	0.	0.
55	10.698	-0.000	-24.467	0.	0.	0.
56	20.070	-0.000	53.032	0.	0.	0.
57	42.305	0.000	120.806	0.	0.	0.
58	34.893	0.000	98.215	0.	0.	0.
59	27.481	-0.000	75.623	0.	0.	0.
60	20.070	-0.000	53.032	0.	0.	0.
SUM	1207.500	0.000	3113.250	-0.001	4625.587	-0.000

(Continued)

(Sheet 5 of 11)

Table 24 (Continued)

***** LOADING CONDITION 2 *****

4. MATRIX OF APPLIED LOADS Q (KIPS & FEET)

Q1	Q2	Q3	Q4	Q5	Q6
1454.250	0.	1683.150	0.	-2740.534	0.

5. STRUCTURE DEFLECTIONS (INCHES)

D1	D2	D3	D4	D5	D6
0.415E-00	0.154E-00	0.175E-01	-0.342E-11	0.311E-03	-0.102E-10

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

FILE	X1	X2	X3	X4	X5	X6
1	0.375E-00	0.292E-00	0.101E-00	0.164E-12	0.311E-03	-0.107E-10
2	0.383E-00	0.200E-00	0.101E-00	0.164E-12	0.311E-03	-0.107E-10
3	0.392E-00	0.100E-00	0.135E-00	0.164E-12	0.311E-03	-0.107E-10
4	0.401E-00	0.165E-00	0.100E-00	0.164E-12	0.311E-03	-0.107E-10
5	-0.412E-00	-0.374E-00	-0.747E-01	0.087E-11	-0.311E-03	-0.845E-11
6	-0.403E-00	-0.202E-00	-0.101E-00	0.087E-11	-0.311E-03	-0.845E-11
7	-0.395E-00	-0.100E-00	-0.135E-00	0.087E-11	-0.311E-03	-0.845E-11
8	0.401E-00	0.165E-00	0.100E-00	0.164E-12	0.311E-03	-0.107E-10
9	0.375E-00	0.292E-00	0.101E-00	0.164E-12	0.311E-03	-0.107E-10
10	0.383E-00	0.200E-00	0.101E-00	0.164E-12	0.311E-03	-0.107E-10
11	0.392E-00	0.100E-00	0.135E-00	0.164E-12	0.311E-03	-0.107E-10
12	0.401E-00	0.165E-00	0.100E-00	0.164E-12	0.311E-03	-0.107E-10
13	-0.412E-00	-0.374E-00	-0.747E-01	0.087E-11	-0.311E-03	-0.845E-11
14	-0.403E-00	-0.202E-00	-0.101E-00	0.087E-11	-0.311E-03	-0.845E-11
15	-0.395E-00	-0.100E-00	-0.135E-00	0.087E-11	-0.311E-03	-0.845E-11
16	0.401E-00	0.165E-00	0.100E-00	0.164E-12	0.311E-03	-0.107E-10
17	0.375E-00	0.292E-00	0.101E-00	0.164E-12	0.311E-03	-0.107E-10
18	0.383E-00	0.200E-00	0.101E-00	0.164E-12	0.311E-03	-0.107E-10
19	0.392E-00	0.100E-00	0.135E-00	0.164E-12	0.311E-03	-0.107E-10
20	0.401E-00	0.165E-00	0.100E-00	0.164E-12	0.311E-03	-0.107E-10
21	-0.412E-00	-0.374E-00	-0.747E-01	0.087E-11	-0.311E-03	-0.845E-11
22	-0.403E-00	-0.202E-00	-0.101E-00	0.087E-11	-0.311E-03	-0.845E-11
23	-0.395E-00	-0.100E-00	-0.135E-00	0.087E-11	-0.311E-03	-0.845E-11
24	0.401E-00	0.165E-00	0.100E-00	0.164E-12	0.311E-03	-0.107E-10
25	0.375E-00	0.292E-00	0.101E-00	0.164E-12	0.311E-03	-0.107E-10
26	0.383E-00	0.200E-00	0.101E-00	0.164E-12	0.311E-03	-0.107E-10
27	0.392E-00	0.100E-00	0.135E-00	0.164E-12	0.311E-03	-0.107E-10
28	0.401E-00	0.165E-00	0.100E-00	0.164E-12	0.311E-03	-0.107E-10
29	-0.412E-00	-0.374E-00	-0.747E-01	0.087E-11	-0.311E-03	-0.845E-11
30	-0.403E-00	-0.202E-00	-0.101E-00	0.087E-11	-0.311E-03	-0.845E-11
31	-0.395E-00	-0.100E-00	-0.135E-00	0.087E-11	-0.311E-03	-0.845E-11
32	0.401E-00	0.165E-00	0.100E-00	0.164E-12	0.311E-03	-0.107E-10
33	0.375E-00	0.292E-00	0.101E-00	0.164E-12	0.311E-03	-0.107E-10
34	0.383E-00	0.200E-00	0.101E-00	0.164E-12	0.311E-03	-0.107E-10
35	0.392E-00	0.100E-00	0.135E-00	0.164E-12	0.311E-03	-0.107E-10
36	0.401E-00	0.165E-00	0.100E-00	0.164E-12	0.311E-03	-0.107E-10
37	-0.412E-00	-0.374E-00	-0.747E-01	0.087E-11	-0.311E-03	-0.845E-11
38	-0.403E-00	-0.202E-00	-0.101E-00	0.087E-11	-0.311E-03	-0.845E-11
39	-0.395E-00	-0.100E-00	-0.135E-00	0.087E-11	-0.311E-03	-0.845E-11
40	0.401E-00	0.165E-00	0.100E-00	0.164E-12	0.311E-03	-0.107E-10
41	0.375E-00	0.292E-00	0.101E-00	0.164E-12	0.311E-03	-0.107E-10
42	0.383E-00	0.200E-00	0.101E-00	0.164E-12	0.311E-03	-0.107E-10
43	0.392E-00	0.100E-00	0.135E-00	0.164E-12	0.311E-03	-0.107E-10
44	0.401E-00	0.165E-00	0.100E-00	0.164E-12	0.311E-03	-0.107E-10
45	-0.412E-00	-0.374E-00	-0.747E-01	0.087E-11	-0.311E-03	-0.845E-11
46	-0.403E-00	-0.202E-00	-0.101E-00	0.087E-11	-0.311E-03	-0.845E-11
47	-0.395E-00	-0.100E-00	-0.135E-00	0.087E-11	-0.311E-03	-0.845E-11
48	0.401E-00	0.165E-00	0.100E-00	0.164E-12	0.311E-03	-0.107E-10
49	0.375E-00	0.292E-00	0.101E-00	0.164E-12	0.311E-03	-0.107E-10
50	0.383E-00	0.200E-00	0.101E-00	0.164E-12	0.311E-03	-0.107E-10
51	0.392E-00	0.100E-00	0.135E-00	0.164E-12	0.311E-03	-0.107E-10
52	0.401E-00	0.165E-00	0.100E-00	0.164E-12	0.311E-03	-0.107E-10
53	-0.412E-00	-0.374E-00	-0.747E-01	0.087E-11	-0.311E-03	-0.845E-11
54	-0.403E-00	-0.202E-00	-0.101E-00	0.087E-11	-0.311E-03	-0.845E-11
55	-0.395E-00	-0.100E-00	-0.135E-00	0.087E-11	-0.311E-03	-0.845E-11
56	0.401E-00	0.165E-00	0.100E-00	0.164E-12	0.311E-03	-0.107E-10
57	0.375E-00	0.292E-00	0.101E-00	0.164E-12	0.311E-03	-0.107E-10
58	0.383E-00	0.200E-00	0.101E-00	0.164E-12	0.311E-03	-0.107E-10
59	0.392E-00	0.100E-00	0.135E-00	0.164E-12	0.311E-03	-0.107E-10
60	0.401E-00	0.165E-00	0.100E-00	0.164E-12	0.311E-03	-0.107E-10

(Continued)

(Sheet 6 of 11)

Table 24 (Continued)

7. PILE FORCES ALONG PILE AXIS (KIPS - PZET)

PILE	P1	P2	P3	P4	P5	P6	CBFTR	FAILURE
								CB BU CO TE
1	2.843	0.000	100.027	0.	0.	0.	0.37	
2	2.910	0.000	85.886	0.	0.	0.	0.32	
3	2.977	0.000	71.744	0.	0.	0.	0.27	
4	3.045	0.000	57.602	0.	0.	0.	0.21	
5	-3.129	-0.000	-39.859	0.	0.	0.	0.15	
6	-3.062	-0.000	-54.001	0.	0.	0.	0.20	
7	-2.995	-0.000	-68.143	0.	0.	0.	0.25	
8	3.045	0.000	57.602	0.	0.	0.	0.21	
9	2.843	0.000	100.027	0.	0.	0.	0.37	
10	2.910	0.000	85.886	0.	0.	0.	0.32	
11	2.977	0.000	71.744	0.	0.	0.	0.27	
12	3.045	0.000	57.602	0.	0.	0.	0.21	
13	-3.129	-0.000	-39.859	0.	0.	0.	0.15	
14	-3.062	-0.000	-54.001	0.	0.	0.	0.20	
15	-2.995	-0.000	-68.143	0.	0.	0.	0.25	
16	3.045	0.000	57.602	0.	0.	0.	0.21	
17	2.843	0.000	100.027	0.	0.	0.	0.37	
18	2.910	0.000	85.886	0.	0.	0.	0.32	
19	2.977	0.000	71.744	0.	0.	0.	0.27	
20	3.045	0.000	57.602	0.	0.	0.	0.21	
21	-3.129	-0.000	-39.859	0.	0.	0.	0.15	
22	-3.062	-0.000	-54.001	0.	0.	0.	0.20	
23	-2.995	-0.000	-68.143	0.	0.	0.	0.25	
24	3.045	0.000	57.602	0.	0.	0.	0.21	
25	2.843	0.000	100.027	0.	0.	0.	0.37	
26	2.910	0.000	85.886	0.	0.	0.	0.32	
27	2.977	0.000	71.744	0.	0.	0.	0.27	
28	3.045	0.000	57.602	0.	0.	0.	0.21	
29	-3.129	-0.000	-39.859	0.	0.	0.	0.15	
30	-3.062	-0.000	-54.001	0.	0.	0.	0.20	
31	-2.995	-0.000	-68.143	0.	0.	0.	0.25	
32	3.045	0.000	57.602	0.	0.	0.	0.21	
33	2.843	0.000	100.027	0.	0.	0.	0.37	
34	2.910	0.000	85.886	0.	0.	0.	0.32	
35	2.977	0.000	71.744	0.	0.	0.	0.27	
36	3.045	0.000	57.602	0.	0.	0.	0.21	
37	-3.129	-0.000	-39.859	0.	0.	0.	0.15	
38	-3.062	-0.000	-54.001	0.	0.	0.	0.20	
39	-2.995	-0.000	-68.143	0.	0.	0.	0.25	
40	3.045	0.000	57.602	0.	0.	0.	0.21	
41	2.843	0.000	100.027	0.	0.	0.	0.37	
42	2.910	0.000	85.886	0.	0.	0.	0.32	
43	2.977	0.000	71.744	0.	0.	0.	0.27	
44	3.045	0.000	57.602	0.	0.	0.	0.21	
45	-3.129	-0.000	-39.859	0.	0.	0.	0.15	
46	-3.062	-0.000	-54.001	0.	0.	0.	0.20	
47	-2.995	-0.000	-68.143	0.	0.	0.	0.25	
48	3.045	0.000	57.602	0.	0.	0.	0.21	
49	2.843	0.000	100.027	0.	0.	0.	0.37	
50	2.910	0.000	85.886	0.	0.	0.	0.32	
51	2.977	0.000	71.744	0.	0.	0.	0.27	
52	3.045	0.000	57.602	0.	0.	0.	0.21	
53	-3.129	-0.000	-39.859	0.	0.	0.	0.15	
54	-3.062	-0.000	-54.001	0.	0.	0.	0.20	
55	-2.995	-0.000	-68.143	0.	0.	0.	0.25	
56	3.045	0.000	57.602	0.	0.	0.	0.21	
57	2.843	0.000	100.027	0.	0.	0.	0.37	
58	2.910	0.000	85.886	0.	0.	0.	0.32	
59	2.977	0.000	71.744	0.	0.	0.	0.27	
60	3.045	0.000	57.602	0.	0.	0.	0.21	

TOTAL NO. FAILURES = 0 LOAD CASE 1

(Continued)

(Sheet 7 of 11)

Table 24 (Continued)

C. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6
1	34.329	0.000	93.995	0.	0.	0.
2	29.920	0.000	80.558	0.	0.	0.
3	25.512	0.000	67.121	0.	0.	0.
4	21.104	0.000	53.683	0.	0.	0.
5	15.573	-0.000	-36.824	0.	0.	0.
6	19.981	-0.000	-50.261	0.	0.	0.
7	24.389	-0.000	-63.699	0.	0.	0.
8	21.104	0.000	53.683	0.	0.	0.
9	34.329	0.000	93.995	0.	0.	0.
10	29.920	0.000	80.558	0.	0.	0.
11	25.512	0.000	67.121	0.	0.	0.
12	21.104	0.000	53.683	0.	0.	0.
13	15.573	-0.000	-36.824	0.	0.	0.
14	19.981	-0.000	-50.261	0.	0.	0.
15	24.389	-0.000	-63.699	0.	0.	0.
16	21.104	0.000	53.683	0.	0.	0.
17	34.329	0.000	93.995	0.	0.	0.
18	29.920	0.000	80.558	0.	0.	0.
19	25.512	0.000	67.121	0.	0.	0.
20	21.104	0.000	53.683	0.	0.	0.
21	15.573	-0.000	-36.824	0.	0.	0.
22	19.981	-0.000	-50.261	0.	0.	0.
23	24.389	-0.000	-63.699	0.	0.	0.
24	21.104	0.000	53.683	0.	0.	0.
25	34.329	0.000	93.995	0.	0.	0.
26	29.920	0.000	80.558	0.	0.	0.
27	25.512	0.000	67.121	0.	0.	0.
28	21.104	0.000	53.683	0.	0.	0.
29	15.573	-0.000	-36.824	0.	0.	0.
30	19.981	-0.000	-50.261	0.	0.	0.
31	24.389	-0.000	-63.699	0.	0.	0.
32	21.104	0.000	53.683	0.	0.	0.
33	34.329	0.000	93.995	0.	0.	0.
34	29.920	0.000	80.558	0.	0.	0.
35	25.512	0.000	67.121	0.	0.	0.
36	21.104	0.000	53.683	0.	0.	0.
37	15.573	-0.000	-36.824	0.	0.	0.
38	19.981	-0.000	-50.261	0.	0.	0.
39	24.389	-0.000	-63.699	0.	0.	0.
40	21.104	0.000	53.683	0.	0.	0.
41	34.329	0.000	93.995	0.	0.	0.
42	29.920	0.000	80.558	0.	0.	0.
43	25.512	0.000	67.121	0.	0.	0.
44	21.104	0.000	53.683	0.	0.	0.
45	15.573	-0.000	-36.824	0.	0.	0.
46	19.981	-0.000	-50.261	0.	0.	0.
47	24.389	-0.000	-63.699	0.	0.	0.
48	21.104	0.000	53.683	0.	0.	0.
49	34.329	0.000	93.995	0.	0.	0.
50	29.920	0.000	80.558	0.	0.	0.
51	25.512	0.000	67.121	0.	0.	0.
52	21.104	0.000	53.683	0.	0.	0.
53	15.573	-0.000	-36.824	0.	0.	0.
54	19.981	-0.000	-50.261	0.	0.	0.
55	24.389	-0.000	-63.699	0.	0.	0.
56	21.104	0.000	53.683	0.	0.	0.
57	34.329	0.000	93.995	0.	0.	0.
58	29.920	0.000	80.558	0.	0.	0.
59	25.512	0.000	67.121	0.	0.	0.
60	21.104	0.000	53.683	0.	0.	0.
SUM	1454.250	-0.000	1683.100	-0.000	-2743.534	-0.000

(Continued)

(Sheet 8 of 11)

Table 24 (Continued)

***** LOADING CONDITION 3 *****

4. MATRIX OF APPLIED LOADS Q (KIPS & F&ET)

Q1	Q2	Q3	Q4	Q5	Q6
182E.950	0.	875.540	0.	-5779.620	0.

5. STRUCTURE DEFLECTIONS (INCHES)

D1	D2	D3	D4	D5	D6
0.552E-00	0.279E-08	-0.239E-01	-0.367E-11	0.325E-03	-0.119E-10

6. PILE DEFLECTIONS ALONG PILE AXIS (INCHES)

PILE	X1	X2	X3	X4	X5	X6
1	0.517E-00	0.440E-00	0.193E-00	0.290E-12	0.325E-03	-0.125E-10
2	0.526E-00	0.332E-00	0.166E-00	0.290E-12	0.325E-03	-0.125E-10
3	0.535E-00	0.225E-00	0.138E-00	0.290E-12	0.325E-03	-0.125E-10
4	0.545E-00	0.110E-00	0.110E-00	0.290E-12	0.325E-03	-0.125E-10
5	-0.530E-00	-0.549E-00	-0.155E-00	0.787E-11	-0.325E-03	-0.996E-11
6	-0.522E-00	-0.440E-00	-0.103E-00	0.787E-11	-0.325E-03	-0.996E-11
7	-0.511E-00	-0.334E-00	-0.211E-00	0.787E-11	-0.325E-03	-0.996E-11
8	0.545E-00	0.110E-00	0.110E-00	0.290E-12	0.325E-03	-0.125E-10
9	0.517E-00	0.440E-00	0.193E-00	0.290E-12	0.325E-03	-0.125E-10
10	0.526E-00	0.332E-00	0.166E-00	0.290E-12	0.325E-03	-0.125E-10
11	0.535E-00	0.225E-00	0.138E-00	0.290E-12	0.325E-03	-0.125E-10
12	0.545E-00	0.110E-00	0.110E-00	0.290E-12	0.325E-03	-0.125E-10
13	-0.530E-00	-0.549E-00	-0.155E-00	0.787E-11	-0.325E-03	-0.996E-11
14	-0.522E-00	-0.440E-00	-0.103E-00	0.787E-11	-0.325E-03	-0.996E-11
15	-0.511E-00	-0.334E-00	-0.211E-00	0.787E-11	-0.325E-03	-0.996E-11
16	0.545E-00	0.110E-00	0.110E-00	0.290E-12	0.325E-03	-0.125E-10
17	0.517E-00	0.440E-00	0.193E-00	0.290E-12	0.325E-03	-0.125E-10
18	0.526E-00	0.332E-00	0.166E-00	0.290E-12	0.325E-03	-0.125E-10
19	0.535E-00	0.225E-00	0.138E-00	0.290E-12	0.325E-03	-0.125E-10
20	0.545E-00	0.110E-00	0.110E-00	0.290E-12	0.325E-03	-0.125E-10
21	-0.530E-00	-0.549E-00	-0.155E-00	0.787E-11	-0.325E-03	-0.996E-11
22	-0.522E-00	-0.440E-00	-0.103E-00	0.787E-11	-0.325E-03	-0.996E-11
23	-0.511E-00	-0.334E-00	-0.211E-00	0.787E-11	-0.325E-03	-0.996E-11
24	0.545E-00	0.110E-00	0.110E-00	0.290E-12	0.325E-03	-0.125E-10
25	0.517E-00	0.440E-00	0.193E-00	0.290E-12	0.325E-03	-0.125E-10
26	0.526E-00	0.332E-00	0.166E-00	0.290E-12	0.325E-03	-0.125E-10
27	0.535E-00	0.225E-00	0.138E-00	0.290E-12	0.325E-03	-0.125E-10
28	0.545E-00	0.110E-00	0.110E-00	0.290E-12	0.325E-03	-0.125E-10
29	-0.530E-00	-0.549E-00	-0.155E-00	0.787E-11	-0.325E-03	-0.996E-11
30	-0.522E-00	-0.440E-00	-0.103E-00	0.787E-11	-0.325E-03	-0.996E-11
31	-0.511E-00	-0.334E-00	-0.211E-00	0.787E-11	-0.325E-03	-0.996E-11
32	0.545E-00	0.110E-00	0.110E-00	0.290E-12	0.325E-03	-0.125E-10
33	0.517E-00	0.440E-00	0.193E-00	0.290E-12	0.325E-03	-0.125E-10
34	0.526E-00	0.332E-00	0.166E-00	0.290E-12	0.325E-03	-0.125E-10
35	0.535E-00	0.225E-00	0.138E-00	0.290E-12	0.325E-03	-0.125E-10
36	0.545E-00	0.110E-00	0.110E-00	0.290E-12	0.325E-03	-0.125E-10
37	-0.530E-00	-0.549E-00	-0.155E-00	0.787E-11	-0.325E-03	-0.996E-11
38	-0.522E-00	-0.440E-00	-0.103E-00	0.787E-11	-0.325E-03	-0.996E-11
39	-0.511E-00	-0.334E-00	-0.211E-00	0.787E-11	-0.325E-03	-0.996E-11
40	0.545E-00	0.110E-00	0.110E-00	0.290E-12	0.325E-03	-0.125E-10
41	0.517E-00	0.440E-00	0.193E-00	0.290E-12	0.325E-03	-0.125E-10
42	0.526E-00	0.332E-00	0.166E-00	0.290E-12	0.325E-03	-0.125E-10
43	0.535E-00	0.225E-00	0.138E-00	0.290E-12	0.325E-03	-0.125E-10
44	0.545E-00	0.110E-00	0.110E-00	0.290E-12	0.325E-03	-0.125E-10
45	-0.530E-00	-0.549E-00	-0.155E-00	0.787E-11	-0.325E-03	-0.996E-11
46	-0.522E-00	-0.440E-00	-0.103E-00	0.787E-11	-0.325E-03	-0.996E-11
47	-0.511E-00	-0.334E-00	-0.211E-00	0.787E-11	-0.325E-03	-0.996E-11
48	0.545E-00	0.110E-00	0.110E-00	0.290E-12	0.325E-03	-0.125E-10
49	0.517E-00	0.440E-00	0.193E-00	0.290E-12	0.325E-03	-0.125E-10
50	0.526E-00	0.332E-00	0.166E-00	0.290E-12	0.325E-03	-0.125E-10
51	0.535E-00	0.225E-00	0.138E-00	0.290E-12	0.325E-03	-0.125E-10
52	0.545E-00	0.110E-00	0.110E-00	0.290E-12	0.325E-03	-0.125E-10
53	-0.530E-00	-0.549E-00	-0.155E-00	0.787E-11	-0.325E-03	-0.996E-11
54	-0.522E-00	-0.440E-00	-0.103E-00	0.787E-11	-0.325E-03	-0.996E-11
55	-0.511E-00	-0.334E-00	-0.211E-00	0.787E-11	-0.325E-03	-0.996E-11
56	0.545E-00	0.110E-00	0.110E-00	0.290E-12	0.325E-03	-0.125E-10
57	0.517E-00	0.440E-00	0.193E-00	0.290E-12	0.325E-03	-0.125E-10
58	0.526E-00	0.332E-00	0.166E-00	0.290E-12	0.325E-03	-0.125E-10
59	0.535E-00	0.225E-00	0.138E-00	0.290E-12	0.325E-03	-0.125E-10
60	0.545E-00	0.110E-00	0.110E-00	0.290E-12	0.325E-03	-0.125E-10

(Continued)

(Sheet 9 of 11)

Table 24 (Continued)

7. PILE FORCES ALONG PILE AXIS (KIPS & FEET)

PILE	F1	F2	F3	F4	F5	F6	C:PTR	FAILURE
								CB BU CC TE
1	3.923	0.000	103.13	0.	0.	0.	0.35	
2	3.993	0.000	08.31	0.	0.	0.	0.33	
3	4.064	0.000	70.49	0.	0.	0.	0.27	
4	4.134	0.000	58.07	0.	0.	0.	0.22	
5	-4.019	-0.000	-02.89	0.	0.	0.	0.31	
6	-3.949	-0.000	-97.71	0.	0.	0.	0.36	
7	-3.879	-0.000	-112.53	0.	0.	0.	0.42	F
8	4.134	0.000	58.07	0.	0.	0.	0.22	
9	3.923	0.000	103.13	0.	0.	0.	0.35	
10	3.993	0.000	08.31	0.	0.	0.	0.33	
11	4.064	0.000	70.49	0.	0.	0.	0.27	
12	4.134	0.000	58.07	0.	0.	0.	0.22	
13	-4.019	-0.000	-02.89	0.	0.	0.	0.31	
14	-3.949	-0.000	-97.71	0.	0.	0.	0.36	
15	-3.879	-0.000	-112.53	0.	0.	0.	0.42	F
16	4.134	0.000	58.07	0.	0.	0.	0.22	
17	3.923	0.000	103.13	0.	0.	0.	0.35	
18	3.993	0.000	08.31	0.	0.	0.	0.33	
19	4.064	0.000	70.49	0.	0.	0.	0.27	
20	4.134	0.000	58.07	0.	0.	0.	0.22	
21	-4.019	-0.000	-02.89	0.	0.	0.	0.31	
22	-3.949	-0.000	-97.71	0.	0.	0.	0.36	
23	-3.879	-0.000	-112.53	0.	0.	0.	0.42	F
24	4.134	0.000	58.07	0.	0.	0.	0.22	
25	3.923	0.000	103.13	0.	0.	0.	0.35	
26	3.993	0.000	08.31	0.	0.	0.	0.33	
27	4.064	0.000	70.49	0.	0.	0.	0.27	
28	4.134	0.000	58.07	0.	0.	0.	0.22	
29	-4.019	-0.000	-02.89	0.	0.	0.	0.31	
30	-3.949	-0.000	-97.71	0.	0.	0.	0.36	
31	-3.879	-0.000	-112.53	0.	0.	0.	0.42	F
32	4.134	0.000	58.07	0.	0.	0.	0.22	
33	3.923	0.000	103.13	0.	0.	0.	0.35	
34	3.993	0.000	08.31	0.	0.	0.	0.33	
35	4.064	0.000	70.49	0.	0.	0.	0.27	
36	4.134	0.000	58.07	0.	0.	0.	0.22	
37	-4.019	-0.000	-02.89	0.	0.	0.	0.31	
38	-3.949	-0.000	-97.71	0.	0.	0.	0.36	
39	-3.879	-0.000	-112.53	0.	0.	0.	0.42	F
40	4.134	0.000	58.07	0.	0.	0.	0.22	
41	3.923	0.000	103.13	0.	0.	0.	0.35	
42	3.993	0.000	08.31	0.	0.	0.	0.33	
43	4.064	0.000	70.49	0.	0.	0.	0.27	
44	4.134	0.000	58.07	0.	0.	0.	0.22	
45	-4.019	-0.000	-02.89	0.	0.	0.	0.31	
46	-3.949	-0.000	-97.71	0.	0.	0.	0.36	
47	-3.879	-0.000	-112.53	0.	0.	0.	0.42	F
48	4.134	0.000	58.07	0.	0.	0.	0.22	
49	3.923	0.000	103.13	0.	0.	0.	0.35	
50	3.993	0.000	08.31	0.	0.	0.	0.33	
51	4.064	0.000	70.49	0.	0.	0.	0.27	
52	4.134	0.000	58.07	0.	0.	0.	0.22	
53	-4.019	-0.000	-02.89	0.	0.	0.	0.31	
54	-3.949	-0.000	-97.71	0.	0.	0.	0.36	
55	-3.879	-0.000	-112.53	0.	0.	0.	0.42	F
56	4.134	0.000	58.07	0.	0.	0.	0.22	
57	3.923	0.000	103.13	0.	0.	0.	0.35	
58	3.993	0.000	08.31	0.	0.	0.	0.33	
59	4.064	0.000	70.49	0.	0.	0.	0.27	
60	4.134	0.000	58.07	0.	0.	0.	0.22	

TOTAL NO. FAILURES = 7 LOAD CASE 0

(Continued)

(Sheet 10 of 11)

Table 24 (Concluded)

8. PILE FORCES ALONG STRUCTURE AXIS (KIPS & FEET)						
PILE	F1	F2	F3	F4	F5	F6
1	36.337	0.000	90.605	0.	0.	0.
2	31.717	0.000	82.524	0.	0.	0.
3	27.098	0.000	68.442	0.	0.	0.
4	22.478	0.000	54.300	0.	0.	0.
5	30.026	-0.000	-77.370	0.	0.	0.
6	34.646	-0.000	-91.451	0.	0.	0.
7	39.266	-0.000	-105.533	0.	0.	0.
8	22.478	0.000	54.300	0.	0.	0.
9	36.337	0.000	90.605	0.	0.	0.
10	31.717	0.000	82.524	0.	0.	0.
11	27.098	0.000	68.442	0.	0.	0.
12	22.478	0.000	54.300	0.	0.	0.
13	30.026	-0.000	-77.370	0.	0.	0.
14	34.646	-0.000	-91.451	0.	0.	0.
15	39.266	-0.000	-105.533	0.	0.	0.
16	22.478	0.000	54.300	0.	0.	0.
17	36.337	0.000	90.605	0.	0.	0.
18	31.717	0.000	82.524	0.	0.	0.
19	27.098	0.000	68.442	0.	0.	0.
20	22.478	0.000	54.300	0.	0.	0.
21	30.026	-0.000	-77.370	0.	0.	0.
22	34.646	-0.000	-91.451	0.	0.	0.
23	39.266	-0.000	-105.533	0.	0.	0.
24	22.478	0.000	54.300	0.	0.	0.
25	36.337	0.000	90.605	0.	0.	0.
26	31.717	0.000	82.524	0.	0.	0.
27	27.098	0.000	68.442	0.	0.	0.
28	22.478	0.000	54.300	0.	0.	0.
29	30.026	-0.000	-77.370	0.	0.	0.
30	34.646	-0.000	-91.451	0.	0.	0.
31	39.266	-0.000	-105.533	0.	0.	0.
32	22.478	0.000	54.300	0.	0.	0.
33	36.337	0.000	90.605	0.	0.	0.
34	31.717	0.000	82.524	0.	0.	0.
35	27.098	0.000	68.442	0.	0.	0.
36	22.478	0.000	54.300	0.	0.	0.
37	30.026	-0.000	-77.370	0.	0.	0.
38	34.646	-0.000	-91.451	0.	0.	0.
39	39.266	-0.000	-105.533	0.	0.	0.
40	22.478	0.000	54.300	0.	0.	0.
41	36.337	0.000	90.605	0.	0.	0.
42	31.717	0.000	82.524	0.	0.	0.
43	27.098	0.000	68.442	0.	0.	0.
44	22.478	0.000	54.300	0.	0.	0.
45	30.026	-0.000	-77.370	0.	0.	0.
46	34.646	-0.000	-91.451	0.	0.	0.
47	39.266	-0.000	-105.533	0.	0.	0.
48	22.478	0.000	54.300	0.	0.	0.
49	36.337	0.000	90.605	0.	0.	0.
50	31.717	0.000	82.524	0.	0.	0.
51	27.098	0.000	68.442	0.	0.	0.
52	22.478	0.000	54.300	0.	0.	0.
53	30.026	-0.000	-77.370	0.	0.	0.
54	34.646	-0.000	-91.451	0.	0.	0.
55	39.266	-0.000	-105.533	0.	0.	0.
56	22.478	0.000	54.300	0.	0.	0.
57	36.337	0.000	90.605	0.	0.	0.
58	31.717	0.000	82.524	0.	0.	0.
59	27.098	0.000	68.442	0.	0.	0.
60	22.478	0.000	54.300	0.	0.	0.
SUM	1825.950	-0.000	875.500	-2.000	-5779.620	-0.001

REFERENCES

- Hrennikoff, A. 1950. "Analysis of Pile Foundations with Batter Piles," Transactions, American Society of Civil Engineers, Vol 76, No. 1, Paper No. 2401, pp 123-126.
- Jones, H. W. and Radhakrishnan, N. 1975. "Modification of the SAP Computer Program to Include a Three-Dimensional Pile Element," U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Mudd, T. J. 1969. "Analysis of Pile Foundations," U. S. Army Engineer District, St. Louis, St. Louis, Mo.
- Murthy, V. N. S. 1964. Behavior of Battered Piles Subjected to Lateral Loads, Thesis presented to the India Institute of Technology.
- Niemi, Jack R. 1976. Letter, LMSD-DA, "Subject: Comments--LMVD Seminar on the Structural Analysis of Pile Foundations, 13-14 January 1976," dated 18 February 1976.
- Prakash, S. 1962. Behavior of Pile Groups Subjected to Lateral Loads, Ph. D. Thesis, University of Illinois, Urbana, Ill.
- Reese, L. C. and Matlock, H. 1956. "Non-Dimensional Solutions for Laterally Loaded Piles With Soil Modulus Assumed Proportional to Depth," Proceedings, Eighth Texas Conference on Soil Mechanics and Foundation Engineering.
- Reese, L. C. and Matlock, H. 1960. "Generalized Solutions for Laterally Loaded Piles," Journal, Soil Mechanics and Foundations Division, American Society of Civil Engineers, Vol 86, No. SM5, Paper No. 2626, pp 63-91.
- Saul, W. E. 1968. "Static and Dynamic Analysis of Pile Foundations," Journal, Structural Division, American Society of Civil Engineers, Vol 94, No. SM5, pp 1071-1100.
- U. S. Army Engineer District, Little Rock. 1964. "Pile Driving and Loading Tests; Lock and Dam No. 4, Arkansas River and Tributaries, Arkansas and Oklahoma," Little Rock, Ark.; Prepared by Fruco & Associates, St. Louis, Mo.

APPENDIX A: USER'S GUIDE FOR PROGRAM PILESTF

General Introduction

1. Documentation for the computer program PILESTF--to compute the pile head stiffness matrix for a linearly elastic pile-soil system--is presented in this appendix and includes a general introduction, previous work, general pile head stiffness analysis, guide for data input, and input-output data for example problems.

2. PILESTF is a finite element computer code (developed by Dr. William P. Dawkins) that can solve for the pile head stiffness matrix. The procedure used is a one-dimensional finite element analysis of a beam on an elastic foundation. The pile is replaced by a linearly elastic system of springs (pile stiffness coefficients) which describe the resistance of the pile to displacements of the structure.

3. PILESTF can be run on the WES G-635, Macon H-6000, and Boeing CDC computers in the time-sharing mode. The program is part of the CORPS library and is identified by the program number X0035. To execute the program, issue one of the following appropriate run commands. On the WES or Macon computer,

RUN WESLIB/CORPS/X0035,R

On the Boeing computer,

OLD,CORPS/UN=CECELB
CALL, CORPS, X0035

Data must be input interactively at execute time. Output comes directly back to the terminal.

Background

4. A typically laterally loaded pile and the notation used in this report are shown in Figure A1. Only a 2D system is shown; extension to three dimensions is immediate. The relationship between forces applied to the pile head and the resulting displacements may be expressed as

$$\begin{Bmatrix} F_x \\ F_z \\ M_y \end{Bmatrix} = \begin{bmatrix} b_{11} & 0 & b_{13} \\ 0 & b_{22} & 0 \\ b_{31} & 0 & b_{33} \end{bmatrix} \begin{Bmatrix} u \\ w \\ \theta \end{Bmatrix} \quad (A1)$$

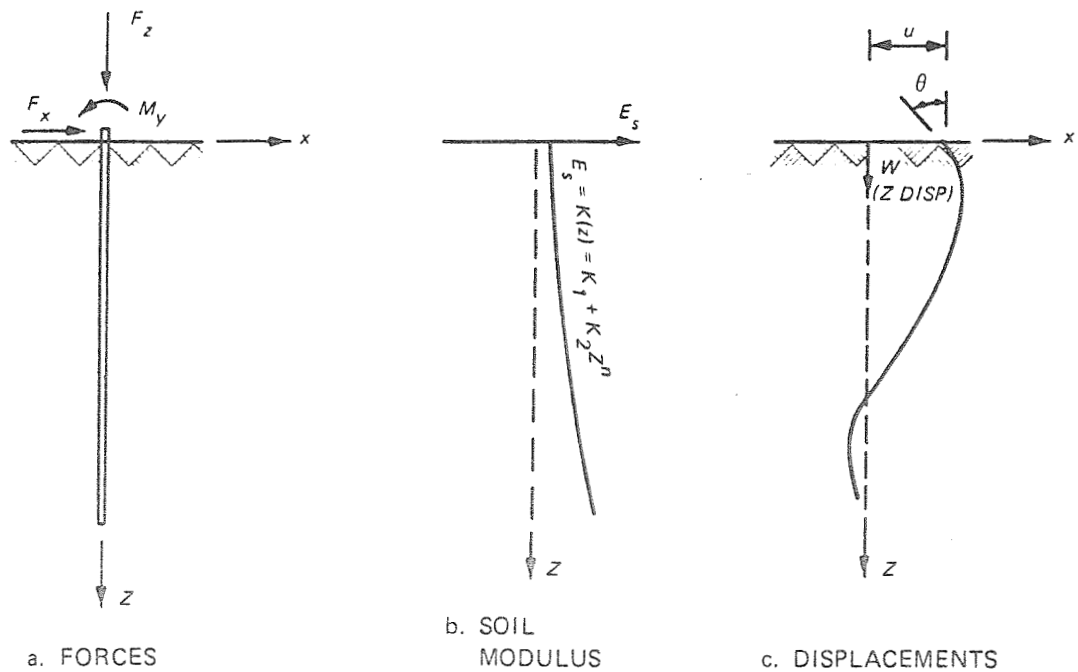


Figure A1. Notation for laterally loaded piles

The $[b]$ matrix in Equation A1 is the pile head stiffness matrix and each term in the matrix, b_{ij} , is equal to the force of type i produced by a unit displacement of type j with all other displacements equal to zero. Because the pile-soil system is assumed to be linearly elastic, energy must be conserved which requires that $b_{ij} = b_{ji}$ for every i and j .

5. Assessment of the values of the b_{ij} coefficients has been based on the finite difference solutions by Reese and Matlock (1956) of the fourth-order differential equation

$$EI \frac{d^4 u}{dz^4} + k(z) u = 0 \quad (A2)$$

where

EI = bending rigidity of the pile

u = lateral displacement

z = distance along the pile

$k(z)$ = soil modulus which may be a function of z as shown in Figure A1.

6. Reese and Matlock (1956) have expressed the lateral force-deformation behavior in the form

$$u = \frac{F_x T^3}{EI} A_u - \frac{M_y T^2}{EI} B_u \quad (A3)$$

and

$$\theta = - \frac{F_x T^2}{EI} A_\theta + \frac{M_y T^2}{EI} B_\theta \quad (A4)$$

where, for instance, with $k(z) = k_2 z^n$,

$$T = \frac{4+n}{\sqrt{k_2}} \sqrt{\frac{EI}{k_2}}$$

and A_u , B_u , A_θ , B_θ are coefficients which depend on the relative magnitudes of EI , $k(z)$, and pile length. Charts giving values of A_u , B_u , A_θ , B_θ for a variety of soil-pile parameters are given in Reese and Matlock (1956).

7. The stiffness terms b_{ij} are readily obtained from Equations A3 and A4 and the tabulated coefficients of Reese and Matlock (1956) by imposing successive unit values of u and θ and evaluating the resulting forces F_x and M_y .

8. Determination of the b_{ij} for extreme cases of a rigid pile-structure connection or a pinned pile-structure connection is straightforward. However, an anomaly arises when the pile-structure connection is assumed to be only partially effective in resisting moment. A previously used method and an alternative procedure for evaluating the b_{ij} stiffness terms for partially fixed head piles are described below.

Previous Pile Head Stiffness Evaluation

9. Niemi (1976) presents a procedure for determining the b_{ij} coefficients under the assumption that the pile is "infinitely" long and the pile-structure connection is capable of producing only a

fraction (DF) of the resisting moment of a completely fixed head pile. First, the relationship between the moment developed in a completely fixed pile and a unit value of lateral displacement ($u = 1, \theta = 0$) is determined.

10. From Equation A4 for $\theta = 0$,

$$M_{yf} = \frac{A_{\theta}}{B_{\theta}} F_x T \quad (A5)$$

The assumption is then made that the pile head produces for any displacement u ,

$$M_y = (DF) M_{yf} \quad (A6)$$

where $0 \leq (DF) \leq 1$.

11. From Equations A3 and A6,

$$u = \frac{F_x T^3}{EI} \left[A_u - (DF) \frac{A_{\theta}}{B_{\theta}} B_u \right] \quad (A7)$$

12. By definition,

$$b_{11} = \frac{F_x}{u} = K_1 \frac{EI}{T^3}$$

where

$$K_1 = \frac{1}{A_u - (DF) \frac{A_{\theta}}{B_{\theta}} B_u} \quad (A8)$$

13. Similarly from Equations A5, A6, and A7, by definition,

$$b_{31} = \frac{M_y}{u} = \frac{(DF) M_{yf}}{u}$$

or

$$b_{31} = K_2 \frac{EI}{T^2}$$

where

$$K_2 = \frac{(DF)}{\frac{B_\theta}{A_\theta} A_u - (DF) B_u} \quad (A9)$$

14. For evaluation of coefficients b_{13} and b_{33} , the assumption is made that the pile head moment for $\theta = 1$, $u = 0$ is

$$M_y = (DF) M_{yf} \quad (A10)$$

15. From Equation A3 with $u = 0$,

$$F_x = \frac{B_u}{A_u} \frac{M_{yf}}{T} \quad (A11)$$

And, from Equations A4 and A11,

$$\theta = \frac{M_{yf} T}{EI} \left[B_\theta - \frac{B_u}{A_u} A_\theta \right] \quad (A12)$$

16. By definition, from Equations A10 and A12,

$$b_{33} = \frac{M_y}{\theta} = \frac{(DF) M_{yf}}{\theta} = K_3 \frac{EI}{T}$$

where

$$K_3 = \frac{(DF)}{B_\theta - \frac{B_u}{A_u} A_\theta} \quad (A13)$$

17. Also, from Equations A11 and A12, as defined in this procedure,

$$b_{13} = \frac{(DF) F_x}{\theta} = (DF) \frac{B_u}{A_u} \frac{M_{yf}}{\theta} = K_4 \frac{EI}{T^2}$$

where

$$K_4 = \frac{DF}{\frac{B_u}{A_u} B_\theta - A_\theta} \quad (A14)$$

18. In summary the pile head stiffness matrix established by this procedure is

$$[b] = \begin{bmatrix} \left[\frac{1}{A_u - (DF) \frac{A_\theta}{B_\theta} B_u} \right] \frac{EI}{T^3} & 0 & \left[\frac{(DF)}{\frac{A_u}{B_u} B_\theta - A_\theta} \right] \frac{EI}{T^2} \\ 0 & b_{22}^* & 0 \\ \left[\frac{(DF)}{\frac{B_\theta}{A_\theta} A_u - (DF) B_u} \right] \frac{EI}{T^2} & 0 & \left[\frac{(DF)}{B_\theta - \frac{B_u}{A_u} A_\theta} \right] \frac{EI}{T} \end{bmatrix} \quad (A15)$$

19. Noting that $A_\theta = B_u$ (see Reese and Matlock (1956)), the term b_{31} may be written as

$$b_{31} = \frac{(DF)}{\frac{A_u}{B_u} B_\theta - (DF) B_u}$$

20. It is apparent that except for pinned head piles ($(DF) = 0$) or fixed head piles ($(DF) = 1$), the pile head stiffness matrix developed by this procedure is unsymmetric and therefore violates the requirement of conservation of energy.

21. It is further to be noted that the effect of partial fixity is different for resistance to lateral translation u than for rotation θ . In the stiffness matrix, Equation A15, resistance to rotation is directly proportional to (DF) while resistance to translation is inversely proportional to (DF) .

* b_{22} is the axial stiffness of the pile and is determined separately from the lateral force-displacement effects by procedures which are not covered in this appendix.

Alternate Derivation

22. For a pinned head pile, $((DF) = 0)$, Equations A3 and A4 yield (with $u = 1$, $\theta = \theta_{\text{free}}$, $M_y = 0$)

$$1 = \frac{F_x T^3}{EI} A_u$$

and

$$|\theta_{\text{free}}| = \frac{F_x T^2}{EI} A_\theta = \frac{A}{A_u} \frac{1}{T} \quad (\text{A16})$$

23. For a partially restrained pile it is assumed that moment resistance develops at a reduced rate (proportional to $(DF) \cdot \theta_{\text{free}}$). Then from Equations A3 and A4,

$$1 = \frac{F_x T^3}{EI} A_u - \frac{M_y T^2}{EI} B_u \quad (\text{A17})$$

$$\theta = -(1 - DF) |\theta_{\text{free}}| = -(1 - DF) \frac{A_\theta}{A_u} \frac{1}{T} = -\frac{F_x T^2}{EI} A_\theta + \frac{M_y T}{EI} B_\theta \quad (\text{A18})$$

Equations A17 and A18 may be solved simultaneously to find

$$b_{11} = F_x = K_1 \frac{EI}{T^3}$$

where

$$K_1 = \frac{1}{A_u} \left[1 + \frac{(DF)}{\frac{A_u B}{B_u A_u} - 1} \right] \quad (\text{A19})$$

$$b_{31} = M_y = K_2 \frac{EI}{T^2}$$

where

$$K_2 = \frac{(DF)}{\frac{B_\theta}{A_\theta} A_u - B_u} \quad (A20)$$

24. For b_{13} and b_{33} , displacements $u = 0$ and $\theta = (DF)$ are imposed at the pile head. Then from Equations A3 and A4,

$$0 = \frac{F_x T^3}{EI} A_u - \frac{M_y T^2}{EI} B_u \quad (A21)$$

$$(DF) = - \frac{F_x T^2}{EI} A_\theta + \frac{M_y T}{EI} B_\theta \quad (A22)$$

Equations A21 and A22 may be solved simultaneously to find

$$b_{33} = M_y = K_3 \frac{EI}{T}$$

where

$$K_3 = \frac{(DF)}{B_\theta - \frac{B_u}{A_u} A_\theta} \quad (A23)$$

and

$$b_{13} = F_x = K_4 \frac{EI}{T^2}$$

where

$$K_4 = \frac{(DF)}{\frac{A_u}{B_u} B_\theta - A_\theta} \quad (A24)$$

25. In summary, by the alternate procedure, the following pile head stiffness matrix is obtained:

$$[b] = \begin{bmatrix} \frac{1}{A_u} \left[1 + \frac{(DF)}{\frac{A_u}{B_u} \frac{B_\theta}{A_\theta} - 1} \right] \frac{EI}{T^3} & 0 & \left[\frac{(DF)}{\frac{A_u}{B_u} B_\theta - A_\theta} \right] \frac{EI}{T^2} \\ 0 & b_{22} & 0 \\ \left[\frac{(DF)}{\frac{B_\theta}{A_\theta} A_u - B_u} \right] \frac{EI}{T^2} & 0 & \left[\frac{(DF)}{B_\theta - \frac{B_u}{A_u} A_\theta} \right] \frac{EI}{T} \end{bmatrix} \quad (A25)$$

Noting that $A_\theta = B_u$, the above stiffness matrix is symmetric and all coefficients are directly proportional to (DF).

26. The values obtained for K_3 and K_4 are the same by either procedure. Values from the two procedures for K_1 and K_2 are compared in Figure A2 for the particular case of an "infinitely" long pile

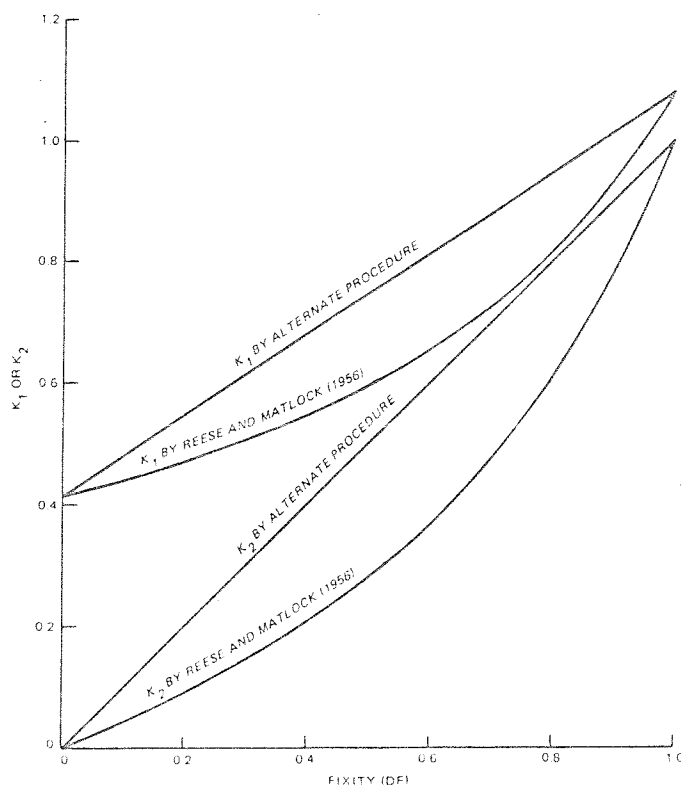


Figure A2. Comparison of stiffness coefficients

with soil modulus $k(z) = k_2 z$. (From Reese and Matlock (1956) and Niemi (1976) for this case, $A_u = 2.435$, $B_u = A_\theta = 1.623$, $B_\theta = 1.749$.)

General Pile Head Stiffness Analysis Introduction

27. The procedures discussed above may be used to develop pile head stiffness matrices provided that appropriate values of A_u , B_u , A_θ , B_θ are available for the particular combinations of EI , $k(z)$, and pile length under consideration. Reese and Matlock (1956) provide these coefficients for only a limited number of variations of pile-soil parameters. In the remainder of this appendix a procedure and attendant computer program are described which permit development of pile head stiffness matrices for either two- or three-dimensional pile-soil systems for any combination of pile-soil parameters. It was anticipated that the pile head stiffness matrices developed by the program would subsequently be used as input for general purpose structural analysis programs. Because many of these general purpose programs do not accommodate unsymmetric stiffness matrices, the alternate procedure for partial fixity described in previous section was adopted.

Pile-Soil Model

28. The procedure used in this appendix is a one-dimensional finite element analysis of a beam on an elastic foundation. The continuous pile-soil system is replaced by a beam resting on discrete springs as shown in Figure A3a and A3b. Freebody diagrams of a general node i and adjacent elements i and $i+1$ are shown in Figure A3c. (Note: subscripts refer to nodes, superscripts refer to elements; e.g., f_i^{i+1} is the shear force at node i in element $i+1$.) Each node undergoes a translation u_i in the x -direction and a rotation θ_i about a y -axis, where x and y are principal axes of the cross section. External nodal forces $F_{x,i}$ and $M_{y,i}$ are assumed to act at each node, although all nodal forces except at the pile head will subsequently be

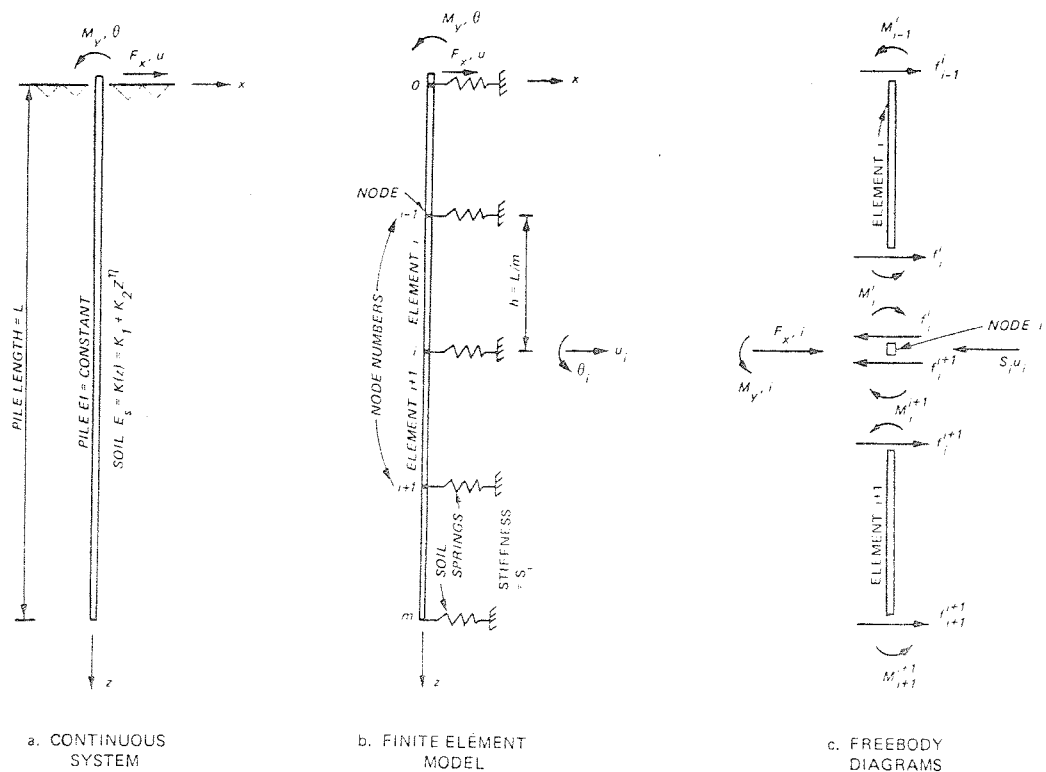


Figure A3. Finite element model of pile-soil system

set to zero. The soil spring at each node produces a force which resists displacement equal to the product of the spring stiffness S_i and the x nodal displacement u_i .

Soil Springs

29. Before analysis of the finite element model can be performed, the stiffness S_i , Figure A3, must be established from the properties of the surrounding soil. At any node the soil modulus is

$$k(z)_i = k_1 + k_2 z^n = k_1 + k_2 (ih)^n$$

A weighted averaging process is used to convert the soil modulus to discrete spring stiffnesses as follows.

At $i = 0$ (pile head):

$$S_0 = \frac{h}{6} [2k(z)_0 + k(z)_1]$$

For $1 \leq i \leq m-1$:

$$S_i = \frac{h}{6} [k(z)_{i-1} + 4k(z)_i + k(z)_{i+1}]$$

And for $i = m$ (bottom of pile):

$$S_m = \frac{h}{6} [k(z)_{m-1} + 2k(z)_m].$$

Element Force-Displacement Relations

30. The end force-displacement relations are obtained from ordinary beam analysis and may be expressed as follows. For element i , at node i :

$$\begin{Bmatrix} f_i^i \\ m_i^i \end{Bmatrix} = \begin{bmatrix} \frac{-12EI}{h^3} & \frac{-6EI}{h^2} \\ \frac{6EI}{h^2} & \frac{2EI}{h} \end{bmatrix} \begin{Bmatrix} u_{i-1} \\ \theta_{i-1} \end{Bmatrix} + \begin{bmatrix} \frac{12EI}{h^3} & \frac{-6EI}{h^2} \\ \frac{-6EI}{h^2} & \frac{4EI}{h} \end{bmatrix} \begin{Bmatrix} u_i \\ \theta_i \end{Bmatrix} \quad (A26)$$

or

$$\tilde{f}_i^i = \tilde{a}_i U_{i-1} + \tilde{b}_i^i U_i \quad (A27)$$

And, for element $i+1$, at node i :

$$\begin{Bmatrix} f_i^{i+1} \\ m_i^{i+1} \end{Bmatrix} = \begin{bmatrix} \frac{12EI}{h^3} & \frac{6EI}{h^2} \\ \frac{6EI}{h^2} & \frac{4EI}{h} \end{bmatrix} \begin{Bmatrix} u_i \\ \theta_i \end{Bmatrix} + \begin{bmatrix} \frac{-12EI}{h^3} & \frac{6EI}{h^2} \\ \frac{-6EI}{h^2} & \frac{2EI}{h} \end{bmatrix} \begin{Bmatrix} u_{i+1} \\ \theta_{i+1} \end{Bmatrix} \quad (A28)$$

or

$$\tilde{f}_i^{i+1} = \tilde{b}_i^{i+1} U_i + \tilde{c}_i U_{i+1} \quad (A29)$$

Nodal Equilibrium

31. For equilibrium at the i th node:

$$f_i^i + f_i^{i+1} + S_i u_i = F_{x,i} \quad (A30)$$

$$m_i^i + m_i^{i+1} = M_{y,i} \quad (A31)$$

which may be written as

$$\begin{Bmatrix} f_i^i \\ m_i^i \end{Bmatrix} + \begin{Bmatrix} f_i^{i+1} \\ m_i^{i+1} \end{Bmatrix} + \begin{bmatrix} S_i & 0 \\ 0 & 0 \end{bmatrix} \begin{Bmatrix} u_i \\ \theta_i \end{Bmatrix} = \begin{Bmatrix} F_{x,i} \\ M_{y,i} \end{Bmatrix} \quad (A32)$$

Or, using the notation of Equations A27 and A29, and introducing

$$\tilde{S}_i = \begin{bmatrix} S_i & 0 \\ 0 & 0 \end{bmatrix}$$

Equation A28 may be written as

$$\tilde{f}_i^i + \tilde{f}_i^{i+1} + \tilde{S}_i U_i = \tilde{F}_i \quad (A33)$$

Finally, combination of Equations A27, A29, and A32 yields

$$\tilde{a}_i U_{i-1} + (\tilde{b}_i^i + \tilde{b}_i^{i+1} + \tilde{S}_i) U_i + \tilde{c}_i U_{i+1} = \tilde{F}_i = 0 \quad (A34)$$

Equation A34 must be satisfied at every node, $1 \leq i \leq m-1$ (note: $F_i = 0$, since no external nodal forces are applied except at the pile head).

Special Conditions at Node m (Bottom of Pile)

32. At node m, because element m+1 does not exist, Equation A34 reduces to

$$a_{m,m-1} U_{m-1} + (b_m^m + s_m) U_m = F_m = 0. \quad (A35)$$

Special Conditions at Node o (Pile Head)

33. Because no element exists above node o, Equation A32 reduces to

$$(b_o^1 + s_o) U_o + c_o U_1 = F_o. \quad (A36)$$

34. Equations A34, A35, and A36 represent m+1 simultaneous equations which relate pile head forces ($F_{x,o}$ and $M_{y,o}$) to displacements along the pile. In order to develop the pile head stiffness matrix, particular combinations of pile head displacements, u_o and θ_o ($M_{y,o}$ for a pinned head pile), are imposed. The forces, $F_{x,o}$ and $M_{y,o}$, resulting from these specified conditions are, by definition, elements of the desired stiffness matrix.

35. For a pinned head pile, the conditions to be specified at the pile head are $u_o = 1$ and $M_{y,o} = 0$. To reflect these conditions Equation A36 (see also Equation A28) must be altered to

$$\begin{bmatrix} 1 & 0 \\ \frac{-6EI}{h^2} & \frac{2EI}{h} \end{bmatrix} \begin{Bmatrix} u_o \\ \theta_o \end{Bmatrix} + \begin{bmatrix} 0 & 0 \\ \frac{-6EI}{h^2} & \frac{4EI}{h} \end{bmatrix} \begin{Bmatrix} u_1 \\ \theta_1 \end{Bmatrix} = \begin{Bmatrix} 1 \\ 0 \end{Bmatrix} \quad (A37)$$

The displacements obtained from the solution of Equations A34, A35, and A37 are then substituted into Equations A26, A28, and A32 (with $i = 0$) to obtain

$$F_{x,o} = \frac{12EI}{h^3} u_o + \frac{6EI}{h^2} \theta_o - \frac{12EI}{h^3} u_1 + \frac{6EI}{h^2} \theta_1 + s_o u_o \quad (A38)$$

and

$$b_{11} = F_{x,o} \quad (A39)$$

For the pinned head pile $b_{13} = b_{31} = b_{33} = 0$. The value of $\theta_o = \theta_{free}$ obtained from this solution is used subsequently for establishing the stiffness coefficients of a fixed or partially restrained pile head.

36. For partially restrained, or fixed, head piles three steps in the solution are required. First, the solution for a pinned head pile is performed to obtain θ_{free} . Then, to establish the b_{11} and b_{31} terms of the stiffness matrix, conditions $u_o = 1$ and $\theta_o = (1 - DF)\theta_{free}$ are imposed at the pile head. These conditions result in altering Equations A36 (and A28) to

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{Bmatrix} u_o \\ \theta_o \end{Bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{Bmatrix} u_1 \\ \theta_1 \end{Bmatrix} = \begin{Bmatrix} 1 \\ (1 - DF)\theta_{free} \end{Bmatrix} \quad (A40)$$

The displacements from solution of Equations A34, A35, and A40, together with Equations A28 and A32 for $i = 0$, yield b_{11} as in Equations A38 and A39, and

$$M_{y,o} = \frac{6EI}{h^2} u_o + \frac{4EI}{h} \theta_o - \frac{6EI}{h^2} u_1 + \frac{2EI}{h} \theta_1 \quad (A41)$$

and

$$b_{31} = M_{y,o} \quad (A42)$$

Finally, for b_{13} and b_{31} , conditions $u_o = 0$ and $\theta_o = (DF)\theta_{free}$ are imposed which result in the following form of Equations A36 (and A28):

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{Bmatrix} u_o \\ \theta_o \end{Bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{Bmatrix} u_1 \\ \theta_1 \end{Bmatrix} = \begin{Bmatrix} 0 \\ (DF) \cdot \theta_{free} \end{Bmatrix} \quad (A43)$$

Displacements from solution of Equations A34, A36, and A43 with Equations A28, A32, A38, and A41 yield

$$b_{13} = F_{x,o}$$

and

$$b_{33} = M_{y,o}$$

37. The preceding sequence of operations completes the determination of the pile head stiffness matrix for a two-dimensional system in the x-z plane where I in all equations is the moment of inertia of the cross section about the y axis (i.e., $I = I_y$).

38. For a three-dimensional system the pile head force displacement relation is expanded to

$$\begin{Bmatrix} F_x \\ F_y \\ F_z \\ M_x \\ M_y \\ M_z \end{Bmatrix} = \begin{bmatrix} b_{11} & 0 & 0 & 0 & b_{15} & 0 \\ 0 & b_{22} & 0 & b_{24} & 0 & 0 \\ 0 & 0 & b_{33}^* & 0 & 0 & 0 \\ 0 & b_{42} & 0 & b_{44} & 0 & 0 \\ b_{51} & 0 & 0 & 0 & b_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & b_{66}^* \end{bmatrix} \begin{Bmatrix} u \\ v \\ w \\ \phi \\ \theta \\ \rho \end{Bmatrix} \quad (A44)$$

* b_{33} and b_{66} are coefficients related to axial and torsional effects, respectively, and their determination is not the subject of this appendix.

In this expression coefficients b_{11} , b_{51} , b_{15} , b_{55} represent effects due to displacements, u and θ , in the x - z plane, and are obtained as described in paragraphs 30 through 36 with $I = I_y$. Coefficients b_{22} , b_{42} , b_{24} , and b_{44} , which are related to displacements v and ϕ , in the y - z plane, may also be obtained from the two-dimensional analysis with $I = I_x$ (moment of inertia of the cross section about the x - x axis).

39. This procedure has been expanded to a layered soil system. The continuous system and the finite element model are shown in Figure A4a and A4b.

40. The stiffness S_i must be established from the properties of the surrounding soil. For any node i in layer 1, the soil modulus is

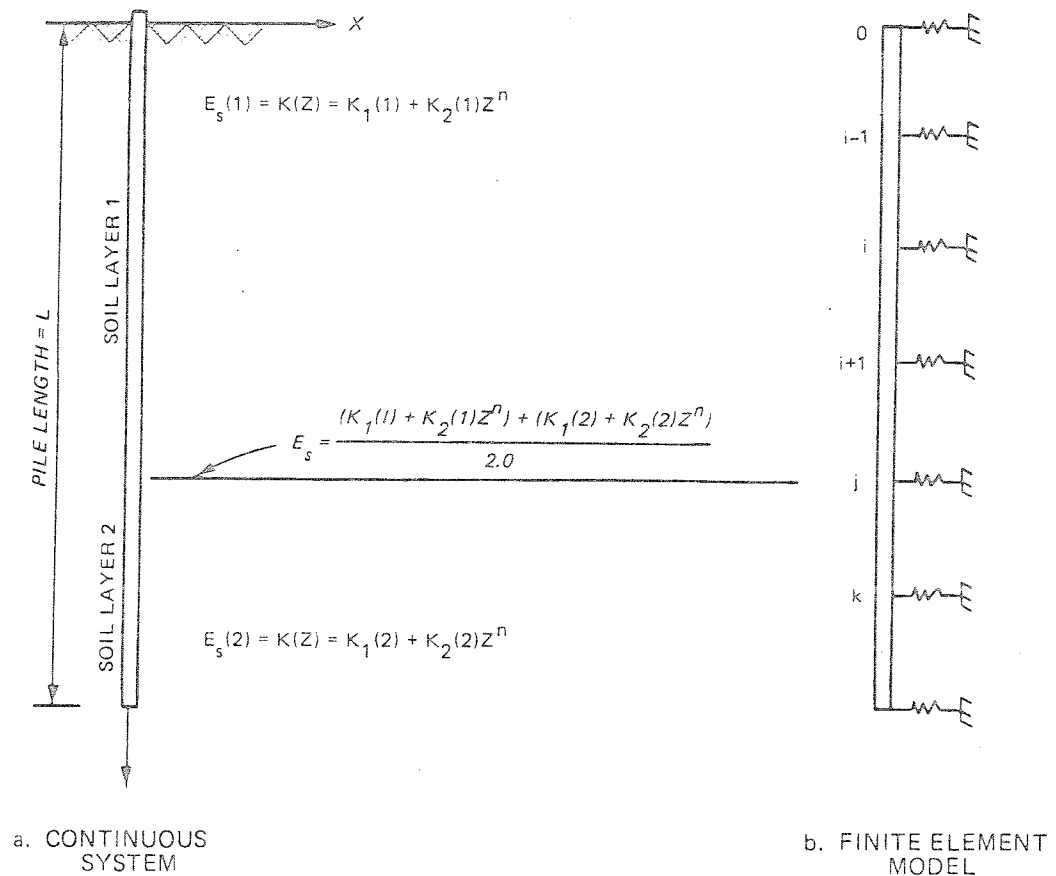


Figure A4. Finite element model of pile-multilayered soil system

$$E_s = K(Z)_i = K_1(1) + K_2(1) Z^n$$

where

$K_1(I)$ = the K_1 constant for layer I

$K_2(I)$ = the K_2 constant for layer I

Z is a length factor that represents the confinement effect. Z will be the depth from the top of the layer to the point if only one layer is present. If more than one layer is present, $Z = Z_{\text{eff}}$ where Z_{eff} is the effective depth assuming that the layer properties under consideration extend all the way to the top of the pile. Z_{eff} is dependent on the ratios of the unit weights of the layers and the depth of the overlying layers. Z is always measured from the top of the pile, not the top of the layer. If node j is located at a soil layer (i.e., layers 1 and 2), the soil modulus is

$$E_s = K(Z)_i = \frac{(K_1(1) + K_2(1)Z_{\text{eff}}^n) + (K_1(2) + K_2(2)Z_{\text{eff}}^n)}{2.0}$$

For any node K in any layer M, the soil modulus is

$$K(Z)_k = K_1(M) + K_2(M)Z_{\text{eff}}^n$$

Guide to Data Input

41. Data should be input to program PILESTF according to the following guide. All input is free field (a comma or at least one blank should separate data items).

GROUP 1 - Title

IHEAD

IHEAD = 60 Character Problem Heading

GROUP 2 - Pile Properties

A. E, G, XL, DF, NDIM

E = Modulus of elasticity

G = Shear modulus

XL = Pile length (if length is input as zero, program calculates increment length as $h = \text{MIN } 12I_x, 12I_y$ and $XL = 200 \times h$, otherwise $h = XL/200$)

DF = Degree of fixity, $0 \leq DF \leq 1$

0 - pinned head

1 - fixed head

NDIM = 2 - two dimensional system

X = U1

3 - three dimensional system

Y = U3

B. XI, YI, XJ, A, AXCO, TOCO

XI = Moment of inertia about X - axis

0 for two dimensional

YI = Moment of inertia about Y - axis

XJ = Torsional moment of Inertia

0 for two dimensional

A = Cross-sectional area

AXCO = Axial stiffness factor

TOCO = Torsional stiffness factor

0 for two dimensional

GROUP 3 - Soil Properties

A. NLAYER

NLAYER = number of soil layers

B. Necessary only if NLAYER = 1

XK1, XK2, ZN

where $E_s = XK1 + XK2 **ZN$

C. Necessary only if NLAYER > 1

XK1(I), XK2(I), ZN(I), DEPTH(I), GAMMA(I)

where $E_s = XK1(I) + XK2(I) **ZN(I)$

DEPTH(I) = Bottom elevation of soil layer I (feet)

GAMMA(I) = Unit weight of soil in layer I

Note: Repeat Group 3-C data NLAYER (number of layers)
number of times

Example Solutions

42. A number of solutions have been obtained for the pile parameters shown in Table A1. The pile problems solved herein are intended only to demonstrate the use of the program and to indicate the influence of some problem parameters on the pile head stiffness.

Discussion of Results

43. Stiffness coefficients obtained with the computer program are compared in Table A2 with values obtained by the procedures in the previous work section using data from Reese and Matlock (1956) for "infinitely" long piles. Except for problems 3A, 6, and 9, the difference between values predicted by the program and those obtained as in the previous work section are less than one percent. The differences in problem 3A illustrate the effect of length; the pile in this problem is not "infinitely" long. This is substantiated by the results of problems 3B and 3C. The length calculated by the computer program for problem 3C is only an approximation to render the pile "infinitely" long and no other significance should be attached to this value.

44. Example problem 1-A is the same as problem 1 except 2 layers of soil with the same properties were used instead of just 1 layer. The answers from both example problems are the same. The same situation applies to example problems 2 and 2-A.

45. Problem 10 illustrates the effect of different cross section moments of inertia. The pile-soil parameters were chosen to permit comparison of stiffness coefficients associated with forces and displacements in the x-z plane. Data are not available in Reese and Matlock (1956) to permit comparisons for coefficients related to the y-z plane.

Conclusions

46. The example solutions demonstrate the capabilities of the computer program to develop the pile head stiffness matrix for lateral effects of a linearly elastic pile-soil system. The program can readily be extended to permit analysis of piles having variable cross section properties. If procedures were available to approximate the resistance of the soil to axial and/or torsional displacements of the pile, the numerical analysis procedure used in the program could be extended to include these effects as well.

Table A1
Pile-Soil Parameters for Example Solutions

Prob.	NDIM	E (psi)	G (psi)	XL (in.)	DF	IX (in. ⁴)	IY (in. ⁴)	J h _j (in.)	A (in. ²)	AXCO	TOCO	K1 (psi)	K2 (psi)/(in.) ²	ZN
1	2	4.3×10^6	--	1200	0	--	833.33	--	100	1	--	10	0	0
2	2	4.3×10^6	--	1200	1	--	833.33	--	100	1	--	0	10	1
3A	2	1.5×10^6	--	360	0	--	322.06	--	63.5	0.5	--	3.123	0	0
3B	2	1.5×10^6	--	1200	0	--	322.06	--	63.5	0.5	--	3.123	0	0
3C	2	1.5×10^6	--	788.5*	0	--	322.06	--	63.5	0.5	--	3.123	0	0
4	2	1.5×10^6	--	360	0	--	322.06	--	63.5	0.5	--	31.230	0	0
5	2	1.5×10^6	--	360	0	--	322.06	--	63.5	0.5	--	312.300	0	0
6	3	4.3×10^6	1.8×10^6	1200	0	833.33	833.33	1666.67	100	1	1	0	10	1
7	3	4.3×10^6	1.8×10^6	1200	1	833.33	833.33	1666.67	100	1	1	0	10	1
8	3	4.3×10^6	1.8×10^6	1200	0.5	833.33	833.33	1666.67	100	1	1	0	10	1
9	3	4.3×10^6	1.8×10^6	1200	1	833.33	833.33	1666.67	100	1	1	0	10	2
10	2	10×10^6	2.5×10^6	1200	1	1440	1000	2440	120	1	1	160	32	1

* Calculated by program, LENGTH input as zero.

Table A2
Comparison of Results

Prob.	b_{11} for 2D and/or b_{22} for 3D (lb/in.) (1)			(b_{13}, b_{31}) for 2D and/or $(b_{15}, b_{51}, b_{24}, b_{42})$ for 3D (lb)(1)			b_{33} for 2D or (b_{44}, b_{55}) for 3D (lb-in.) (1)		
	Program	R&M (2)	% Diff. (3)	Program	R&M (2)	% Diff. (3)	Program	R&M (2)	% Diff. (3)
1	9.732×10^2	9.729×10^2	0.12	--	--	--	--	--	--
2	2.849×10^4	2.843×10^4	0.53	1.356×10^6	1.356×10^6	0	1.045×10^8	1.045×10^8	0
3A	2.306×10^2	2.463×10^2	-6.37	--	--	--	--	--	--
3B	2.464×10^2	2.463×10^2	0.20	--	--	--	--	--	--
3C	2.465×10^2	2.463×10^2	0.04	--	--	--	--	--	--
4	1.384×10^3	1.385×10^3	0	--	--	--	--	--	--
5	7.791×10^3	7.788×10^3	0.17	--	--	--	--	--	--
6	1.090×10^4	1.084×10^4	1.38	--	--	--	--	--	--
7	2.849×10^4	2.843×10^4	0.53	1.356×10^6	1.356×10^6	0	--	--	--
8	1.969×10^4	1.964×10^4	0.71	6.779×10^5	6.778×10^5	0.1	1.045×10^8	1.356×10^6	0
9	2.046×10^5	2.014×10^5	6.06	5.393×10^6	5.356×10^6	2.32	5.226×10^7	5.226×10^7	0
10	9.424×10^4	9.381×10^4	0.76	4.162×10^6	4.148×10^6	0.29	2.143×10^8	2.137×10^8	0.89
	(b_{11})	(b_{51})		(b_{44})	(b_{55})		(b_{44})	(b_{55})	
	1.084×10^5	-5.165×10^6	--	3.046×10^8	3.039×10^8	--	3.046×10^8	3.039×10^8	0.23
	(b_{22})	(b_{42})							

- (1) For 3D pile with IX = IY: $b_{11} = b_{22}$, $b_{15} = b_{51} = -b_{42}$, $b_{44} = b_{55}$.
(2) Coefficients by procedures of Part II with data from Reese and Matlock (1956).
(3) % Diff. = (Program Value - R&M)/R&M*100.
(4) Data are not available in Reese and Matlock (1956) for these values.

ENTER HEADING (60 CHARACTERS MAX.)
 =PROB. 1 - 2D, CONSTANT SOIL MODULUS, PINNED HEAD

ENTER PILE DATA UNDER HEADINGS

E	G	LENGTH	FIXITY	NDIM		
4.3D6	0	1200	0	2		
IX	IY	J	H	AXCD	TOCD	
0	833.33	0	100	1	0	

INPUT THE NUMBER OF SOIL LAYERS
 NLayer

= 1

ENTER SOIL DATA UNDER HEADINGS
 FOR SOIL MODULUS $ES = K1 + K2 \cdot Z \cdot Z^n$
 K1 K2 ZN

= 10 0 0

OUTPUT FROM PLSTF
 HEADING
 PROB. 1 - 2D, CONSTANT SOIL MODULUS, PINNED HEAD

E	G	LENGTH	FIXITY	NDIM		
4.300D 06	0.	1.200D 03	0.	2		
IX	IY	J	H	AXCD	TOCD	
0.	8.333D 02	0.	1.000D 02	1.000	0.	

SOIL DATA

NUMBER OF SOIL LAYERS
 NLayer

1
 K1 K2 ZN
 1.000D 01 0. 0.

PILE HEAD STIFFNESS MATRIX FOR 2-D PILE

9.7317D 02	0.	0.
0.	3.5833D 05	0.
0.	0.	0.

DO YOU WANT ANOTHER RUN? (1=YES, 0=NO)

=1

B11

B12

B13

☐

= data + c
 LMVDFI

B21

B22

B23

☐

= equal to

B31

B32

B33

ENTER HEADING (60 CHARACTERS MAX.)
 =PROB. 1A - 2D, CONSTANT SOIL MODULUS, 2 SOIL LAYERS

ENTER PILE DATA UNDER HEADINGS

E	G	LENGTH	FIXITY	NDIM		
4.3D6	0	1200	0	2		

IX	IY	J	A	AXCD	TCCD
0	833.33	0	100	1	0

INPUT THE NUMBER OF SOIL LAYERS
 NLayer
 = 2

ENTER SOIL DATA UNDER HEADINGS
 FOR SOIL MODULUS $ES = K1 + K2 \cdot Z + ZN$

K1	K2	ZN	DEPTH	GAMMA
10	0	0	600	50
10	0	0	1200	50

OUTPUT FROM PLSTF
 HEADING
 PROB. 1A - 2D, CONSTANT SOIL MODULUS, 2 SOIL LAYERS

PILE DATA

E	G	LENGTH	FIXITY	NDIM		
4.300D 06	0.	1.200D 03	0.	2		

IX	IY	J	A	AXCD	TCCD
0.	8.333D 02	0.	1.000D 02	1.000	0.

SOIL DATA

NUMBER OF SOIL LAYERS
 NLayer
 2

K1	K2	ZN	DEPTH	GAMMA
1.000D 01 0.		0.	6.000D 02	5.000D 01
1.000D 01 0.		0.	1.200D 03	5.000D 01

FILE HEAD STIFFNESS MATRIX FOR 2-D PILE

9.7317D 02	0.	0.
0.	3.5833D 05	0.
0.	0.	0.

DO YOU WANT ANOTHER RUN? (1=YES, 0=NO)
 =1

ENTER HEADING (60 CHARACTERS MAX.)
 =PROB.2 - 2D, LINEAR SOIL MODULUS, FIXED HEAD

ENTER PILE DATA UNDER HEADINGS					
E	G	LENGTH	FIXITY	NDIM	
4.3D6	0	1200	1	2	
IX	IY	J	H	AXED	TOCD
0	833.33	0	100	1	0

INPUT THE NUMBER OF SOIL LAYERS
 NLayer

= 1

ENTER SOIL DATA UNDER HEADINGS
 FOR SOIL MODULUS $ES = K1 + K2 \cdot Z \cdot ZN$

K1	K2	ZN
0	10	1

= 0 10 1

OUTPUT FROM PLSTF
 HEADING
 PROB.2 - 2D, LINEAR SOIL MODULUS, FIXED HEAD

PILE DATA

E	G	LENGTH	FIXITY	NDIM	
4.300D 06	0.	1.200D 03	1.000	2	
IX	IY	J	H	AXED	TOCD
0.	8.333D 02	0.	1.000D 02	1.000	0.

SOIL DATA

NUMBER OF SOIL LAYERS
 NLayer

1
 K1 K2 ZN
 0. 1.000D 01 1.000D 00

PILE HEAD STIFFNESS MATRIX FOR 2-D PILE

2.8490D 04	0.	1.3558D 06
0.	3.5833D 05	0.
1.3558D 06	0.	1.0451D 08

DO YOU WANT ANOTHER RUN? (1=YES, 0=NO)
 =1

ENTER HEADING (60 CHARACTERS MAX.)
 =PROB. 2A - 2D, LINEAR SOIL MODULUS, 2 SOIL LAYERS

ENTER PILE DATA UNDER HEADINGS

	E	G	LENGTH	FIXITY	NDIM
=	4.3D6	0	1200	1	2

	IX	IY	J	A	AXCD	TCCD
=	0	833.33	0	100	1	0

INPUT THE NUMBER OF SOIL LAYERS
 NLayer

 = 2

ENTER SOIL DATA UNDER HEADINGS
 FOR SOIL MODULUS $ES = K1 + K2 \cdot Z \cdot ZN$

	K1	K2	ZN	DEPTH	GAMMA
=	0	10	1	600	50
=	0	10	1	1200	50

OUTPUT FROM PLSTF
 HEADING
 PROB. 2A - 2D, LINEAR SOIL MODULUS, 2 SOIL LAYERS

PILE DATA

	E	G	LENGTH	FIXITY	NDIM
4.300D 06	0.	1.200D 03	1.000	2	

	IX	IY	J	A	AXCD	TCCD
0.	8.333D 02	0.	1.000D 02	1.000 0.		

SOIL DATA

NUMBER OF SOIL LAYERS
 NLayer
 2

	K1	K2	ZN	DEPTH	GAMMA
0.	1.000D 01	1.000D 00	6.000D 02	5.000D 01	
0.	1.000D 01	1.000D 00	1.200D 03	5.000D 01	

PILE HEAD STIFFNESS MATRIX FOR 2-D PILE

2.8490D 04	0.	1.3558D 06
0.	3.5833D 05	0.
1.3558D 06	0.	1.0451D 08

DO YOU WANT ANOTHER RUN? (1=YES, 0=NO)
 =1

ENTER HEADING (60 CHARACTERS MAX.)
 =PROB. 3B - SAME AS 3A EXCEPT "LONG" PILE

ENTER PILE DATA UNDER HEADINGS						
E	G	LENGTH	FIXITY	NDIM		
1.5D6	0	1200	0	2		
IX	IY	J	H	HXCD	TOCD	
0	322.06	0	63.5	0.5	0	

INPUT THE NUMBER OF SOIL LAYERS
 NLayer

= 1

ENTER SOIL DATA UNDER HEADINGS
 FOR SOIL MODULUS $ES = K1 + K2 \cdot Z + ZN$
 K1 K2 ZN

3.123	0	0
-------	---	---

OUTPUT FROM PLSTF
 HEADING
 PROB. 3B - SAME AS 3A EXCEPT "LONG" PILE

PILE DATA						
E	G	LENGTH	FIXITY	NDIM		
1.500D 06	0.	1.200D 03	0.	2		
IX	IY	J	H	HXCD	TOCD	
0.	3.221D 02	0.	6.350D 01	0.500	0.	

SOIL DATA

NUMBER OF SOIL LAYERS
 NLayer

1

K1	K2	ZN
3.123D 00 0.		0.

PILE HEAD STIFFNESS MATRIX FOR 2-D PILE

2.4639D 02	0.	0.
0.	3.9688D 04	0.
0.	0.	0.

DO YOU WANT ANOTHER RUN? (1=YES, 0=NO)

=1

ENTER HEADING (60 CHARACTERS MAX.)
 =PROB. 3A - 2D, CONST."SOFT" SOIL MOD., "SHORT" PILE

ENTER PILE DATA UNDER HEADINGS

E	G	LENGTH	FIXITY	NDIM		
1.506	0	360	0	2		
IX	IY	J	H	AXCD	TOCD	
0	322.06	0	63.5	0.5	0	

INPUT THE NUMBER OF SOIL LAYERS
 NLAYER
 = 1

ENTER SOIL DATA UNDER HEADINGS
 FOR SOIL MODULUS $ES=K1+K2 \cdot Z \cdot ZN$

K1	K2	ZN
3.123	0	0

OUTPUT FROM PLSTF
 HEADING
 PROB. 3A - 2D, CONST."SOFT" SOIL MOD., "SHORT" PILE

PILE DATA

E	G	LENGTH	FIXITY	NDIM		
1.500D 06	0.	3.600D 02	0.	2		
IX	IY	J	H	AXCD	TOCD	
0.	3.221D 02	0.	6.350D 01	0.500 0.		

SOIL DATA

NUMBER OF SOIL LAYERS
 NLAYER
 1

K1	K2	ZN
3.123D 00 0.		0.

PILE HEAD STIFFNESS MATRIX FOR 2-D PILE

2.3058D 02	0.	0.
0.	1.3229D 05	0.
0.	0.	0.

DO YOU WANT ANOTHER RUN? (1=YES, 0=NO)
 =1

ENTER HEADING (60 CHARACTERS MAX.)
 =PROB. 3C - SAME AS 3A EXCEPT LENGTH CALC. BY PROG.

ENTER PILE DATA UNDER HEADINGS

E	G	LENGTH	FIXITY	NDIM		
1.506	0	0	0	2		
IX	IY	J	H	AXCD	TOCD	
0	322.06	0	63.5	0.5	0	

INPUT THE NUMBER OF SOIL LAYERS
 NLayer
 = 1

ENTER SOIL DATA UNDER HEADINGS
 FOR SOIL MODULUS ES=K1+K2*Z**ZN

K1	K2	ZN
3.123	0	0

OUTPUT FROM PLSTF
 HEADING
 PROB. 3C - SAME AS 3A EXCEPT LENGTH CALC. BY PROG.

PILE DATA

E	G	LENGTH	FIXITY	NDIM		
1.500D 06	0.	1.577D 03	0.	2		
IX	IY	J	H	AXCD	TOCD	
0.	3.221D 02	0.	6.350D 01	0.500	0.	

SOIL DATA

NUMBER OF SOIL LAYERS
 NLayer
 1

K1	K2	ZN
3.123D 00	0.	0.

PILE HEAD STIFFNESS MATRIX FOR 2-D PILE

2.4648D 02	0.	0.
0.	3.0201D 04	0.
0.	0.	0.

DO YOU WANT ANOTHER RUN? (1=YES, 0=NO)
 =1

ENTER HEADING (60 CHARACTERS MAX.)
 =PROB. 4 - SAME AS 3A EXCEPT STIFFER SOIL

ENTER PILE DATA UNDER HEADINGS

E	G	LENGTH	FIXITY	NDIM
1.5D6	0	360	0	2

IX	IY	J	H	AXCD	TDCD
0	322.06	0	63.5	0.5	0

INPUT THE NUMBER OF SOIL LAYERS
 NLayer

= 1

ENTER SOIL DATA UNDER HEADINGS
 FOR SOIL MODULUS $ES = K1 + K2 \cdot Z \cdot ZN$

K1	K2	ZN
31.23	0	0

OUTPUT FROM PLSTF
 HEADING
 PROB. 4 - SAME AS 3A EXCEPT STIFFER SOIL

PILE DATA

E	G	LENGTH	FIXITY	NDIM
1.500D 06	0.	3.600D 02	0.	2

IX	IY	J	H	AXCD	TDCD
0.	3.221D 02	0.	6.350D 01	0.500	0.

SOIL DATA

NUMBER OF SOIL LAYERS
 NLayer

1

K1	K2	ZN
3.123D 01	0.	0.

PILE HEAD STIFFNESS MATRIX FOR 2-D PILE

1.3840D 03	0.	0.
0.	1.3229D 05	0.
0.	0.	0.

DO YOU WANT ANOTHER RUN? (1=YES, 0=NO)
 =1

ENTER HEADING (60 CHARACTERS MAX.)
 =PROB. 5 - SAME AS 3A AND 4 EXCEPT STIFFER SOIL

ENTER PILE DATA UNDER HEADINGS

E	G	LENGTH	FIXITY	NDIM		
1.5D6	0	360	0	2		
IX	IY	J	A	HXCD	TOCD	
0	322.06	0	63.5	0.5	0	

INPUT THE NUMBER OF SOIL LAYERS
 NLayer

= 1

ENTER SOIL DATA UNDER HEADINGS
 FOR SOIL MODULUS $ES = K1 + K2 \cdot Z \cdot ZN$
 K1 K2 ZN

= 312.3 0 0

OUTPUT FROM PLSTF

HEADING

PROB. 5 - SAME AS 3A AND 4 EXCEPT STIFFER SOIL

PILE DATA

E	G	LENGTH	FIXITY	NDIM		
1.500D 06	0.	3.600D 02	0.	2		
IX	IY	J	A	HXCD	TOCD	
0.	3.221D 02	0.	6.350D 01	0.500	0.	

SOIL DATA

NUMBER OF SOIL LAYERS
 NLayer

1

K1	K2	ZN
3.123D 02 0.		0.

PILE HEAD STIFFNESS MATRIX FOR 2-D PILE

7.7913D 03	0.	0.
0.	1.3229D 05	0.
0.	0.	0.

DO YOU WANT ANOTHER RUN? (1=YES, 0=NO)

=1

ENTER HEADING (60 CHARACTERS MAX.)
 =PROB. 6 - 3D, LINEAR SOIL MODULUS, PINNED HEAD

ENTER PILE DATA UNDER HEADINGS

E	G	LENGTH	FIXITY	NDIM
4.3D6	1.8D6	1200	0	3

IX	IY	J	H	AXCD	TCCD
833.33	833.33	1666.67	100	1	1

INPUT THE NUMBER OF SOIL LAYERS
 NLayer
 = 1

ENTER SOIL DATA UNDER HEADINGS
 FOR SOIL MODULUS ES=K1+K2+Z+ZM
 K1 K2 ZM

0	10	1
---	----	---

OUTPUT FROM PLSTF
 HEADING
 PROB. 6 - 3D, LINEAR SOIL MODULUS, PINNED HEAD

PILE DATA

E	G	LENGTH	FIXITY	NDIM
4.300D 06	1.800D 06	1.200D 03	0.	3

IX	IY	J	H	AXCD	TCCD
8.333D 02	8.333D 02	1.667D 03	1.000D 02	1.000	1.000

SOIL DATA

NUMBER OF SOIL LAYERS
 NLayer
 1
 K1 K2 ZM
 0. 1.000D 01 1.000D 00

PILE HEAD STIFFNESS MATRIX FOR 3-D PILE

1.0901D 04	0.	0.	0.	0.	0.
0.	1.0901D 04	0.	0.	0.	0.
0.	0.	3.5833D 05	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	2.5000D 06

DO YOU WANT ANOTHER RUN? (1=YES, 0=NO)
 =1

B11	B12	B13	B14	B15	B16
B21	B22	B23	B24	B25	B26
B31	B32	B33	B34	B35	B36
B41	B42	B43	B44	B45	B46
B51	B52	B53	B54	B55	B56
B61	B62	B63	B64 _{A32}	B65	B66

ENTER HEADING (60 CHARACTERS MAX.)
 =PROB. 7 - SAME AS 6 EXCEPT FIXED HEAD

ENTER PILE DATA UNDER HEADINGS

	E	G	LENGTH	FIXITY	NDIM	
=	4.3D6	1.8D6	1200	1	3	
	IX	IY	J	H	AXCD	TDCD
=	833.33	833.33	1666.67	100	1	1

INPUT THE NUMBER OF SOIL LAYERS
 NLAYER

= 1

ENTER SOIL DATA UNDER HEADINGS
 FOR SOIL MODULUS $ES = K1 + K2 \cdot Z \cdot Z$

	K1	K2	ZN
=	0	10	1

OUTPUT FROM PLSTF
 HEADING
 PROB. 7 - SAME AS 6 EXCEPT FIXED HEAD

PILE DATA

E	G	LENGTH	FIXITY	NDIM	
4.300D 06	1.800D 06	1.200D 03	1.000	3	
IX	IY	J	H	AXCD	TDCD
8.333D 02	8.333D 02	1.667D 03	1.000D 02	1.000	1.000

SOIL DATA

NUMBER OF SOIL LAYERS
 NLAYER

1

K1	K2	ZN
0.	1.000D 01	1.000D 00

PILE HEAD STIFFNESS MATRIX FOR 3-D PILE

2.8490D 04	0.	0.	0.	1.3558D 06	0.
0.	2.8490D 04	0.	-1.3558D 06	0.	0.
0.	0.	3.5833D 05	0.	0.	0.
0.	-1.3558D 06	0.	1.0451D 08	0.	0.
1.3558D 06	0.	0.	0.	1.0451D 08	0.
0.	0.	0.	0.	0.	2.5000D 06

DO YOU WANT ANOTHER RUN? (1=YES, 0=NO)
 =1

ENTER HEADING (60 CHARACTERS MAX.)
 =PROB. 8 - SAME AS 7 EXCEPT PARTIALLY RESTRAINED HEAD

ENTER PILE DATA UNDER HEADINGS

	E	G	LENGTH	FIXITY	NDIM
=	4.3D6	1.8D6	1200	0.5	3

	IX	IY	J	H	HXCD	YUCD
=	833.33	833.33	1666.67	100	1	1

INPUT THE NUMBER OF SOIL LAYERS
 NLayer

= 1

ENTER SOIL DATA UNDER HEADINGS
 FOR SOIL MODULUS $ES = K1 + K2 \cdot Z \cdot Z$

	K1	K2	ZN
=	0	10	1

OUTPUT FROM PLSTF
 HEADING
 PROB. 8 - SAME AS 7 EXCEPT PARTIALLY RESTRAINED HEAD

PILE DATA

	E	G	LENGTH	FIXITY	NDIM
	4.300D 06	1.800D 06	1.200D 03	0.500	3

	IX	IY	J	H	HXCD	YUCD
	8.333D 02	8.333D 02	1.667D 03	1.000D 02	1.000	1.000

SOIL DATA

NUMBER OF SOIL LAYERS
 NLayer

1

	K1	K2	ZN
0.	1.000D 01	1.000D 00	

PILE HEAD STIFFNESS MATRIX FOR 3-D PILE

1.9695D 04	0.	0.	0.	6.7791D 05	0.
0.	1.9695D 04	0.	-6.7791D 05	0.	0.
0.	0.	3.5833D 05	0.	0.	0.
0.	-6.7791D 05	0.	5.2256D 07	0.	0.
6.7791D 05	0.	0.	0.	5.2256D 07	0.
0.	0.	0.	0.	0.	2.5000D 06

DO YOU WANT ANOTHER RUN? (1=YES, 0=NO)

=1

ENTER HEADING (60 CHARACTERS MAX.)
 =PROB. 9 - SAME AS 7 EXCEPT EXPONENTIAL SOIL MODULUS

ENTER PILE DATA UNDER HEADINGS

	E	G	LENGTH	FIXITY	NDIM	
=	4.3D6	1.8D6	1200	1	3	
	IX	IY	J	A	AXCD	TCCD
=	833.33	833.33	1666.67	100	1	1

INPUT THE NUMBER OF SOIL LAYERS
 NLayer

 = 1

ENTER SOIL DATA UNDER HEADINGS
 FOR SOIL MODULUS $ES = K1 + K2 \cdot Z \cdot ZM$

	K1	K2	ZM
=	0	10	2

OUTPUT FROM PLSTF
 HEADING
 PROB. 9 - SAME AS 7 EXCEPT EXPONENTIAL SOIL MODULUS

PILE DATA

	E	G	LENGTH	FIXITY	NDIM	
	4.300D 06	1.800D 06	1.200D 03	1.000	3	
	IX	IY	J	A	AXCD	TCCD
	8.333D 02	8.333D 02	1.667D 03	1.000D 02	1.000	1.000

SOIL DATA

NUMBER OF SOIL LAYERS
 NLayer
 1

	K1	K2	ZM
0.	1.000D 01	2.000D 00	

PILE HEAD STIFFNESS MATRIX FOR 3-D PILE

2.0465D 05	0.	0.	0.	5.3927D 06	0.
0.	2.0465D 05	0.	-5.3927D 06	0.	0.
0.	0.	3.5833D 05	0.	0.	0.
0.	-5.3927D 06	0.	2.1433D 08	0.	0.
5.3927D 06	0.	0.	0.	2.1433D 08	0.
0.	0.	0.	0.	0.	2.5000D 06

DO YOU WANT ANOTHER RUN? (1=YES,0=NO)
 =1

ENTER HEADING (60 CHARACTERS MAX.)
 =PROB. 10 - 3D, DIFF. IX & IY, LINEAR SOIL MODULUS

ENTER PILE DATA UNDER HEADINGS

E	G	LENGTH	FIXITY	NDIM
10.06	2.506	1200	1	3

IX	IY	J	A	AXCD	TOCD
1440	1000	2440	120	1	1

INPUT THE NUMBER OF SOIL LAYERS
 NLAYER

= 1

ENTER SOIL DATA UNDER HEADINGS
 FOR SOIL MODULUS $ES = K1 + K2 \cdot Z \cdot ZN$

K1	K2	ZN
160	32	1

OUTPUT FROM PLSTF
 HEADING
 PROB. 10 - 3D, DIFF. IX & IY, LINEAR SOIL MODULUS

PILE DATA

E	G	LENGTH	FIXITY	NDIM
1.000D 07	2.500D 06	1.200D 03	1.000	3

IX	IY	J	A	AXCD	TOCD
1.440D 03	1.000D 03	2.440D 03	1.200D 02	1.000	1.000

SOIL DATA

NUMBER OF SOIL LAYERS
 NLAYER

1

K1	K2	ZN
1.600D 02	3.200D 01	1.000D 00

PILE HEAD STIFFNESS MATRIX FOR 3-D PILE

9.4239D 04	0.	0.	0.	4.1617D 06	0.
0.	1.0838D 05	0.	-5.1653D 06	0.	0.
0.	0.	1.0000D 06	0.	0.	0.
0.	-5.1653D 06	0.	4.0736D 08	0.	0.
4.1617D 06	0.	0.	0.	3.0462D 08	0.
0.	0.	0.	0.	0.	5.0833D 06

DO YOU WANT ANOTHER RUN? (1=YES, 0=NO)
 =0

ENTER HEADING (60 CHARACTERS MAX.)
 =PROB. 11 - SAME AS 9 EXCEPT 3 SOIL LAYERS

ENTER PILE DATA UNDER HEADINGS

E	G	LENGTH	FIXITY	NDIM	IX	IY	J	A	AXCD	TOCD
4.3D6	1.8D6	1200	1	3	833.33	833.33	1666.67	100	1	1

INPUT THE NUMBER OF SOIL LAYERS
 NLAYER
 = 3

ENTER SOIL DATA UNDER HEADINGS
 FOR SOIL MODULUS $ES = K1 + K2 * Z + ZN$

K1	K2	ZN	DEPTH	GAMMA
10	0	0	300	50
10	0	0	600	40
0	10	1	1200	50

OUTPUT FROM PLSTF
 HEADING
 PROB. 11 - SAME AS 9 EXCEPT 3 SOIL LAYERS

PILE DATA

E	G	LENGTH	FIXITY	NDIM	IX	IY	J	A	AXCD	TOCD
4.300D 06	1.800D 06	1.200D 03	1.000	3	8.333D 02	8.333D 02	1.667D 03	1.000D 02	1.000	1.000

SOIL DATA

NUMBER OF SOIL LAYERS
 NLAYER
 3

K1	K2	ZN	DEPTH	GAMMA
1.000D 01	0.	0.	3.000D 02	5.000D 01
1.000D 01	0.	0.	6.000D 02	4.000D 01
0.	1.000D 01	1.000D 00	1.200D 03	5.000D 01

PILE HEAD STIFFNESS MATRIX FOR 3-D PILE

1.9529D 03	0.	0.	0.	1.8931D 05	0.
0.	1.9529D 03	0.	-1.8931D 05	0.	0.
0.	0.	3.5833D 05	0.	0.	0.
0.	-1.8931D 05	0.	3.6911D 07	0.	0.
1.8931D 05	0.	0.	0.	3.6911D 07	0.
0.	0.	0.	0.	0.	2.5000D 06

DO YOU WANT ANOTHER RUN? (1=YES, 0=NO)
 =0

ENTER HEADING (60 CHARACTERS MAX.)
 =PROB. 12 - SAME AS 11 EXCEPT DIFF. SOIL PROPERTIES

ENTER PILE DATA UNDER HEADINGS

	E	G	LENGTH	FIXITY	NDIM	
=	4.3D6	1.8D6	1200	1	3	
	IX	IY	J	A	AXCD	TOCD
=	833.33	833.33	1666.67	100	1	1

INPUT THE NUMBER OF SOIL LAYERS
 NLayer

= 3

ENTER SOIL DATA UNDER HEADINGS
 FOR SOIL MODULUS $ES = K1 + K2 * Z + ZN$

	K1	K2	ZN	DEPTH	GAMMA
=	10	0	0	300	50
=	0	10	1	600	40
=	0	10	2	1200	50

OUTPUT FROM PLSTF

HEADING

PROB. 12 - SAME AS 11 EXCEPT DIFF. SOIL PROPERTIES

PILE DATA

E	G	LENGTH	FIXITY	NDIM	
4.300D 06	1.800D 06	1.200D 03	1.000	3	
IX	IY	J	A	AXCD	TOCD
8.333D 02	8.333D 02	1.667D 03	1.000D 02	1.000	1.000

SOIL DATA

NUMBER OF SOIL LAYERS

NLayer

3

K1	K2	ZN	DEPTH	GAMMA
1.000D 01 0.	0.	0.	3.000D 02	5.000D 01
0.	1.000D 01	1.000D 00	6.000D 02	4.000D 01
0.	1.000D 01	2.000D 00	1.200D 03	5.000D 01

PILE HEAD STIFFNESS MATRIX FOR 3-D PILE

2.2926D 03	0.	0.	0.	2.4064D 05	0.
0.	2.2926D 03	0.	-2.4064D 05	0.	0.
0.	0.	3.5833D 05	0.	0.	0.
0.	-2.4064D 05	0.	4.5295D 07	0.	0.
2.4064D 05	0.	0.	0.	4.5295D 07	0.
0.	0.	0.	0.	0.	2.5000D 06

DO YOU WANT ANOTHER RUN? (1=YES, 0=NO)
 =0

APPENDIX B: USER'S GUIDE FOR PROGRAM FDRAW

General Introduction

1. Documentation for the computer program FDRAW--an interactive graphics post-processor--is presented in this appendix and includes a general introduction, guide for data input, and example problems.

2. FDRAW is capable of displaying pile geometry, resultant axial forces, several different pile loading factors, and elastic center diagrams. Program commands control the display. The program was developed by Mr. John Jobst, St. Louis District.

3. FDRAW runs on the WES G-635, Macon H-6000, and Boeing CDC computers in the time-sharing mode. It is limited to execution on a Tektronix 4014. The program is part of the CORPS library and is identified by the program number X0036. To execute the program, issue one of the following run commands. On the WES or Macon computer,

```
OLD WESLIB/CORPS/X0036,R
GCS2D
device - TK4
```

On the Boeing computer,

```
OLD,CORPS/UN=CECELB
CALL,CORPS,X0036
```

4. Two bits of information are prompted for by the program before any commands may be given:

- a. The name of the plotting file created by an analysis run of X0034.
- b. The radius of the figures to be drawn on the screen (pile coordinate units per inch of screen).

5. After this, any valid FDRAW command may be given. The program assumes load case 1 to be the current load case until it is changed by giving the "LOAD" command.

COMMANDS:

HELP	To obtain a list of valid commands.
RADI	To redefine the radius of the figures drawn on the screen (units that the coordinates of the piles are given in per inch of screen).

{ DONUT OPTION?

PLAIN = basic geometry plot

SUBRE = plain + pile numbers

ICINB = SUBR + batter values

LOAD To change the current load case.

GEOM To display pile locations, with the options of printing the batter for each battered pile and/or numbering the pile.

COMB To display the combined bending factor for each pile and the portion of that factor due solely to the axial load on the pile, for the current load case.

First use Q?

$$C.B.F. = \frac{Q3}{FA} + \frac{Q4}{FB4} + \frac{Q5}{FB5}$$

where Q3 = vertical load along U₃ axis (kips)

Q4 = moment about U₁ axis (kip-ft)

Q5 = moment about U₂ axis (kip-ft)

FA = allowable axial load (kips)

FB4 = allowable moment about minor principal axis (kip-ft)

FB5 = allowable moment about major principal axis (kip-ft)

PLF To display the pile load factor and P.L.F. Flag for each pile for the current load case.

For pile in compression:

$$P.L.F. = \text{MAX} \begin{Bmatrix} C.B.F. \\ A.F. \end{Bmatrix} \quad P.L.F. \text{ Flag} = \begin{Bmatrix} BC \\ C \end{Bmatrix}$$

For pile in tension:

$$P.L.F. = \text{MAX} \begin{Bmatrix} C.B.F. \\ A.F. \end{Bmatrix} \quad P.L.F. \text{ Flag} = \begin{Bmatrix} BT \\ T \end{Bmatrix}$$

AXFC To display the axial factor and P.L.F. Flag for each pile for the current load case.

For pile in compression:

$$A.F. = \frac{Q3}{CALOW}$$

Where CALOW = Allowable Compressive Load (kips)

For pile in tension:

$$A.F. = \left| \frac{Q3}{TALOW} \right|$$

where TALOW = Allowable Tensile Load (kips)

FORCE	To display the axial force, Q3, for each pile for the current load case.
CCOMB	Similar to "COMB" except that it displays the critical combined bending factor for all load cases and the critical load case number, for each pile.
CPLF	Similar to "PLF" except that it displays the critical pile load factor for all load cases and the critical load case number, for each pile.
CCAXFC	Similar to "AXFC" except that it displays the critical axial factor for all load cases and the critical load case number, for all pile in compression.
CTAXFC	To display everything "CCAXFC" does, except for all pile in tension.
ELCEN	To display the elastic center and resultant force diagrams for all load cases.
END	To end FDRAW.

Guide for Data Input

6. Program X0034 of the CORPS library creates a plotting file to be used as the input data file for this program. Data are written to this file according to the following guide. All input is in free field (a comma or at least one blank should separate data items) except Group 5.

Group 1 - Pile Data

A. LINE, NP

LINE = five digit line number

NP = total number of piles in the foundation

B. Note: Repeat NP (Number of Piles) number of times

LINE, U1, U2, U3, H, ANG

U1 = distance from origin to pile along U1-axis (feet)

U2 = distance from origin to pile along U2-axis (feet)

U3 = distance from origin to pile along U3-axis (feet)

H = batter H vertical on 1 horizontal 0 -- vertical pile

ANG = clockwise angle between the positive U1 axis of the structure and the U1 axis (direction of batter) of the pile (degrees)

Group 2 - Loading Control Data

LINE,NLDCS

NLDCS - Number of Loading Conditions

Group 3 - Elastic Center Data

LINE,EC1,EC2,EC31,EC32

EC1 - U1 coordinate of elastic center in U1-U3 plane

EC2 - U2 coordinate of elastic center in U2-U3 plane

EC31 - U3 coordinate of elastic center in U2-U3 plane

EC32 - U3 coordinate of elastic center in U2-U3 plane

Group 4 - Applied Loads

LINE,Q1,Q2,Q3,Q5,Q4

Q1 = horizontal load along U_1 -axis (kips)

Q2 = horizontal load along U_2 -axis (kips)

Q3 = vertical load along U_3 -axis (kips)

Q5 = moment about U_2 -axis (kip-ft)

Q4 = moment about U_1 -axis (kip-ft)

Group 5 - Load Factors

LINE,LC,CBF,PLF,FLAG,AFFC,STFC,Q3

	Cols
LC = Loading Case	6-8
CBF = Combined bending factor	9-18
PLF = Pile load factor	19-28
FLAG = Flag denoting compression or tension	30-31
C = compression	
T = tension	
BC = compression in combined bending	
BT = tension in combined bending	
B = if axial force = 0	
AFFC = Axial factor	32-41
STFC = Steel axial factor	42-51
Q3 = Axial force	52-61

Note: Repeat Group 5 data NP (Number of piles) Number of times.
Then repeat Groups 4 and 5 data NLDCS (number of loading conditions) number of times.

Example Problems

7. The examples which follow illustrate the displays available from FDRAW. The data used are the output from example problem 9 presented on pages 101-109 of the main text of this report. The input data are stored in a file and are presented in Table B1. There is 1 load case and 27 piles in the foundation.

Table B1
Input Data for Example Problems

10000	27	1.50	0.	3.00	270.00	-130.605	0.000	0.000	5287.422
10010	14.00	1.50	0.	3.00	270.00	0.	0.	0.	
10020	10.00	1.50	0.	3.00	270.00	-20.40	-0.02	-0.02	
10030	6.00	1.50	0.	3.00	270.00	-19.91	-0.02	-0.02	
10040	2.00	1.50	0.	3.00	270.00	-19.42	-0.02	-0.02	
10050	-2.00	1.50	0.	3.00	270.00	-18.92	-0.02	-0.02	
10060	-6.00	1.50	0.	3.00	270.00	-18.43	-0.02	-0.02	
10070	-10.00	1.50	0.	3.00	270.00	-17.94	-0.02	-0.02	
10080	-14.00	1.50	0.	3.00	270.00	-17.45	-0.02	-0.02	
10090	-18.00	1.50	0.	3.00	270.00	-16.96	-0.02	-0.02	
10100	-22.00	1.50	0.	3.00	270.00	-16.47	-0.02	-0.02	
10110	-26.00	1.50	0.	3.00	270.00	-15.98	-0.02	-0.02	
10120	-30.00	1.50	0.	3.00	270.00	-15.49	-0.02	-0.02	
10130	-34.00	1.50	0.	3.00	270.00	-15.00	-0.02	-0.02	
10140	-38.00	1.50	0.	3.00	270.00	-14.51	-0.02	-0.02	
10150	-42.00	1.50	0.	3.00	270.00	-14.02	-0.02	-0.02	
10160	-46.00	1.50	0.	3.00	270.00	-13.53	-0.02	-0.02	
10170	-50.00	1.50	0.	3.00	270.00	-13.04	-0.02	-0.02	
10180	-54.00	1.50	0.	3.00	270.00	-12.55	-0.02	-0.02	
10190	-58.00	1.50	0.	3.00	270.00	-12.06	-0.02	-0.02	
10200	-62.00	1.50	0.	3.00	270.00	-11.57	-0.02	-0.02	
10210	-66.00	1.50	0.	3.00	270.00	-11.08	-0.02	-0.02	
10220	-70.00	1.50	0.	3.00	270.00	-10.59	-0.02	-0.02	
10230	-74.00	1.50	0.	3.00	270.00	-10.10	-0.02	-0.02	
10240	-78.00	1.50	0.	3.00	270.00	-9.61	-0.02	-0.02	
10250	-82.00	1.50	0.	3.00	270.00	-9.12	-0.02	-0.02	
10260	-86.00	1.50	0.	3.00	270.00	-8.63	-0.02	-0.02	
10270	-90.00	1.50	0.	3.00	270.00	-8.14	-0.02	-0.02	
10280	-94.00	1.50	0.	3.00	270.00	-7.65	-0.02	-0.02	
10290	-98.00	1.50	0.	3.00	270.00	-7.16	-0.02	-0.02	
10300	-102.00	1.50	0.	3.00	270.00	-6.67	-0.02	-0.02	
10310	-106.00	1.50	0.	3.00	270.00	-6.18	-0.02	-0.02	
10320	-110.00	1.50	0.	3.00	270.00	-5.69	-0.02	-0.02	
10330	-114.00	1.50	0.	3.00	270.00	-5.20	-0.02	-0.02	
10340	-118.00	1.50	0.	3.00	270.00	-4.71	-0.02	-0.02	
10350	-122.00	1.50	0.	3.00	270.00	-4.22	-0.02	-0.02	
10360	-126.00	1.50	0.	3.00	270.00	-3.73	-0.02	-0.02	
10370	-130.00	1.50	0.	3.00	270.00	-3.24	-0.02	-0.02	
10380	-134.00	1.50	0.	3.00	270.00	-2.75	-0.02	-0.02	
10390	-138.00	1.50	0.	3.00	270.00	-2.26	-0.02	-0.02	
10400	-142.00	1.50	0.	3.00	270.00	-1.77	-0.02	-0.02	
10410	-146.00	1.50	0.	3.00	270.00	-1.28	-0.02	-0.02	
10420	-150.00	1.50	0.	3.00	270.00	-0.79	-0.02	-0.02	
10430	-154.00	1.50	0.	3.00	270.00	-0.30	-0.02	-0.02	
10440	-158.00	1.50	0.	3.00	270.00	0.19	-0.02	-0.02	
10450	-162.00	1.50	0.	3.00	270.00	0.68	-0.02	-0.02	
10460	-166.00	1.50	0.	3.00	270.00	1.17	-0.02	-0.02	
10470	-170.00	1.50	0.	3.00	270.00	1.66	-0.02	-0.02	
10480	-174.00	1.50	0.	3.00	270.00	2.15	-0.02	-0.02	
10490	-178.00	1.50	0.	3.00	270.00	2.64	-0.02	-0.02	
10500	-182.00	1.50	0.	3.00	270.00	3.13	-0.02	-0.02	
10510	-186.00	1.50	0.	3.00	270.00	3.62	-0.02	-0.02	
10520	-190.00	1.50	0.	3.00	270.00	4.11	-0.02	-0.02	
10530	-194.00	1.50	0.	3.00	270.00	4.60	-0.02	-0.02	
10540	-198.00	1.50	0.	3.00	270.00	5.09	-0.02	-0.02	
10550	-202.00	1.50	0.	3.00	270.00	5.58	-0.02	-0.02	
10560	-206.00	1.50	0.	3.00	270.00	6.07	-0.02	-0.02	
10570	-210.00	1.50	0.	3.00	270.00	6.56	-0.02	-0.02	
10580	-214.00	1.50	0.	3.00	270.00	7.05	-0.02	-0.02	
10590	-218.00	1.50	0.	3.00	270.00	7.54	-0.02	-0.02	
10600	-222.00	1.50	0.	3.00	270.00	8.03	-0.02	-0.02	
10610	-226.00	1.50	0.	3.00	270.00	8.52	-0.02	-0.02	
10620	-230.00	1.50	0.	3.00	270.00	9.01	-0.02	-0.02	
10630	-234.00	1.50	0.	3.00	270.00	9.50	-0.02	-0.02	
10640	-238.00	1.50	0.	3.00	270.00	9.99	-0.02	-0.02	
10650	-242.00	1.50	0.	3.00	270.00	10.48	-0.02	-0.02	
10660	-246.00	1.50	0.	3.00	270.00	10.97	-0.02	-0.02	
10670	-250.00	1.50	0.	3.00	270.00	11.46	-0.02	-0.02	
10680	-254.00	1.50	0.	3.00	270.00	11.95	-0.02	-0.02	
10690	-258.00	1.50	0.	3.00	270.00	12.44	-0.02	-0.02	
10700	-262.00	1.50	0.	3.00	270.00	12.93	-0.02	-0.02	
10710	-266.00	1.50	0.	3.00	270.00	13.42	-0.02	-0.02	
10720	-270.00	1.50	0.	3.00	270.00	13.91	-0.02	-0.02	
10730	-274.00	1.50	0.	3.00	270.00	14.40	-0.02	-0.02	
10740	-278.00	1.50	0.	3.00	270.00	14.89	-0.02	-0.02	
10750	-282.00	1.50	0.	3.00	270.00	15.38	-0.02	-0.02	
10760	-286.00	1.50	0.	3.00	270.00	15.87	-0.02	-0.02	
10770	-290.00	1.50	0.	3.00	270.00	16.36	-0.02	-0.02	
10780	-294.00	1.50	0.	3.00	270.00	16.85	-0.02	-0.02	
10790	-298.00	1.50	0.	3.00	270.00	17.34	-0.02	-0.02	
10800	-302.00	1.50	0.	3.00	270.00	17.83	-0.02	-0.02	
10810	-306.00	1.50	0.	3.00	270.00	18.32	-0.02	-0.02	
10820	-310.00	1.50	0.	3.00	270.00	18.81	-0.02	-0.02	
10830	-314.00	1.50	0.	3.00	270.00	19.30	-0.02	-0.02	
10840	-318.00	1.50	0.	3.00	270.00	19.79	-0.02	-0.02	
10850	-322.00	1.50	0.	3.00	270.00	20.28	-0.02	-0.02	
10860	-326.00	1.50	0.	3.00	270.00	20.77	-0.02	-0.02	
10870	-330.00	1.50	0.	3.00	270.00	21.26	-0.02	-0.02	
10880	-334.00	1.50	0.	3.00	270.00	21.75	-0.02	-0.02	
10890	-338.00	1.50	0.	3.00	270.00	22.24	-0.02	-0.02	
10900	-342.00	1.50	0.	3.00	270.00	22.73	-0.02	-0.02	
10910	-346.00	1.50	0.	3.00	270.00	23.22	-0.02	-0.02	
10920	-350.00	1.50	0.	3.00	270.00	23.71	-0.02	-0.02	
10930	-354.00	1.50	0.	3.00	270.00	24.20	-0.02	-0.02	
10940	-358.00	1.50	0.	3.00	270.00	24.69	-0.02	-0.02	
10950	-362.00	1.50	0.	3.00	270.00	25.18	-0.02	-0.02	
10960	-366.00	1.50	0.	3.00	270.00	25.67	-0.02	-0.02	
10970	-370.00	1.50	0.	3.00	270.00	26.16	-0.02	-0.02	
10980	-374.00	1.50	0.	3.00	270.00	26.65	-0.02	-0.02	
10990	-378.00	1.50	0.	3.00	270.00	27.14	-0.02	-0.02	
11000	-382.00	1.50	0.	3.00	270.00	27.63	-0.02	-0.02	
11010	-386.00	1.50	0.	3.00	270.00	28.12	-0.02	-0.02	
11020	-390.00	1.50	0.	3.00	270.00	28.61	-0.02	-0.02	
11030	-394.00	1.50	0.	3.00	270.00	29.10	-0.02	-0.02	
11040	-398.00	1.50	0.	3.00	270.00	29.59	-0.02	-0.02	
11050	-402.00	1.50	0.	3.00	270.00	30.08	-0.02	-0.02	
11060	-406.00	1.50	0.	3.00	270.00	30.57	-0.02	-0.02	
11070	-410.00	1.50	0.	3.00	270.00	31.06	-0.02	-0.02	
11080	-414.00	1.50	0.	3.00	270.00	31.55	-0.02	-0.02	
11090	-418.00	1.50	0.	3.00	270.00	32.04	-0.02	-0.02	
11100	-422.00	1.50	0.	3.00	270.00	32.53	-0.02	-0.02	
11110	-426.00	1.50	0.	3.00	270.00	33.02	-0.02	-0.02	
11120	-430.00	1.50	0.	3.00	270.00	33.51	-0.02	-0.02	
11130	-434.00	1.50	0.	3.00	270.00	34.00	-0.02	-0.02	
11140	-438.00	1.50	0.	3.00	270.00	34.49	-0.02	-0.02	
11150	-442.00	1.50	0.	3.00	270.00	34.98	-0.02	-0.02	
11160	-446.00	1.50	0.	3.00	270.00	35.47	-0.02	-0.02	
11170	-450.00	1.50	0.	3.00	270.00	35.96	-0.02	-0.02	
11180	-454.00	1.50	0.	3.00	270.00	36.45	-0.02	-0.02	
11190	-458.00	1.50	0.	3.00	270.00	36.94	-0.02	-0.02	
11200	-462.00	1.50	0.	3.00	270.00	37.43	-0.02	-0.02	
11210	-466.00	1.50	0.	3.00	270.00	37.92	-0.02	-0.02	
11220	-470.00	1.50	0.	3.00	270.00	38.41	-0.02	-0.02	
11230	-474.00	1.50	0.	3.00	270.00	38.90	-0.02	-0.02	
11240	-478.00	1.50	0.	3.00	270.00	39.39	-0.02	-0.02	
11250	-482.00	1.50	0.	3.00	270.00	39.88	-0.02	-0.02	
11260	-486.00	1.50	0.	3.00	270.00	40.37	-0.02	-0.02	
11270	-490.00	1.50	0.	3.00	270.00	40.86	-0.02	-0.02	
11280	-494.00	1.50	0.	3.00	270.00	41.35	-0.02	-0.02	
11290	-498.00	1.50	0.	3.00	270.00	41.84	-0.02	-0.02	
11300	-502.00	1.50	0.	3.00	270.00	42.33	-0.02	-0.02	
11310	-506.00	1.50	0.	3.00	270.00	42.82	-0.02	-0.02	
11320	-510.00	1.50	0.	3.00	270.00	43.31	-0.02	-0.02	
11330									

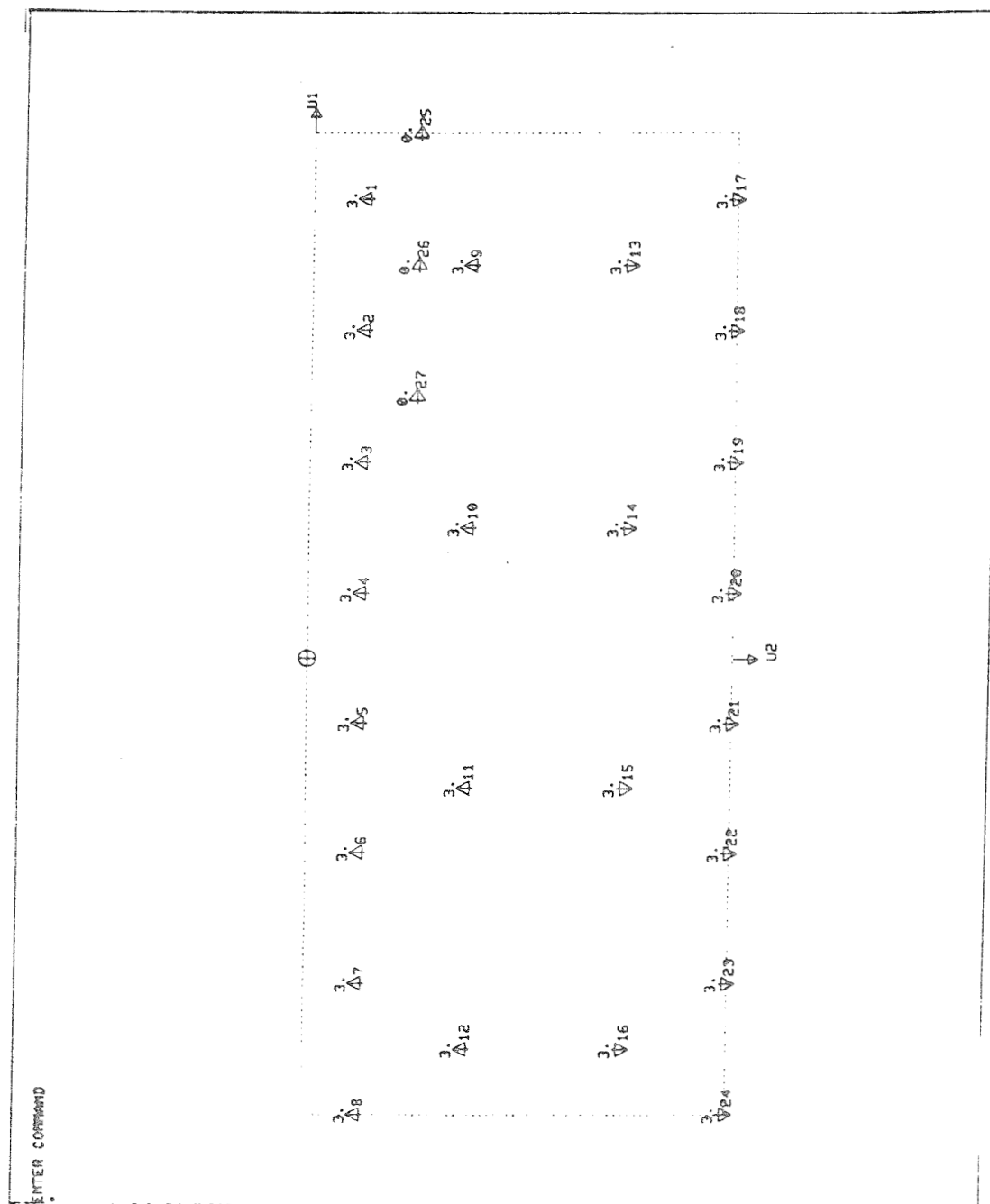


Figure B1. Display of pile numbers, locations, and batter. Enter command GEOM to obtain this diagram

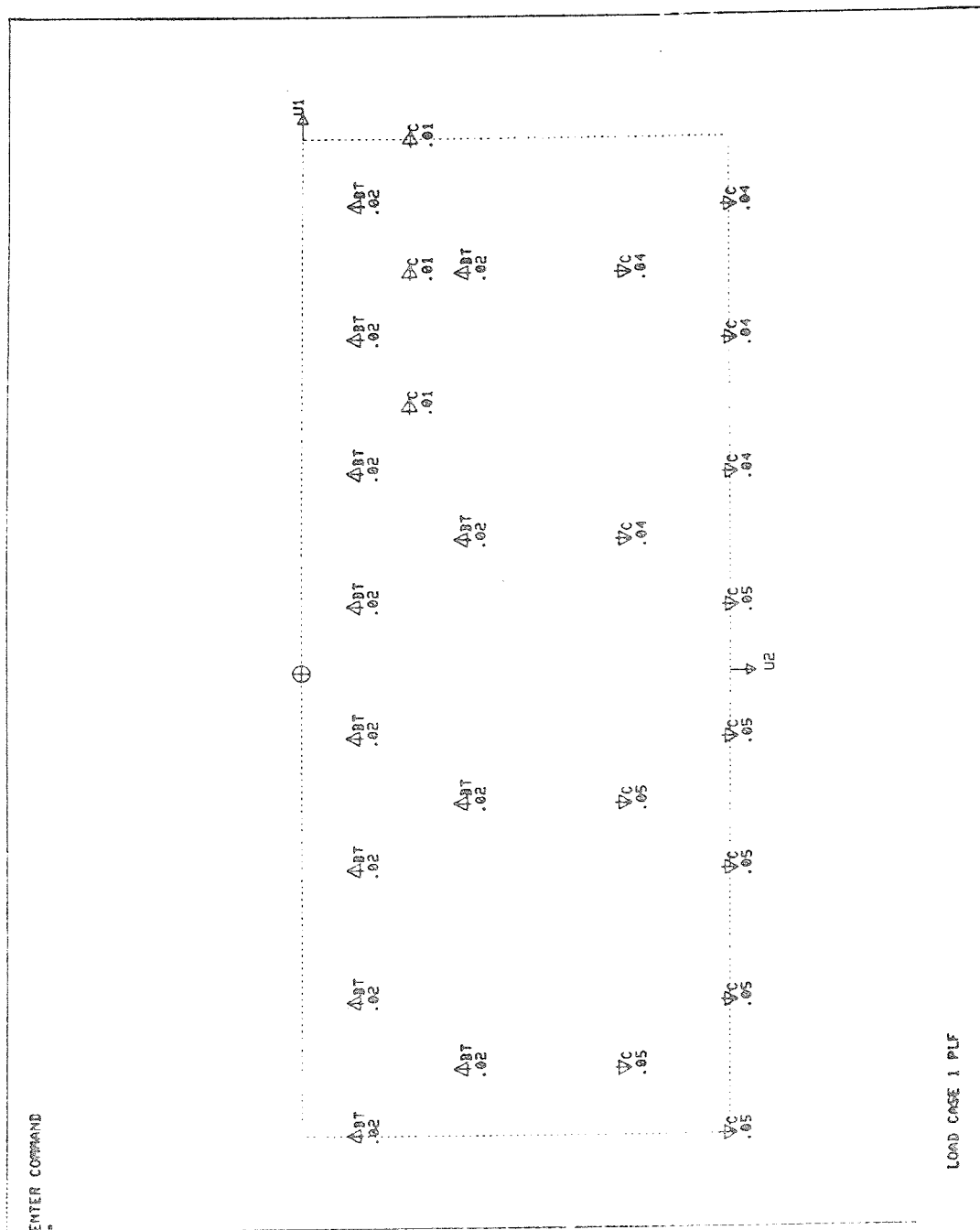


Figure B3. Display of the pile load factor and the PLF flag for each pile, for the current load case. Enter command PLF to obtain this diagram

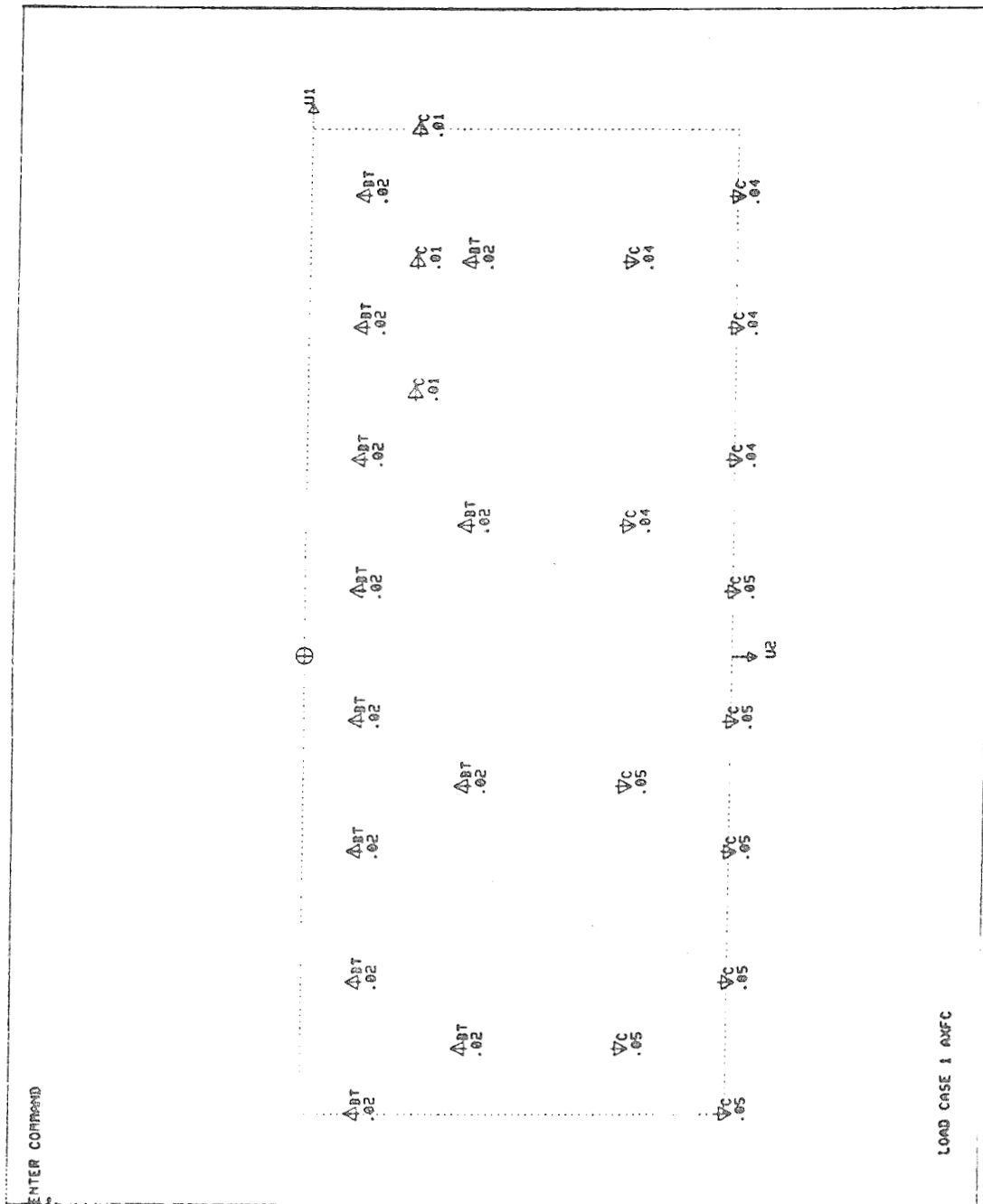


Figure B4. Display of the axial factor and the pile load factor flag for each pile, for the current load case. Enter the command AXFC to obtain this diagram

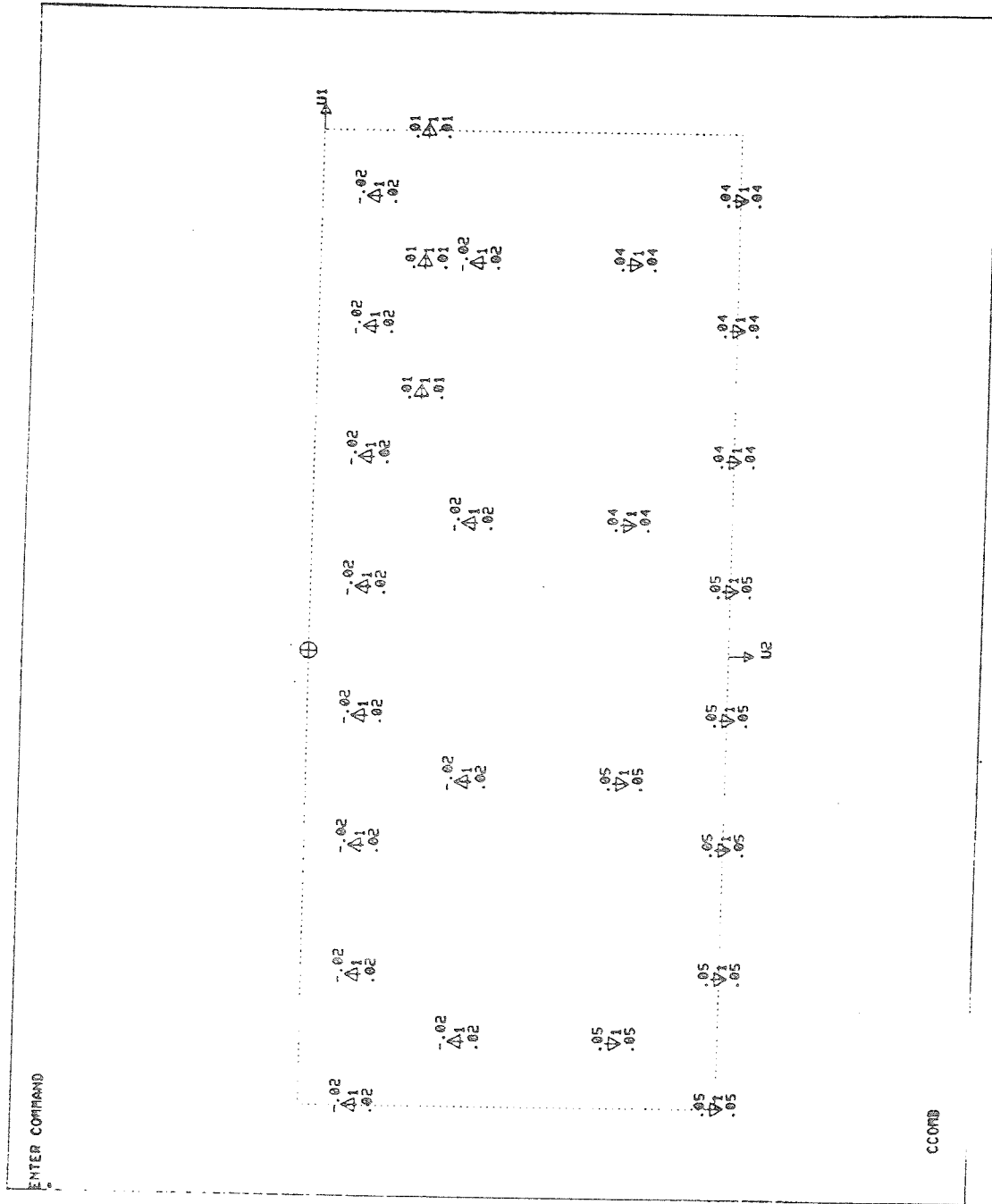


Figure B6. Display of the critical combined bending factor for all load cases and the critical load case numbers, for all piles. Enter the command CCOMB to obtain this diagram



Figure B7. Display of the critical pile load factor for all load cases and the critical load case number, for each pile. Enter the command CPLF to obtain this diagram

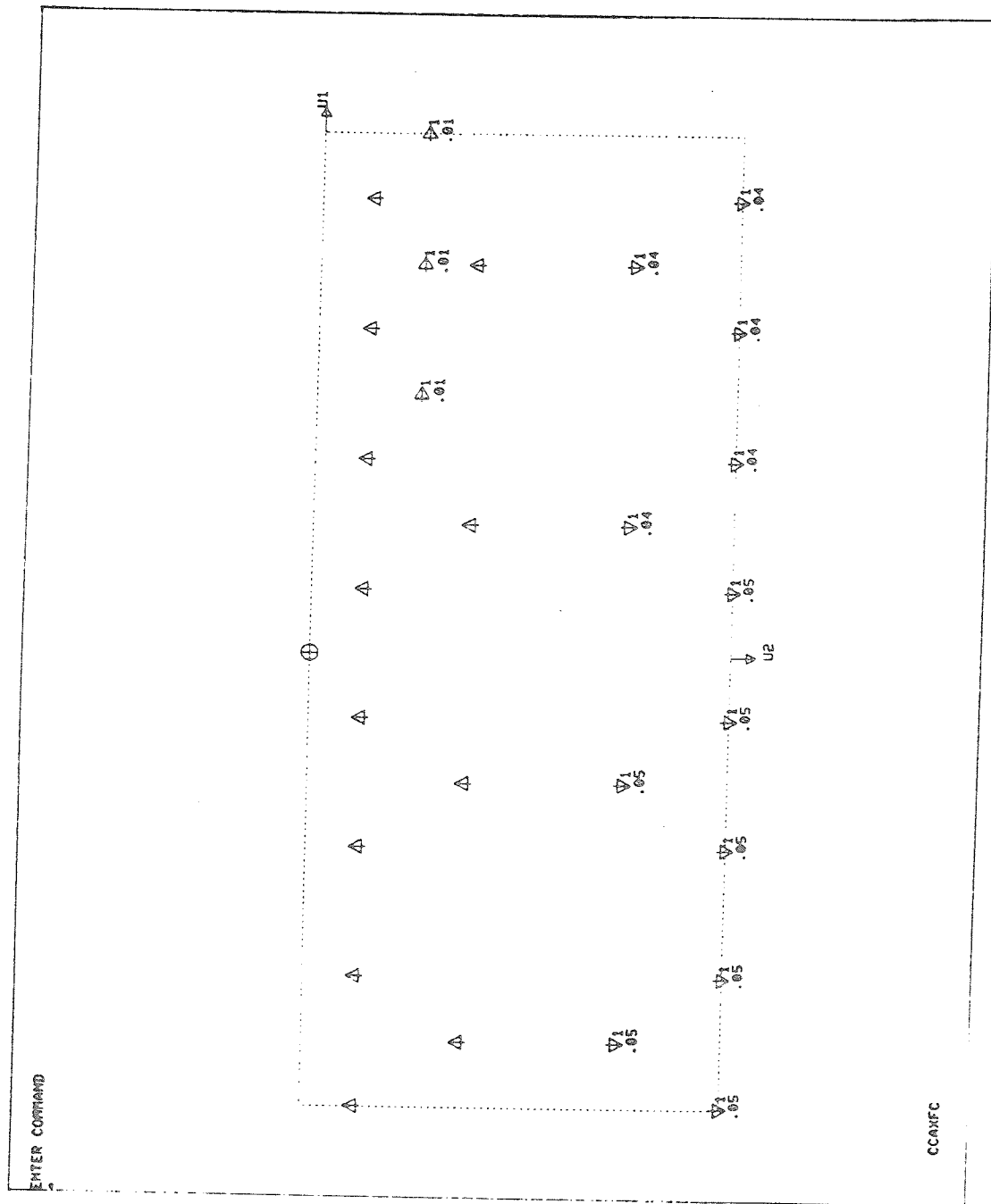




Figure B9. Display of the critical axial factor for all load cases and the critical load case number for each pile in tension. Enter the command CTAXFX to obtain this diagram

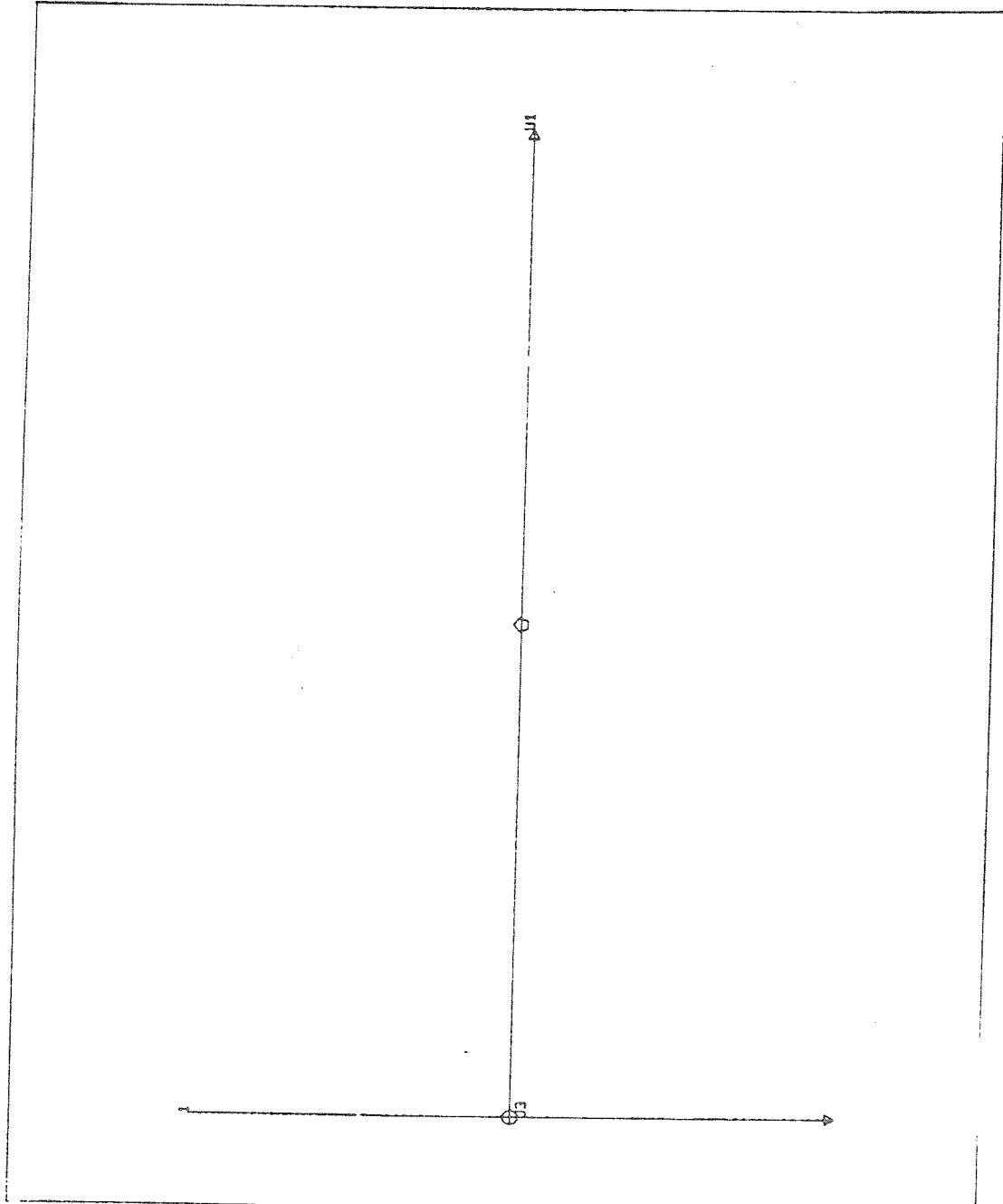


Figure B10. Display of the elastic center and the resultant force for load case one in the U1-U3 plane. Enter the command ELCEN to obtain this diagram and the ones shown in Figures B11 and B12

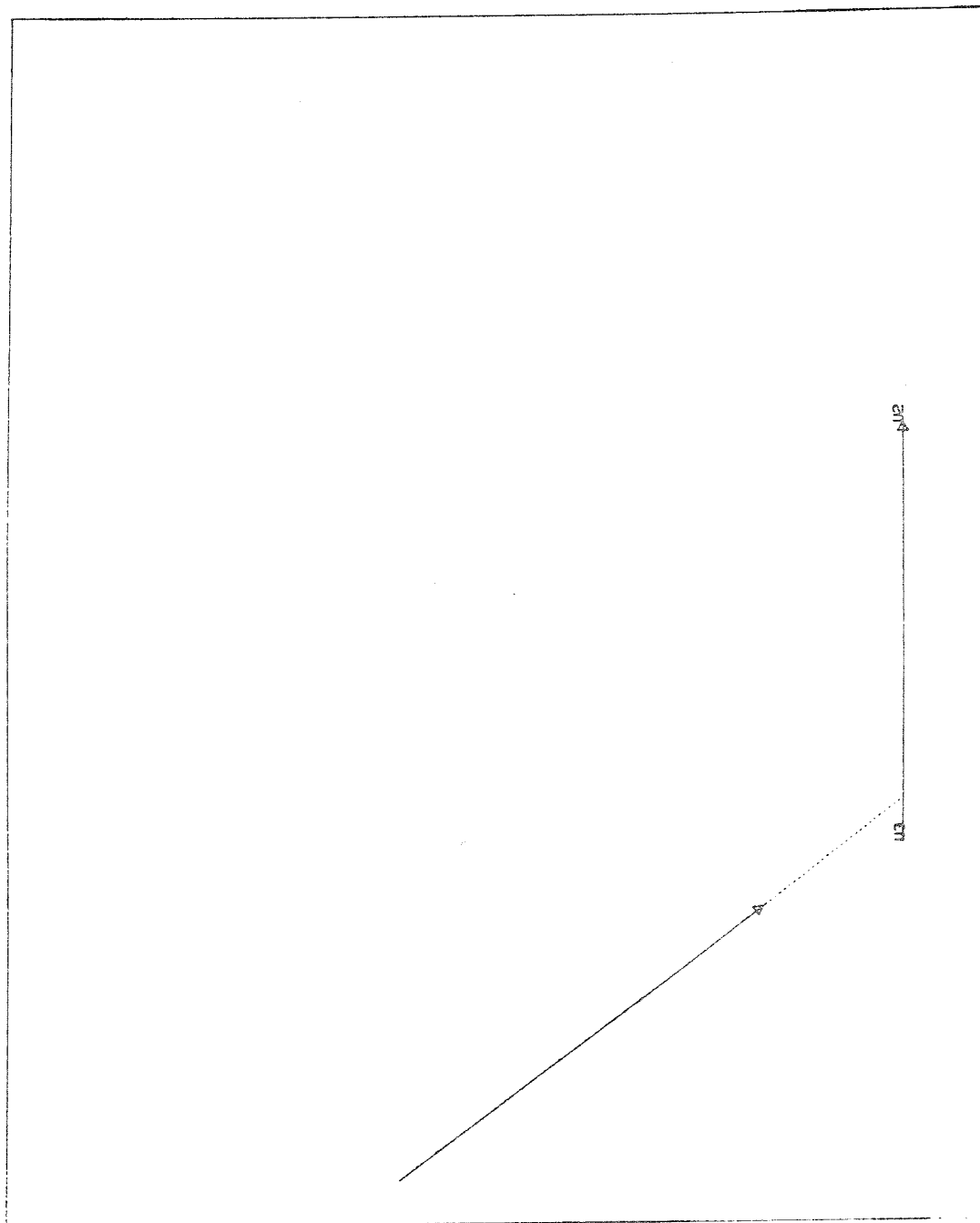


Figure B11. Display of the elastic center and resultant forces for load case one in the U2-U3 plane. Enter command ELCEM to obtain this diagram and the ones in Figures B10 and B12

ENTER COMMAND
.

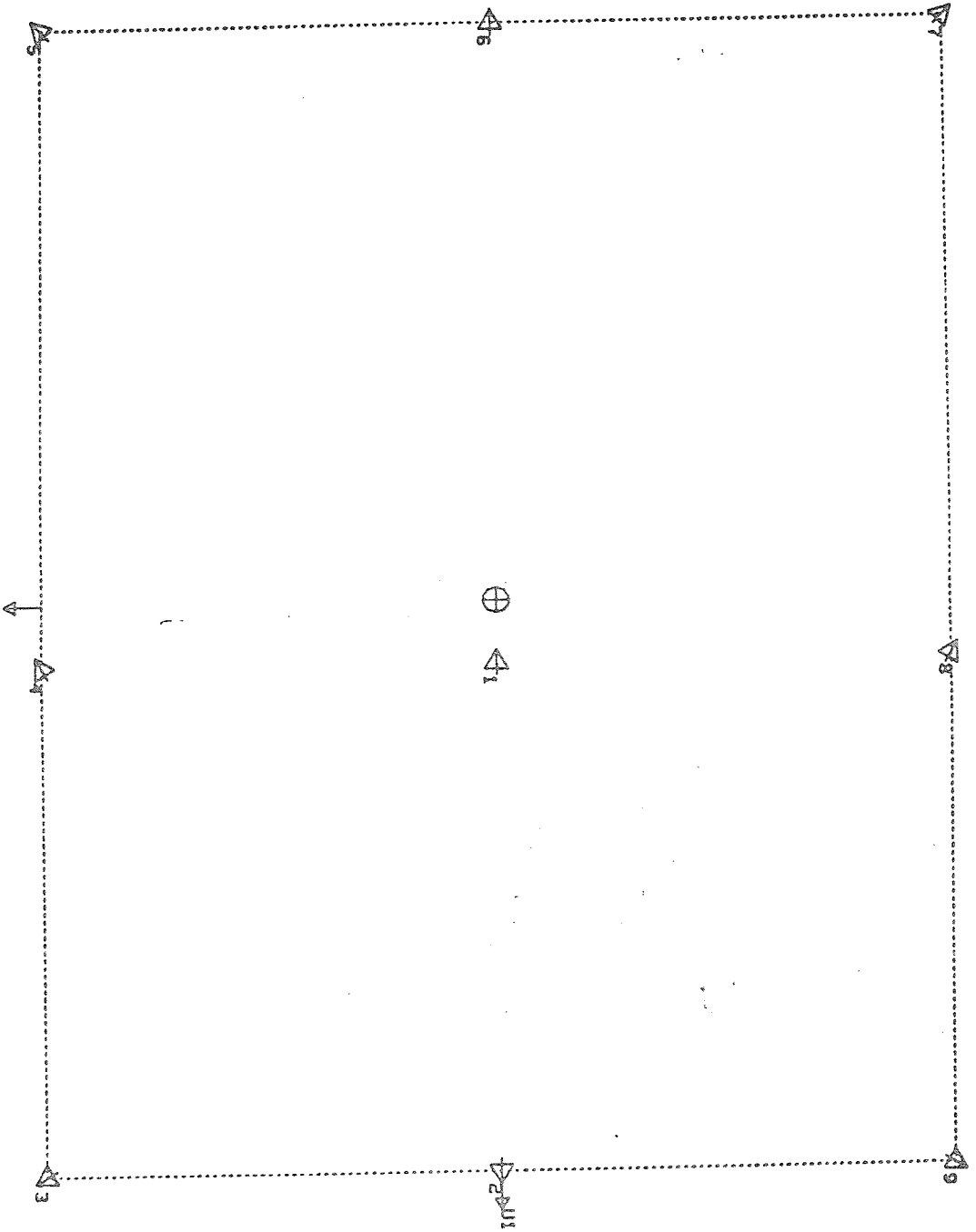
RESULTANT FORCE DIAGRAMS SUMMARY

LC	01	03	OR	U1
1	0.	344.90	344.90	0.
LC	02	03	OR	U2
1	276.96	344.90	442.34	15.33

Figure B12. Display of the summary of the resultant force diagrams. Enter command ELCEN to obtain this diagram and the ones in Figures B10 and B11

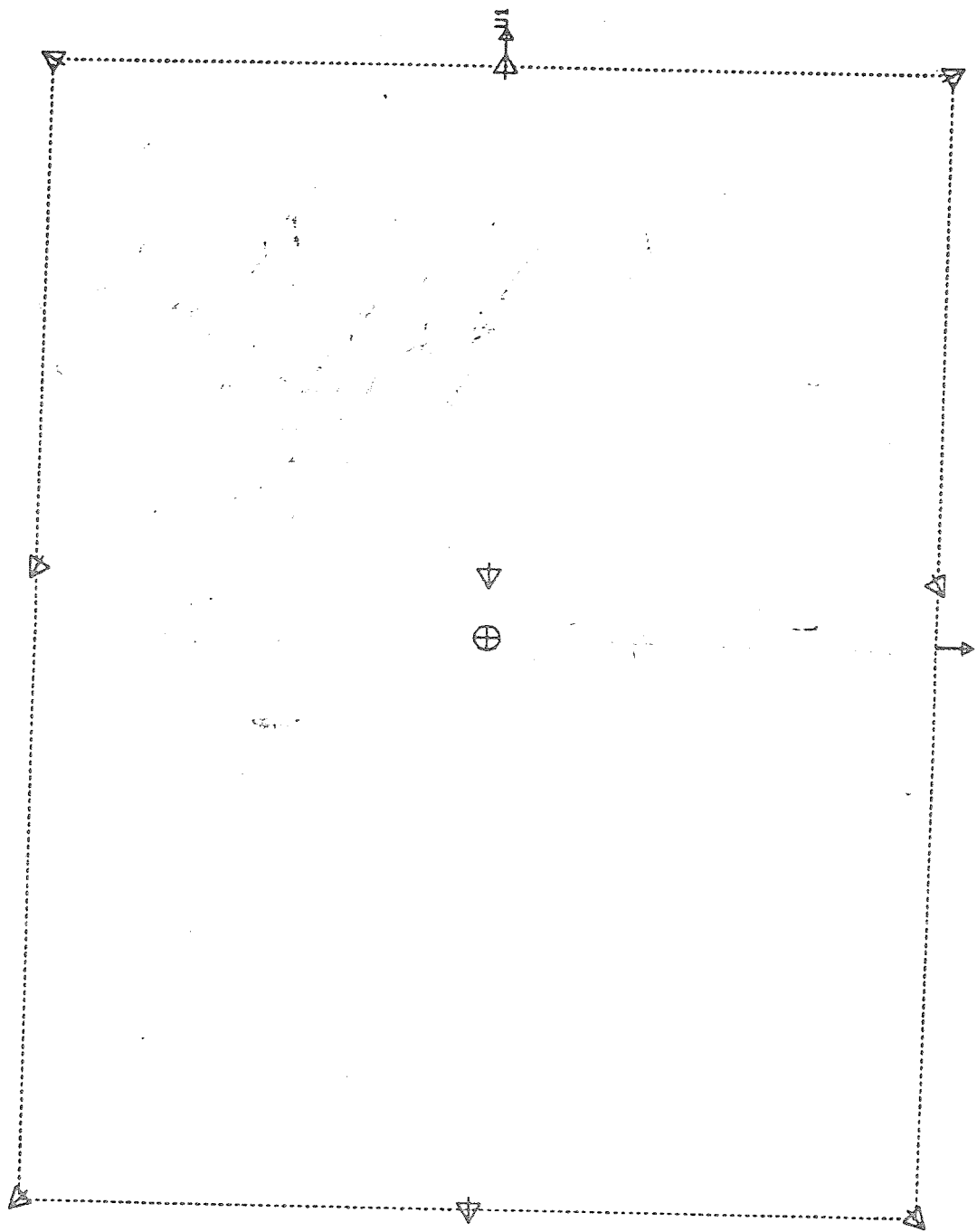
ENTER COMMAND

5UGAR = + pile numbers



ENTER COMMAND

PLAIN



ENTER COMMAND

ICADs = + pole numbers & letters

