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A COMPUTER PROGRAM FOR NONLINEAR EARTHQUAKE ANALYSIS OF CONCRETE ARCH DAMS

USER GUIDE

BY

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AND
RICHARD B. REIMER

MARCH 1992

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF CALIFORNIA
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ABSTRACT

The modeling and dynamic analysis of a concrete arch dam, the impounded water, and the foundation rock is an important step in the earthquake safety evaluation of the system. A linear earthquake analysis assuming the dam is an elastic monolithic structure usually indicates tensile arch stresses that exceed the tensile strength of concrete. Since arch dams are constructed as cantilever monoliths, the joints between the monoliths cannot develop the tensile stresses predicted in a linear analysis. In reality, the contraction joints are expected to open and close during an earthquake, releasing arch stresses and redistributing the internal forces.

The computer program ADAP–88 is a finite element analysis program for computing the earthquake response of arch dams including the nonlinear effect of contraction joint opening. The nonlinear joint elements are combined with shell, solid, and fluid finite elements to model a complete arch dam system. Special consideration is given to resolving the stress distribution near the joints by using a refined mesh of solid elements. A numerical procedure for solving the equations of motion assumes that the nonlinearity in the model is restricted to the joints. The cantilever monoliths between contraction joints are modeled as linear substructures, resulting in a significant reduction of computation in the iterative solution of the nonlinear equations of motion. ADAP–88 includes a finite element mesh generator for typical arch dam geometries. The computer program RESVOR is used to compute the added mass for the water impounded in the reservior, assuming the fluid is incompressible.

The computer programs and sample input and output files are available from the National Information Service for Earthquake Engineering (NISEE) at the University of California at Berkeley. To obtain information about acquiring ADAP–88, please contact:

NISEE/Computer Applications
Earthquake Engineering Research Center
404A Davis Hall
University of California at Berkeley
Berkeley, CA 94720

Phone: (510) 642–5113
FAX: (510) 643–5264

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Chapter 1

INTRODUCTION

Concrete arch dams are usually constructed as cantilever monoliths separated by contraction joints. Since the joints cannot transfer substantial tensile stresses in the arch direction, the joints may open as the dam vibrates in response to earthquake ground motion. A seismic safety evaluation of an arch dam often relies on a linear dynamic analysis assuming that the dam is a monolithic structure. The joint opening behavior is not represented and, hence, a linear analysis can indicate unrealistically large tensile stresses in the arch direction.

The earthquake response of arch dams is further complicated by the important effects of dam–water interaction, dam–foundation rock interaction, and the spatial variation of the input motion along the interface between the dam and canyon. It is not possible to include these frequency–dependent effects along with the nonlinear joint behavior in an analysis procedure without some approximation.

The ADAP–88 computer program implements a nonlinear solution procedure which has been developed for computing the earthquake response of arch dams including the effects of joint opening (Fenves 1989). The contraction joints are modeled by a nonlinear joint element, a detailed discretization near the joint helps resolve stress concentrations, and the dam body is modeled by shell elements. A substructure procedure, in conjunction with the observation that only a few contraction joints in the dam have to be included in the model, provides an efficient numerical solution. The foundation rock is represented as a massless finite element model and uniform free–field motion is specified at the canyon–dam interface.

Dam–water interaction effects in the earthquake analysis are represented by an added mass matrix for the incompressible water in the reservoir. The computer program RESVOR computes the added mass from a finite element analysis of the impounded water (Kuo, 1982). RESVOR has been extended to diagonalize the full added mass matrix to improve the efficiency of the substructure solution procedure used in ADAP–88.

An important conclusion of a recently completed parameter study is that it is necessary to include at least three contraction joints in the model of an arch dam to represent the effects of contraction joint opening during an earthquake (Fenves, et al., 1992). Including more than three contraction joints in the model does not substantially affect the stress distribution compared with a three joint model. For earthquake analysis of typical dams, using three joints in a model provides a resonable tradeoff between accuracy of the analysis and the size of the model.

This report documents the use of the current version of the ADAP–88 program and supercedes the description of the program in the appendix of (Fenves, et al., 1989). The differences between the current user guide and and the earlier version are marked by a vertical line at the left margin.

Chapter 2 of this report defines important terms used in the mesh generation and describes the parameters controlling the earthquake analysis. Chapter 3 contains the description of the input file for ADAP–88. Chapter 4 describes the output from ADAP–88. For completeness, Chapter 5 contains a description of the program RESVOR for computing the added mass of the impounded water. Finally, the appendices provide guidelines for installing the programs and list sample input files for ADAP–88 and RESVOR.

Chapter 2

MESH GENERATION AND ANALYSIS OPTIONS

2.1 Mesh Generation

ADAP–88 includes a finite element mesh generator for three–centered arch dams of arbitrary geometry with contraction joints. The foundation mesh generated by the program assumes a prismatic shape for the canyon. The mesh generator includes options for creating plots of the mesh by substructure, element type, or material type. The user specifies the plot options and a point in the global coordinate system from which to view the mesh. The mesh generation is similar to the original version of the ADAP program (Clough, et al., 1973). This chapter describes the terms and assumptions in the program to assist the user with preparing input data for generating a finite element mesh of an arch dam and performing static and dynamic analyses.

2.1.1 Definition of Mesh Generation Terms

Figure 1 shows the plan view of a dam crest. The *reference surface* is the vertical cylindrical surface that passes through the upstream edge of the crest. Points I, OR and OL are, respectively, the centers of inner, right–outer and left–outer portions of the reference surface. Points PR and PL are the points of compound curvature, points where the curvature changes. The *reference plane* is a vertical plane that passes through point I and the base of the dam. An angle to reference plane refers to the central angle between a point on the reference surface and the reference plane. Depending on the location of the point on the reference surface, center of inner, right–outer, or left–outer arc, is used in definition of the angle to reference plane. For points m_1, m_2, and m_3 on the reference surface in Fig. 1, the angles to the reference plane are ϕ_1, ϕ_2, and ϕ_3, respectively.

A right–hand, X–Y–Z global coordinate system is defined such that the Y–Z plane coincides with the reference plane with the Z–axis lying on the reference surface in the upward direction. The origin of the coordinate system is at the base of the dam.

The geometry of the dam is specified at *design elevations*. Geometric properties of the dam at other elevations are computed from the data at the design elevations using cubic interpolation. A typical horizontal cross section of a dam is shown in Fig. 2. The centers of the inner upstream and downstream arcs may have arbitrary X and Y coordinates, although the centers illustrated in Fig. 2 are on the Y–axis for clarity. The upstream and downstream arcs may be three–centered. Again with reference to Fig. 2, the points of compound curvatures for the arcs, P1, P2, P3 and P4, are specified by *compounding angles* ϕ_1, ϕ_2, ϕ_3, and ϕ_4 measured from lines parallel to the Y–axis. The abutment lines are assumed to be radial with respect to the upstream face and are specified by *angles to abutment* ϕ_5 and ϕ_6.

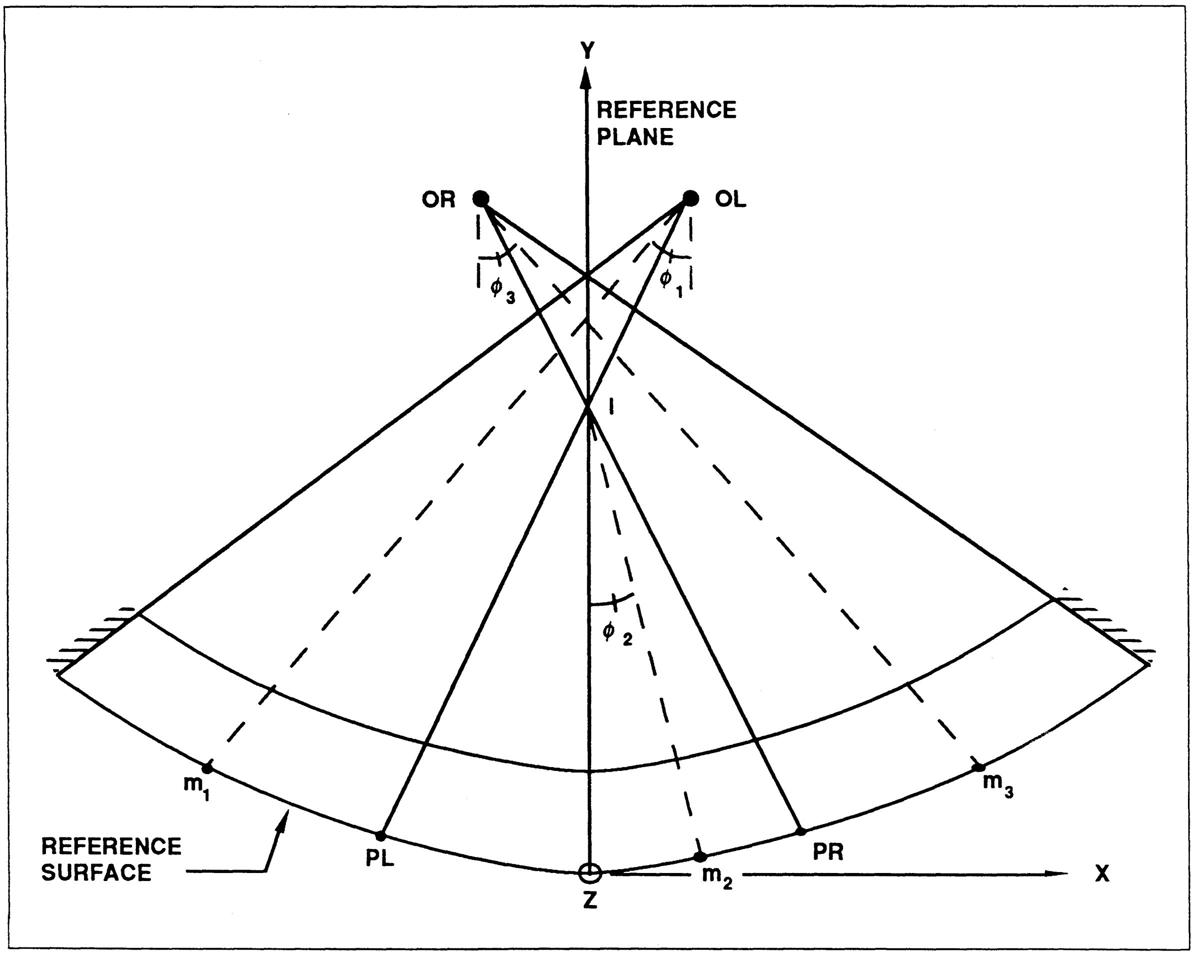

Figure 1. Plan View of Dam Crest

The elevations of horizontal sections of the finite element mesh are *mesh elevations*. These are based on two different sets of elevations: (i) user–specified elevations, called *initial mesh elevations*, and (ii) elevations corresponding to the intersection of the joints and the abutment, called *joint–abutment elevations*. All joint–abutment elevations are used as mesh elevations, whereas certain initial mesh elevations may be disregarded as described in the next section.

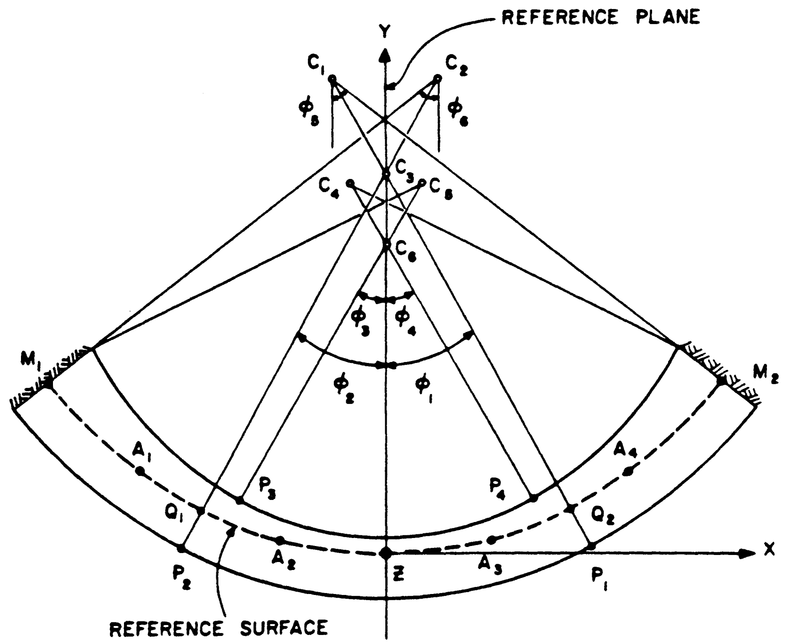

Figure 2. Typical Horizontal Section of Dam

Each contraction joint is located normal to the upstream surface and is specified by an angle to the reference plane at the crest elevation. A contraction joint is modeled by joint elements and a portion of the dam on each side of a joint is discretized with 3–D solid elements to resolve the stress distribution near the joint. A *3–D solid block* is defined as the 3–D solid elements at one side of a joint. Thus, two 3–D solid blocks are associated with each contraction joint. The user must provide the initial mesh elevations such that at least three elevations intersect each contraction joint.

2.1.2 Generation of Dam Mesh

A preliminary dam mesh is generated as a grid of horizontal and vertical lines on the reference surface, as shown in Fig. 3. The end points of the horizontal lines at the mesh elevations correspond to the intersection of the reference surface and abutment, as shown by points M1 and M2 in Fig. 2.

Lines ab and cd in Fig. 3 are two joints in the dam which are located by angles to the reference plane. Points b and d are the intersection of the joints and the abutment. The elevations of these points are computed by cubic interpolation from the design elevations for which the angles to the reference plane at abutment are available, as indicated in Fig. 2.

Points b' and d' are two abutment nodes at the same elevations as points b and d, respectively. The angle between these points and the reference plane are computed using the same procedure for locating the abutment nodes (M1 and M2 in Fig. 2).

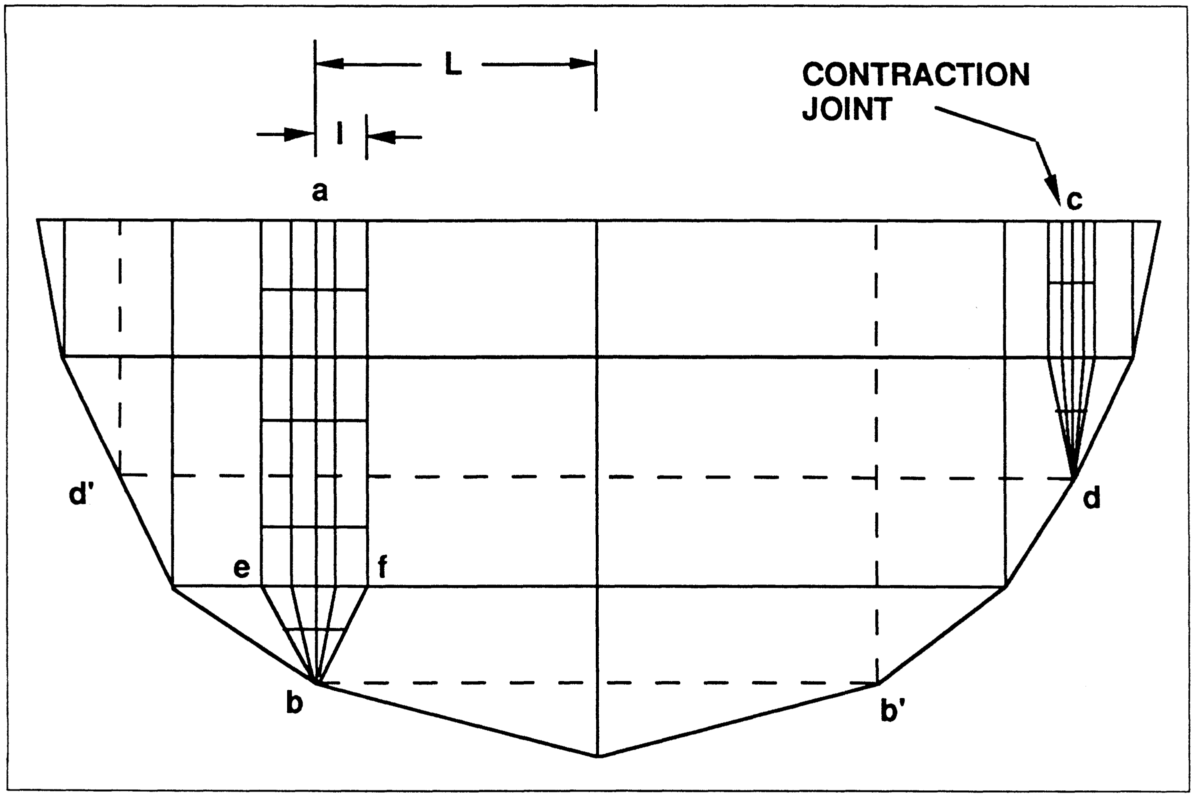

Figure 3. Finite Element Mesh on Reference Surface of Dam

The 3–D solid blocks are also represented in the reference surface as shown in Fig. 3. The width of each block in the arch direction is controlled by the *width ratio*, a user–specified parameter. This ratio is defined as l/L where l is the width of the block and L is the distance from the joint to the next vertical line of the mesh as shown in Fig. 3. Both l and L are measured on the reference surface.

After a two–dimensional mesh is generated on the reference surface, the mesh is projected on the upstream and downstream faces to obtain a three–dimensional mesh of the dam. The centers of the upstream face are used in this projection to avoid difficulties associated with the irregular elements near the abutment.

The nodal points of the shell elements are completely generated by the projection of the reference surface mesh on the upstream and downstream faces. However, the 3–D elements in the projected mesh are further divided to obtain the specified number of 3–D elements through the thickness of the dam.

The mesh generation procedure may result in an excessive number of horizontal sections and inappropriate aspect ratios for the shell elements. To avoid this problem two measures are taken:

- A user–specified mesh elevation that is within a threshold distance to any joint–abutment elevation is disregarded. The threshold is based on a user–specified height ratio (Record C.1 in Chapter 3) and smallest element size associated with the initial mesh elevations.
- If the joint–abutment elevations corresponding to a pair of joints at opposite sides of the crown are too close, the elevations are combined to give a nearly horizontal line on the reference surface. To avoid large slopes, this degeneration is allowed only for joint–abutment elevations that are within two consecutive user–specified mesh elevations.

2.1.3 Generation of Foundation Mesh

The foundation mesh corresponds to a canyon with a prismatic shape. Figure 4 shows the projection of the right abutment on the X–Z plane. The abutment lines at various mesh elevations are shown by A_1–B_1, A_2–B_2, ..., and points C_1, C_2, ..., are the mid–points of these lines. The foundation model consists of several layers of 3–D solid elements. The interfaces of the layers are parallel to the Y–axis and they intersect the X–Z plane at right angles to the line passing through C_1, C_2, ... The interfaces of the layers are shown as C_1–C_1^*, C_2–C_2^*, ..., in Fig. 4.

There are three foundation mesh types depending on the volume of the foundation rock included in the model and the number of 3–D solid elements. The discretization of the foundation is shown in Fig. 5 for a typical interface between foundation layers. Point C is the mid–point of the abutment line and points A and B are the projections of the upstream and downstream nodes of the abutment on the interface. The nodal points of the rigid support of the model are located on a semi–circle of radius R centered at the mid–point of the abutment lines. Values for R in terms of dam height, H, and also the number of 3–D elements in each layer are shown in Table 1 for the three foundation mesh types.

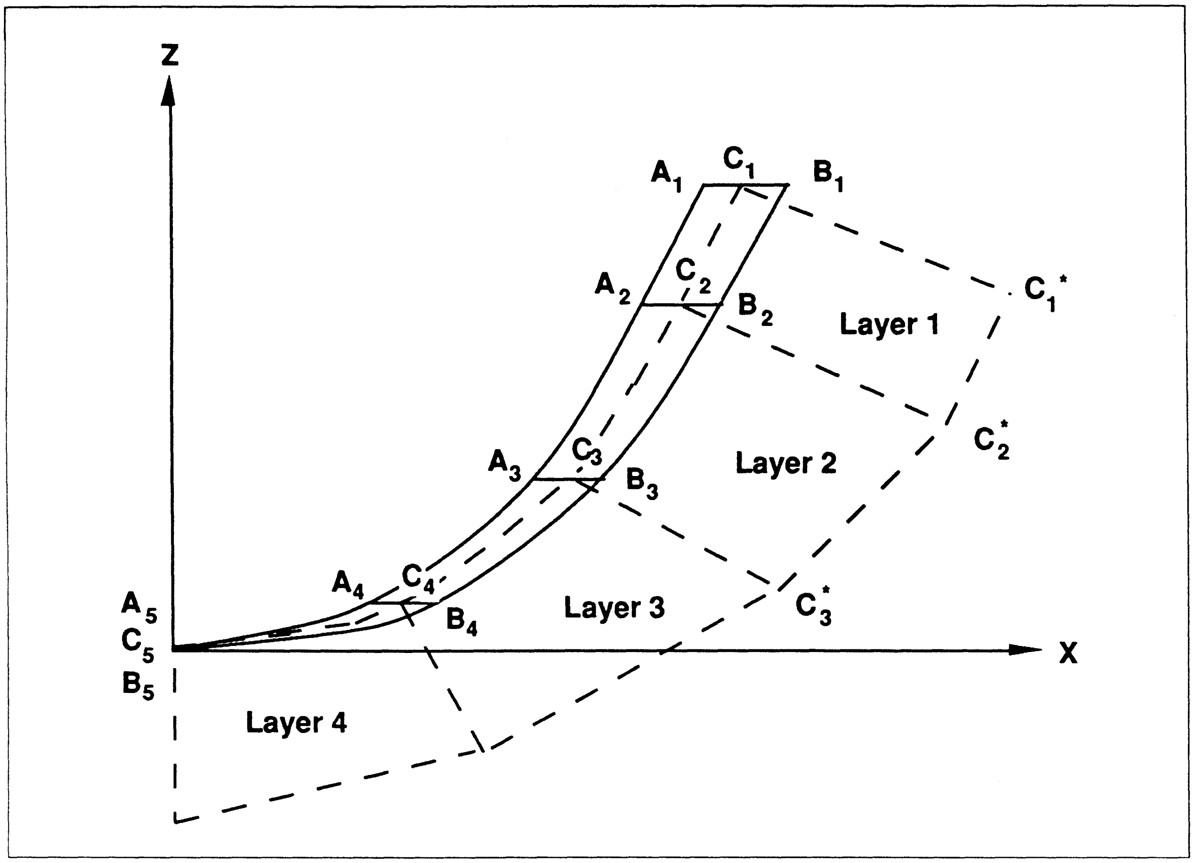

Figure 4. Projection of Abutment and Foundation Model on X–Z Plane

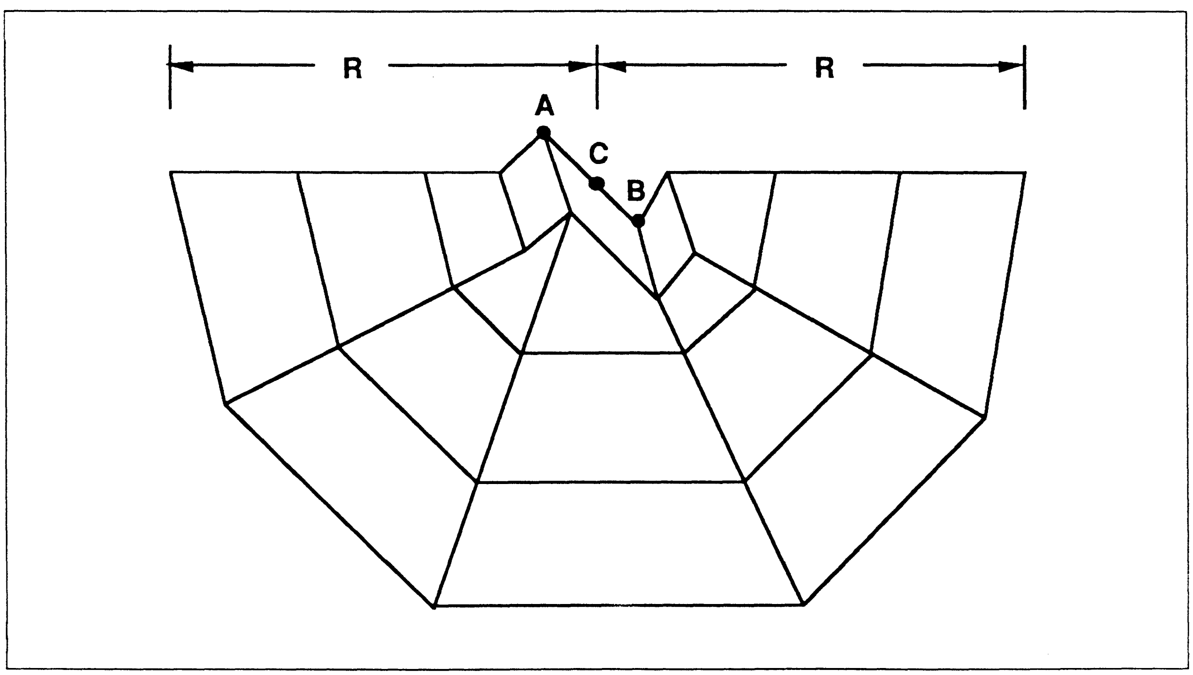

Figure 5. Foundation Mesh on Interface of Layers of 3–D Solid Elements

Table 1. Parameters for Foundation Mesh Generation

Foundation Mesh Type	No. of 3–D Elements in Each Layer	Radius, R
1	8	H
2	13	H
3	18	1.5H

2.2 Parameters for Joint Elements

The joint element has a nonlinear relationship between the stresses transferred by the joint and the relative displacement at the joint, as shown in Fig. 6 (Fenves, et al., 1989). The directions 1, 2 and 3, respectively correspond to the vertical tangential direction, horizontal tangential direction, and normal direction. The input parameters KN and Q0 in Records E and I, as described in Chapter 3, correspond to the normal stiffness, k, and normal strength, q_0, respectively. The tangential stiffness of the element is specified by the KS input parameter. Both KN and KS should have large values to enforce displacement continuity at the contraction joints. Excessively large values, however, may produce an ill–conditioned numerical solution because of large differences in the terms in the structural stiffness matrix. Appropriate values of KN and KS depend on the precision for floating point variables. The following value is recommended:

KN, KS = $(n*E)/L$

where E is the modulus of elasticity of the concrete and L is the length of the adjacent 3–D solid element in the direction normal to the joint. Depending on the precision of floating point compution, n may range from 10 to 100, with larger values for greater precision.

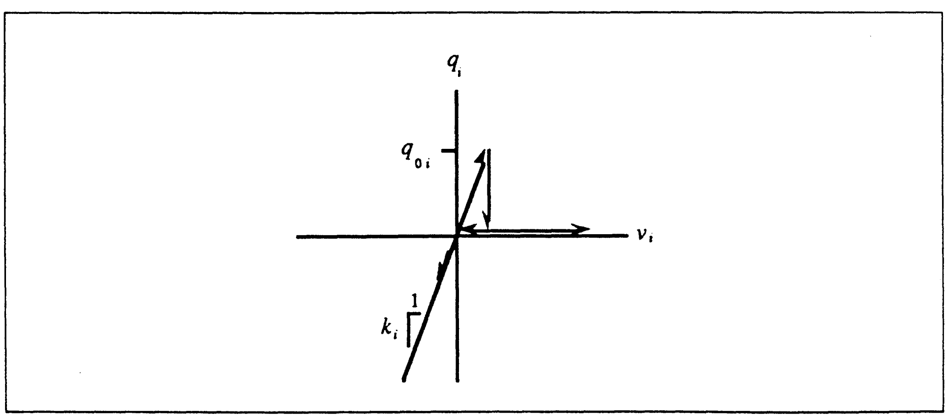

Figure 6. Stress–Relative Displacement Relationship for Joint Element, for i=1, 2, and 3

The normal tensile strength of the joints can be specified with an appropriate Q0 value. Q0 may be set equal to zero to specify no–tension property of the joints. To represent a dam as a monolithic structure a sufficiently large Q0 value should be specified so that the joints do not open.

Slippage in the transverse direction of the joint is simulated by reducing the tangential stiffness for a specified threshold value of the normal displacement. The normal displacement at which slippage is allowed is given by the input parameters SLPT1 and SLPT2 in Record E of Chapter 3. Once a joint opens this amount, the tangential stiffness is reduced by a factor specified by the input parameters SCAL1 and SCAL2. The threshold value and reduction factor are separately specified for slippage in the vertical and horizontal directions, which are the 1 and 2 directions, respectively.

2.3 Static Analysis

Two different load cases can be included in the static analysis. The first load case corresponds to the gravity loads. The second load case corresponds to water and/or temperature loads acting on the entire dam.

In the static analysis for gravity loads, the construction sequence of the dam is represented by considering the dam as independent cantilevers, which are defined by the mesh generator. The gravity load analysis is performed for alternate cantilevers so that the response of each cantilever to its dead weight is independent of the other cantilevers. This type of gravity load analysis was used in the original version of ADAP (Clough, et al., 1973).

The program uses a nonlinear solution procedure in the second static analysis to allow opening of the contraction joints under hydrostatic and temperature loads. Usually a nonlinear static analysis can be performed in a single load step. The multi–load step solution procedure should be used if the single load step fails to converge. In each step of the multi–step procedure, a fraction of static load is applied to the dam and the load is successively increased until the response under the full static load is obtained.

The type of static analysis is determined by item LSAT in Record D. The joint element properties and control parameters for the static analysis are given in Record I.

2.4 Earthquake Analysis

The earthquake analysis is controlled by several parameters in Record D of the input data. The time integration procedure is determined by two parameters β and γ, although the Newmark average acceleration procedure is recommended with β=0.25 and γ=0.50. The appropriate time step for the integration procedure is problem dependent; it should be selected such that the high frequency components of the response are properly represented and the nonlinear solution procedure converges.

The control of the iterations for each time step is determined by parameters in Record D. NIT is the maximum number of iterations for each time step. If this limit is reached without convergence, an error message will be printed but the solution will proceed to the next time step. The criteria for convergence within a time step are determined by two input parameters, TOL1 and TOL2. If the earthquake analysis is preceded by a static analysis for water and/or temperature loads, convergence is achieved when the change in strain energy of the joints in the latest iteration is less than TOL1*U, where U is the strain energy of the joints under the static loads. If a static analysis is not performed (which is not recommended) TOL2 is the strain energy to use as the tolerance for convergence.

Appropriate values for TOL1 and TOL2 depend on the floating precision for the computer. For real variables of four or eight bytes, tolerances of TOL1=1.0e–4 or TOL1=1.0e–10, respectively, are recommended. When the first static load case is included in the analysis, the tolerance value computed from the static strain energy is printed by the program. This value may be used for TOL2 if no static analysis is performed prior to an earthquake analysis.

Care is required in selecting convergence tolerances because tolerances that are too will prevent convergence, whereas tolerances that are too large will produce a solution that may be in error. Suitable values for the tolerances should be determined from a convergence study for each problem. A linear earthquake analysis should require two iterations for each time step and generally the maximum number of iterations in each time step of a nonlinear earthquake analysis should not exceed ten.

Chapter 3

INPUT DATA FOR ADAP–88

The input file for ADAP–88, named *adapi*, consists of a number of records in free–format. Each record is processed by one FORTRAN 77 free–format read statement. The items in a record can be separated by a comma or at least one space and they may be entered on any number of lines.

The user may select any physical units for the dimensional quantities in the input. The dimensions of the output quantities are consistent with the input units.

Record A — Title

The title entered on one line is printed on the output for identification. The title is limited to 72 characters.

Record B — Master Control Parameters

NLM	Number of initial mesh elevations
MESHFN	indicator for type of foundation mesh; =0 for rigid foundation; =1, =2, =3 for foundation mesh types 1, 2, and 3, respectively
WATL	z–coordinate of water level
WDEN	Weight density of water
GRAV	Acceleration due to gravity
REFT	Reference temperature for static analysis
NPLOT	Number of plots of finite element mesh; = 0, for no plots
ISYM	Code for symmetry; = 0, for general dam geometry; = 1, for symmetric dam subjected to symmetric loads; = –1, for symmetric dam subjected to antisymmetric loads For analysis of a symmetric dam (ISYM≠0), the crown section is the plane of symmetry and the program applies appropriate boundary conditions at nodal points on the plane.

Record C — Generation of Finite Element Mesh

C.1 — Control Parameters

RI	Radius of inner portion of the reference surface
RO(1)	Radius of the right outer portion of the reference surface
RO(2)	Radius of the left outer portion of the reference surface
NL	Number of design elevations
IEL	=1 if the same compounding angles are specified for all elevations; =0 otherwise
IRL	=1 if the same compounding angles are specified for right and left portions of the dam; =0 otherwise
IIE	=1 if the same compounding angles are specified for intrados and extrados faces of the dam; =0 otherwise
NRL	=1 if the same radii are specified for right and left portions of the intrados and extrados arcs; =0 otherwise
IPLT	=1 if the generated finite element mesh is to be plotted; =0 otherwise
FINC	width ratio of the 3–D block
DMRAT	height ratio used in generation of finite element mesh; a user–specified mesh elevation which is within DMRAT*HMIN distance from a joint–abutment elevation is disregarded by the program, where HMIN is the smallest element height implied by the user–specified mesh elevations (see Section 2.1.2).
NTAN	number of 3–D solid elements in arch direction of 3–D block
NTHK	number of 3–D solid elements through thickness of 3–D block

C.2 — Compounding Angles and Angles to Abutments

One record is provided for each of NL design elevations in increasing order of elevations. If IEL=1, compounding angles for all elevations except the first may be entered as zero. If IRL=1, compounding angles for left arcs may be entered as zero. If IIE=1, compounding angles for extrados arcs may be entered as zero.

EL	Design elevation
FCI(1)	Compounding angle of the right intrados arc
FCI(2)	Compounding angle of the left intrados arc
FCE(1)	Compounding angle of the right extrados arc
FCE(2)	Compounding angle of the left extrados arc

FA(1) Angle to right abutment

FA(2) Angle to left abutment

C.3 — Contraction Joint Data

In the current version, the total number of contraction joints is limited to eighteen (18).

C.3.1 Contraction Joints to the Right of Crown Section

NJR Number of contraction joints to the right of the crown section

ANGR(i) Angles to the reference plane for contraction joint to the right of the crown section, i=1,2...NJR, in increasing order.

C.3.2 Contraction Joints to the Left of Crown Section

NJL Number of contraction joints to the left of the crown section

ANGL(i) Angles to the reference plane for contraction joint to the left of the crown section, i=1,2...NJL, in increasing order.

C.4 — Temperature Data

Two records are provided, the first for the upstream face and the second for the downstream face. Each record should list the temperature at the design elevations, in order of increasing elevation.

C.5 — Initial Mesh Elevations

One record provides initial elevations for the NLM mesh elevations in increasing order.

C.6 — Intrados and Extrados Arcs

C.6.1 Y–coordinates of Centers and Radii of Arcs

For each design elevation, one record specifies the Y–coordinates of the centers and radii of the upstream and downstream face arcs. A total of NL records must be provided in order of increasing design elevations.

YII y–coordinate of center of intrados inner arc

YEI y–coordinate of center of extrados inner arc

RII Radius of intrados inner arc

REI Radius of extrados inner arc

RIO(1) Radius of intrados right outer arc

REO(1) Radius of extrados right outer arc

RIO(2) Radius of intrados left outer arc

REO(2) Radius of extrados left outer arc

C.6.2 X–coordinates of the Centers of Inner Arcs

Two records are provided, the first for the downstream face and the second for the upstream face. Each record should list the X–coordinates of centers of the inner arcs at the design elevations, in order of increasing elevation.

C.7 — Control for Mesh Plots

Repeat the following data for each of the NPLOT mesh plots requested in Record B. Skip this record if NPLOT =0.

PTYPE = 1, plot by substructure; = 2, plot by element type; = 3, plot by material type

OPLOT = 1, X axis vertical; = 2, Y axis vertical; =3, Z axis vertical

V(1), V(2), V(3) X, Y, Z coordinates of viewpoint of mesh

C.7.1 Plot by Substructure, PTYPE=1

N Number of substructures to plot; = 0, plot all substructures, do not enter SUB.

SUB(1) First substructure number

•

•

SUB(N) Last substructure number

C.7.2 Plot by Element Type, PTYPE=2

N Number of element sets to plot

ETYP(1) Element type: = 1, joint elements; = 2, 3–D solid elements; = 3, 3–D shell elements; = 4, thick shell elements

FRM(1) First element number of specified type

TO(1) Last element number of specified type

•

•

•

ETYP(N) Element type: = 1, joint elements; = 2, 3–D solid elements; = 3, 3–D shell elements; = 4, thick shell elements

FRM(N) First element number of specified type

TO(N) Last element number of specified type

C.7.3 Plot by Material Type, PTYPE=3

N Number of materials to plot

MAT(1) First material number

•

•

•

MAT(N) Last material number

Record D — Control Parameters for Static and Earthquake Analysis

DT	Time step for integration of equations of motion
NT	Number of time steps; enter zero to suppress earthquake analysis
NIT	Maximum number of iterations for each time step
BETA	β parameter for time integration; 0.25 is recommended
GAMMA	γ parameter for time integration; 0.50 is recommended
B0	cofficient b_0 for mass proportional Rayleigh damping
B1	cofficient b_1 for stiffness proportional Rayleigh damping
TOL1	Tolerance coefficient for iterations used when LSTAT(1)=1, that is when earthquake analysis is preceded by static analysis for water and/or temperature loads
TOL2	Actual tolerance for iterations used when LSTAT(1)=0, i.e. no static analysis is performed for water and/or temperature loads
IOUT	Computed response is printed every IOUT time steps
IAVENV	Number of time steps over which stresses are averaged in computing stress envelopes; stresses are averaged over the current and IAVENV−1 previous time steps
IPRS	= 1, for printing information about iterations for each time step; = 0, only print number of iterations for each time step. The number of iterations, history of joint opening and joint slippage, and equilibrium error measured by energy norm are printed when IPRS=1.
NGM	Number of ground motion components, = 1, = 2, or = 3
IDIR	NGM codes for directions of ground motion; enter 1, 2, 3 for ground motion in the X, Y, and Z directions, respectively
NPLM	Maximum number of time points used for any of the ground motion records
LSTAT(1)	= 1, perform static analysis for water load and/or temperature effects; = 0, otherwise
LSTAT(2)	= 1, perform static analysis for gravity loads; = 0, otherwise

MWAT Control for dam-water interaction effects to be included in earthquake analysis;
= 0, if interaction is neglected;
= 1, if interaction is represented by a diagonal added mass matrix;

NUMNS Total number of nodal points at upstream face used in computation of added mass; enter zero if MWAT=0.

NODSSW Number of nodal points at upstream face of each dam substructure used in the model of the reservoir; enter one number for each substructure except for the foundation. If MWAT= 0, enter zero for each substructure. In the current version, NODSSW is limited to eighty (80) for each substructure.

Record E — Properties of Joint Elements for Earthquake Analysis

One record is required for each contraction joint, starting with the joint at the right of the model and proceeding to the left.

KN Normal stiffness for joint elements

KS Tangential stiffness for joint elements

Q0 Tensile strength for joint elements

SLPT1 Normal joint displacement threshold for allowing slippage in the vertical direction

SCAL1 Reduction factor for tangential stiffness in vertical direction when normal joint displacement exceeds SLPT1

SLPT2 Normal joint displacement threshold for allowing slippage in the horizontal direction

SCAL2 Reduction factor for tangential stiffness in horizontal direction when normal joint displacement exceeds SLPT2

Note: SLPT1 must be equal to or smaller than SLPT2.

Record F — Control of Output

F.1 — Control Parameters

ISEL Flag for stress envelopes from earthquake analysis: = 0 , envelopes are computed for selected elements; = 1, envelopes are computed for all elements.

ISAVE Flag for saving the earthquake response: = 1, the earthquake response is saved for post processing; = 0, the response is not saved.

IALL Flag for stresses from static analysis: = 0, static stresses are computed only for elements for which earthquake stresses are requested (either envelope or history); = 1, static stresses are computed for all elements.

IPRST Flag for stresses and displacements from static analysis: = 0, print total static stresses only; = 1, in addition to total static stresses, for each static load case print element stresses, boundary and substructure displacements, joint displacements, and joint stresses.

F.2 — Request of Response Histories

Five types of response histories from an earthquake analysis will be computed for:

- Nodal point displacements
- Joint displacements
- Stresses in 3–D solid elements
- Stresses in 3–D shell elements
- Stresses in thick shell elements

Details of the response output are given in chapter 4. Five records, one for each of the above types must be provided in the indicated order. A record has the following information:

NC Number of items, displacement or stress components

ID(1) Nodal point or element number for item 1

CMP(1) Displacement or stress component number for item 1

•

•

•

ID(NC) Nodal point or element number for item NC

CMP(NC) Displacement or stress component number for item NC

The element numbers must be entered in increasing order for the stresses of the 3–D solid, 3–D shell and thick shell elements.

F.3 — Request for Joint Displacement and Element Stress Envelopes

Envelopes of stresses in solid and shell elements and envelopes of joint displacements may be requested. Element stresses can be averaged over several time steps, according to the input parameter IAVENV in Record D.

F.3.1 Envelope of Joint Displacements

One record is required for requesting joint displacement envelopes

NC Number of locations where joint displacements are requested.

ID(1) Element number for the first location

CMP(1) Integration point for the first location

.

.

.

ID(NC) Element number for the NC'th location

CMP(NC) Integration point for the NC'th location

F.3.2 Envelope for Stresses in Elements

Three records, one for each of three element types, must be provided if ISEL=0.

F.3.2.1 3–D Solid Elements

NEN3D Number of 3–D solid elements for which envelopes are to be computed. In the current version, NEN3D is limited to 1000.

NLD3D(i) Element numbers, i=1,2...NEN3D, in increasing order.

F.3.2.2 3–D Shell Elements

NENS1 Number of 3–D shell elements for which envelopes are to be computed. In the current version, NENS1 is limited to 50.

NLS1(i) Element numbers, i=1,2...NENS1, in increasing order.

F.3.2.3 Thick Shell Elements

NENS2 Number of thick shell elements for which envelopes are to be computed. In the current version, NENS2 is limited to 100.

NLS2(i) Element numbers, i=1,2...NENS2, in increasing order.

Record G — Nodal Point Numbering at Dam–Water Interface

This record is skipped if dam–water interaction is neglected by setting MWAT=0 in Record D. If MWAT=1 then for each substructure, two records are required to specify the relationship between the numbering of the nodal points for the dam model in ADAP–88 and the nodal point numbering for the reservoir model in RESVOR. The order of the substructures should be the same as that for NODSSW in Record D.

G.1 — Upstream Nodal Points for Reservoir Model

The nodal point numbers at the upstream face of the the reservoir model. For symmetric dams (ISYM≠0 in Record B), the nodal points at the crown section are entered with a negative sign.

G.2 — Upstream Nodal Points for Dam Model

The corresponding nodal point numbers at the upstream face of the dam model.

Record H — Material Properties for Dam and Foundation

H.1 — 3–D Solid Elements

One or two records are required depending if the foundation is modeled. The first record specifies material properties for 3–D elements in the dam body and should be supplied for all cases.

The second record specifies material properties for 3–D elements in the foundation if MESHF>0. Orthotropic material properties can be specified for the 3–D solid elements. This is intended to account for the different material properties of the foundation in vertical and horizontal directions. The axes of orthotropy is assumed to coincide with the global X–Y–Z axes.

An input item marked by an asterisk may be set to zero to indicate it has the same value as the previous item.

H.1.1 Material Properties for Dam

MAT	Material identification, enter 1
ISOT	= 0 for isotropic material, or = 1 for orthotropic material
E(1)	Modulus of elasticity, E_{xx}
E(2)	Modulus of elasticity, E_{yy} *
E(3)	Modulus of elasticity, E_{zz} *
E(4)	Poisson's ratio, ν_{xy}
E(5)	Poisson's ratio, ν_{xz} *
E(6)	Poisson's ratio, ν_{yz} *
E(7)	Shear modulus, G_{xy}
E(8)	Shear modulus, G_{yz} *
E(9)	Shear modulus, G_{zx} *
E(10)	Coefficient of thermal expansion for X–direction
E(11)	Coefficient of thermal expansion for Y–direction *
E(12)	Coefficient of thermal expansion for Z–direction *
E(13)	unit weight

H.1.2 Material Properties for Foundation

This record is not required if MESHFN=0.

MAT	Material identification, enter 2
ISOT	= 0 for isotropic material, or = 1 for orthotropic material
E(1)	Modulus of elasticity, E_{xx}
E(2)	Modulus of elasticity, E_{yy} *
E(3)	Modulus of elasticity, E_{zz} *
E(4)	Poisson's ratio, ν_{xy}
E(5)	Poisson's ratio, ν_{xz} *
E(6)	Poisson's ratio, ν_{yz} *
E(7)	Shear modulus, G_{xy}
E(8)	Shear modulus, G_{yz} *
E(9)	Shear modulus, G_{zx} *
E(10)	Coefficient of thermal expansion for X–direction
E(11)	Coefficient of thermal expansion for Y–direction *
E(12)	Coefficient of thermal expansion for Z–direction *
E(13)	unit weight

H.2 — 3–D Shell and Thick Shell Elements

EE	Modulus of elasticity
ENU	Poisson's ratio
RHO	unit weight
ALP	Coefficient of thermal expansion

Record I — Joint Element Properties and Control for Water/Temperature Analysis

This record is required for static analysis of the dam for hydrostatic and temperature loads.

I.1 — Control Parameters

NSTEP	Number of load steps, such that the load fraction for step i is i/NSTEP.
NIT	Maximum number of iterations for each step; execution terminates if solution does not converge.

I.2 — Joint Element Properties

One record is required for each contraction joint, starting at the right of the model and proceeding to the left.

KN	Normal stiffness for joint elements
KS	Tangential stiffness for joint elements
Q0	Tensile strength for joint elements

Record J — Earthquake Ground Motion Records

Following the order specified by IDIR in Record D, three records should be provided for each of the NGM ground motion components.

J.1 — Title

The title with a maximum of 64 characters is printed on the output for identification of the ground motion record

J.2 — Control Parameters

NLP	Number of time points defining the ground motion record
SFTR	Scale factor for ground motion

J.3 — Ground Acceleration Values

NLP pairs of data in order of increasing time:

T	Time value
P	Acceleration at time T

Chapter 4

OUTPUT FROM ADAP–88

The output from an ADAP–88 execution is stored in the file named *adapo*. The output file contains an echo of all the input data and a results of the static and earthquake analyses.

The user can request the program to print earthquake response histories for nodal point displacements, joint element displacements, stresses in 3–D solid elements, stresses in 3–D shell elements, and stresses in thick shell elements. Envelopes of the maximum and minimum arch, cantilever, and shear stresses for all element types can be requested. Envelopes can also be requested for the normal and tangential displacements of the joint elements. All stresses and joint displacements include the static and dynamic responses. This chapter describes the response quantities in the output file, as controlled by the parameters in Record F of the input file. Displacement and stress histories and envelopes can be written to a binary file for post–processing.

4.1 Nodal Point Displacements

The nodal displacement component numbers 1 to 5 refer to the X–, Y–, and Z–displacements and the A– and B–rotations of the nodal points, respectively. The program computes and prints the displacements with respect to the specified support motion at the boundary. The displacements are the dynamic response and exclude the displacements caused by the static loads.

4.2 Joint Element Displacements

The displacements of a joint element are the relative normal and tangential displacements between two surfaces of the element, computed at the integration points. Positive normal displacement corresponds to opening of the joint. In contrast to the nodal point displacements, the joint displacements include the effects of the earthquake as well as the temperature and water loads, if such loads are included in the analysis. Up to four displacement components can be requested for each joint element at the integration points shown in Fig. 7 and Table 2. At each integration point, the displacement components 1, 2 and 3, respectively correspond to the vertical tangential displacement, horizontal tangential displacement, and normal displacement.

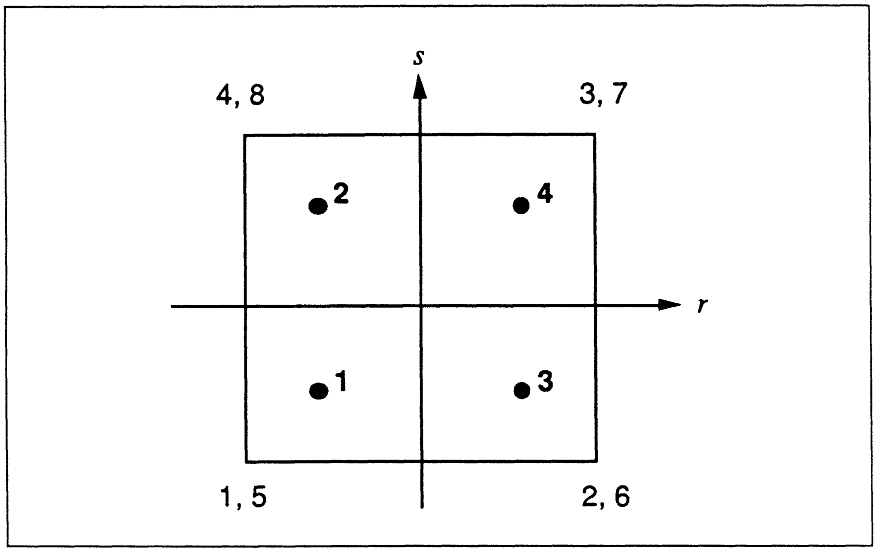

Figure 7. Integration Points for Joint Element

Table 2. Natural Coordinates of Integration Points for Joint Element

Point	r	s
1	–0.5774	–0.5774
2	–0.5774	+0.5774
3	+0.5774	–0.5774
4	+0.5774	+0.5774

4.3 Stresses in 3–D Solid Elements

The stresses are computed for the 3–D solid elements in the dam, except for the elements immediately adjacent to shell elements. The stress points are located at the center of upstream and downstream faces. Stresses are not computed for the interior elements if more than two elements are used through the dam thickness. Thus, a 3–D solid element will generally have only one stress point. For two special cases, an element has two stress points, one at the upstream face and one at the downstream face: (i) when one element is used through the dam thickness (NTHK=1), and (ii) for the 3–D solid elements below the contraction joint, as shown by the triangle bef in Fig. 3.

The numbering of the stress components is given in Table 3. The second column in the table corresponds to the second stress point (downstream face) for the special cases mentioned above. Based on the definition of local coordinate system, σ_{xx}, σ_{yy}, and σ_{xy} correspond to arch, cantilever and shear stresses, respectively.

Table 3. Stress Components in 3–D Solid Elements

Stress Component	Point 1	Point 2
σ_{xx}	1	7
σ_{yy}	2	8
σ_{zz}	3	9
σ_{xy}	4	10
σ_{yz}	5	11
σ_{zx}	6	12

4.4 Stresses in 3–D Shell Elements

The stresses in the 16–node 3–D shell element are given at ten points located at the upstream and downstream faces. The locations of these points in the natural coordinate system *r–s–t* are shown in Fig. 8. Points 1, 3, 5, 7 and 9 are located at the upstream face, whereas, points 2, 4, 6, 8 and 10 are located at the downstream face.

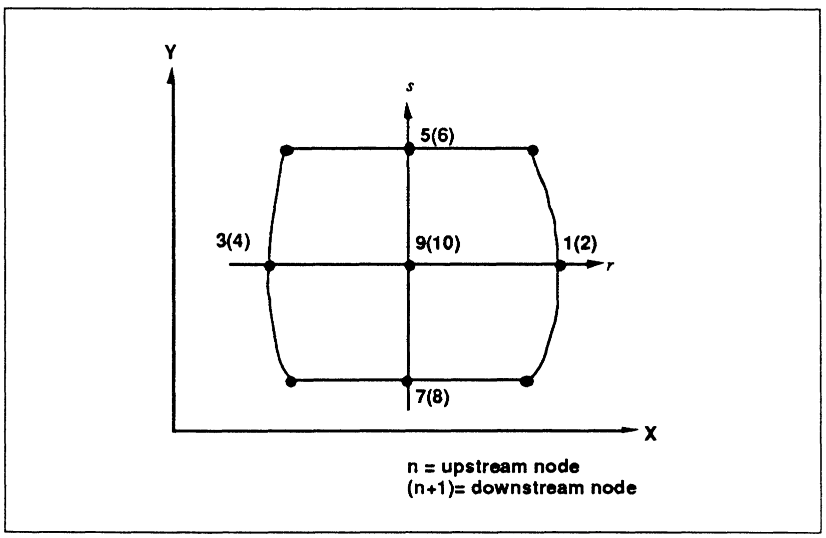

Figure 8. Points for Stress Output in 3–D Shell Element

The 12–node 3–D shell element used near the abutments is obtained from a 16–node element in which 6 nodes of a face degenerate into two nodes. Consequently, Fig. 8 also identifies the stress points of the 12–node element. Stresses are not calculated at points 7 and 8 of a 12–node element , so a request of stresses of these points is not permitted.

Six stress components are associated with each stress point. The numbering of the sixty (60) stress components is given in Table 4. Based on the definition of local coordinate system, σ_{xx}, σ_{yy}, and σ_{xy} are approximations of the arch, cantilever and shear stresses, respectively.

4.5 Stresses in Thick Shell and Transition Elements

For these elements stresses are computed at eight stress points at the upstream and downstream faces. The locations of these points are given in Table 5 and Fig. 9. The points 1, 3, 5 and 7 are at the downstream face and the points 2, 4, 6 and 8 are at the upstream face.

Table 4. Stress Components in 3–D Shell Elements

Stress Component	1	2	3	4	5	6	7	8	9	10
σ_{xx}	1	7	13	19	25	31	37	43	49	55
σ_{yy}	2	8	14	20	26	32	38	44	50	56
σ_{zz}	3	9	15	21	27	33	39	45	51	57
σ_{xy}	4	10	16	22	28	34	40	46	52	58
σ_{yz}	5	11	17	23	29	35	41	47	53	59
σ_{zx}	6	12	18	24	30	36	42	48	54	60

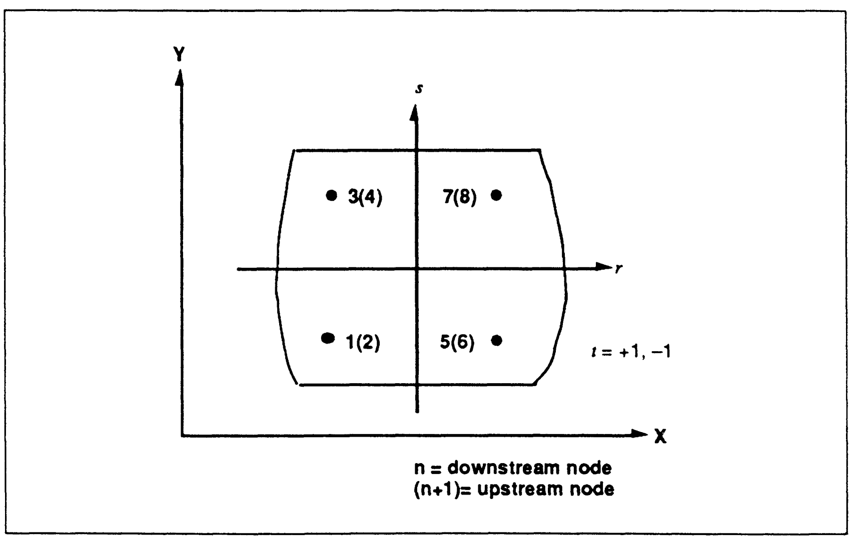

Figure 9. Points for Stress Output in Thick Shell and Transition Elements

At each stress point five stress components are calculated (σ_{zz} is assumed to be zero). The numbering of the forty (40) stress components is given in Table 6. Based on the definition of local coordinate system x–y–z, σ_{xx}, σ_{yy}, and σ_{xy} correspond to arch, cantilever and shear stresses, respectively.

Table 5. Natural Coordinates of Integration Points for Thick Shell and Transition Elements

Point	*r*	*s*	*t*
1	–0.5774	–0.5774	–1
2	–0.5774	–0.5774	+1
3	–0.5774	+0.5774	–1
4	–0.5774	+0.5774	+1
5	+0.5774	–0.5774	–1
6	+0.5774	–0.5774	+1
7	+0.5774	+0.5774	–1
8	+0.5774	+0.5774	+1

Table 6. Stress Components in Thick Shell and Transition Elements

Stress Component	1	2	3	4	5	6	7	8
σ_{xx}	1	6	11	16	21	26	31	36
σ_{yy}	2	7	12	17	22	27	32	37
σ_{xy}	3	8	13	18	23	28	33	38
σ_{yz}	4	9	14	19	24	29	34	39
σ_{zx}	5	10	15	20	25	30	35	40

4.6 Saving Response Histories and Response Envelopes

Response histories and response envelopes requested in Record F can be saved for post–processing by specifying ISAVE=1 in Record F.1. The data are written in binary form on FORTRAN logical unit 15 as the records described below.

4.6.1 Response Histories

When the response histories are saved, two records are written for each of the five types of response histories requested in Record F.2.

Record 1 — This record contains (i) the total number of displacement or stress components, (ii) element or nodal point numbers, and (iii) stress or displacement component numbers. These data are written in exactly the same order that they are specified in Record F.2.

Record 2 — This record contains three items: (i) IOUT, the output interval from Record D, (ii) DT, the time step, and (iii) SHIS, the response history array. Row *i* of array SHIS is the response at time IOUT*DT*(i–1). Columns of the array correspond to the requested response quantities in the order they are specified in Record F.2.

4.6.2 Response Envelopes

When the envelopes of maximum and minimum stresses are saved, two records are written for each of the three response envelopes specified in Record F.3.

Record 1 — This record is similar to Record 1 above for the response histories. It contains: (i) the total number of stress components for which envelopes are requested, (ii) element numbers, and (iii) stress component numbers. Note that for the response histories this information is supplied in the input data, whereas for the response envelopes it is computed by the program.

Record 2 — This record contains the array SV which has three rows. Each column contains values for a requested stress component in the sequence given by Record 1 (and also in the printed output for the response). The first row is the total static stress. The second and the third rows are the maximum and minimum values of the total (static plus earthquake) stresses, respectively.

Chapter 5

INPUT DATA FOR RESVOR

The RESVOR program performs a finite element analysis of water impounded in a reservoir to give the added mass matrix assuming the fluid is incompressible. The program is described in (Kuo, 1982) and, as discussed in (Fenves, et al., 1989), the added mass matrix is diagonalized for use in ADAP–88. The use of RESVOR is substantially the same as the earlier version (Fenves, et al., 1989).

The diagonalized final added mass matrix generated by RESVOR is written on FORTRAN logical unit 16 as a binary file. This file should be available to ADAP–88 if dam–water interaction effects are included in the earthquake analysis.

The added mass matrix computed by RESVOR is associated with translational degrees–of–freedom of nodal points at the dam–water–interface. Thus, if NUMNS is the numer of upstream nodes, the added mass will be saved as a one–dimensional array of order 3*NUMNS. For the purpose of defining the added mass matrix for use in ADAP–88, the user must renumber the interface nodes following the sequence in which these nodes appear in the numbering of all the reservoir nodes. The new node numbers, 1 to NUMNS, should be used to prepare Record G of the input data for the ADAP–88 program.

The data in the input file consist of a number of records in free–format. Each record, which consists of several items, is processed by one free–format read statement in the FORTRAN 77 language. The items in a record can be separated by a comma or at least one space and they may be entered on any number of lines.

The physical units for the dimensional quantities must be consistent with the units used in the input for ADAP–88.

Record A — Title

The title is entered on one line (maximum of 80 characters).

Record B — Master Control Parameters

NUMNP	Total number of fluid nodal points in the reservoir
NUMNS	Number of fluid nodal points on the dam–water interface
N3DEL	Number of three–dimensional fluid elements

N2DEL	Number of two–dimensional fluid elements on the dam–water interface
WMASS	Mass density of water
GRAV	Acceleration due to gravity
WATL	Z–coordinate of free surface of reservoir
ICOMP	Control for comparison between finite element and Westergaard solutions. If ICOMP=1, 2 or 3, the nodal pressures and nodal forces due to uniform acceleration of the dam–water interface of dam in X, Y or Z direction are computed by the finite element methods as well as the generalized Westergaard formula for the purpose of comparison. This computation is not performed if ICOMP=0.

Record C — Nodal Coordinates and Boundary Conditions

One record is required for each node of the reservoir mesh except for nodes that are generated.

N	Node number
X	X–coordinate
Y	Y–coordinate
Z	Z–coordinate
IBC	Boundary condition code: = 0, for all nodes except those at the free surface and dam–water interface; = 1 for all nodes at the free surface except those on dam–water interface; = –1, for nodes on dam–water interface excluding nodes at water surface; = –2, for nodes at the free surface on the dam–water interface.
KN	Node generation increment

Nodal points located on a straight line between node N1 on the upstream end of the reservoir and node N2 on the dam–water interface can be generated. The boundary condition code for generated nodes will be the same as that for node N1. The record for node N1 should be entered followed by the record for node N2. The spacing of the nodes will be successively reduced towards the dam by a factor equal to 0.8. The node generation increment should be entered as KN for the N1 record and KN for the N2 record should be zero.

Record D — Two–dimensional Elements on Dam–Water Interface

One record is required for each element. If the element is at the free surface and its upper nodes do not coincide with nodes of the dam model, two records are required and the element number, NEL, is entered with a negative sign. The elements should be entered in increasing order of the actual element numbers.

Record D.1 Data For All Elements

NEL or –NEL	Element number
NCON(1)	Nodal point 1
NCON(2)	Nodal point 2
.	
.	
NCON(8)	Nodal point 8
NINT	Integration order, 2 or 3 ; NINT=2 is recommended

Record D.2 Required If Element Number Is Negative

Z2	Z–coordinate of the upper nodes of the corresponding dam element
Z0	Z–coordinate of the mid–height nodes of the corresponding dam element
Z1	Z–coordinate of the lower nodes of the corresponding dam element

Except for the nodes at the free surface, all of the reservoir nodes at the dam–water interface are assumed to coincide with nodes in the dam model.

Record E — Three–dimensional Fluid Elements

Two records are required for each element and the elements are entered in increasing order of the element numbers.

Record E.1 Element Number

NE	Element number
NINT	Integration order, 2 or 3 ; NINT=2 is recommended

Record E.2 Nodal Point Connectivity

NP(1)	Nodal point 1
NP(2)	Nodal point 2
.	
.	
NP(16)	Nodal point 16

Appendix A

EXAMPLE FILES

This appendix lists the input files for a symmetric model of Morrow Point dam, of which the model of the dam body is shown in Fig. 10. The ADAP–88 input file is *adapi*, and the RESVOR input file is *resi*.

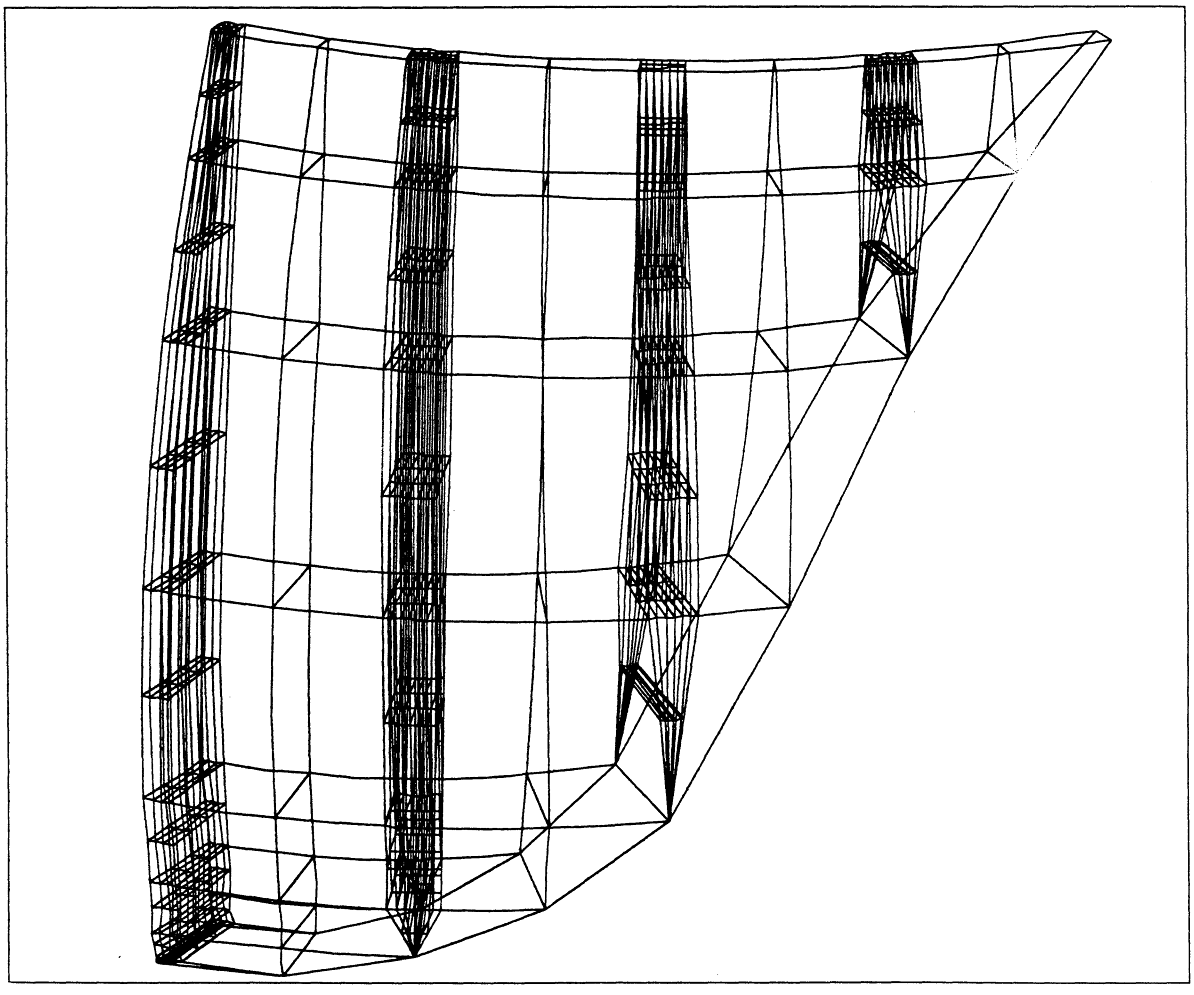

Figure 10. Finite Element Mesh of Morrow Point Dam

Input File *adapi*

```
 Static and Earthquake Analysis of Morrow Point Dam, Case 8
 5  1 460. 62.6   32.16    00.0  0  +1
  375.  375.  375.  9  1  1  1  0  0  .2  .02  3  3
6700.  0.0  0.0  0.0  0.0                          00.00     00.00
6705.  0.0  0.0  0.0  0.0                          14.75     14.75
6730.  0.0  0.0  0.0  0.0                          29.55     29.55
6790.  0.0  0.0  0.0  0.0                          44.35     44.35
6865.  0.0  0.0  0.0  0.0                         48.125    48.125
6940.  0.0  0.0  0.0  0.0                          49.60     49.60
7015.  0.0  0.0  0.0  0.0                          50.25     50.25
7090.  0.0  0.0  0.0  0.0                         51.625    51.625
7165.  0.0  0.0  0.0  0.0                         54.875    54.875
3  13.72   27.44   41.16
4 0   13.72   27.44   41.16
0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
6704.2  6746.  6900.   7107.   7165.
   153.849   200.329   136.621   234.756   136.621   234.756   136.621   234.756
   156.212   202.571   141.973   240.091   141.973   240.091   141.973   240.091
   158.910   205.025   147.409   245.349   147.409   245.349   147.409   245.349
   175.322   218.736   173.104   268.176   173.104   268.176   173.104   268.176
   199.146   236.946   201.335   289.896   201.335   289.896   201.335   289.896
   235.373   262.748   236.820   313.109   236.820   313.109   236.820   313.109
   283.500   294.855   279.872   335.729   279.872   335.729   279.872   335.729
   333.697   333.904   325.883   358.144   325.883   358.144   325.883   358.144
   375.000   375.000   363.000   375.000   363.000   375.000   363.000   375.000
0.0  0.0 0.0 0.0  0.0 0.0  0.0 0.0  0.0
0.0  0.0 0.0 0.0  0.0 0.0  0.0 0.0  0.0
 .01 ,80,16, .25 , .5 , 1.37 , 0.001732 , .5e-4 ,  .3 1 3 1   2 2 3 2049 1  1 1 217  12
28  44  60
1.e9 1.e9  0.0   100 .001 100 .001
1.e9 1.e9  0.0   100 .001 100 .001
1.e9 1.e9  0.0   100 .001 100 .001
2.e9 2.e9  0.0   100 .001 100 .001
1 0  0 1

9
  1245 1 1245 2 1245 3
  1246 1 1246 2 1246 3
  1247 1 1247 2 1247 3

24
  1 1   1 2   1 3   3 4
  7 1   7 2   7 3   9 4
  25 1   25 2   25 3   27 4
  55 1   55 2   55 3   55 4
  56 1   56 2   56 3   56 4
  57 1   57 2   57 3   57 4


48
  13 1   13 2   15 1   15 2 25 1   25 2   27 1   27 2 85 1   85 2   87 1   87 2 109 1       109 2
111 1   111 2 229 1   229 2   231 1   231 2 265 1   265 2   267 1   267 2
 406 1 406 2     408 1 408 2
 409 1 409 2     411 1 411 2
 445 1 445 2     447 1 447 2
 448 1 448 2     450 1 450 2
```

```
 451 1 451 2    453 1 453 2
 454 1 454 2    456 1 456 2
0
32
  16 1  16  2  16  6  16  7  16  11  16  12  16  16  16  17  16  21  16  22  16  26  16
27  16  31  16  32  16  36   16  37
  17 1  17  2  17  6  17  7  17  11  17  12  17  16  17  17  17  21  17  22  17  26  17
27  17  31  17  32  17  36   17  37


192
   1  1   1  3   2  1   2  3   3  2   3  4   4  1   4  3   5  1   5  3   6  2   6  4
   7  1   7  3   8  1   8  3   9  2   9  4  10  1  10  3  11  1  11  3  12  2  12  4
  13  1  13  3  14  1  14  3  15  2  15  4  16  1  16  3  17  1  17  3  18  2  18  4
  19  1  19  3  20  1  20  3  21  2  21  4  22  1  22  3  23  1  23  3  24  2  24  4
  25  1  25  3  26  1  26  3  27  2  27  4  28  1  28  3  29  1  29  3  30  2  30  4
  31  1  31  3  32  1  32  3  33  2  33  4  34  1  34  3  35  1  35  3  36  2  36  4
  37  1  37  3  38  1  38  3  39  2  39  4  40  1  40  3  41  1  41  3  42  2  42  4
  43  1  43  3  44  1  44  3  45  2  45  4  46  1  46  3  47  1  47  3  48  2  48  4
  49  1  49  3  50  1  50  3  51  2  51  4  52  1  52  3  53  1  53  3  54  2  54  4
  55  1  55  3  56  1  56  3  57  2  57  4  58  1  58  3  59  1  59  3  60  2  60  4
  61  1  61  3  62  1  62  3  63  2  63  4  64  1  64  3  65  1  65  3  66  2  66  4
  67  1  67  3  68  1  68  3  69  2  69  4  70  1  70  3  71  1  71  3  72  2  72  4
  73  1  73  3  74  1  74  3  75  2  75  4  76  1  76  3  77  1  77  3  78  2  78  4
  79  1  79  3  80  1  80  3  81  2  81  4  82  1  82  3  83  1  83  3  84  2  84  4
  85  1  85  3  86  1  86  3  87  2  87  4  88  1  88  3  89  1  89  3  90  2  90  4
  91  1  91  3  92  1  92  3  93  2  93  4  94  1  94  3  95  1  95  3  96  2  96  4

      1 2 3 4 5   34 35   49 50 51   78  91

      1 27 29 59 105   31 109   33 61 113   129   131,


      5 6 7 8 9   35 36 37   51 52 53 54 55

      78 79 80   91 92 93 94 95  116 117

      127 128 129   148   157,

      117 199 205 243 341   121 207 345   125 201 209 245 349

      129 211 353   131 203 213 247 357   215 361

      217 249 365   397   399,


      9 10 11 12 13   37 38 39   55 56 57 58 59

      80 81 82   95 96 97 98 99   117 118 119

      129 130 131 132 133   148 149 150   157 158 159 160 161

      174 175   181 182 183   194   199,

      369 515 525 571 721   373 527 725   377 517 529 573 729

      381 531 733   385 519 533 575 737   389 535 741
```

```
393 521 537 577 745   397 539 749   399 523 541 579 753

543 757   545 581 761   809   811,

13 14 15 16 -17   39 40 -41   59 60 61 62 -63

82 83 -84   99 100 101 102 -103   119 120 -121

133 134 135 136 -137   150 151 -152   161 162 163 164 -165

175 176 -177   183 184 185 186 -187   194 195 -196

199 200 201 202 -203   208 -209   211 212 -213   -216   -217,


765 975 989 1043 1245   769 991 1249   773 977 993 1045 1253

777 995 1257   781 979 997 1047 1261   785 999 1265

789 981 1001 1049 1269   793 1003 1273   797 983 1005 1051 1277

801 1007 1281   805 985 1009 1053 1285   809 1011 1289

811 987 1013 1055 1293   1015 1297   1017 1057 1301   1365   1367
```

```
 1 0 540000000.  0.0  0.0  .2  0.0  0.0
0.0 0.0  0.0    .0000056 0.0  0.0       150.
 2 0 360000000.  0.0  0.0  .2  0.0  0.0
0.0 0.0  0.0    .0000056 0.0  0.0       0.0
540000000.    .2       150.                               .0000056
1 10
1.e9  1.e9 0.0
1.e9  1.e9 0.0
1.e9  1.e9 0.0
2.e9  2.e9 0.0
upstream
2048 32.16
    0.0000    0.0000    0.0100    0.0000    0.0200    0.0000    0.0300    0.0000
    0.0400    0.0000    0.0500    0.0000    0.0600    0.0000    0.0700    0.0000
    0.0800    0.0000    0.0900    0.0000    0.1000    0.0000    0.1100    0.0000
      .
      .
      . entire stream direction record not shown
      .
      .
   20.3600    0.0000   20.3700    0.0000   20.3800    0.0000   20.3900    0.0000
   20.4000    0.0000   20.4100    0.0000   20.4200    0.0000   20.4300    0.0000
   20.4400    0.0000   20.4500    0.0000   20.4600    0.0000   20.4700    0.0000
vert
2048 32.16
    0.0000    0.0000    0.0100    0.0000    0.0200    0.0000    0.0300    0.0000
    0.0400    0.0000    0.0500    0.0000    0.0600    0.0000    0.0700    0.0000
    0.0800    0.0000    0.0900    0.0000    0.1000    0.0000    0.1100    0.0000
      .
      .
      . entire vertical direction record not shown
      .
      .
   20.3600    0.0000   20.3700    0.0000   20.3800    0.0000   20.3900    0.0000
   20.4000    0.0000   20.4100    0.0000   20.4200    0.0000   20.4300    0.0000
   20.4400    0.0000   20.4500    0.0000   20.4600    0.0000   20.4700    0.0000
```

Input File *resi*

```
MP Dam  - - - Diagonal Mass  - - First Procedure
 1302  217  360   72      1.94       32.2       460.00    0
    1  0.3067E+03 -0.1200E+04  0.460E+03   1  217    1
 1086  0.3067E+03  0.1592E+03  0.460E+03  -2    0    1
    2  0.2939E+03 -0.1200E+04  0.460E+03   1  217   27
 1087  0.2939E+03  0.1421E+03  0.460E+03  -2    0   27
    3  0.2801E+03 -0.1200E+04  0.460E+03   1  217   29
 1088  0.2801E+03  0.1256E+03  0.460E+03  -2    0   29
    4  0.2642E+03 -0.1200E+04  0.460E+03   1  217   59
 1089  0.2642E+03  0.1089E+03  0.460E+03  -2    0   59
    5  0.2474E+03 -0.1200E+04  0.460E+03   1  217   63
 1090  0.2474E+03  0.9314E+02  0.460E+03  -2    0   63
    6  0.2295E+03 -0.1200E+04  0.460E+03   1  217   97
 1091  0.2295E+03  0.7846E+02  0.460E+03  -2    0   97
    7  0.2109E+03 -0.1200E+04  0.460E+03   1  217  103
 1092  0.2109E+03  0.6489E+02  0.460E+03  -2    0  103
    8  0.1927E+03 -0.1200E+04  0.460E+03   1  217  141
 1093  0.1927E+03  0.5332E+02  0.460E+03  -2    0  141
    9  0.1740E+03 -0.1200E+04  0.460E+03   1  217  149
 1094  0.1740E+03  0.4281E+02  0.460E+03  -2    0  149
   10  0.1537E+03 -0.1200E+04  0.460E+03   1  217  191
 1095  0.1537E+03  0.3293E+02  0.460E+03  -2    0  191
   11  0.1328E+03 -0.1200E+04  0.460E+03   1  217  201
 1096  0.1328E+03  0.2430E+02  0.460E+03  -2    0  201
   12  0.1112E+03 -0.1200E+04  0.460E+03   1  217  247
 1097  0.1112E+03  0.1685E+02  0.460E+03  -2    0  247
   13  0.8910E+02 -0.1200E+04  0.460E+03   1  217  259
 1098  0.8910E+02  0.1074E+02  0.460E+03  -2    0  259
   14  0.6720E+02 -0.1200E+04  0.460E+03   1  217  309
 1099  0.6720E+02  0.6071E+01  0.460E+03  -2    0  309
   15  0.4507E+02 -0.1200E+04  0.460E+03   1  217  323
 1100  0.4507E+02  0.2718E+01  0.460E+03  -2    0  323
   16  0.2257E+02 -0.1200E+04  0.460E+03   1  217  377
 1101  0.2257E+02  0.6800E+00  0.460E+03  -2    0  377
   17  0.0000E+00 -0.1200E+04  0.460E+03   1  217  393
 1102  0.0000E+00  0.0000E+00  0.460E+03  -2    0  393
   18 -0.2257E+02 -0.1200E+04  0.460E+03   1  217  451
 1103 -0.2257E+02  0.6800E+00  0.460E+03  -2    0  451
   19 -0.4507E+02 -0.1200E+04  0.460E+03   1  217  467
 1104 -0.4507E+02  0.2718E+01  0.460E+03  -2    0  467
   20 -0.6720E+02 -0.1200E+04  0.460E+03   1  217  521
 1105 -0.6720E+02  0.6071E+01  0.460E+03  -2    0  521
   21 -0.8910E+02 -0.1200E+04  0.460E+03   1  217  535
 1106 -0.8910E+02  0.1074E+02  0.460E+03  -2    0  535
   22 -0.1112E+03 -0.1200E+04  0.460E+03   1  217  585
 1107 -0.1112E+03  0.1685E+02  0.460E+03  -2    0  585
   23 -0.1328E+03 -0.1200E+04  0.460E+03   1  217  597
 1108 -0.1328E+03  0.2430E+02  0.460E+03  -2    0  597
   24 -0.1537E+03 -0.1200E+04  0.460E+03   1  217  643
 1109 -0.1537E+03  0.3293E+02  0.460E+03  -2    0  643
   25 -0.1740E+03 -0.1200E+04  0.460E+03   1  217  653
 1110 -0.1740E+03  0.4281E+02  0.460E+03  -2    0  653
   26 -0.1927E+03 -0.1200E+04  0.460E+03   1  217  695
 1111 -0.1927E+03  0.5332E+02  0.460E+03  -2    0  695
   27 -0.2109E+03 -0.1200E+04  0.460E+03   1  217  703
 1112 -0.2109E+03  0.6489E+02  0.460E+03  -2    0  703
   28 -0.2295E+03 -0.1200E+04  0.460E+03   1  217  741
 1113 -0.2295E+03  0.7846E+02  0.460E+03  -2    0  741
   29 -0.2474E+03 -0.1200E+04  0.460E+03   1  217  747
 1114 -0.2474E+03  0.9314E+02  0.460E+03  -2    0  747
   30 -0.2642E+03 -0.1200E+04  0.460E+03   1  217  781
 1115 -0.2642E+03  0.1089E+03  0.460E+03  -2    0  781
   31 -0.2801E+03 -0.1200E+04  0.460E+03   1  217  785
 1116 -0.2801E+03  0.1256E+03  0.460E+03  -2    0  785
   32 -0.2939E+03 -0.1200E+04  0.460E+03   1  217  815
 1117 -0.2939E+03  0.1421E+03  0.460E+03  -2    0  815
   33 -0.3067E+03 -0.1200E+04  0.460E+03   1  217  817
 1118 -0.3067E+03  0.1592E+03  0.460E+03  -2    0  817
   34  0.2838E+03 -0.1200E+04  0.4335E+03   0  217   31
 1119  0.2838E+03  0.1225E+03  0.4335E+03  -1    0   31
   35  0.2516E+03 -0.1200E+04  0.4335E+03   0  217   65
 1120  0.2516E+03  0.8859E+02  0.4335E+03  -1    0   65
   36  0.2152E+03 -0.1200E+04  0.4335E+03   0  217  105
 1121  0.2152E+03  0.5883E+02  0.4335E+03  -1    0  105
   37  0.1780E+03 -0.1200E+04  0.4335E+03   0  217  151
 1122  0.1780E+03  0.3542E+02  0.4335E+03  -1    0  151
   38  0.1362E+03 -0.1200E+04  0.4335E+03   0  217  203
 1123  0.1362E+03  0.1572E+02  0.4335E+03  -1    0  203
   39  0.9154E+02 -0.1200E+04  0.4335E+03   0  217  261
 1124  0.9154E+02  0.1214E+01  0.4335E+03  -1    0  261
   40  0.4634E+02 -0.1200E+04  0.4335E+03   0  217  325
 1125  0.4634E+02 -0.7386E+01  0.4335E+03  -1    0  325
   41  0.0000E+00 -0.1200E+04  0.4335E+03   0  217  395
 1126  0.0000E+00 -0.1030E+02  0.4335E+03  -1    0  395
   42 -0.4634E+02 -0.1200E+04  0.4335E+03   0  217  469
 1127 -0.4634E+02 -0.7386E+01  0.4335E+03  -1    0  469
   43 -0.9154E+02 -0.1200E+04  0.4335E+03   0  217  537
 1128 -0.9154E+02  0.1214E+01  0.4335E+03  -1    0  537
   44 -0.1362E+03 -0.1200E+04  0.4335E+03   0  217  599
 1129 -0.1362E+03  0.1572E+02  0.4335E+03  -1    0  599
   45 -0.1780E+03 -0.1200E+04  0.4335E+03   0  217  655
 1130 -0.1780E+03  0.3542E+02  0.4335E+03  -1    0  655
   46 -0.2152E+03 -0.1200E+04  0.4335E+03   0  217  705
 1131 -0.2152E+03  0.5883E+02  0.4335E+03  -1    0  705
   47 -0.2516E+03 -0.1200E+04  0.4335E+03   0  217  749
 1132 -0.2516E+03  0.8859E+02  0.4335E+03  -1    0  749
   48 -0.2838E+03 -0.1200E+04  0.4335E+03   0  217  787
 1133 -0.2838E+03  0.1225E+03  0.4335E+03  -1    0  787
   49  0.2864E+03 -0.1200E+04  0.4070E+03   0  217   33
 1134  0.2864E+03  0.1207E+03  0.4070E+03  -1    0   33
   50  0.2713E+03 -0.1200E+04  0.4070E+03   0  217   61
 1135  0.2713E+03  0.1026E+03  0.4070E+03  -1    0   61
   51  0.2550E+03 -0.1200E+04  0.4070E+03   0  217   67
 1136  0.2550E+03  0.8539E+02  0.4070E+03  -1    0   67
   52  0.2376E+03 -0.1200E+04  0.4070E+03   0  217   99
 1137  0.2376E+03  0.6921E+02  0.4070E+03  -1    0   99
   53  0.2190E+03 -0.1200E+04  0.4070E+03   0  217  107
 1138  0.2190E+03  0.5416E+02  0.4070E+03  -1    0  107
   54  0.2008E+03 -0.1200E+04  0.4070E+03   0  217  143
 1139  0.2008E+03  0.4122E+02  0.4070E+03  -1    0  143
   55  0.1817E+03 -0.1200E+04  0.4070E+03   0  217  153
 1140  0.1817E+03  0.2940E+02  0.4070E+03  -1    0  153
   56  0.1609E+03 -0.1200E+04  0.4070E+03   0  217  193
 1141  0.1609E+03  0.1825E+02  0.4070E+03  -1    0  193
   57  0.1394E+03 -0.1200E+04  0.4070E+03   0  217  205
 1142  0.1394E+03  0.8439E+01  0.4070E+03  -1    0  205
   58  0.1169E+03 -0.1200E+04  0.4070E+03   0  217  249
 1143  0.1169E+03 -0.6300E-01  0.4070E+03  -1    0  249
   59  0.9387E+02 -0.1200E+04  0.4070E+03   0  217  263
 1144  0.9387E+02 -0.7069E+01  0.4070E+03  -1    0  263
   60  0.7089E+02 -0.1200E+04  0.4070E+03   0  217  311
 1145  0.7089E+02 -0.1243E+02  0.4070E+03  -1    0  311
   61  0.4758E+02 -0.1200E+04  0.4070E+03   0  217  327
 1146  0.4758E+02 -0.1629E+02  0.4070E+03  -1    0  327
   62  0.2385E+02 -0.1200E+04  0.4070E+03   0  217  379
 1147  0.2385E+02 -0.1864E+02  0.4070E+03  -1    0  379
   63  0.0000E+00 -0.1200E+04  0.4070E+03   0  217  397
 1148  0.0000E+00 -0.1943E+02  0.4070E+03  -1    0  397
   64 -0.2385E+02 -0.1200E+04  0.4070E+03   0  217  453
 1149 -0.2385E+02 -0.1864E+02  0.4070E+03  -1    0  453
   65 -0.4758E+02 -0.1200E+04  0.4070E+03   0  217  471
 1150 -0.4758E+02 -0.1629E+02  0.4070E+03  -1    0  471
   66 -0.7089E+02 -0.1200E+04  0.4070E+03   0  217  523
 1151 -0.7089E+02 -0.1243E+02  0.4070E+03  -1    0  523
   67 -0.9387E+02 -0.1200E+04  0.4070E+03   0  217  539
 1152 -0.9387E+02 -0.7069E+01  0.4070E+03  -1    0  539
   68 -0.1169E+03 -0.1200E+04  0.4070E+03   0  217  587
 1153 -0.1169E+03 -0.6300E-01  0.4070E+03  -1    0  587
   69 -0.1394E+03 -0.1200E+04  0.4070E+03   0  217  601
 1154 -0.1394E+03  0.8439E+01  0.4070E+03  -1    0  601
   70 -0.1609E+03 -0.1200E+04  0.4070E+03   0  217  645
 1155 -0.1609E+03  0.1825E+02  0.4070E+03  -1    0  645
   71 -0.1817E+03 -0.1200E+04  0.4070E+03   0  217  657
 1156 -0.1817E+03  0.2940E+02  0.4070E+03  -1    0  657
   72 -0.2008E+03 -0.1200E+04  0.4070E+03   0  217  697
 1157 -0.2008E+03  0.4122E+02  0.4070E+03  -1    0  697
   73 -0.2190E+03 -0.1200E+04  0.4070E+03   0  217  707
 1158 -0.2190E+03  0.5416E+02  0.4070E+03  -1    0  707
   74 -0.2376E+03 -0.1200E+04  0.4070E+03   0  217  743
 1159 -0.2376E+03  0.6921E+02  0.4070E+03  -1    0  743
   75 -0.2550E+03 -0.1200E+04  0.4070E+03   0  217  751
 1160 -0.2550E+03  0.8539E+02  0.4070E+03  -1    0  751
   76 -0.2713E+03 -0.1200E+04  0.4070E+03   0  217  783
 1161 -0.2713E+03  0.1026E+03  0.4070E+03  -1    0  783
   77 -0.2864E+03 -0.1200E+04  0.4070E+03   0  217  789
 1162 -0.2864E+03  0.1207E+03  0.4070E+03  -1    0  789
   78  0.2585E+03 -0.1200E+04  0.3645E+03   0  217   69
 1163  0.2585E+03  0.8290E+02  0.3645E+03  -1    0   69
   79  0.2235E+03 -0.1200E+04  0.3645E+03   0  217  109
 1164  0.2235E+03  0.4963E+02  0.3645E+03  -1    0  109
   80  0.1865E+03 -0.1200E+04  0.3645E+03   0  217  155
 1165  0.1865E+03  0.2292E+02  0.3645E+03  -1    0  155
   81  0.1437E+03 -0.1200E+04  0.3645E+03   0  217  207
 1166  0.1437E+03  0.4700E-01  0.3645E+03  -1    0  207
   82  0.9709E+02 -0.1200E+04  0.3645E+03   0  217  265
 1167  0.9709E+02 -0.1702E+02  0.3645E+03  -1    0  265
   83  0.4932E+02 -0.1200E+04  0.3645E+03   0  217  329
 1168  0.4932E+02 -0.2724E+02  0.3645E+03  -1    0  329
   84  0.0000E+00 -0.1200E+04  0.3645E+03   0  217  399
 1169  0.0000E+00 -0.3073E+02  0.3645E+03  -1    0  399
   85 -0.4932E+02 -0.1200E+04  0.3645E+03   0  217  473
 1170 -0.4932E+02 -0.2724E+02  0.3645E+03  -1    0  473
   86 -0.9709E+02 -0.1200E+04  0.3645E+03   0  217  541
 1171 -0.9709E+02 -0.1702E+02  0.3645E+03  -1    0  541
   87 -0.1437E+03 -0.1200E+04  0.3645E+03   0  217  603
 1172 -0.1437E+03  0.4700E-01  0.3645E+03  -1    0  603
   88 -0.1865E+03 -0.1200E+04  0.3645E+03   0  217  659
 1173 -0.1865E+03  0.2292E+02  0.3645E+03  -1    0  659
   89 -0.2235E+03 -0.1200E+04  0.3645E+03   0  217  709
 1174 -0.2235E+03  0.4963E+02  0.3645E+03  -1    0  709
   90 -0.2585E+03 -0.1200E+04  0.3645E+03   0  217  753
 1175 -0.2585E+03  0.8290E+02  0.3645E+03  -1    0  753
   91  0.2601E+03 -0.1200E+04  0.3220E+03   0  217   71
 1176  0.2601E+03  0.8257E+02  0.3220E+03  -1    0   71
   92  0.2440E+03 -0.1200E+04  0.3220E+03   0  217  101
 1177  0.2440E+03  0.6456E+02  0.3220E+03  -1    0  101
   93  0.2265E+03 -0.1200E+04  0.3220E+03   0  217  111
 1178  0.2265E+03  0.4754E+02  0.3220E+03  -1    0  111
   94  0.2089E+03 -0.1200E+04  0.3220E+03   0  217  145
 1179  0.2089E+03  0.3272E+02  0.3220E+03  -1    0  145
   95  0.1902E+03 -0.1200E+04  0.3220E+03   0  217  157
 1180  0.1902E+03  0.1899E+02  0.3220E+03  -1    0  157
   96  0.1693E+03 -0.1200E+04  0.3220E+03   0  217  195
 1181  0.1693E+03  0.5868E+01  0.3220E+03  -1    0  195
   97  0.1474E+03 -0.1200E+04  0.3220E+03   0  217  209
 1182  0.1474E+03 -0.5791E+01  0.3220E+03  -1    0  209
   98  0.1241E+03 -0.1200E+04  0.3220E+03   0  217  251
 1183  0.1241E+03 -0.1600E+02  0.3220E+03  -1    0  251
   99  0.1000E+03 -0.1200E+04  0.3220E+03   0  217  267
 1184  0.1000E+03 -0.2449E+02  0.3220E+03  -1    0  267
  100  0.7574E+02 -0.1200E+04  0.3220E+03   0  217  313
 1185  0.7574E+02 -0.3103E+02  0.3220E+03  -1    0  313
  101  0.5094E+02 -0.1200E+04  0.3220E+03   0  217  331
 1186  0.5094E+02 -0.3577E+02  0.3220E+03  -1    0  331
  102  0.2556E+02 -0.1200E+04  0.3220E+03   0  217  381
 1187  0.2556E+02 -0.3866E+02  0.3220E+03  -1    0  381
  103  0.0000E+00 -0.1200E+04  0.3220E+03   0  217  401
 1188  0.0000E+00 -0.3963E+02  0.3220E+03  -1    0  401
  104 -0.2556E+02 -0.1200E+04  0.3220E+03   0  217  455
 1189 -0.2556E+02 -0.3866E+02  0.3220E+03  -1    0  455
  105 -0.5094E+02 -0.1200E+04  0.3220E+03   0  217  475
 1190 -0.5094E+02 -0.3577E+02  0.3220E+03  -1    0  475
  106 -0.7574E+02 -0.1200E+04  0.3220E+03   0  217  525
 1191 -0.7574E+02 -0.3103E+02  0.3220E+03  -1    0  525
  107 -0.1000E+03 -0.1200E+04  0.3220E+03   0  217  543
 1192 -0.1000E+03 -0.2449E+02  0.3220E+03  -1    0  543
  108 -0.1241E+03 -0.1200E+04  0.3220E+03   0  217  589
 1193 -0.1241E+03 -0.1600E+02  0.3220E+03  -1    0  589
  109 -0.1474E+03 -0.1200E+04  0.3220E+03   0  217  605
 1194 -0.1474E+03 -0.5791E+01  0.3220E+03  -1    0  605
  110 -0.1693E+03 -0.1200E+04  0.3220E+03   0  217  647
 1195 -0.1693E+03  0.5868E+01  0.3220E+03  -1    0  647
  111 -0.1902E+03 -0.1200E+04  0.3220E+03   0  217  661
 1196 -0.1902E+03  0.1899E+02  0.3220E+03  -1    0  661
  112 -0.2089E+03 -0.1200E+04  0.3220E+03   0  217  699
 1197 -0.2089E+03  0.3272E+02  0.3220E+03  -1    0  699
  113 -0.2265E+03 -0.1200E+04  0.3220E+03   0  217  711
 1198 -0.2265E+03  0.4754E+02  0.3220E+03  -1    0  711
  114 -0.2440E+03 -0.1200E+04  0.3220E+03   0  217  745
 1199 -0.2440E+03  0.6456E+02  0.3220E+03  -1    0  745
  115 -0.2601E+03 -0.1200E+04  0.3220E+03   0  217  755
 1200 -0.2601E+03  0.8257E+02  0.3220E+03  -1    0  755
  116  0.2284E+03 -0.1200E+04  0.2610E+03   0  217  113
 1201  0.2284E+03  0.4771E+02  0.2610E+03  -1    0  113
  117  0.1937E+03 -0.1200E+04  0.2610E+03   0  217  159
 1202  0.1937E+03  0.1698E+02  0.2610E+03  -1    0  159
  118  0.1514E+03 -0.1200E+04  0.2610E+03   0  217  211
 1203  0.1514E+03 -0.1026E+02  0.2610E+03  -1    0  211
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 119  0.1035E+03 -0.1200E+04  0.2610E+03   0  217  269
1204  0.1035E+03 -0.3120E+02  0.2610E+03  -1    0  269
 120  0.5291E+02 -0.1200E+04  0.2610E+03   0  217  333
1205  0.5291E+02 -0.4400E+02  0.2610E+03  -1    0  333
 121  0.0000E+00 -0.1200E+04  0.2610E+03   0  217  403
1206  0.0000E+00 -0.4841E+02  0.2610E+03  -1    0  403
 122 -0.5291E+02 -0.1200E+04  0.2610E+03   0  217  477
1207 -0.5291E+02 -0.4400E+02  0.2610E+03  -1    0  477
 123 -0.1035E+03 -0.1200E+04  0.2610E+03   0  217  545
1208 -0.1035E+03 -0.3120E+02  0.2610E+03  -1    0  545
 124 -0.1514E+03 -0.1200E+04  0.2610E+03   0  217  607
1209 -0.1514E+03 -0.1026E+02  0.2610E+03  -1    0  607
 125 -0.1937E+03 -0.1200E+04  0.2610E+03   0  217  663
1210 -0.1937E+03  0.1698E+02  0.2610E+03  -1    0  663
 126 -0.2284E+03 -0.1200E+04  0.2610E+03   0  217  713
1211 -0.2284E+03  0.4771E+02  0.2610E+03  -1    0  713
 127  0.2270E+03 -0.1200E+04  0.2000E+03   0  217  115
1212  0.2270E+03  0.5090E+02  0.2000E+03  -1    0  115
 128  0.2115E+03 -0.1200E+04  0.2000E+03   0  217  147
1213  0.2115E+03  0.3438E+02  0.2000E+03  -1    0  147
 129  0.1944E+03 -0.1200E+04  0.2000E+03   0  217  161
1214  0.1944E+03  0.1874E+02  0.2000E+03  -1    0  161
 130  0.1747E+03 -0.1200E+04  0.2000E+03   0  217  197
1215  0.1747E+03  0.3439E+01  0.2000E+03  -1    0  197
 131  0.1534E+03 -0.1200E+04  0.2000E+03   0  217  213
1216  0.1534E+03 -0.1046E+02  0.2000E+03  -1    0  213
 132  0.1303E+03 -0.1200E+04  0.2000E+03   0  217  253
1217  0.1303E+03 -0.2287E+02  0.2000E+03  -1    0  253
 133  0.1057E+03 -0.1200E+04  0.2000E+03   0  217  271
1218  0.1057E+03 -0.3337E+02  0.2000E+03  -1    0  271
 134  0.8043E+02 -0.1200E+04  0.2000E+03   0  217  315
1219  0.8043E+02 -0.4159E+02  0.2000E+03  -1    0  315
 135  0.5431E+02 -0.1200E+04  0.2000E+03   0  217  335
1220  0.5431E+02 -0.4760E+02  0.2000E+03  -1    0  335
 136  0.2732E+02 -0.1200E+04  0.2000E+03   0  217  383
1221  0.2732E+02 -0.5131E+02  0.2000E+03  -1    0  383
 137  0.0000E+00 -0.1200E+04  0.2000E+03   0  217  405
1222  0.0000E+00 -0.5255E+02  0.2000E+03  -1    0  405
 138 -0.2732E+02 -0.1200E+04  0.2000E+03   0  217  457
1223 -0.2732E+02 -0.5131E+02  0.2000E+03  -1    0  457
 139 -0.5431E+02 -0.1200E+04  0.2000E+03   0  217  479
1224 -0.5431E+02 -0.4760E+02  0.2000E+03  -1    0  479
 140 -0.8043E+02 -0.1200E+04  0.2000E+03   0  217  527
1225 -0.8043E+02 -0.4159E+02  0.2000E+03  -1    0  527
 141 -0.1057E+03 -0.1200E+04  0.2000E+03   0  217  547
1226 -0.1057E+03 -0.3337E+02  0.2000E+03  -1    0  547
 142 -0.1303E+03 -0.1200E+04  0.2000E+03   0  217  591
1227 -0.1303E+03 -0.2287E+02  0.2000E+03  -1    0  591
 143 -0.1534E+03 -0.1200E+04  0.2000E+03   0  217  609
1228 -0.1534E+03 -0.1046E+02  0.2000E+03  -1    0  609
 144 -0.1747E+03 -0.1200E+04  0.2000E+03   0  217  649
1229 -0.1747E+03  0.3439E+01  0.2000E+03  -1    0  649
 145 -0.1944E+03 -0.1200E+04  0.2000E+03   0  217  665
1230 -0.1944E+03  0.1874E+02  0.2000E+03  -1    0  665
 146 -0.2115E+03 -0.1200E+04  0.2000E+03   0  217  701
1231 -0.2115E+03  0.3438E+02  0.2000E+03  -1    0  701
 147 -0.2270E+03 -0.1200E+04  0.2000E+03   0  217  715
1232 -0.2270E+03  0.5090E+02  0.2000E+03  -1    0  715
 148  0.1927E+03 -0.1200E+04  0.1460E+03   0  217  163
1233  0.1927E+03  0.2243E+02  0.1460E+03  -1    0  163
 149  0.1534E+03 -0.1200E+04  0.1460E+03   0  217  215
1234  0.1534E+03 -0.7880E+01  0.1460E+03  -1    0  215
 150  0.1064E+03 -0.1200E+04  0.1460E+03   0  217  273
1235  0.1064E+03 -0.3213E+02  0.1460E+03  -1    0  273
 151  0.5492E+02 -0.1200E+04  0.1460E+03   0  217  337
1236  0.5492E+02 -0.4740E+02  0.1460E+03  -1    0  337
 152  0.0000E+00 -0.1200E+04  0.1460E+03   0  217  407
1237  0.0000E+00 -0.5275E+02  0.1460E+03  -1    0  407
 153 -0.5492E+02 -0.1200E+04  0.1460E+03   0  217  481
1238 -0.5492E+02 -0.4740E+02  0.1460E+03  -1    0  481
 154 -0.1064E+03 -0.1200E+04  0.1460E+03   0  217  549
1239 -0.1064E+03 -0.3213E+02  0.1460E+03  -1    0  549
 155 -0.1534E+03 -0.1200E+04  0.1460E+03   0  217  611
1240 -0.1534E+03 -0.7880E+01  0.1460E+03  -1    0  611
 156 -0.1927E+03 -0.1200E+04  0.1460E+03   0  217  667
1241 -0.1927E+03  0.2243E+02  0.1460E+03  -1    0  667
 157  0.1888E+03 -0.1200E+04  0.9200E+02   0  217  165
1242  0.1888E+03  0.2781E+02  0.9200E+02  -1    0  165
 158  0.1711E+03 -0.1200E+04  0.9200E+02   0  217  199
1243  0.1711E+03  0.1183E+02  0.9200E+02  -1    0  199
 159  0.1514E+03 -0.1200E+04  0.9200E+02   0  217  217
1244  0.1514E+03 -0.2959E+01  0.9200E+02  -1    0  217
 160  0.1294E+03 -0.1200E+04  0.9200E+02   0  217  255
1245  0.1294E+03 -0.1642E+02  0.9200E+02  -1    0  255
 161  0.1057E+03 -0.1200E+04  0.9200E+02   0  217  275
1246  0.1057E+03 -0.2800E+02  0.9200E+02  -1    0  275
 162  0.8085E+02 -0.1200E+04  0.9200E+02   0  217  317
1247  0.8085E+02 -0.3719E+02  0.9200E+02  -1    0  317
 163  0.5479E+02 -0.1200E+04  0.9200E+02   0  217  339
1248  0.5479E+02 -0.4399E+02  0.9200E+02  -1    0  339
 164  0.2763E+02 -0.1200E+04  0.9200E+02   0  217  385
1249  0.2763E+02 -0.4821E+02  0.9200E+02  -1    0  385
 165  0.0000E+00 -0.1200E+04  0.9200E+02   0  217  409
1250  0.0000E+00 -0.4964E+02  0.9200E+02  -1    0  409
 166 -0.2763E+02 -0.1200E+04  0.9200E+02   0  217  459
1251 -0.2763E+02 -0.4821E+02  0.9200E+02  -1    0  459
 167 -0.5479E+02 -0.1200E+04  0.9200E+02   0  217  483
1252 -0.5479E+02 -0.4399E+02  0.9200E+02  -1    0  483
 168 -0.8085E+02 -0.1200E+04  0.9200E+02   0  217  529
1253 -0.8085E+02 -0.3719E+02  0.9200E+02  -1    0  529
 169 -0.1057E+03 -0.1200E+04  0.9200E+02   0  217  551
1254 -0.1057E+03 -0.2800E+02  0.9200E+02  -1    0  551
 170 -0.1294E+03 -0.1200E+04  0.9200E+02   0  217  593
1255 -0.1294E+03 -0.1642E+02  0.9200E+02  -1    0  593
 171 -0.1514E+03 -0.1200E+04  0.9200E+02   0  217  613
1256 -0.1514E+03 -0.2959E+01  0.9200E+02  -1    0  613
 172 -0.1711E+03 -0.1200E+04  0.9200E+02   0  217  651
1257 -0.1711E+03  0.1183E+02  0.9200E+02  -1    0  651
 173 -0.1888E+03 -0.1200E+04  0.9200E+02   0  217  669
1258 -0.1888E+03  0.2781E+02  0.9200E+02  -1    0  669
 174  0.1492E+03 -0.1200E+04  0.6900E+02   0  217  219
1259  0.1492E+03  0.9450E+00  0.6900E+02  -1    0  219
 175  0.1045E+03 -0.1200E+04  0.6900E+02   0  217  277
1260  0.1045E+03 -0.2429E+02  0.6900E+02  -1    0  277
 176  0.5433E+02 -0.1200E+04  0.6900E+02   0  217  341
1261  0.5433E+02 -0.4052E+02  0.6900E+02  -1    0  341
 177  0.0000E+00 -0.1200E+04  0.6900E+02   0  217  411
1262  0.0000E+00 -0.4628E+02  0.6900E+02  -1    0  411
 178 -0.5433E+02 -0.1200E+04  0.6900E+02   0  217  485
1263 -0.5433E+02 -0.4052E+02  0.6900E+02  -1    0  485
 179 -0.1045E+03 -0.1200E+04  0.6900E+02   0  217  553
1264 -0.1045E+03 -0.2429E+02  0.6900E+02  -1    0  553
 180 -0.1492E+03 -0.1200E+04  0.6900E+02   0  217  615
1265 -0.1492E+03  0.9450E+00  0.6900E+02  -1    0  615
 181  0.1468E+03 -0.1200E+04  0.4600E+02   0  217  221
1266  0.1468E+03  0.4901E+01  0.4600E+02  -1    0  221
 182  0.1260E+03 -0.1200E+04  0.4600E+02   0  217  257
1267  0.1260E+03 -0.8654E+01  0.4600E+02  -1    0  257
 183  0.1032E+03 -0.1200E+04  0.4600E+02   0  217  279
1268  0.1032E+03 -0.2041E+02  0.4600E+02  -1    0  279
 184  0.7915E+02 -0.1200E+04  0.4600E+02   0  217  319
1269  0.7915E+02 -0.2982E+02  0.4600E+02  -1    0  319
 185  0.5375E+02 -0.1200E+04  0.4600E+02   0  217  343
1270  0.5375E+02 -0.3682E+02  0.4600E+02  -1    0  343
 186  0.2714E+02 -0.1200E+04  0.4600E+02   0  217  387
1271  0.2714E+02 -0.4118E+02  0.4600E+02  -1    0  387
 187  0.0000E+00 -0.1200E+04  0.4600E+02   0  217  413
1272  0.0000E+00 -0.4265E+02  0.4600E+02  -1    0  413
 188 -0.2714E+02 -0.1200E+04  0.4600E+02   0  217  461
1273 -0.2714E+02 -0.4118E+02  0.4600E+02  -1    0  461
 189 -0.5375E+02 -0.1200E+04  0.4600E+02   0  217  487
1274 -0.5375E+02 -0.3682E+02  0.4600E+02  -1    0  487
 190 -0.7915E+02 -0.1200E+04  0.4600E+02   0  217  531
1275 -0.7915E+02 -0.2982E+02  0.4600E+02  -1    0  531
 191 -0.1032E+03 -0.1200E+04  0.4600E+02   0  217  555
1276 -0.1032E+03 -0.2041E+02  0.4600E+02  -1    0  555
 192 -0.1260E+03 -0.1200E+04  0.4600E+02   0  217  595
1277 -0.1260E+03 -0.8654E+01  0.4600E+02  -1    0  595
 193 -0.1468E+03 -0.1200E+04  0.4600E+02   0  217  617
1278 -0.1468E+03  0.4901E+01  0.4600E+02  -1    0  617
 194  0.1024E+03 -0.1200E+04  0.2800E+02   0  217  281
1279  0.1024E+03 -0.1828E+02  0.2800E+02  -1    0  281
 195  0.5341E+02 -0.1200E+04  0.2800E+02   0  217  345
1280  0.5341E+02 -0.3476E+02  0.2800E+02  -1    0  345
 196  0.0000E+00 -0.1200E+04  0.2800E+02   0  217  415
1281  0.0000E+00 -0.4063E+02  0.2800E+02  -1    0  415
 197 -0.5341E+02 -0.1200E+04  0.2800E+02   0  217  489
1282 -0.5341E+02 -0.3476E+02  0.2800E+02  -1    0  489
 198 -0.1024E+03 -0.1200E+04  0.2800E+02   0  217  557
1283 -0.1024E+03 -0.1828E+02  0.2800E+02  -1    0  557
 199  0.1020E+03 -0.1200E+04  0.1000E+02   0  217  283
1284  0.1020E+03 -0.1721E+02  0.1000E+02  -1    0  283
 200  0.7831E+02 -0.1200E+04  0.1000E+02   0  217  321
1285  0.7831E+02 -0.2665E+02  0.1000E+02  -1    0  321
 201  0.5322E+02 -0.1200E+04  0.1000E+02   0  217  347
1286  0.5322E+02 -0.3369E+02  0.1000E+02  -1    0  347
 202  0.2688E+02 -0.1200E+04  0.1000E+02   0  217  389
1287  0.2688E+02 -0.3809E+02  0.1000E+02  -1    0  389
 203  0.0000E+00 -0.1200E+04  0.1000E+02   0  217  417
1288  0.0000E+00 -0.3958E+02  0.1000E+02  -1    0  417
 204 -0.2688E+02 -0.1200E+04  0.1000E+02   0  217  463
1289 -0.2688E+02 -0.3809E+02  0.1000E+02  -1    0  463
 205 -0.5322E+02 -0.1200E+04  0.1000E+02   0  217  491
1290 -0.5322E+02 -0.3369E+02  0.1000E+02  -1    0  491
 206 -0.7831E+02 -0.1200E+04  0.1000E+02   0  217  533
1291 -0.7831E+02 -0.2665E+02  0.1000E+02  -1    0  533
 207 -0.1020E+03 -0.1200E+04  0.1000E+02   0  217  559
1292 -0.1020E+03 -0.1721E+02  0.1000E+02  -1    0  559
 208  0.5301E+02 -0.1200E+04  0.7100E+01   0  217  349
1293  0.5301E+02 -0.3262E+02  0.7100E+01  -1    0  349
 209  0.0000E+00 -0.1200E+04  0.7100E+01   0  217  419
1294  0.0000E+00 -0.3850E+02  0.7100E+01  -1    0  419
 210 -0.5301E+02 -0.1200E+04  0.7100E+01   0  217  493
1295 -0.5301E+02 -0.3262E+02  0.7100E+01  -1    0  493
 211  0.5273E+02 -0.1200E+04  0.4200E+01   0  217  351
1296  0.5273E+02 -0.3122E+02  0.4200E+01  -1    0  351
 212  0.2664E+02 -0.1200E+04  0.4200E+01   0  217  391
1297  0.2664E+02 -0.3561E+02  0.4200E+01  -1    0  391
 213  0.0000E+00 -0.1200E+04  0.4200E+01   0  217  421
1298  0.0000E+00 -0.3710E+02  0.4200E+01  -1    0  421
 214 -0.2664E+02 -0.1200E+04  0.4200E+01   0  217  465
1299 -0.2664E+02 -0.3561E+02  0.4200E+01  -1    0  465
 215 -0.5273E+02 -0.1200E+04  0.4200E+01   0  217  495
1300 -0.5273E+02 -0.3122E+02  0.4200E+01  -1    0  495
 216  0.0000E+00 -0.1200E+04  0.2100E+01   0  217  423
1301  0.0000E+00 -0.3586E+02  0.2100E+01  -1    0  423
 217  0.0000E+00 -0.1200E+04  0.0000E+00   0  217  425
1302  0.0000E+00 -0.3443E+02  0.0000E+00  -1    0  425
   -1 1086 1088 1134    0 1087 1119    0    0     2
465. 436. 407.
   -2 1088 1090 1136 1134 1089 1120 1135 1119     2
465. 436. 407.
   -3 1090 1092 1138 1136 1091 1121 1137 1120     2
465. 436. 407.
   -4 1092 1094 1140 1138 1093 1122 1139 1121     2
465. 436. 407.
   -5 1094 1096 1142 1140 1095 1123 1141 1122     2
465. 436. 407.
   -6 1096 1098 1144 1142 1097 1124 1143 1123     2
465. 436. 407.
   -7 1098 1100 1146 1144 1099 1125 1145 1124     2
465. 436. 407.
   -8 1100 1102 1148 1146 1101 1126 1147 1125     2
465. 436. 407.
   -9 1102 1104 1150 1148 1103 1127 1149 1126     2
465. 436. 407.
  -10 1104 1106 1152 1150 1105 1128 1151 1127     2
465. 436. 407.
  -11 1106 1108 1154 1152 1107 1129 1153 1128     2
465. 436. 407.
  -12 1108 1110 1156 1154 1109 1130 1155 1129     2
465. 436. 407.
  -13 1110 1112 1158 1156 1111 1131 1157 1130     2
465. 436. 407.
  -14 1112 1114 1160 1158 1113 1132 1159 1131     2
465. 436. 407.
  -15 1114 1116 1162 1160 1115 1133 1161 1132     2
465. 436. 407.
  -16 1116 1118 1162    0 1117    0    0 1133     2
465. 436. 407.
   17 1134 1136 1176    0 1135 1163    0    0     2
   18 1136 1138 1178 1176 1137 1164 1177 1163     2
   19 1138 1140 1180 1178 1139 1165 1179 1164     2
   20 1140 1142 1182 1180 1141 1166 1181 1165     2
   21 1142 1144 1184 1182 1143 1167 1183 1166     2
   22 1144 1146 1186 1184 1145 1168 1185 1167     2
   23 1146 1148 1188 1186 1147 1169 1187 1168     2
   24 1148 1150 1190 1188 1149 1170 1189 1169     2
   25 1150 1152 1192 1190 1151 1171 1191 1170     2
   26 1152 1154 1194 1192 1153 1172 1193 1171     2
   27 1154 1156 1196 1194 1155 1173 1195 1172     2
   28 1156 1158 1198 1196 1157 1174 1197 1173     2
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1079	1081	1085	0	1296	1298	1302	0	1080	1084	0	0	1297	1301	0	0
356	2														
213	215	217	0	430	432	434	0	214	0	0	216	431	0	0	433
357	2														
430	432	434	0	647	649	651	0	431	0	0	433	648	0	0	650
358	2														
647	649	651	0	864	866	868	0	648	0	0	650	865	0	0	867
359	2														
864	866	868	0	1081	1083	1085	0	865	0	0	867	1082	0	0	1084
360	2														
1081	1083	1085	0	1298	1300	1302	0	1082	0	0	1084	1299	0	0	1301

Appendix B

INSTALLATION OF ADAP–88

Dynamic Storage Allocation

The large arrays in the program are stored in blank common and a memory manager allocates storage dynamically. The overall size of the problem that the program can analyze is determined by the size of the blank common block. Within the program, the size of the blank common block is established by the size of integer array IA in the main program and by the corresponding variable MTOT. If the storage required for an analysis exceeds MTOT, the program will print a message indicating the storage deficit. Increasing the capacity involves increasing MTOT and the dimension of the IA array.

The dynamic storage allocation in the program can be adapted to computers with various word lengths. The storage allocation is a function of the ratio of the word length for real numbers to the word length for integers. These word lengths, which are called LREAL and LINTG in the program, depend on the compiler and the desired floating point precision (single or double). The values should be initialized in the main program during installation of the program.

Mesh Plotting

The finite element mesh plotting is implemented using five subroutines supplied in the UNIX operating system library. If the library is available, it can be linked with the ADAP–88 program. If the library is not available, the subroutines must be implemented with system dependent functions to perform the plotting. The calls to the plotting subroutines used in ADAP–88 are defined as follows.

OPENPL()	open a plot file
CLOSEPL()	close plot file
SPACE (X1,Y1,X2,Y2)	Define view on the plot area with lower left corner (X1,Y1) and upper right corner (X2,Y2)
LINE (X1,Y1,X2,Y2)	Draw a line from (X1,Y1) to (X2,Y2)
MOVE (X1,Y1)	Move pen to (X1,Y1)

Appendix C

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