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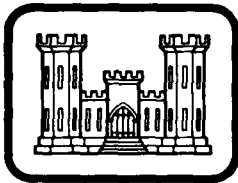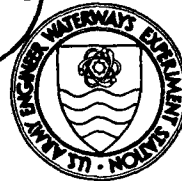
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INSTRUCTION REPORT K-81-4

USER'S GUIDE: COMPUTER PROGRAM FOR DESIGN AND ANALYSIS OF CAST-IN-PLACE TUNNEL LININGS (NEWTUN)

by

William J. Holtham and James R. Fay

U. S. Army Engineer Division, New England
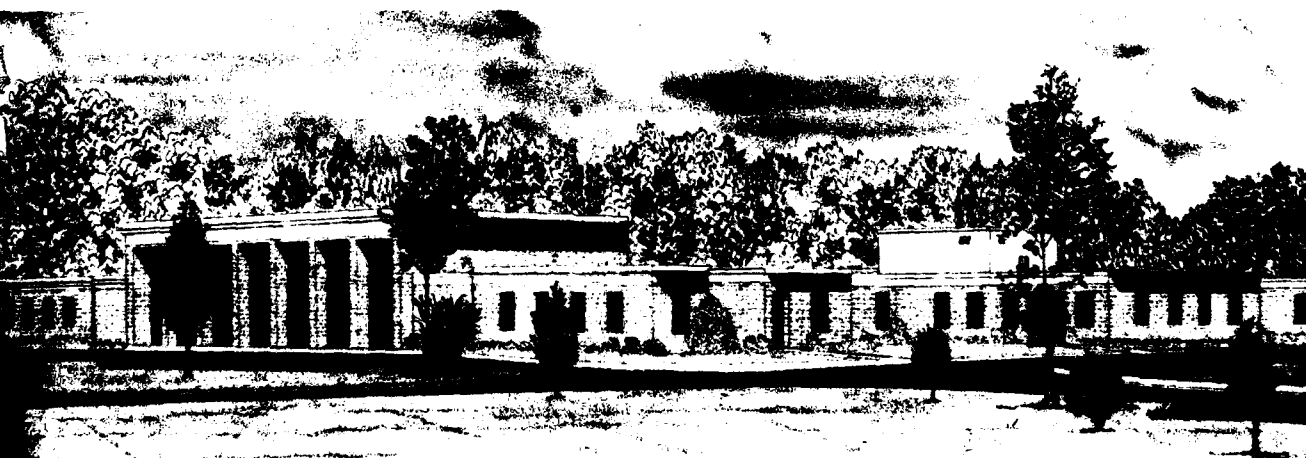424 Trapelo Road, Waltham, Mass. 02154

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March 1981

Final Report

A report under the Computer-Aided Structural Engineering (CASE) Project

Approved For Public Release; Distribution Unlimited

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

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

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DEPARTMENT OF THE ARMY
OFFICE OF THE CHIEF OF ENGINEERS
WASHINGTON, D.C. 20314

REPLY TO
ATTENTION OF:

DAEN-CWE-DS

25 March 1981

SUBJECT: Instruction Report K-81-4, User's Guide: Computer Program for
Design and Analysis of Cast-In-Place Tunnel Linings (NEWTUN)

All Corps Elements with Civil Works Responsibilities

1. The subject user's guide documents a computer program named NEWTUN that
can be used for designing and reviewing cast-in-place tunnel linings. The
program was originally developed by the New England Division using funds
provided by the Civil Works Directorate; Office, Chief of Engineers. Although
this effort was not directly part of the Computer-Aided Structural Engineering
(CASE) project, this report is being published under the CASE banner because
its subject matter is consistent with the goals and objectives of the CASE
project. As is the goal with all CASE projects, the intent is to provide
an organized, cost-effective approach by making available to the structural
engineer applicable computer programs ready for use when the design need
arises.

2. Structural engineers will be readily able to tell by the description
of the programs and by the examples given in the report of the applicability
toward their needs. Detailed documentation of the programs may be obtained
from the Engineering Computer Programs Library (ECPL) of the U. S. Army
Engineer Waterways Experiment Station (WES), Vicksburg, MS.

3. We strongly encourage the use of this program where applicable throughout
the Corps.

FOR THE CHIEF OF ENGINEERS:

LLOYD A. DUSCHA, P.E.
Chief, Engineering Division
Directorate of Civil Works

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
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18. SUPPLEMENTARY NOTES

This report was prepared under the Computer-Aided Structural Engineering (CASE) Project. A list of published CASE reports is printed on the inside of the back cover.

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

Computer applications	Structural analysis
Computer programs	Tunnels
NEWTUN (Computer program)	

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

This user's guide describes and gives instructions for using the computer program NEWTUN. The purpose of NEWTUN is to analyze tunnels with continuous cross section. NEWTUN is a revision of an existing general-purpose program called EFFRAM which analyzes plane frame structures on elastic foundations. This interactive computer program uses the stiffness method of structural analysis and the theory of beam elements on an elastic foundation. The program is part of the Conversationally Oriented Real-Time Program-

(Continued)

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20. ABSTRACT (Continued)

Generating System (CORPS), a Corps-wide time-sharing program library sponsored
by the Office, Chief of Engineers, and managed by the Computer Applications
Groups, ADP Center, Waterways Experiment Station.

Preface

This report documents a computer program called NEWTUN that could be useful for the design and analysis of cast-in-place tunnel linings. The program is a modification of an existing general-purpose frame analysis program called EFFRAM. This report also describes a procedure for performing a tunnel lining analysis.

The program was developed by Messrs. William J. Holtham and James R. Fay of the U. S. Army Engineer Division, New England, using funds provided directly by the Civil Works Directorate, Office, Chief of Engineers (OCE). Mr. Robert J. Smith, Chief, Structural Section, Civil Works Directorate, reviewed the work and was the OCE point of contact.

OCE also provided funds to the Automatic Data Processing (ADP) Center, U. S. Army Engineer Waterways Experiment Station (WES), to monitor the work and publish this report. Dr. N. Radhakrishnan, Special Technical Assistant, ADP Center, and Mr. H. Wayne Jones, Computer-Aided Design Group, ADP Center, monitored the work and reviewed this report. Mr. Donald L. Neumann was Chief of the ADP Center.

Although this effort was not part of the Computer-Aided Structural Engineering (CASE) Project currently being funded by OCE, this report is published under that banner because its subject matter is relevant to the CASE Project.

Directors of WES during the period of development and the publication of this report were COL J. L. Cannon, CE, and COL N. P. Conover, CE. Technical Director was Mr. F. R. Brown.

Contents

Conversion Factors, Inch-Pound to Metric (SI)
Units of Measurement

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

Multiply	By	To Obtain
cubic inches	16.387064	cubic centimetres
feet	0.3048	metres
inches	2.54	centimetres
kips (1000 lb force)	4.448222	kilonewtons
foot-kips (force)	1.355818	kilonewton-metres
kips (force) per cubic foot	157.087477	kilopascals per metre
kips (force) per foot	14.593904	kilonewtons per metre
kips (force) per square foot	47.880263	kilopascals
pounds (force) per square inch	6.894757	kilopascals
tons (2000 lb force) per foot	29.187808	kilonewtons

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM	PROGRAM NO.
NEWTUN--Design and Analysis of Cast-in-Place Tunnel Linings	713 F7 D0063

PREPARING AGENCY

U. S. Army Engineer Division, New England

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM	
William J. Holtham	November 1979	PHASE	STAGE
James R. Fay			

A. PURPOSE OF PROGRAM

The program computes joint deflections and member end forces for continuous
tunnel linings which are subjected to joint loads and joint displacements.
The tunnel lining to be analyzed may be founded in an elastic medium. The
program will compute the external pressure on the lining and
will perform iterations to remove tension in the analogous spring loading,
if desired.

B. PROGRAM SPECIFICATIONS

The program is restricted to 75 members and 55 nodal points.
The maximum nodal point difference is 10.

C. METHODS

Finite element techniques utilizing the direct stiffness method of matrix
analysis are the basis for the program. The elastic medium theory is based
on Winkler's comcept of analogous springs.

D. EQUIPMENT DETAILS

The program is written in FORTRAN IV and operates on Honeywell 6000 Series
computers and the Boeing CDC CYBER 175 system.

E. INPUT-OUTPUT

Input allows computations for any number of sections with any number of load-
ings. Output provides a listing of descriptive data for the plane frame, joint
displacements, external pressures with location of compression and tension
zones, and member end forces. Input can be in the conversational mode and can
be manipulated along with output through a terminal or through data files. The
program has the capability of generating nodal points, elements, and element
loads.

F. ADDITIONAL REMARKS
1. Handles variable rock conditions.
2. External springs can be placed on any element.
3. External springs can have one- or two-way action.
4. External springs can be located on either side of the element by reversal
    of the I and J node numbers.
5. The program is part of the CORPS system maintained by the WES ADP Center on
    the WES, Macon, and Boeing computers.

WES _{FORM} 2205   REPLACES ENG FORM 2883 WHICH IS OBSOLETE.

USER'S GUIDE: COMPUTER PROGRAM FOR DESIGN AND ANALYSIS

OF CAST-IN-PLACE TUNNEL LININGS (NEWTUN)

Introduction

1. The purpose of this user's guide is to demonstrate the use of
NEWTUN,* a computer program that can be used to analyze tunnels with a
continuous cross section. NEWTUN is a revision of an existing general-
purpose program called EFFRAM** which iteratively analyzes plane frame
structures on elastic foundations. The documentation for EFFRAM is avail-
able from the Engineering Computer Program Library (ECPL) of the U. S.
Army Engineer Waterways Experiment Station (WES). The documentation ex-
plains the program's method of solution, the stiffness method of struc-
tural analysis, and the theory for beam elements on an elastic founda-
tion. Excerpts from the EFFRAM documentation are included in Appendix A
to this report. The main text contains information pertaining to tunnel
applications and data preparation.

2. A lined tunnel is a frame structure surrounded by an elastic
medium; thus, it lends itself to analysis by EFFRAM. NEWTUN has many in-
put options and can handle any shape tunnel constructed in an elastic mate-
rial. Unlike some mathematical models, NEWTUN has springs over the entire
length of an element to simulate the subgrade modulus of the foundation
material. (For tunnels in rock, the subgrade modulus is referred to as
the rock modulus.)

3. There are a few characteristics of the program that should be
mentioned for tunnel application. The first consideration is the ar-
rangement of nodal points and elements. For symmetrically shaped and
loaded tunnels, it is useful to model only half the structure using
appropriate end restraints. The example problems in Appendix B demon-
strate this technique. Of course, the entire structure can be modeled;

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however, it will be necessary to have one node restrained in either the global X or Y direction or else erroneous displacements will occur. Using more nodes and elements will increase the accuracy of the results. The program has node generating capability; however, at present circular segments cannot be generated. Certain load types should be used for various loading conditions. For hydrostatic loads on curved linings, nodal point loads should be used by replacing the resultant load with its global X and Y components. Element loads and loads that vary linearly or uniformly can be used on straight-line segments. The use of lineraly distributed element loads on curved sections should be avoided.

4. NEWTUN does have some limitations. Any discontinuous lining (e.g., a precast segmental concrete lining) cannot be modeled because it is not possible to insert a hinge within a section. It should be noted that, when a precast tunnel lining is grouted after being placed, it can act as a continuous lining until it is subjected to loads that may crack the grout in a segment joint.

General Description for Tunnel Analysis

5. This section will highlight the information in Engineer Manual 1110-2-2901 (Headquarters, Department of the Army 1978) that is essential for modeling continuous tunnel lining. Discussion will be confined to tunnels in rock. Two variables that have a profound effect on the usefulness of this program for tunnels in rock are the rock load on the lining and the rock modulus. These items are discussed in EM 1110-2-2901. Several factors to be considered are presented in Chapter 3, "Design," of the EM. It is suggested that the user become familiar with the contents of this reference and he exercise keen engineering judgment when analyzing a tunnel lining.

6. There are many factors to consider when studying a tunnel problem. A thorough examination of the geologic conditions is important if a representative model is to be made. Rock conditions are described in EM 1110-2-2901 in paragraph 2-4, "Interpretation of Geologic Data." Rock loads based on the general rock condition are outlined in Table 3-1, "Estimate of Rock Load," of the EM. These values should be used

only for preliminary designs; the final design should incorporate values obtained from District geologists. Unlike many other types of structures, there are no standard loading conditions to be applied to tunnels. An explanation of the possible loads acting on a lining is found in EM 1110-2-2901 in paragraph 3-7, "Permanent Tunnel Linings." The list of general design conditions in subparagraph 3-7.b(8), "Design Guidance," is a guide and it is likely that more load conditions may be induced for a particular tunnel.

7. NEWTUN is an attractive tunnel analysis program because it has an option that permits simulating the actual rock mass conditions by inputting the rock modulus. The rock modulus used in NEWTUN is applied over an entire element, not just at the nodes. (See Appendix A for the theory of the program and the elastic supports.) This feature results in an accurate simulation of the in situ conditions provided an adequate rock modulus is determined. An extensive treatment of selecting rock modulus is presented in EM 1110-2-2901 in subparagraph 3-7b(6), "Method for Determining Value of Foundation," and in paragraph 7.2.2, "Supplementary Comments on Significant Geological and Mechanical Properties." It is possible under some circumstances to have a rock modulus that varies around the lining. There are other computer programs and theories to assist the user in such situations.

Preparation of Data

8. The frame geometry is defined by numbering each nodal point and each frame member. No restrictions are imposed on the pattern of nodal point or member numbering systems. However, the total number of nodal points cannot exceed 55, with the maximum difference between member nodal points of 10. The total number of members is restricted to 75.

9. All nodal point coordinates are given in the global system (Figure 1) and must be positive. Assuming the paper acts as the global plane, the X axis is horizontal and the Y axis is vertical. The input sign convention for loads calls for positive horizontal forces to the
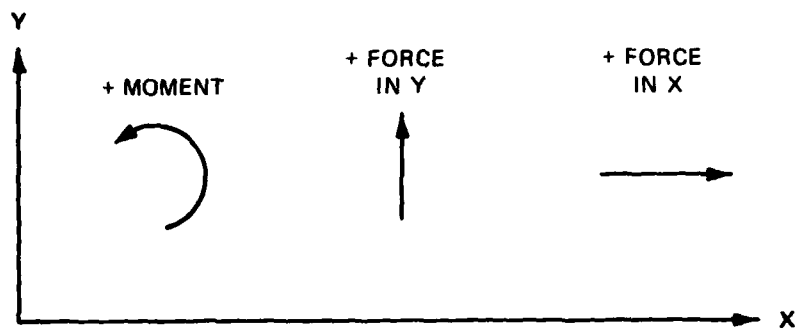
Figure 1. Global coordinate system

right, positive vertic··' forces upwards, and positive moments counterclockwise.

10. The boundary conditions are then determined in global coordinates. The type of restraint provided at each nodal point for the X direction, Y direction, and rotation is described using a three-digit code (see Figure 2). A zero (0) indicates that that node is free to move in the specified direction and that a load is to be specified at
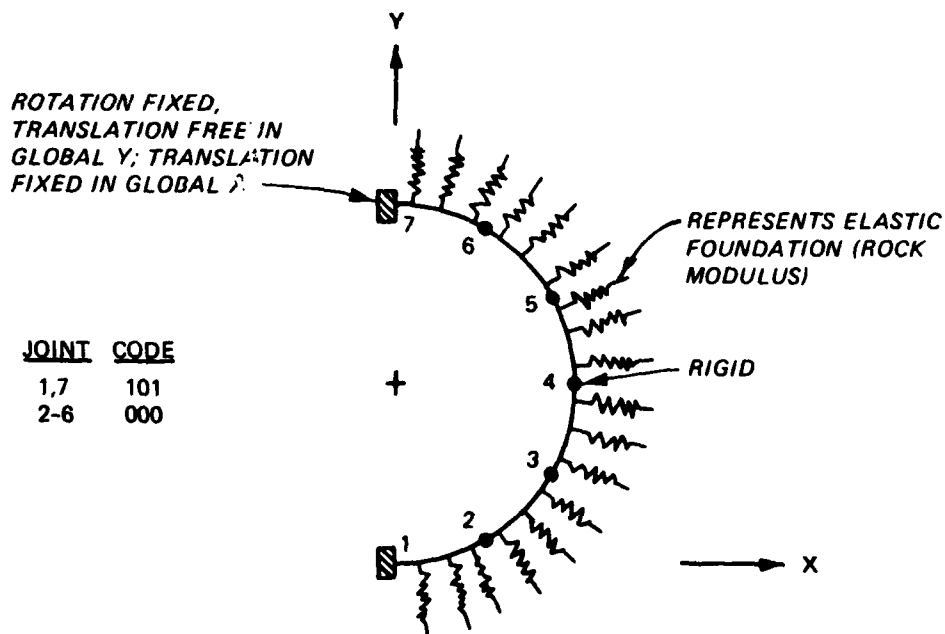
Figure 2. Typical nodal point restraint codes

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the node. A one (1) indicates that the node is fixed in the correspond-
ing direction and that a displacement and/or rotation is to be specified
at the node.

11. The program allows both nodal point loads and element loads
to be entered as data. Nodal point loads include a force in the X and
Y directions and a moment about the node. The sign convention is shown
in Figure 1. The element loads are of the following types:

      a. Type 1: concentrated load.

      b. Type 2: uniformly distributed load.

      c. Type 3: concentrated moment.

      d. Type 4: triangular distributed load.

as shown in Figure 3.
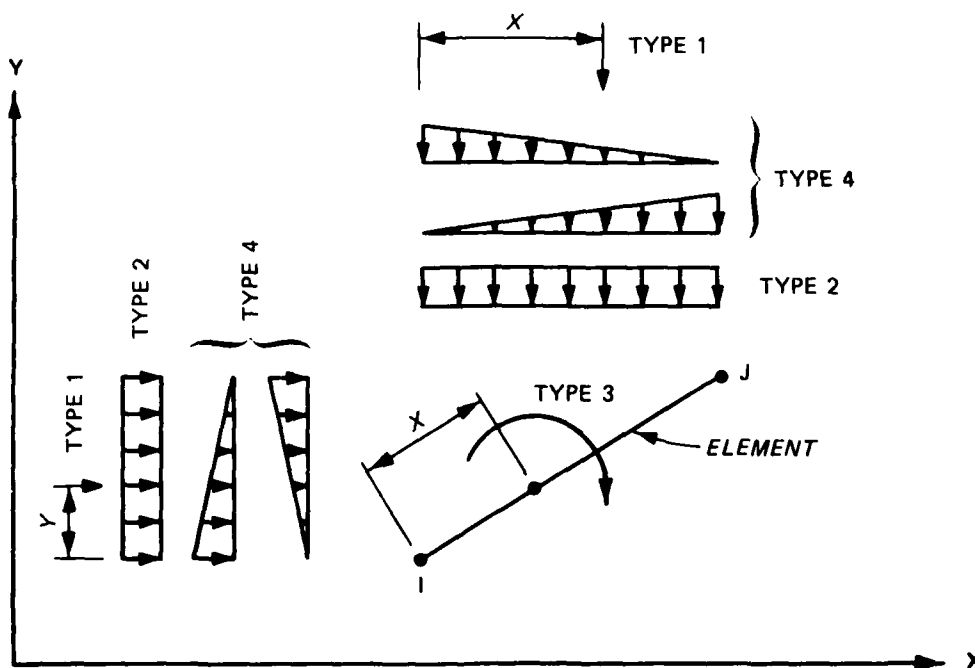
Figure 3. Element loads

Guide for Data Input

12. Data are entered by groups in free field format in the order
shown below. Data may be entered in response to prompts given by the

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program* or by being typed into a data file which is read by the program. If a data file is used, it should have line numbers at the time it is read by the program.

Section title 1	A. Appears with section properties
Section title 2	A. Appears with section properties
Section title 3	A. Appears with section properties
Specification line 1	A. Number of nodal points B. Number of elements C. Number of loading conditions
Nodal point data (see paragraphs 13-15 for genera- tion of nodal point data)	A. Nodal point number B. Restraint code** C. X coordinate D. Y coordinate E. Displacement in X direction[†] F. Displacement in Y direction[†] G. Rotation about node (radians)[†]
Element data (see paragraphs 16-18 for generation of element property data)	A. Member number B. Node number on "I" end C. Node number on "J" end D. Smallest cross-sectional area of member E. Young's modulus (force/length^2) F. Foundation spring constant (force/ length^2)[††] G. Moment of inertia of cross section H. Relative flexural stiffness of end I when end J is fully fixed[∫]

(Continued)

* See Appendix B for example problems demonstrating the conversational mode of data input.

** This is a three-digit code. The first digit is for the X direction, the second digit is for the Y direction, and the third is for rotation.

= 0 if the load is to be specified or displacement is unknown

= 1 if restraint is to be specified

† This is specified only if the restraint code equals one in that direction.

†† Foundation spring = modulus of subgrade reaction (force/length^3) × width of element (length).

∫ For a prismatic member, enter 0 and the computer will compute the value.

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Element data (continued)	I. Relative flexural stiffness of end J when end I is fully fixed*
	J. Flexural carry-over factor from end I to end J*
Loading condition title line	A. Appears with loading and computation output only
Specification line 2	A. Number of nodal point load entries that follow
	B. NITER: = 0 , iterations to remove tension; = -1 , no iterations to remove tension
Nodal point load data	A. Nodal point number
	B. Force in X direction (global)**
	C. Force in Y direction (global)**
	D. Moment about node (global)**
Element load data (see paragraph 19 for generation of element loads)	A. Element number
	B. Load type code:
	= 1 concentrated load
	= 2 uniformly distributed load
	= 3 concentrated moment
	= 4 triangular distributed load
	C. Magnitude of load:
	for load types 1 and 3, total force on element
	for load type 2, force per unit length on element
	for load type 4, force per unit length on element at weighted end
	D. Location code:
	for load type 1, = global distance from I node to force†
	for load type 2, = 0
	for load type 3, = distance along element from I node to moment

(Continued)

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* For a prismatic member, enter 0 and the computer will compute the value.

** This is specified only if the restraint code at the node equals zero in that direction.

† Use global X distance with loads in global Y direction and global Y distance with loads in global X direction.

Element load data   D. Location code (continued):
(continued)
                               for load type 4,
                                 = 0 if node I is weighted
                                 = 1 if node J is weighted

                           E. Direction code:

                               for load types 1, 2, and 4
                               force direction code

                                 = 1 for Y axis
                                 = 2 for X axis

                               for load type 3 = 0

Specification line 3   A. Indicates end of member input

(At this point, repeat the procedure from the loading
condition title line if more than one loading condition
is to be analyzed; or repeat the procedure from section
title 1 if more than one section is to be analyzed.)

End of data   A. Type

                               $END

                           to terminate input data

Nodal point data generation

13. _Restrictions._ The nodal point data lines must be in in-
creasing order of nodal point numbers (1 to n).

14. _Generation._ Nodal point data generation occurs when
the difference between the nodal point number of the variable read and
that of the previous variable is greater than one. It should be noted
that:

   a. The restraint code and specified displacement of any
       generated nodal point is always equal to zero.

   b. The values of the X or Y coordinates of the generated
       node may increase or decrease. The increment is com-
       puted by taking the difference in the coordinates given
       and dividing by the number of elements to be generated.

Element property data generation

15. _Restrictions:_

   a. The element data lines must be in order of increasing
       element number (1 to n).

   b. If the subgrade modulus is to be generated in a linear
       distribution, the length of each element must be the
       same.

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16. <u>Generation.</u> Generation occurs when the difference in successive element numbers is greater than one. It should be noted that:

    <u>a</u>. The nodal point number of the I node and J node may increase or decrease between the numbers given. The increment is computed by taking the difference between the numbers given for the I and J nodes.

    <u>b</u>. The area, modulus of elasticity, moment of inertia, stiffness coefficients, and carry-over factors are set to those of the previous element.

    <u>c</u>. The modulus of subgrade reaction is generated linearly from the previous value to the given value. (Refer to the restriction in subparagraph 15b above.) The generated value is an average for the element. If the modulus distribution is triangular, the value given should be the largest value along the element. That value will be the average for the element.

Element load data generation
(load types 2 and 4)

17. <u>Restrictions:</u>

    <u>a</u>. The element number must be greater than 100. The number represents the beginning element and the final element the load is to be generated over.

    <u>b</u>. The elements need not be the same length since the lengths are computed from the coordinate values.

    <u>c</u>. For load type 4, the first part of the number represents the element from which the coordinate of the I node is taken. The last part represents the element from which the coordinate of the J node is taken.

    <u>d</u>. For load type 4, the I and J nodes must be on the same ends for all elements.

Program Diagnostics

18. The following are some programmed stops inside the program with appropriate messages to explain the errors which are encountered:

*** DATA ERROR - LTYPE INCORRECT, LOAD OMITTED ELEMENT _____ ***

The load type code entered is a number other than 1, 2, 3, or 4. This load is omitted from any computations.

*** ERROR - THE NODAL POINT DIFFERENCE AT BAR # IS = ____ -
    MAX DIFF = 10 ***

The nodal point difference, which determines the band width of the total
structure stiffness matrix, is greater than 10.

*** ITERATIONS HAVE NOT CONVERGED, MAX = 10 ***

The program is limited to 10 iterations to remove tension in the elastic
springs, and is dependent on the variation of the limits of integration.
If the limits vary by more than 0.05 length units, an iteration is
required.

References

Ashton, W. D. and Meyers, B. L. 1977. Notes on Direct Stiffness Analysis of Structural Systems, Ashton and Meyers Publishers, Rock Island, Ill.

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Headquarters, Department of the Army. 1978. "Design of Miscellaneous Structures: Tunnels and Shafts in Rock," Engineer Manual 1110-2-2901, Washington, D. C.

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Orenstein, G. S. 1973. "Computer Study of Steel Tunnel Supports," Technical Report C-73-2, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Terzaghi, K. 1955. "Evaluation of Coefficients of Subgrade Reaction," Geotechnique, Vol V, No. 1, pp 297-326.

Introduction

1. The "Plane Frame Analysis by Direct Stiffness" computer pro-
gram acquired from the Rock Island District (Ashton and Meyers 1977) and
subsequently revised by the New England Division provided a production-
oriented program for matrix analysis of frame structures. However, anal-
ysis is limited to those structures restrained in space by various types
of supports (i.e., fixed, pin, roller, etc.). Structural problems are
often encountered where the structure is founded on an elastic material.
The foundation reaction is dependent on both the stiffness of the struc-
ture and the elastic foundation. Eduard Winkler first presented a theo-
retical approach to the problem of elastic foundations in 1867. The
idealized foundation is analogous to an infinite number of independent
springs, where the elastic constant corresponds to the modulus of sub-
grade reaction of the foundation. The reaction stress is proportional
to the deflection. The "Beams on Elastic Foundations" program written
by Professor John T. Christian of MIT applied the elastic theory to pris-
matic beam elements.

2. EFFRAM combines and expands the analysis capabilities of each
program into a single program that can analyze frame structures on an
elastic foundation. In this program, no element need be on an elastic
foundation, but the option has been provided.

General Description

3. The plane frame is composed of members lying in one plane and
having axes of symmetry in that plane. The joints between the members
are considered as rigid connections. Forces and displacements acting on

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* Complete documentation of EFFRAM is given in Holtham and Fay and is
   available from the Engineering Computer Program Library (ECPL) of the
   U. S. Army Engineer Waterways Experiment Station.

the frame are in the plane of the frame. Each nodal point (joint) between elements (members) has three potential displacements. These three degrees of freedom consist of displacements along either of the global axes or rotation about the joint. For any one element, there are two nodal points, each having three degrees of freedom. These displacements are related to the applied member forces by the stiffness of the element and by the stiffness of the elastic foundation.

4. A frame member stiffness matrix (six simultaneous equations, each consisting of a force-stiffness-displacement relationship) can be established for each member in the structural system. The superposition of the individual member stiffness matrix provides the overall or total structure stiffness matrix. The solution follows once the total stiffness matrix is established.

Method of Solution

5. The method of solution used in EFFRAM begins with computation of the properties of the individual member stiffness matrix in the local coordinate system of the member. If the member is founded on an elastic foundation, the foundation stiffness matrix is computed and added to the member stiffness matrix. The new matrix is transferred to the assumed global coordinate system using a transformation matrix. The member stiffness in global coordinates must now be modified to account for specified boundary conditions consisting of specified displacements. Since finite element techniques allow the addition of the stiffness matrices, the displacement restraint need not be specified in the direction of the elastic foundation (perpendicular to the element). The modified frame element stiffness matrices are next added to form the total frame structure stiffness matrix which relates the structure displacements and the applied loads. This matrix is banded and symmetrical. It is necessary to store and operate on the band using a modified version of Gaussian elimination to determine the displacements. From this, the member forces and reaction stress of the elastic foundation are determined.

6. In the analogous springs of the Winkler model, the foundation properties are considered identical in tension and compression, thus implying that the foundation can support tensile stress. For most cases this is not a real assumption. In order to take into account the effects of beam uplift, an iterative process was developed whereby only those areas of the beam element in compression are used in computing the foundation stiffness matrix.

7. The foundation stiffness matrix is composed of a set of integral equations in terms of a dimensionless parameter. To find each term of the foundation matrix, the equations are evaluated over the limits of the compression areas in terms of this parameter. In the first analysis, the springs are on the total element. If tension areas occur, iterations are performed until the limits no longer change ($\pm$ 0.05 units).

8. Unusual circumstances may arise where the foundation will have two-way action (tension or compression). The program has an option which will allow this action.

Appendix B: Example Problems

1. Two example problems are presented in this appendix to illustrate the use of NEWTUN. Both examples model the tunnel of the Park River Auxiliary Conduit, Hartford, Conn. The tunnel is circular with a 22-ft inside diameter and a concrete liner 13 in. thick. The modulus of elasticity of the liner is 519,119 ksf, and the surrounding rock has a rock modulus of 1000 kcf. A 1-ft length of tunnel is used for the analysis.

2. Comparisons were made between NEWTUN and the method outlined in Engineer Manual 1110-2-2901 (Headquarters, Department of the Army 1978) and results from another program called TUNNEL (Orenstein 1973). Both comparisons showed favorable results.

Example Problem 1

3. A vertical rock load of 1 kip/ft is the only loading case used in this example (Figure B1). Included in this example are the loading

ROCK LOAD = 1 kip/ft

CONCRETE LINING:
f'_c = 4,000 psi
E = 519,119 kcf
A = 1.08 ft^2/ft
I = 0.106 ft^4

SHALE

22-ft ID

t = 13 in.
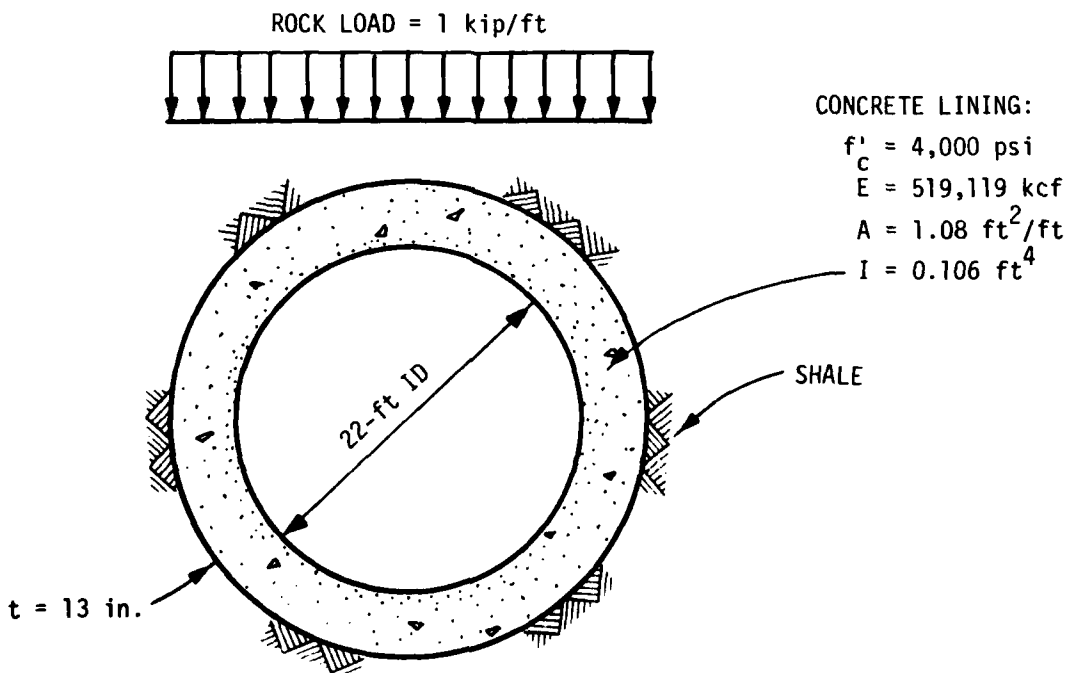
Figure B1. Physical problem treated in example 1

diagram, typical computer input and output, and results from NEWTUN.
Figure B2 shows the computer model; Figure B3 shows the rock modulus
computation. Table B1 gives a sample execution of the program with
conversational input. Table B2 shows the output from this run.

4. The vertical 1-kip/ft rock load is modeled as a set of concen-
trated loads applied at the nodal points. This is the normal method of
converting a distributed load to a set of concentrated (lumped) loads;
i.e.,
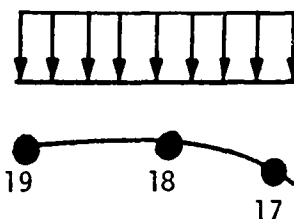
The applied load at any node is the sum of the load half way to each
adjacent node. For example, for node 18,

$$\text{left side} = 1/2 \left[1 \text{ kip/ft} \times (2.00 - 0.0)\right] = 1.00 \text{ kip}$$
$$+ \underline{\text{right side} = 1/2 \left[1 \text{ kip/ft} \times (3.95 - 2.0)\right] = 0.97 \text{ kip}}$$
$$\text{TOTAL} \qquad 1.97 \text{ kip}$$

For node 19,

$$\text{left side} = (\text{no load to left}) \qquad\qquad = 0.0 \text{ kip}$$
$$+ \underline{\text{right side} = 1/2 \left[1 \text{ kip/ft} \times (2.00 - 0.0)\right] = 1.00 \text{ kip}}$$
$$\text{TOTAL} \qquad 1.00 \text{ kip}$$

The remaining nodal loads can be calculated using this same procedure.

NODE	RESTRAINT CODE	X COORDINATE	Y COORDINATE
1	101	0.00	0.00
2	0	2.00	0.18
3	0	3.95	0.70
4	0	5.77	1.55
5	0	7.42	2.70
6	0	8.84	4.12
7	0	10.00	5.77
8	0	10.85	7.59
9	0	11.37	9.54
10	0	11.54	11.54
11	0	11.37	13.55
12	0	10.85	15.49
13	0	10.00	17.31
14	0	8.84	18.96
15	0	7.42	20.38
16	0	5.77	21.54
17	0	3.95	22.39
18	0	2.00	22.91
19	101	0.00	23.08
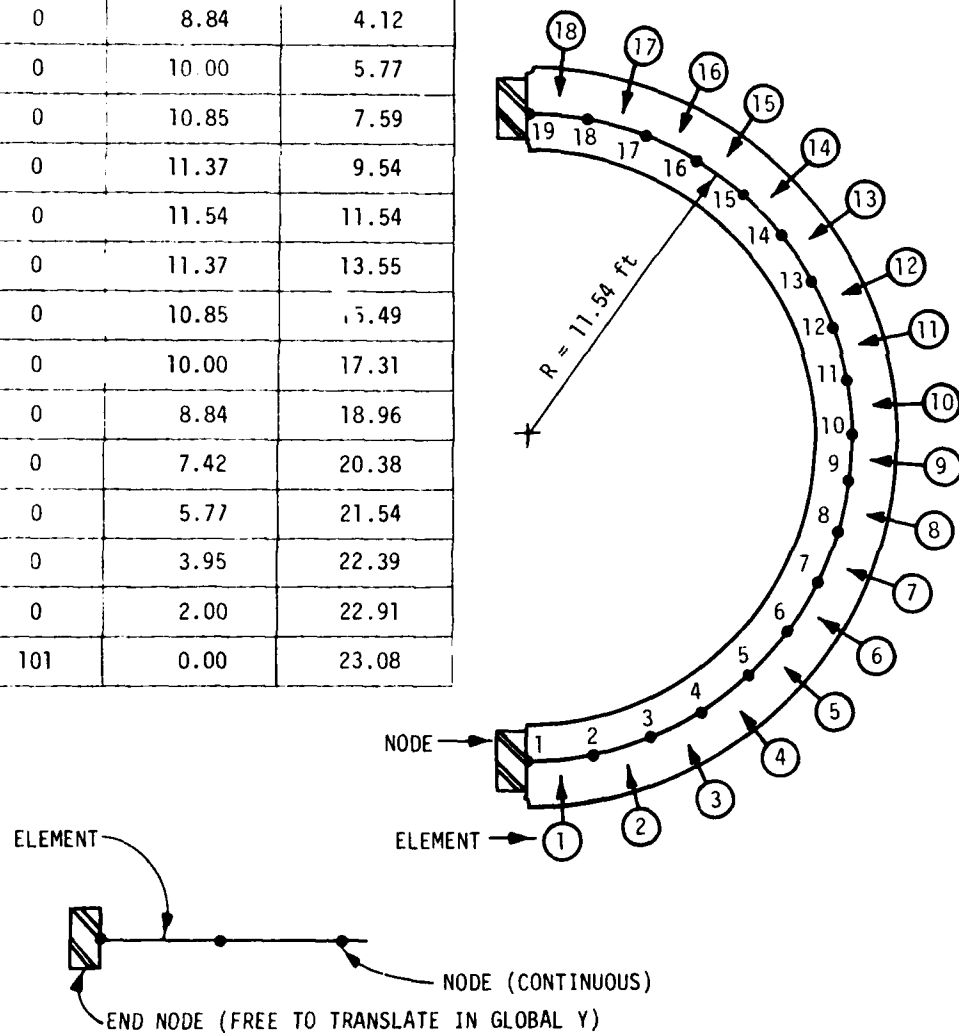
Figure B2.   Computer model for example 1

GIVEN:

Elastic Modulus = E_r = 1000 ksi   ⎱ obtained
                                       ⎰ from lab
Rock Quality Designation = RQD = 0.85   ⎰ tests

FIND:

Rock Modulus = k

from Figure 7.2, page K-123 of EM 1110-2-2901,

the Modulus Reduction Factor $\frac{E}{E_r}$ = 0.22

where   E = elastic modulus of rock mass
        E_r = elastic modulus of rock material

therefore, if

$$\frac{E}{E_r} = 0.22$$

$$E = 0.22E_r$$

$$= 0.22(1000 \text{ ksi})$$

$$= 220 \text{ ksi}$$

use Equation 3-21, page 3-49 of EM 1110-2-2901,
to obtain k

$$k = \frac{E}{(1 + \nu)d}$$

where ν = Poisson's ratio = 0.3
        d = borehole diameter = 24.17 ft

$$k = \frac{220}{(1 + 0.3)(24.17 \times 12)} \left(1728 \frac{\text{in.}^3}{\text{ft}^3}\right)$$

$$= 1008 \text{ kcf}$$

use k = 1000 kcf

Figure B3. Rock modulus computations for example 1

B4

Table B1

Sample Execution of NEWTUN with Conversational Input

Example Problem 1

DATA FILE DESCRIPTION (47 CHARACTERS MAX):
INCLUDE 'CAT$PASS/FILENAME$PASS' ONLY, NO USER ID
IF YOU WISH TO INPUT DATA FROM TERMINAL, TYPE
CARRIAGE RETURN.
    ?
ENTER NEW NAME FOR DATA FILE TO BE CREATED, OR
TYPE CARRIAGE RETURN IF YOU DO NOT WISH TO SAVE DATA.
    ? ITUN3
ENTER OUTPUT FILE NAME—CARRIAGE RETURN PRINTS
OUTPUT AT TERMINAL.
    ? OTUN3

DATA IS ENTERED IN GROUPS THAT WILL BE DESCRIBED
IN THE ORDER OF THEIR ENTRY--ALONG WITH AN
IDENTIFYING SYMBOL FOR EACH GROUP.   SEPARATE
DATA ON EACH LINE BY COMMAS OR AT LEAST ONE
SPACE.   YOU MAY REQUEST SHORT CUES FOR IDENTIFYING
SYMBOLS ONLY.   SYMBOLS ARE:
        * = TITLE LINE
        # = NODAL POINT DATA
        % = ELEMENT DATA
        + = NODAL POINT LOAD
        $ = ELEMENT LOAD
        & = SPECIFICATION LINE

SEE BRIEF FOR DETAILED INFORMATION ON INPUT DATA

SHORT OR LONG CUES! (SH OR LO)
    ? LO

GROUP * : ENTER TITLE FOR THIS PROBLEM ON
NEXT THREE LINES. (66 CHAR. MAX. PER LINE)
ENTER $END IN FIRST LINE IF YOU DO NOT WISH TO
CONTINUE.
*   ? NEWTUN FOR THE DESIGN OF TUNNELS
*   ? 13 INCH CONCRETE LINER, 22 FT. DIAMETER TUNNEL
*   ? PARK RIVER DESIGN (NOMINAL SUPPORT)

(Continued)   (Sheet 1 of 3)

GROUP & :FIRST SPECIFICATION LINE
ENTER NO. OF NODAL POINTS, NO. OF ELEMENTS,
AND NO. OF LOADING CONDITIONS.
&   ? 19 18 1

GROUP # : ENTER NODAL POINT DATA AS FOLLOWS:
NODAL PT. NO., RESTRAINT CODE (3 DIGIT), X-COOR,
Y-COOR, DISPL IN X-DIR, DISPL IN Y-DIR
ROTATION ABOUT NODE (RADIANS).
? 1 101 0 0 0 0 0 0
? 2 0 2.00 0.18 0 0 0
? 3 0 3.95 0.70 0 0 0
? 4 0 5.77 1.55 0 0 0
? 5 0 7.42 2.70 0 0 0
? 6 0 8.84 4.12 0 0 0
? 7 0 9.99 5.77 0 0 0
? 8 0 10.85 7.59 0 0 0
? 9 0 11.37 9.54 0 0 0
? 10 0 11.54 11.54 0 0 0
? 11 0 11.37 13.55 0 0 0
? 12 0 10.85 15.49 0 0 0
? 13 0 9.99 17.31 0 0 0
? 14 0 8.84 18.96 0 0 0
? 15 0 7.41 20.38 0 0 0
? 16 0 5.77 21.54 0 0 0
? 17 0 3.95 22.39 0 0 0
? 18 0 2.00 22.91 0 0 0
? 19 101 0.0 23.08 0 0 0

GROUP % : ENTER ELEMENT DATA AS FOLLOWS:
ELEMENT NO.,NODE NO. I END,NODE NO. J END
CROSS-SECT. AREA,YOUNG'S MODULUS
FDN. ROCK MODULUS,MOMENT OF INERTIA
FLEXURAL STIFF. I END,FLEXURAL STIFF. J END,
FLEXURAL CARRY-OVER FROM I END TO J END
%   ? 1 1 2 1.08 519119 1000.0 0.106 0 0 0
%   ? 18 18 19 1.08 519119 1000.0 0.106 0 0 0

ENTER TITLE FOR LOADING CONDITION 1
*   ? ROCK LOAD ONLY

(Continued)   (Sheet 2 of 3)

Table B1 (Concluded)

_____

GROUP & :SPECIFICATION LINE FOR LOADING CONDITION 1
ENTER NO. OF NODAL PT. LOAD LINE ENTRIES TO FOLLOW,
AND A ZERO IF YOU WANT ITERATIONS PERFORMED
TO REMOVE TENSION IN SPRINGS,OTHERWISE,
ENTER A -1 TO ELIMINATE ITERITIVE PROCESS.
&   ? 10 0

GROUP + :ENTER NODAL PT. LOADS AS FOLLOWS:
NODAL POINT NO.,FORCE IN X-DIR,FORCE IN Y-DIR,
MOMENT ABOUT NODE.
+   ? 10 0 -0.09 0
+   ? 11 0 -0.35 0
+   ? 12 0 -0.69 0
+   ? 13 0 -1.00 0
+   ? 14 0 -1.29 0
+   ? 15 0 -1.54 0
+   ? 16 0 -1.74 0
+   ? 17 0 -1.88 0
+   ? 18 0 -1.97 0
+   ? 19 0 -1.00 0

GROUP $:ENTER ELEMENT LOAD DATA AS FOLLOWS:
ELEMENT NO.,LOAD TYPE CODE,MAGNITUDE OF LOAD,
LOAD LOCATION,FORCE DIRECTION CODE
(TYPE ALL ZERO'S TO TERMINATE LOAD DATA)
$? 0 0 0 0 0

DO YOU WANT SHORT OR LONG CUES FOR THIS SECTION?
  ? SH

*   ? $END

WOULD YOU LIKE ANOTHER RUN? (YES OR NO)
  ? NO

*

_____

(Sheet 3 of 3)

B7

Table B2

Listing of Output File Created from Execution Sequence

For Example Problem 1 Shown in Table B1

LIST OTUN3

** NEWTUN **   ANALYSIS OF CAST IN PLACE TUNNELS

NEWTUN FOR THE DESIGN OF TUNNELS
13 INCH CONCRETE LINER, 22 FT. DIAMETER TUNNEL
PARK RIVER DESIGN (NOMINAL SUPPORT)

NUMBER OF NODES =   19
NUMBER OF ELEMENTS = 18
NUMBER OF LOADINGS = 1

(RESTRAINT CODE =1 SPECIFY RESTRAINT, =0 SPECIFY LOAD)

NODE	RESTRAINT CODE	X-COOR	Y-COOR	SPECIFIED DISPLACEMENTS X	Y	ROT
1	101	0.	0.	0.	0.	0.
2	0	2.00	0.18	0.	0.	0.
3	0	3.95	0.70	0.	0.	0.
4	0	5.77	1.55	0.	0.	0.
5	0	7.42	2.70	0.	0.	0.
6	0	8.84	4.12	0.	0.	0.
7	0	9.99	5.77	0.	0.	0.
8	0	10.85	7.59	0.	0.	0.
9	0	11.37	9.54	0.	0.	0.
10	0	11.54	11.54	0.	0.	0.
11	0	11.37	13.55	0.	0.	0.
12	0	10.85	15.49	0.	0.	0.
13	0	9.99	17.31	0.	0.	0.
14	0	8.84	18.96	0.	0.	0.
15	0	7.41	20.38	0.	0.	0.
16	0	5.77	21.54	0.	0.	0.
17	0	3.95	22.39	0.	0.	0.
18	0	2.00	22.91	0.	0.	0.
19	101	0.	23.08	0.	0.	0.

(Continued)   (Sheet 1 of 6)

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Table B2 (Continued)

ELEMENT	I	J	AREA	ELASTIC-MOD	SPRING CONST
1	1	2	0.110000E 01	0.519119E 06	0.100000E 04
2	2	3	0.110000E 01	0.519119E 06	0.100000E 04
3	3	4	0.110000E 01	0.519119E 06	0.100000E 04
4	4	5	0.110000E 01	0.519119E 06	0.100000E 04
5	5	6	0.110000E 01	0.519119E 06	0.100000E 04
6	6	7	0.110000E 01	0.519119E 06	0.100000E 04
7	7	8	0.110000E 01	0.519119E 06	0.100000E 04
8	8	9	0.110000E 01	0.519119E 06	0.100000E 04
9	9	10	0.110000E 01	0.519119E 06	0.100000E 04
10	10	11	0.110000E 01	0.519119E 06	0.100000E 04
11	11	12	0.110000E 01	0.519119E 06	0.100000E 04
12	12	13	0.110000E 01	0.519119E 06	0.100000E 04
13	13	14	0.110000E 01	0.519119E 06	0.100000E 04
14	14	15	0.110000E 01	0.519119E 06	0.100000E 04
15	15	16	0.110000E 01	0.519119E 06	0.100000E 04
16	16	17	0.110000E 01	0.519119E 06	0.100000E 04
17	17	18	0.110000E 01	0.519119E 06	0.100000E 04
18	18	19	0.110000E 01	0.519119E 06	0.100000E 04

ELEMENT	MOM INERTIA	STIFF IJ	STIFF JI	COF IJ	COF JI
1	0.100000E 00	4.000000	4.000000	0.500000	0.500000
2	0.100000E 00	4.000000	4.000000	0.500000	0.500000
3	0.100000E 00	4.000000	4.000000	0.500000	0.500000
4	0.100000E 00	4.000000	4.000000	0.500000	0.500000
5	0.100000E 00	4.000000	4.000000	0.500000	0.500000
6	0.100000E 00	4.000000	4.000000	0.500000	0.500000
7	0.100000E 00	4.000000	4.000000	0.500000	0.500000
8	0.100000E 00	4.000000	4.000000	0.500000	0.500000
9	0.100000E 00	4.000000	4.000000	0.500000	0.500000
10	0.100000E 00	4.000000	4.000000	0.500000	0.500000
11	0.100000E 00	4.000000	4.000000	0.500000	0.500000
12	0.100000E 00	4.000000	4.000000	0.500000	0.500000
13	0.100000E 00	4.000000	4.000000	0.500000	0.500000
14	0.100000E 00	4.000000	4.000000	0.500000	0.500000
15	0.100000E 00	4.000000	4.000000	0.500000	0.500000
16	0.100000E 00	4.000000	4.000000	0.500000	0.500000
17	0.100000E 00	4.000000	4.000000	0.500000	0.500000
18	0.100000E 00	4.000000	4.000000	0.500000	0.500000

(Continued)

(Sheet 2 of 6)

ROCK LOAD ONLY

NUMBER OF NODAL POINT LOAD CARDS =   10

SPECIFIED NODAL POINT LOADS

NODE	FX	FY	MOM
10	0.	-0.090	0.
11	0.	-0.350	0.
12	0.	-0.690	0.
13	0.	-1.000	0.
14	0.	-1.290	0.
15	0.	-1.540	0.
16	0.	-1.740	0.
17	0.	-1.880	0.
18	0.	-1.970	0.
19	0.	-1.000	0.

ELEMENT LOADS

LOAD TYPE * =1 CONCENTRATED LOAD
            =2 UNIFORM DISTRIBUTED LOAD
            =3 CONCENTRATED MOMENT
            =4 TRIANGULAR DISTRIBUTED LOAD

LOCATION CODE-   *LOAD TYPES 1 AND 3:
                 DISTANCE FROM I NODE
                 *LOAD TYPE 2: =0
                 *LOAD TYPE 4:
                 =0 NODE I WEIGHTED, =1 NODE J WEIGHTED

DIRECTION CODE-   *LOAD TYPES 1-4:
                 X=2, Y=1

ELEMENT	NODE I	J	LOAD TYPE	MAGNITUDE OF LOAD	LOCATION CODE	DIRECTION CODE

(Continued)   (Sheet 3 of 6)

ELEMENTS ON AN ELASTIC FOUNDATION

ELEMENT	SPRING PRESSURE	
	I	J
1	0.111415E 01	0.113347E 01
2	0.109222E 01	0.115354E 01
3	0.106871E 01	0.117264E 01
4	0.104883E 01	0.119862E 01
5	0.102877E 01	0.122638E 01
6	0.101346E 01	0.126574E 01
7	0.102393E 01	0.133689E 01
8	0.103027E 01	0.139396E 01
9	0.104996E 01	0.143565E 01
10	0.106075E 01	0.141759E 01
11	0.978173E 00	0.120488E 01
12	0.717539E 00	0.691237E 00
13	0.209308E 00	0.
14	0.	0.
15	0.	0.
16	0.	0.
17	0.	0.
18	0.	0.

NUMBER OF ITERATIONS =   3

(Continued)   (Sheet 4 of 6)

ELEMENT ZONE   LIMITS OF INTEGRATION (MAX=20)

Element	Zone				
1	ODD	0.	,	2.008,	
2	ODD	0.	,	2.018,	
3	ODD	0.	,	2.009,	
4	ODD	0.	,	2.011,	
5	ODD	0.	,	2.008,	
6	ODD	0.	,	2.011,	
7	ODD	0.	,	2.013,	
8	ODD	0.	,	2.018,	
9	ODD	0.	,	2.007,	
10	ODD	0.	,	2.017,	
11	ODD	0.	,	2.008,	
12	ODD	0.	,	2.013,	
13	ODD	0.	,	1.320,	2.011,
14	EVEN	0.	,	2.015,	
15	EVEN	0.	,	2.009,	
16	EVEN	0.	,	2.009,	
17	EVEN	0.	,	2.018,	
18	EVEN	0.	,	2.007,	

NODAL POINT DISPLACEMENTS

NODE	X-DISPL	Y-DISPL	ROT-DISPL
1	0.	-0.11186E-02	0.
2	-0.43378E-04	-0.11420E-02	-0.19741E-04
3	-0.71554E-04	-0.12129E-02	-0.40994E-04
4	-0.68622E-04	-0.13263E-02	-0.62894E-04
5	-0.20191E-04	-0.14751E-02	-0.86186E-04
6	0.87515E-04	-0.16469E-02	-0.11124E-03
7	0.26856E-03	-0.18283E-02	-0.14056E-03
8	0.53212E-03	-0.20031E-02	-0.16933E-03
9	0.87177E-03	-0.21409E-02	-0.18931E-03
10	0.12522E-02	-0.22190E-02	-0.19088E-03
11	0.16116E-02	-0.22345E-02	-0.15472E-03
12	0.18422E-02	-0.22192E-02	-0.60764E-04
13	0.18370E-02	-0.22696E-02	0.95663E-04
14	0.15440E-02	-0.25233E-02	0.28811E-03
15	0.10427E-02	-0.30804E-02	0.44065E-03
16	0.51758E-03	-0.38791E-02	0.49049E-03
17	0.14809E-03	-0.47374E-02	0.41897E-03
18	-0.26211E-05	-0.54011E-02	0.23998E-03
19	0.	-0.56487E-02	0.

(Continued)

(Sheet 5 of 6)

END ACTIONS WITH NODAL POINT LOADS

| ELEMENT | AXIAL I | SHEAR I | MOMENT I |
	AXIAL J	SHEAR J	MOMENT J
1	12.880	-1.159	0.097
	-12.880	-1.091	-0.172
2	12.878	-1.115	0.172
	-12.878	-1.144	-0.163
3	12.879	-1.132	0.163
	-12.879	-1.111	-0.219
4	12.879	-1.106	0.219
	-12.879	-1.146	-0.229
5	12.880	-1.136	0.229
	-12.880	-1.120	-0.312
6	12.876	-1.162	0.312
	-12.876	-1.121	-0.438
7	12.883	-1.039	0.438
	-12.883	-1.328	-0.253
8	12.912	-1.011	0.253
	-12.912	-1.428	0.045
9	12.963	-0.852	-0.045
	-12.963	-1.642	0.708
10	12.964	-0.556	-0.708
	-12.964	-1.956	1.998
11	12.768	-0.274	-1.998
	-12.768	-1.950	3.605
12	12.287	-0.066	-3.605
	-12.287	-1.404	4.960
13	11.529	-0.089	-4.960
	-11.529	-0.067	5.023
14	10.446	-1.085	-5.023
	-10.446	1.085	2.836
15	9.233	-1.541	-2.836
	-9.233	1.541	-0.260
16	8.075	-1.581	0.260
	-8.075	1.581	-3.437
17	7.188	-1.157	3.437
	-7.188	1.157	-5.771
18	6.708	-0.433	5.771
	-6.708	0.433	-6.641

*** $END ***

Example Problem 2

5. The tunnel section used in this example is the same as that used in example 1. The four loading cases that are used are delineated in the loading diagram shown in Figure B4. These loading cases include the weight of the lining material which was not considered in example 1.

6. Table B3 shows the execution of the program from a data file. The data file needed to run this problem is shown in Table B4. The listing of the output file is given in Table B5.

7. Figure B5 gives the formula used in calculating the nodal loads due to the rock load. Figure B6 shows sample calculations to obtain the nodal load for node 16 for load case 1. Figure B7 gives the formulas for calculating nodal loads due to water loading. Figures B8 and B9 show sample calculations for nodal loads at node 16 for load cases 2 and 3, respectively. Figure B10 shows a plot of the moment in the concrete lining for each load case of example 2.

ROCK LOAD = 0.275 tons/ft

180-ft INTERNAL HEAD
150-ft EXTERNAL
100-ft INTERNAL
185-ft EXTERNAL
185-ft EXTERNAL

LC-2   LC-3   LC-4

WATER LOADS

22-ft ID

INVERT

SHALE

CONCRETE LINING:

f'_c = 4,000 psi

E = 519,119 kcf

A = 108 ft^2/ft

I = 0.106 ft^4

R = 1,000 kcf
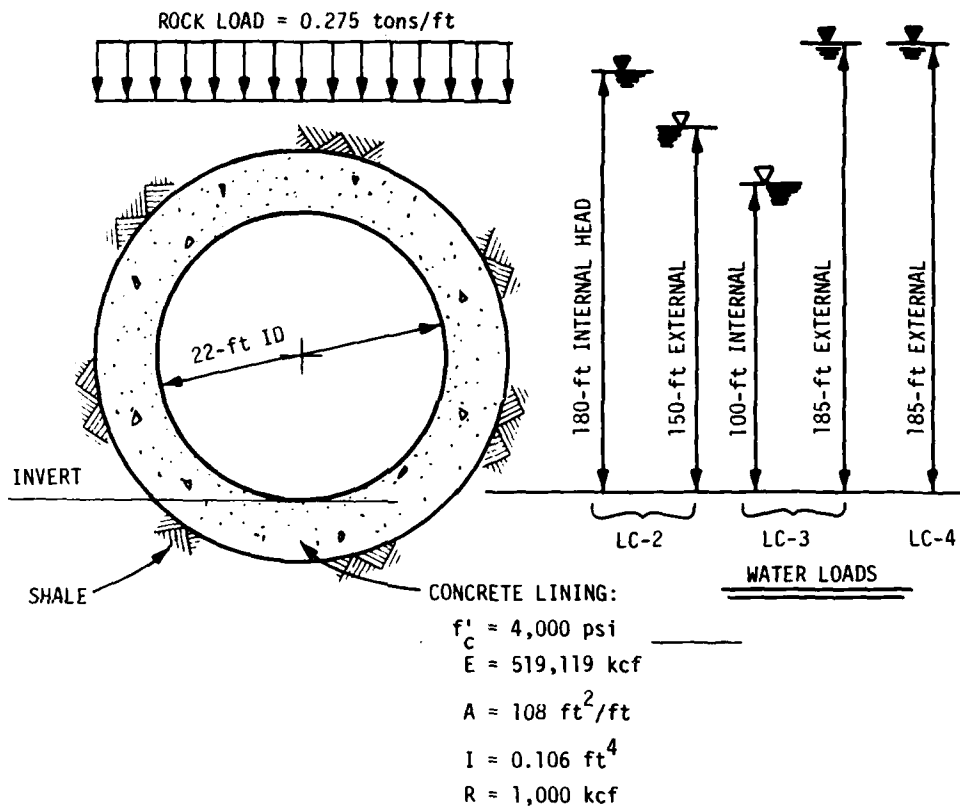
LOAD CASE	DESCRIPTION
1	ROCK LOAD + WEIGHT OF LINING
2	ROCK LOAD + WEIGHT OF LINING + 30-ft NET INTERNAL HEAD
3	ROCK LOAD + WEIGHT OF LINING + 85-ft NET EXTERNAL HEAD
4	ROCK LOAD + WEIGHT OF LINING + 185-ft NET EXTERNAL HEAD

NOTE: COMPUTER MODEL AND ROCK MODULUS FOR THIS EXAMPLE
        ARE THE SAME AS THOSE FOR EXAMPLE 1 (SEE FIGURES
        B2 AND B3).

Figure B4.   Physical problem treated in example 2

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Table B3

Execution of NEWTUN from the Data File

For Example Problem 2 Shown in Table B4

DATA FILE DESCRIPTION (47 CHARACTERS MAX):
INCLUDE 'CAT$PASS/FILENAME$PASS' ONLY, NO USER ID
IF YOU WISH TO INPUT DATA FROM TERMINAL, TYPE
CARRIAGE RETURN.
  ? TUNIN
ENTER OUTPUT FILE NAME--CARRIAGE RETURN PRINTS
OUTPUT AT TERMINAL.
  ? TUNOUT

WOULD YOU LIKE ANOTHER RUN? (YES OR NO)
  ? NO

*

Table B4

Data File For Example 2

```
1000 NEWTON EXAMPLE PROBLEM
1010 13 INCH CONCRETE LINER 22 FT DIAM TUNNEL    (title lines)
1020 PARK RIVER DESIGN (NORMAL ROCK SUPPORT)
1030 19,18,4                                      (specification line)
1040 1,101,0,0,0,0,0,0,0
1050 2,0,2,004,0,175,0,0,0
1060 3,0,3,943,0,696,0,0,0
1070 4,0,5,771,1,546,0,0,0
1080 5,0,7,419,2,700,0,0,0
1090 6,0,8,842,4,123,0,0,0
1100 7,0,9,996,5,771,0,0,0
1110 8,0,10,846,7,594,0,0,0
1120 9,0,11,367,9,530,0,0,0
1130 10,0,11,542,11,542,0,0,0          (nodal data)
1140 11,0,11,367,13,546,0,0,0
1150 12,0,10,846,15,490,0,0,0
1160 13,0,9,996,17,313,0,0,0
1170 14,0,8,842,18,961,0,0,0
1180 15,0,7,419,20,384,0,0,0
1190 16,0,5,771,21,538,0,0,0
1200 17,0,3,943,22,382,0,0,0
1210 18,0,2,004,22,903,0,0,0
1220 19,101,0,0,23,084,0,0,0
1230 1,1,2,1.08,519119,1000,0,106,0,0,0     (element data)
1240 18,18,19,1,1.08,519119,1000,0,106,0,0,0
1250 LC-1 ROCK LOAD 0.275T FT                (load case title line)
1260 19,0                                    (load case specification node line)
1270 1,0,-0,16,0
1280 2,0,-0,32,0
1290 3,0,-0,32,0
1300 4,0,-0,32,0
1310 5,0,-0,32,0
1320 6,0,-0,32,0
1330 7,0,-0,32,0
1340 8,0,-0,32,0
1350 9,0,-0,32,0
1360 10,0,-0,36,0          (nodal load data)
1370 11,0,-0,53,0
1380 12,0,-0,71,0
1390 13,0,-0,90,0
1400 14,0,-1,07,0
1410 15,0,-1,21,0
1420 16,0,-1,32,0
1430 17,0,-1,41,0
1440 18,0,-1,47,0
1450 19,0,-0,82,0
1460 0,0,0,0,0              (load case specification element line)
1470 LC-2 ROCK LOAD PLUS INTERNAL HEAT      (load case title line)
1480 19,0                                    (load case specification node line)
1490 1,0,00,-1,00,0
1500 2,0,29,-1,97,0
1510 3,0,58,-1,91,0
1520 4,0,86,-1,81,0
1530 5,1,12,-1,66,0
1540 6,1,36,-1,46,0
1550 7,1,58,-1,23,0
1560 8,1,75,-,96,0
1570 9,1,88,-,65,0
1580 10,1,96,-,36,0         (nodal load data)
1590 11,1,97,-,18,0
```

(Continued)   (Sheet 1 of 2)

B17

Table B4 (Concluded)

```
1600  12.1.93...01..0
1610  13.1.810..150.0
1620  14.1.630..580.0
1630  15.1.390..450.0
1640  16.1.100..580.0
1650  17..790..670.0
1660  18..390..730.0
1670  19.0...290.0
1680  0.0.0.0.0                              (load case specification element line)
1690  LC-3 ROOF LOAD PLUS EXTERNAL HEAD      (load case title line)
1700  19.0                                   (load case specification node line)
1710  1.0.00.6.09.0
1720  2.-2.17.11.99.0
1730  3.-4.27.11.42.0
1740  4.-6.24.10.49.0
1750  5.-8.00.9.82.0
1760  6.-9.51.7.66.0
1770  7.-10.71.5.86.0
1780  8.-11.59.3.90.0
1790  9.-12.09.1.81.0
1800  10.-12.24..-.760.0                     (nodal load data)
1810  11.-12.00.-2.65.0
1820  12.-11.41.-4.56.0
1830  13.-10.43.-6.35.0
1840  14.-9.24.-8.02.0
1850  15.-7.63.-10.43.0
1860  16.-6.00.-11.71.0
1870  17.-4.10.-12.67.0
1880  18.-2.08.-13.25.0
1890  19.0..-6.85.0
1900  0.0.0.0.0                              (load case specification element line)
1910  LC-5 CONSTRUCTION CONDITION            (load case title line)
1920  19.0                                   (load case specification node line)
1930  1.0.00.12.08.0
1940  2.-4.25.23.77.0
1950  3.-8.34.22.60.0
1960  4.-12.14.20.71.0
1970  5.-15.50.18.16.0
1980  6.-18.32.15.06.0
1990  7.-20.52.11.52.0
2000  8.-22.03.7.70.0
2010  9.-22.83.3.70.0
2020  10.-22.90.-0.36.0                      (nodal load data)
2030  11.-22.23.-4.46.0
2040  12.-21.00.-8.35.0
2050  13.-19.14.-11.95.0
2060  14.-16.76.-15.13.0
2070  15.-13.94.-17.93.0
2080  16.-10.76.-19.36.0
2090  17.-7.76.-21.52.0
2100  18.-3.70.-22.47.0
2110  19.0.00.-11.47.0
2120  0.0.0.0.0                              (load case specification element line)
2130  $END                                   (terminate data file)
```

(Sheet 1 of 2)

B18

Table B5

Listing of Output Results for Example 2

1

** NEWTUN ** ANALYSIS OF CAST IN PLACE TUNNELS

NEWTUN EXAMPLE PROBLEM
13 INCH CONCRETE LINER 22 FT DIAM TUNNEL
PARK RIVER DESIGN (NORMAL ROCK SUPPORT)

NUMBER OF NODES =   19
NUMBER OF ELEMENTS = 18
NUMBER OF LOADINGS = 4

(RESTRAINT CODE =1 SPECIFY RESTRAINT, =0 SPECIFY LOAD)

| | RESTRAINT | | | SPECIFIED DISPLACEMENTS | | |
NODE	CODE	X-COOR	Y-COOR	X	Y	ROT
1	101	0.	0.	0.	0.	0.
2	0	2.00	0.18	0.	0.	1.
3	0	3.95	0.70	0.	0.	0.
4	0	5.77	1.55	0.	0.	0.
5	0	7.42	2.70	0.	0.	0.
6	0	8.84	4.12	0.	0.	0.
7	0	10.00	5.77	0.	0.	0.
8	0	10.85	7.59	0.	0.	0.
9	0	11.37	9.53	0.	0.	0.
10	0	11.54	11.54	0.	0.	0.
11	0	11.37	13.55	0.	0.	0.
12	0	10.85	15.49	0.	0.	0.
13	0	10.00	17.31	0.	0.	0.
14	0	8.84	18.96	0.	0.	0.
15	0	7.42	20.36	0.	0.	0.
16	0	5.77	21.54	0.	0.	0.
17	0	3.95	22.39	0.	0.	0.
18	0	2.00	22.91	0.	0.	0.
19	101	0.	23.08	0.	0.	0.

(Continued)

(Sheet 1 of 18)

Table B5 (Continued)

ELEMENT	I	J	AREA	ELASTIC-MOD	SPRING CONST
1	1	2	0.108000E 01	0.519119E 06	0.100000E 04
2	2	3	0.108000E 01	0.519119E 06	0.100000E 04
3	3	4	0.108000E 01	0.519119E 06	0.100000E 04
4	4	5	0.108000E 01	0.519119E 06	0.100000E 04
5	5	6	0.108000E 01	0.519119E 06	0.100000E 04
6	6	7	0.108000E 01	0.519119E 06	0.100000E 04
7	7	8	0.108000E 01	0.519119E 06	0.100000E 04
8	8	9	0.108000E 01	0.519119E 06	0.100000E 04
9	9	10	0.108000E 01	0.519119E 06	0.100000E 04
10	10	11	0.108000E 01	0.519119E 06	0.100000E 04
11	11	12	0.108000E 01	0.519119E 06	0.100000E 04
12	12	13	0.108000E 01	0.519119E 06	0.100000E 04
13	13	14	0.108000E 01	0.519119E 06	0.100000E 04
14	14	15	0.108000E 01	0.519119E 06	0.100000E 04
15	15	16	0.108000E 01	0.519119E 06	0.100000E 04
16	16	17	0.108000E 01	0.519119E 06	0.100000E 04
17	17	18	0.108000E 01	0.519119E 06	0.100000E 04
18	18	19	0.108000E 01	0.519119E 06	0.100000E 04

ELEMENT	MOM INERTIA	STIFF IJ	STIFF JI	COF IJ	COF JI
1	0.110000E 00	4.000000	4.000000	0.500000	0.500000
2	0.110000E 00	4.000000	4.000000	0.500000	0.500000
3	0.110000E 00	4.000000	4.000000	0.500000	0.500000
4	0.110000E 00	4.000000	4.000000	0.500000	0.500000
5	0.110000E 00	4.000000	4.000000	0.500000	0.500000
6	0.110000E 00	4.000000	4.000000	0.500000	0.500000
7	0.110000E 00	4.000000	4.000000	0.500000	0.500000
8	0.110000E 00	4.000000	4.000000	0.500000	0.500000
9	0.110000E 00	4.000000	4.000000	0.500000	0.500000
10	0.110000E 00	4.000000	4.000000	0.500000	0.500000
11	0.110000E 00	4.000000	4.000000	0.500000	0.500000
12	0.110000E 00	4.000000	4.000000	0.500000	0.500000
13	0.110000E 00	4.000000	4.000000	0.500000	0.500000
14	0.110000E 00	4.000000	4.000000	0.500000	0.500000
15	0.110000E 00	4.000000	4.000000	0.500000	0.500000
16	0.110000E 00	4.000000	4.000000	0.500000	0.500000
17	0.110000E 00	4.000000	4.000000	0.500000	0.500000
18	0.110000E 00	4.000000	4.000000	0.500000	0.500000

LC-1 ROCK LOAD 0.275T/FT

(Continued)

NUMBER OF NODAL POINT LOAD CARDS =   19

SPECIFIED NODAL POINT LOADS

NODE	FX	FY	MOM
1	0.	-0.160	0.
2	0.	-0.320	0.
3	0.	-0.320	0.
4	0.	-0.320	0.
5	0.	-0.320	0.
6	0.	-0.320	0.
7	0.	-0.320	0.
8	0.	-0.320	0.
9	0.	-0.320	0.
10	0.	-0.360	0.
11	0.	-0.530	0.
12	0.	-0.710	0.
13	0.	-0.900	0.
14	0.	-1.070	0.
15	0.	-1.210	0.
16	0.	-1.320	0.
17	0.	-1.410	0.
18	0.	-1.470	0.
19	0.	-0.820	0.

ELEMENT LOADS

LOAD TYPE * =1 CONCENTRATED LOAD
              =2 UNIFORM DISTRIBUTED LOAD
              =3 CONCENTRATED MOMENT
              =4 TRIANGULAR DISTRIBUTED LOAD

LOCATION CODE-   *LOAD TYPES 1 AND 3:
                   DISTANCE FROM I NODE
                  *LOAD TYPE 2: =0
                  *LOAD TYPE 4:
                   =0 NODE I WEIGHTED, =1 NODE J WEIGHTED

DIRECTION CODE-   *LOAD TYPES 1-4:
                    X=2, Y=1

(Continued)   (Sheet 3 of 18)

Table B5 (Continued)

ELEMENT	NODE I	J	LOAD TYPE	MAGNITUDE OF LOAD	LOCATION CODE	DIRECTION CODE

ELEMENTS ON AN ELASTIC FOUNDATION

ELEMENT	SPRING I	PRESSURE J
1	0.121950E 01	0.123552E 01
2	0.119140E 01	0.124252E 01
3	0.115213E 01	0.123929E 01
4	0.110817E 01	0.123479E 01
5	0.105640E 01	0.122510E 01
6	0.100927E 01	0.122624E 01
7	0.965042E 00	0.122936E 01
8	0.928718E 00	0.123352E 01
9	0.887988E 00	0.121106E 01
10	0.845478E 00	0.113649E 01
11	0.715021E 00	0.888689E 00
12	0.442099E 00	0.398478E 00
13	0.	0.
14	0.	0.
15	0.	0.
16	0.	0.
17	0.	0.
18	0.	0.

NUMBER OF ITERATIONS =   3

(Continued)

ELEMENT ZONE   LIMITS OF INTEGRATION (MAX=20)

1	ODD	0. ,	2.008,
2	ODD	0. ,	2.018,
3	ODD	0. ,	2.009,
4	ODD	0. ,	2.011,
5	ODD	0. ,	2.008,
6	ODD	0. ,	2.017,
7	ODD	0. ,	2.009,
8	ODD	0. ,	2.008,
9	ODD	0. ,	2.017,
10	ODD	0. ,	2.017,
11	ODD	0. ,	2.008,
12	ODD	0. ,	2.009,
13	EVEN	0. ,	2.017,
14	EVEN	0. ,	1.994,
15	EVEN	0. ,	2.029,
16	EVEN	0. ,	2.009,
17	EVEN	0. ,	2.018,
18	EVEN	0. ,	2.007,

NODAL POINT DISPLACEMENTS

NODE	X-DISPL	Y-DISPL	ROT-DISPL
1	0.	-0.12244E-02	0.
2	-0.42323E-04	-0.12443E-02	-0.16407E-04
3	-0.71616E-04	-0.13050E-02	-0.34280E-04
4	-0.74014E-04	-0.14024E-02	-0.52947E-04
5	-0.36755E-04	-0.15307E-02	-0.73219E-04
6	0.52815E-04	-0.16797E-02	-0.95472E-04
7	0.20653E-03	-0.18383E-02	-0.11990E-03
8	0.42900E-03	-0.19866E-02	-0.14292E-03
9	0.71326E-03	-0.21034E-02	-0.15886E-03
10	0.10319E-02	-0.21690E-02	-0.15786E-03
11	0.13251E-02	-0.21818E-02	-0.12368E-03
12	0.15021E-02	-0.21716E-02	-0.40906E-04
13	0.14770E-02	-0.22209E-02	0.90766E-04
14	0.12196E-02	-0.24406E-02	0.24121E-03
15	0.81817E-03	-0.28876E-02	0.34927E-03
16	0.39953E-03	-0.35160E-02	0.38007E-03
17	0.11437E-03	-0.41775E-02	0.32187E-03
18	-0.16338E-05	-0.46871E-02	0.18443E-03
19	0.	-0.48777E-02	0.

(Continued)   (Sheet 5 of 18)

END ACTIONS WITH NODAL POINT LOADS

ELEMENT	AXIAL I	SHEAR I	MOMENT I
	AXIAL J	SHEAR J	MOMENT J
1	12.267	-1.265	0.017
	-12.267	-1.195	-0.093
2	12.209	-1.217	0.093
	-12.209	-1.233	-0.095
3	12.100	-1.218	0.095
	-12.100	-1.178	-0.165
4	11.941	-1.171	0.165
	-11.941	-1.179	-0.199
5	11.736	-1.165	0.199
	-11.736	-1.118	-0.303
6	11.491	-1.098	0.303
	-11.491	-1.148	-0.326
7	11.225	-1.015	0.326
	-11.225	-1.181	-0.249
8	10.950	-0.875	0.249
	-10.950	-1.291	0.067
9	10.687	-0.690	-0.067
	-10.687	-1.428	0.702
10	10.417	-0.357	-0.702
	-10.417	-1.653	1.910
11	10.033	-0.075	-1.910
	-10.033	-1.564	3.347
12	9.509	0.093	-3.347
	-9.509	-0.982	4.440
13	8.797	-0.179	-4.440
	-8.797	0.179	4.079
14	7.872	-0.987	-4.079
	-7.872	0.987	2.110
15	6.916	-1.225	-2.110
	-6.916	1.225	-0.376
16	6.017	-1.273	0.376
	-6.017	1.273	-2.934
17	5.337	-0.947	2.934
	-5.337	0.947	-4.844
18	4.965	-0.401	4.844
	-4.965	0.401	-5.649

LC-2 ROCK LOAD PLUS INTERNAL HEAD

(Continued)   (Sheet 6 of 18)

NUMBER OF NODAL POINT LOAD CARDS =   19

SPECIFIED NODAL POINT LOADS

NODE	FX	FY	MOM
1	0.	-1.000	0.
2	0.290	-1.970	0.
3	0.580	-1.910	0.
4	0.860	-1.810	0.
5	1.120	-1.660	0.
6	1.360	-1.460	0.
7	1.580	-1.230	0.
8	1.750	-0.960	0.
9	1.880	-0.650	0.
10	1.960	-0.360	0.
11	1.970	-0.180	0.
12	1.930	-0.010	0.
13	1.810	0.150	0.
14	1.630	0.300	0.
15	1.390	0.450	0.
16	1.100	0.580	0.
17	0.790	0.670	0.
18	0.390	0.730	0.
19	0.	0.290	0.

ELEMENT LOADS

LOAD TYPE * =1 CONCENTRATED LOAD
          =2 UNIFORM DISTRIBUTED LOAD
          =3 CONCENTRATED MOMENT
          =4 TRIANGULAR DISTRIBUTED LOAD

LOCATION CODE-   *LOAD TYPES 1 AND 3:
                  DISTANCE FROM I NODE
                 *LOAD TYPE 2: =0
                 *LOAD TYPE 4:
                  =0 NODE I WEIGHTED, =1 NODE J WEIGHTED

DIRECTION CODE-   *LOAD TYPES 1-4:
                   X=2, Y=1

ELEMENT	NODE		LOAD	MAGNITUDE	LOCATION	DIRECTION
	I	J	TYPE	OF LOAD	CODE	CODE

(Continued)   (Sheet 7 of 18)

ELEMENTS ON AN ELASTIC FOUNDATION

ELEMENT	SPRING I	PRESSURE J
1	0.993190E 00	0.100527E 01
2	0.975429E 00	0.101257E 01
3	0.951448E 00	0.101391E 01
4	0.925156E 00	0.101422E 01
5	0.893329E 00	0.101125E 01
6	0.864796E 00	0.101551E 01
7	0.838110E 00	0.102141E 01
8	0.816958E 00	0.102888E 01
9	0.793574E 00	0.101993E 01
10	0.770731E 00	0.978370E 00
11	0.690692E 00	0.827191E 00
12	0.521573E 00	0.519707E 00
13	0.198525E 00	0.
14	0.	0.
15	0.	0.
16	0.	0.
17	0.	0.
18	0.	0.

NUMBER OF ITERATIONS =   3

(Continued)   (Sheet 8 of 18)

ELEMENT ZONE   LIMITS OF INTEGRATION (MAX=20)

1 ODD	0.	,	2.008,
2 ODD	0.	,	2.018,
3 ODD	0.	,	2.009,
4 ODD	0.	,	2.011,
5 ODD	0.	,	2.008,
6 ODD	0.	,	2.017,
7 ODD	0.	,	2.009,
8 ODD	0.	,	2.008,
9 ODD	0.	,	2.017,
10 ODD	0.	,	2.017,
11 ODD	0.	,	2.008,
12 ODD	0.	,	2.009,
13 ODD	0.	,	1.979, 2.017,
14 EVEN	0.	,	1.994,
15 EVEN	0.	,	2.029,
16 EVEN	0.	,	2.009,
17 EVEN	0.	,	2.018,
18 EVEN	0.	,	2.007,

NODAL POINT DISPLACEMENTS

NODE	X-DISPL	Y-DISPL	ROT-DISPL
1	0.	-0.99720E-03	0.
2	0.10119E-05	-0.10092E-02	-0.12118E-04
3	0.10714E-04	-0.10451E-02	-0.24759E-04
4	0.37617E-04	-0.11015E-02	-0.37559E-04
5	0.89437E-04	-0.11739E-02	-0.51300E-04
6	0.17411E-03	-0.12560E-02	-0.66507E-04
7	0.29896E-03	-0.13405E-02	-0.83154E-04
8	0.46659E-03	-0.14147E-02	-0.99153E-04
9	0.67250E-03	-0.14651E-02	-0.11080E-03
10	0.89853E-03	-0.14785E-02	-0.11110E-03
11	0.11049E-02	-0.14542E-02	-0.90688E-04
12	0.12345E-02	-0.14108E-02	-0.39669E-04
13	0.12285E-02	-0.14022E-02	0.46817E-04
14	0.10538E-02	-0.15092E-02	0.15670E-03
15	0.75397E-03	-0.17907E-02	0.24879E-03
16	0.41620E-03	-0.22297E-02	0.28440E-03
17	0.16552E-03	-0.27138E-02	0.24574E-03
18	0.38269E-04	-0.30947E-02	0.14219E-03
19	0.	-0.32385E-02	0.

(Continued)   (Sheet 9 of 18)

END ACTIONS WITH NODAL POINT LOADS

ELEMENT	AXIAL I AXIAL J	SHEAR I SHEAR J	MOMENT I MOMENT J
1	0.020	-1.006	0.003
	-0.020	-0.997	-0.016
2	-0.038	-0.999	0.016
	0.038	-1.002	-0.026
3	-0.145	-0.983	0.026
	0.145	-0.987	-0.043
4	-0.303	-0.979	0.043
	0.303	-0.966	-0.086
5	-0.510	-0.961	0.086
	0.510	-0.946	-0.141
6	-0.753	-0.933	0.141
	0.753	-0.958	-0.167
7	-1.019	-0.877	0.167
	1.019	-0.985	-0.120
8	-1.306	-0.791	0.120
	1.306	-1.058	0.077
9	-1.588	-0.656	-0.077
	1.588	-1.173	0.522
10	-1.892	-0.499	-0.522
	1.892	-1.272	1.230
11	-2.322	-0.270	-1.230
	2.322	-1.271	2.188
12	-2.891	-0.088	-2.188
	2.891	-0.986	3.091
13	-3.592	-0.090	-3.091
	3.592	-0.142	3.212
14	-4.459	-0.577	-3.212
	4.459	0.577	2.062
15	-5.363	-1.045	-2.062
	5.363	1.045	-0.057
16	-6.215	-1.037	0.057
	6.215	1.037	-2.141
17	-6.891	-0.782	2.141
	6.891	0.782	-3.719
18	-7.249	-0.325	3.719
	7.249	0.325	-4.372

LC-3 ROCK LOAD PLUS EXTERNAL HEAD

(Continued)   (Sheet 10 of 18)

NUMBER OF NODAL POINT LOAD CARDS =   19

SPECIFIED NODAL POINT LOADS

NODE	FX	FY	MOM
1	0.	6.090	0.
2	-2.170	11.990	0.
3	-4.270	11.420	0.
4	-6.240	10.490	0.
5	-8.000	9.220	0.
6	-9.510	7.660	0.
7	-10.710	5.860	0.
8	-11.590	3.900	0.
9	-12.090	1.810	0.
10	-12.240	-0.360	0.
11	-12.000	-2.650	0.
12	-11.410	-4.860	0.
13	-10.480	-6.950	0.
14	-9.240	-8.820	0.
15	-7.630	-10.430	0.
16	-6.000	-11.710	0.
17	-4.100	-12.670	0.
18	-2.080	-13.250	0.
19	0.	-6.850	0.

ELEMENT LOADS

LOAD TYPE * =1 CONCENTRATED LOAD
            =2 UNIFORM DISTRIBUTED LOAD
            =3 CONCENTRATED MOMENT
            =4 TRIANGULAR DISTRIBUTED LOAD

LOCATION CODE-   *LOAD TYPES 1 AND 3:
                  DISTANCE FROM I NODE
                  *LOAD TYPE 2: =0
                  *LOAD TYPE 4:
                  =0 NODE I WEIGHTED, =1 NODE J WEIGHTED

DIRECTION CODE-   *LOAD TYPES 1-4:
                  X=2, Y=1

ELEMENT	NODE		LOAD	MAGNITUDE	LOCATION	DIRECTION
	I	J	TYPE	OF LOAD	CODE	CODE

(Continued)   (Sheet 11 of 18)

ELEMENTS ON AN ELASTIC FOUNDATION

ELEMENT	SPRING I	PRESSURE J
1	0.899391E 00	0.928743E 00
2	0.852459E 00	0.955864E 00
3	0.798761E 00	0.979925E 00
4	0.751190E 00	0.102243E 01
5	0.709362E 00	0.107185E 01
6	0.690016E 00	0.115451E 01
7	0.687319E 00	0.123777E 01
8	0.693635E 00	0.129725E 01
9	0.664313E 00	0.125327E 01
10	0.575781E 00	0.103303E 01
11	0.245817E 00	0.385992E 00
12	0.	0.
13	0.	0.
14	0.	0.
15	0.	0.
16	0.	0.
17	0.	0.
18	0.	0.

NUMBER OF ITERATIONS = 4

(Continued)   (Sheet 12 of 18)

ELEMENT ZONE   LIMITS OF INTEGRATION (MAX=20)

1	ODD	0.	,	2.008,
2	ODD	0.	,	2.018,
3	ODD	0.	,	2.009,
4	ODD	0.	,	2.011,
5	ODD	0.	,	2.008,
6	ODD	0.	,	2.017,
7	ODD	0.	,	2.009,
8	ODD	0.	,	2.008,
9	ODD	0.	,	2.017,
10	ODD	0.	,	2.017,
11	ODD	0.	,	2.008,
12	EVEN	0.	,	2.009,
13	EVEN	0.	,	2.017,
14	EVEN	0.	,	1.994,
15	EVEN	0.	,	2.029,
16	EVEN	0.	,	2.009,
17	EVEN	0.	,	2.018,
18	EVEN	0.	,	2.007,

NODAL POINT DISPLACEMENTS

NODE	X-DISPL	Y-DISPL	ROT-DISPL
1	0.	-0.90303E-03	0.
2	-0.28443E-03	-0.95810E-03	-0.31835E-04
3	-0.53745E-03	-0.11326E-02	-0.70219E-04
4	-0.72144E-03	-0.14185E-02	-0.11197E-03
5	-0.80215E-03	-0.18053E-02	-0.15732E-03
6	-0.74823E-03	-0.22641E-02	-0.20527E-03
7	-0.53306E-03	-0.27656E-02	-0.25415E-03
8	-0.15471E-03	-0.32563E-02	-0.29161E-03
9	0.35488E-03	-0.36866E-02	-0.30357E-03
10	0.91779E-03	-0.40195E-02	-0.27247E-03
11	0.13973E-02	-0.42636E-02	-0.16394E-03
12	0.16056E-02	-0.44992E-02	0.35989E-04
13	0.14395E-02	-0.48854E-02	0.27726E-03
14	0.96017E-03	-0.55618E-02	0.48513E-03
15	0.38830E-03	-0.65275E-02	0.58370E-03
16	-0.81659E-04	-0.76513E-02	0.57469E-03
17	-0.29447E-03	-0.87340E-02	0.47300E-03
18	-0.23651E-03	-0.95405E-02	0.27005E-03
19	0.	-0.98411E-02	0.

(Continued)   (Sheet 13 of 18)

Table B5 (Continued)

END ACTIONS WITH NODAL POINT LOADS

ELEMENT	AXIAL I AXIAL J	SHEAR I SHEAR J	MOMENT 1 MOMENT J
1	80.469	-1.128	0.379
	-80.469	-0.697	-0.821
2	80.409	-0.849	0.821
	-80.409	-0.962	-0.743
3	80.294	-1.003	0.743
	-80.294	-0.769	-1.039
4	80.123	-0.792	1.039
	-80.123	-0.976	-0.945
5	79.910	-0.947	0.945
	-79.910	-0.825	-1.190
6	79.660	-0.729	1.190
	-79.660	-1.114	-0.959
7	79.404	-0.654	0.959
	-79.404	-1.267	-0.529
8	79.178	-0.376	0.529
	-79.178	-1.619	0.516
9	79.004	-0.188	-0.516
	-79.004	-1.757	1.898
10	78.850	0.690	-1.898
	-78.850	-2.349	4.807
11	78.573	0.666	-4.807
	-78.573	-1.367	6.801
12	78.035	0.058	-6.801
	-78.035	-0.058	6.917
13	77.184	-1.023	-6.917
	-77.184	1.023	4.853
14	76.145	-2.037	-4.853
	-76.145	2.037	0.792
15	75.023	-1.031	-0.792
	-75.023	1.031	-1.300
16	74.050	-1.584	1.300
	-74.050	1.584	-4.481
17	73.321	-1.250	4.481
	-73.321	1.250	-7.004
18	72.923	-0.676	7.004
	-72.923	0.676	-8.361

LC-5 CONSTRUCTION CONDITION

(Continued)   (Sheet 14 of 18)

Table B5 (Continued)

NUMBER OF NODAL POINT LOAD CARDS =   19

SPECIFIED NODAL POINT LOADS

NODE	FX	FY	MOM
1	0.	12.080	0.
2	-4.250	23.770	0.
3	-8.340	22.600	0.
4	-12.140	20.710	0.
5	-15.500	18.160	0.
6	-18.320	15.060	0.
7	-20.520	11.520	0.
8	-22.030	7.700	0.
9	-22.830	3.700	0.
10	-22.900	-0.360	0.
11	-22.280	-4.460	0.
12	-21.000	-8.350	0.
13	-19.140	-11.950	0.
14	-16.760	-15.130	0.
15	-13.940	-17.820	0.
16	-10.760	-19.960	0.
17	-7.760	-21.520	0.
18	-3.700	-22.470	0.
19	0.	-11.470	0.

ELEMENT LOADS

LOAD TYPE * =1 CONCENTRATED LOAD
=2 UNIFORM DISTRIBUTED LOAD
=3 CONCENTRATED MOMENT
=4 TRIANGULAR DISTRIBUTED LOAD

LOCATION CODE-   *LOAD TYPES 1 AND 3:
DISTANCE FROM I NODE
*LOAD TYPE 2: =0
*LOAD TYPE 4:
=0 NODE I WEIGHTED, =1 NODE J WEIGHTED

DIRECTION CODE-   *LOAD TYPES 1-4:
X=2, Y=1

ELEMENT	NODE I	J	LOAD TYPE	MAGNITUDE OF LOAD	LOCATION CODE	DIRECTION CODE

(Continued)   (Sheet 15 of 18)

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ELEMENTS ON AN ELASTIC FOUNDATION

ELEMENT	SPRING PRESSURE	
	I	J
1	0.	0.
2	0.	0.
3	0.	0.
4	0.	0.
5	0.	0.
6	0.	0.
7	0.	0.
8	0.	0.
9	0.	0.
10	0.502813E 00	0.104907E 00
11	0.820942E 00	0.255364E 00
12	0.860922E 00	0.224433E 00
13	0.732114E 00	0.100573E 00
14	0.520710E 00	0.
15	0.267984E 00	0.
16	0.130788E 00	0.
17	0.	0.
18	0.	0.

NUMBER OF ITERATIONS = 6

(Continued)　　　　　　(Sheet 16 of 18)

Table B5 (Continued)

ELEMENT ZONE   LIMITS OF INTEGRATION (MAX=20)

1	EVEN	0.	,	2.008,
2	EVEN	0.	,	2.018,
3	EVEN	0.	,	2.009,
4	EVEN	0.	,	2.011,
5	EVEN	0.	,	2.008,
6	EVEN	0.	,	2.017,
7	EVEN	0.	,	2.009,
8	EVEN	0.	,	2.008,
9	EVEN	0.	,	2.017,
10	ODD	0.	,	2.017,
11	ODD	0.	,	2.008,
12	ODD	0.	,	2.009,
13	ODD	0.	,	2.017,
14	ODD	0.	,	1.909, 1.994,
15	ODD	0.	,	1.341, 2.029,
16	ODD	0.	,	0.836, 2.009,
17	EVEN	0.	,	2.018,
18	EVEN	0.	,	2.007,

NODAL POINT DISPLACEMENTS

NODE	X-DISPL	Y-DISPL	ROT-DISPL
1	0.	0.10936E-01	0.
2	-0.47287E-03	0.10724E-01	-0.16994E-03
3	-0.81804E-03	0.10108E-01	-0.32487E-03
4	-0.93614E-03	0.92025E-02	-0.43463E-03
5	-0.80432E-03	0.81554E-02	-0.48074E-03
6	-0.47999E-03	0.71385E-02	-0.45301E-03
7	-0.85794E-04	0.62605E-02	-0.35482E-03
8	0.21656E-03	0.55797E-02	-0.19755E-03
9	0.29724E-03	0.50529E-02	-0.14528E-04
10	0.11745E-03	0.45776E-02	0.14198E-03
11	-0.23800E-03	0.40588E-02	0.24741E-03
12	-0.65940E-03	0.34464E-02	0.30700E-03
13	-0.10332E-02	0.27425E-02	0.32063E-03
14	-0.12746E-02	0.19879E-02	0.30040E-03
15	-0.13193E-02	0.12730E-02	0.22964E-03
16	-0.11561E-02	0.68427E-03	0.16238E-03
17	-0.85687E-03	0.21872E-03	0.12923E-03
18	-0.45762E-03	-0.10786E-03	0.77802E-04
19	0.	-0.23032E-03	0.

(Continued)   (Sheet 17 of 18)

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Table B5 (Concluded)

END ACTIONS WITH NODAL POINT LOADS

| ELEMENT | AXIAL I | SHEAR I | MOMENT I |
	AXIAL J	SHEAR J	MOMENT J
1	136.791	-0.182	4.650
	-136.791	0.182	-5.016
2	136.786	0.626	5.016
	-136.786	-0.626	-3.751
3	136.782	0.629	3.751
	-136.782	-0.629	-2.489
4	136.759	1.173	2.489
	-136.759	-1.173	-0.130
5	136.716	0.915	0.130
	-136.716	-0.915	1.707
6	136.625	1.064	-1.707
	-136.625	-1.064	3.853
7	136.459	0.615	-3.853
	-136.459	-0.615	5.089
8	136.215	0.114	-5.089
	-136.215	-0.114	5.318
9	135.857	-0.880	-5.318
	-135.857	0.880	3.543
10	135.351	-0.836	-3.543
	-135.351	0.187	2.646
11	134.652	-1.409	-2.646
	-134.652	0.308	1.112
12	133.861	-1.193	-1.112
	-133.861	0.098	0.030
13	133.012	-0.982	-0.030
	-133.012	0.149	-0.896
14	132.155	-1.384	0.896
	-132.155	0.907	-3.000
15	131.350	0.982	3.000
	-131.350	-1.153	-0.736
16	130.649	-0.247	0.736
	-130.649	0.193	-1.138
17	130.543	-0.315	1.138
	-130.543	0.315	-1.772
18	130.259	-0.439	1.772
	-130.259	0.439	-2.654

*** $END ***

(Sheet 18 of 18)

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W

W = ROCK LOAD, tsf

R_i = INTERNAL RADIUS

R_e = EXTERNAL RADIUS

θ = ANGLE FROM VERTICAL

ϕ = ANGLE OF SEGMENT

X_e

F

t

ϕ θ

P_i

R_e

X_e = HORIZONTAL PROJECTION OF EXTERNAL FACE

F = VERTICAL ROCK FORCE

$X_e = R_e \sin \left(\theta + \frac{\phi}{2}\right) - R_e \sin \left(\theta - \frac{\phi}{2}\right)$

$F = WX_e$

Figure B5.   Formula for calculating rock loads for example 2

<u>LOAD CASE 1 = ROCK LOAD + WEIGHT OF LINING</u>

Rock Load = 0.275 tons/ft

For a 13-in. lining, R_e = 12.083 ft

θ = 30 degrees

ϕ = 10 degrees

<u>At Node 16,</u>

$$X_e = R_e \sin \left(\theta + \frac{\phi}{2}\right) - R_e \sin \left(\theta - \frac{\phi}{2}\right)$$

$$= 1.824 \text{ ft}$$

So, if $F = WX_e$, F = 1.0032 kips due to rock load

To this, add the load due to the weight of the tunnel lining:

$$\text{Weight of a 13-in. lining} = \left(\pi R_e^2 - \pi R_i^2\right) 0.150 \text{ kcf}$$

$$= 11.78 \text{ kips/ft}$$

Therefore, for one 10-degree segment, the weight of the tunnel lining

$$= \frac{11.78 \text{ kips/ft}}{36 \text{ segments}}$$

$$= 0.32 \text{ kips/ft}$$

<u>Total Load at Node 16</u>

Add F to the weight of the tunnel lining:

1.0032 kips + 0.32 kips = 1.32 kips

Figure B6.   Sample calculation of nodal loads at node 16 for load case 1,
example 2

h_i = INTERNAL WATER HEAD AT INVERT, ft

h_e = EXTERNAL WATER HEAD AT INVERT, ft

R_i = INTERNAL RADIUS

R_e = EXTERNAL RADIUS

θ = ANGLE FROM VERTICAL

ϕ = ANGLE OF SEGMENT

F_i = FORCE DUE TO INTERAL HEAD
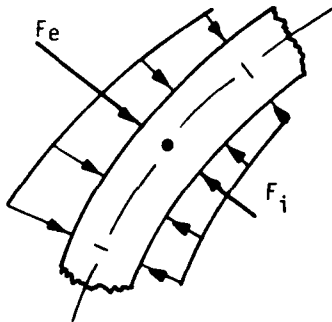
F_i = FORCE DUE TO INTERNAL HEAD

F_e = FORCE DUE TO EXTERNAL HEAD

S_i = INTERNAL SEGMENT LENGTH

S_e = EXTERNAL SEGMENT LENGTH

F_n = NET FORCE
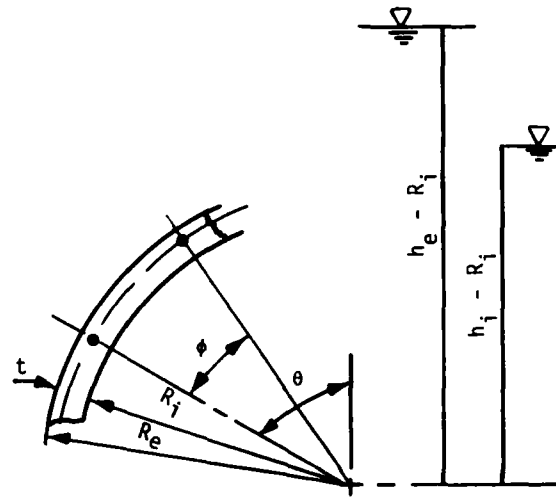
$$F_i = [(h_i - R_i) - \cos \theta R_i] \, S_i \gamma_w$$

$$F_e = [(h_e - R_i) - \cos \theta R_e] \, S_e \gamma_w$$

$$S_i = \frac{\pi 2 R_i}{\text{No. of segments}}$$

$$S_e = \frac{\pi 2 R_e}{\text{No. of segments}}$$

$$F_n = F_e - F_i$$

Figure B7. Formula for calculating water loads for example 2

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LOAD CASE 2 = ROCK LOAD + WEIGHT OF LINING + INTERNAL HEAD

For a 13-in. lining, 36-segment model, ϕ = 10 degrees

R_i = 11 ft,

so $S_i = \frac{\pi 2(11)}{36}$ = 1.920 ft

R_e = 12.083 ft,

so $S_e = \frac{\pi 2(12.083)}{36}$ = 2.109 ft

For Node 16,

$F_i = [(h_i - R_i) - R_i \cos \theta] S_i \gamma_w$

$= [(180 - 11) - 11 \cos 30](1.92)0.0624$

$= 19.11$ kips

$F_e = [(h_e - R_i) - R_e \cos \theta] S_e \gamma_w$

$= [(150 - 11) - 12.083 \cos 30](2.109)0.0624$

$= 16.92$ kips

$F_n = F_e - F_i$
$= 16.92 - 19.11 = -2.19$ kips

$F_x = F_n \sin \theta = -2.19 \sin 30 = 1.10$ kips→

$F_y = F_n \cos \theta = -2.19 \cos 30 = 1.897$ kips↑

Adjust F_y

The Rock Load and Lining Weight from Load Case 1 was 1.32 kips. So,

$F_y = 1.897 - 1.32 = 0.58$ kips↑

Figure B8. Sample calculation of nodel loads at node 16 for load case 2, example 2

LOAD CASE 3 = ROCK LOAD + WEIGHT OF LINING + EXTERNAL HEAD

For Node 16,

$$F_i = [(100 - 11) - 11 \cos 30](1.92)0.0624$$
$$= 9.52 \text{ kips}$$

$$F_e = [(185 - 11) - 12.083 \cos 30](2.109)0.0624$$
$$= 21.52 \text{ kips}$$

$$F_n = F_e - F_i$$
$$= 21.52 - 9.52 = 12.00 \text{ kips}$$

$$F_x = 12.0 \sin 30 = -6.0 \text{ kips} \leftarrow$$

$$F_y = 12.0 \cos 30 = -10.39 \text{ kips} \downarrow$$
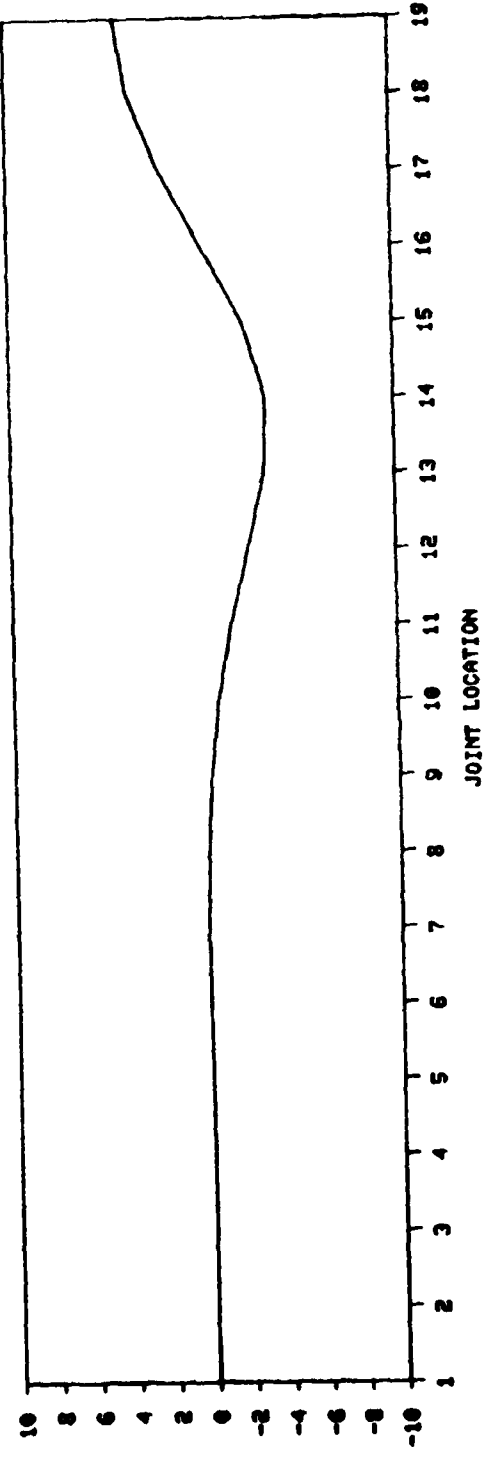
Adjust F_y

The Rock Load and Lining Weight from Load Case 1 was 1.32 kips
So,

$$F_y = -10.39 + (-1.32) = -11.71 \text{ kips} \downarrow$$

Figure B9. Sample calculation of nodal loads at node 16 for load case 3, example 2
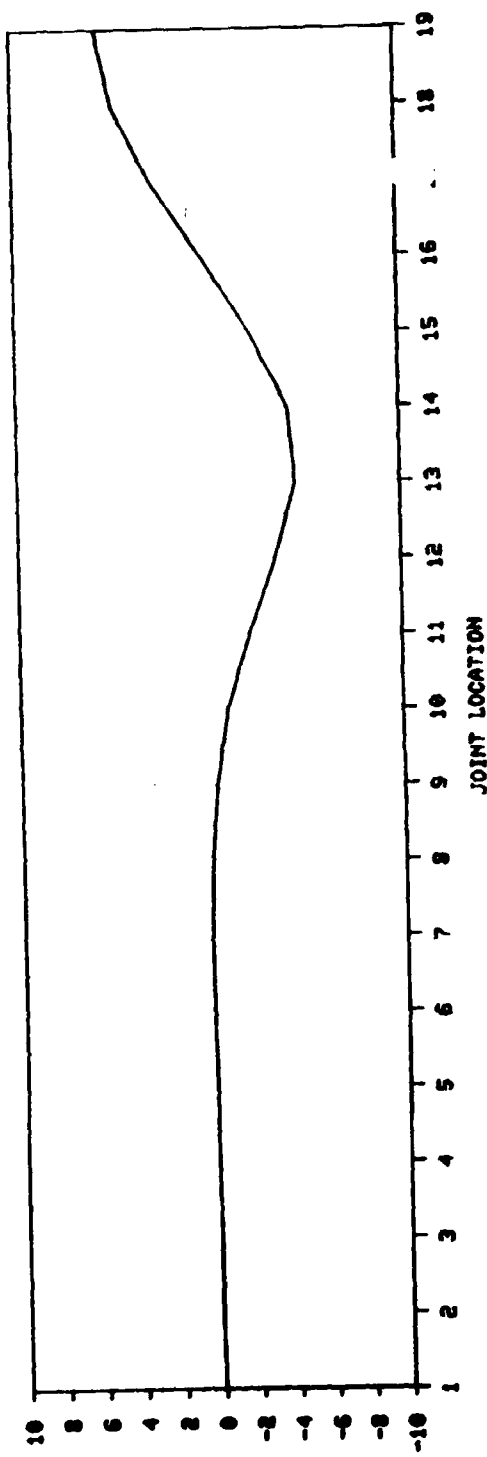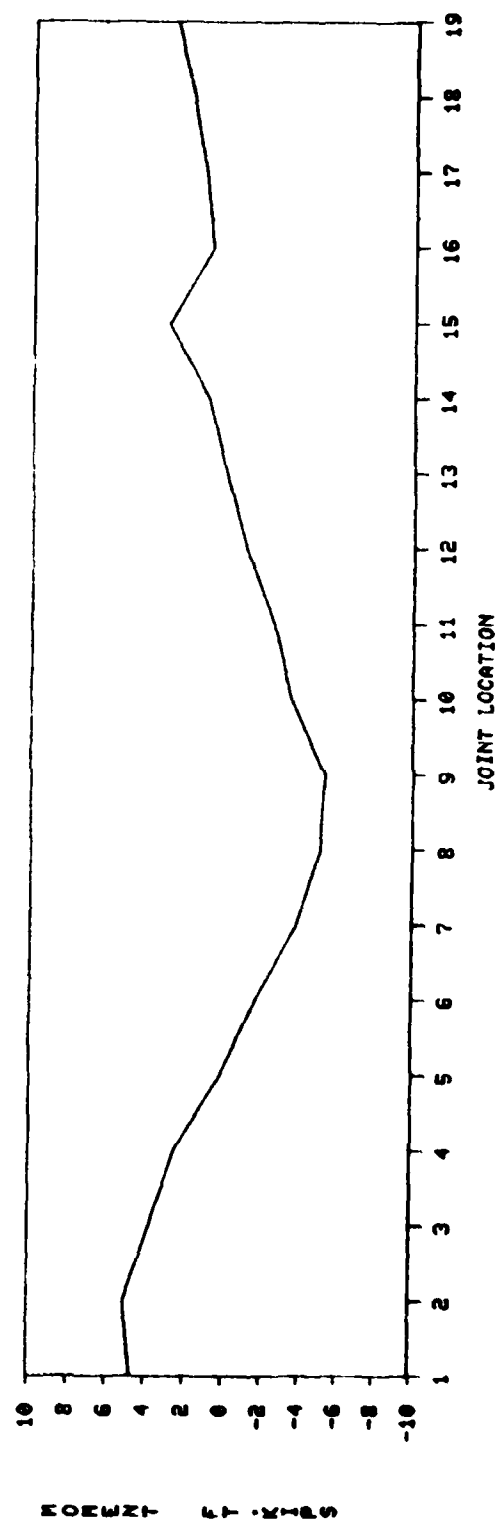
a. Load case 1

b. Load case 2

Figure B10. Plot of moment in the concrete lining for example 2 (sheet 1 of 2)

JOINT LOCATION

c. Load case 3

JOINT LOCATION
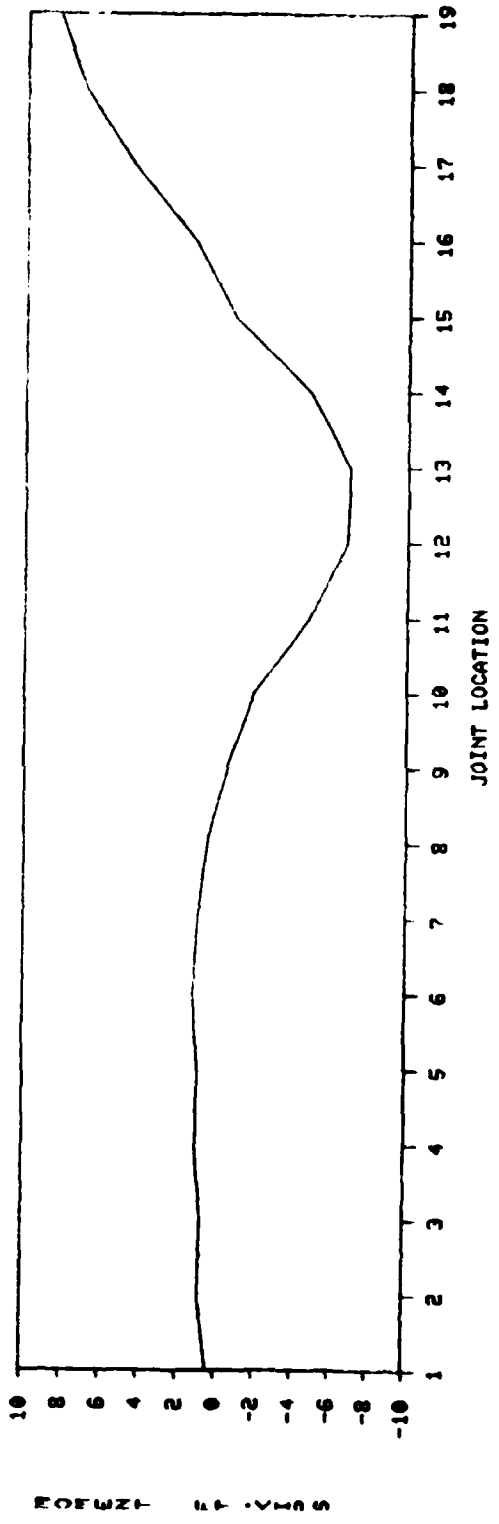
d. Load case 5

Figure B10. (sheet 2 of 2)

B43

Holtham, William J.
  User's guide : Computer program for design and analysis
of cast-in-place tunnel linings (NEWTUN) : final report /
by William J. Holtham, James R. Fay, U.S. Army Engineer
Division, New England ; prepared for Office, Chief of
Engineers, U.S. Army ; monitored by Automatic Data
Processing Center, U.S. Army Engineer Waterways Experiment
Station. -- Vicksburg, Miss. : U.S. Army Engineer Waterways
Experiment Station ; Springfield, Va. : available from
NTIS, 1981.
  15, [46] p. : ill. ; 27 cm. -- (Instruction report / U.S.
Army Engineer Waterways Experiment Station ; K-81-4)
  Cover title.
  "March 1981."
  "A report under the Computer-Aided Structural Engineering
(CASE) Project."
  Bibliography: p. 15.

  1. Mathematical analysis. 2. NEWTUN (Computer program).
3. Tunnels. I. Fay, James R. II. United States.
Army. Corps of Engineers. New England. III. United
States. Army. Corps of Engineers. Office of the Chief of

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Engineers. IV. United States. Army Engineer Waterways
Experiment Station. Automatic Data Processing Center.
V. Title VI. Series: Instruction report (United
States. Army Engineer Waterways Experiment Station) ; K-81-4.
TA7.W341 no.K-81-4

WATERWAYS EXPERIMENT STATION REPORTS
PUBLISHED UNDER THE COMPUTER-AIDED
STRUCTURAL ENGINEERING (CASE) PROJECT

	Title	Date
Technical Report K-78-1	List of Computer Programs for Computer-Aided Structural Engineering	Feb 1978
Instruction Report O-79-2	User's Guide: Computer Program with Interactive Graphics for Analysis of Plane Frame Structures (CFRAME)	Mar 1979
Technical Report K-80-1	Survey of Bridge-Oriented Design Software	Jan 1980
Technical Report K-80-2	Evaluation of Computer Programs for the Design/Analysis of Highway and Railway Bridges	Jan 1980
Instruction Report K-80-1	User's Guide: Computer Program for Design/Review of Curvilinear Conduits/Culverts (CURCON)	Feb 1980
Instruction Report K-80-3	A Three-Dimensional Finite Element Data Edit Program	Mar 1980
Instruction Report K-80-4	A Three-Dimensional Stability Analysis/Design Program (3DSAD)	
	Report 1: General Geometry Module	Jun 1980
Instruction Report K-80-6	Basic User's Guide: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)	Dec 1980
Instruction Report K-80-7	User's Reference Manual: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)	Dec 1980
Technical Report K-80-4	Documentation of Finite Element Analyses	
	Report 1: Longview Outlet Works Conduit	Dec 1980
	Report 2: Anchored Wall Monolith, Bay Springs Lock	Dec 1980
Technical Report K-80-5	Basic Pile Group Behavior	Dec 1980
Instruction Report K-81-2	User's Guide: Computer Program for Design and Analysis of Sheet Pile Walls by Classical Methods (CSHTWAL)	
	Report 1: Computational Processes	Feb 1981
	Report 2: Interactive Graphics Options	Mar 1981
Instruction Report K-81-3	Validation Report: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)	Feb 1981
Instruction Report K-81-4	User's Guide: Computer Program for Design and Analysis of Cast-in-Place Tunnel Linings (NEWTUN)	Mar 1981
Instruction Report K-81-6	User's Guide: Computer Program for Optimum Nonlinear Dynamic Design of Reinforced Concrete Slabs Under Blast Loading (CBARCS)	Mar 1981
Instruction Report K-81-7	User's Guide: Computer Program for Design or Investigation of Orthogonal Culverts (CORTCUL)	Mar 1981

N

DATE

ILME