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Waterways Experiment Station

Computer Aided Structural Engineering Project

User's Guide: Arch Dam Stress Analysis System (ADSAS)

by CASE Arch Dam Task Group

WES

Approved For Public Release; Distribution Is Unlimited

Prepared for Headquarters, U.S. Army Corps of Engineers

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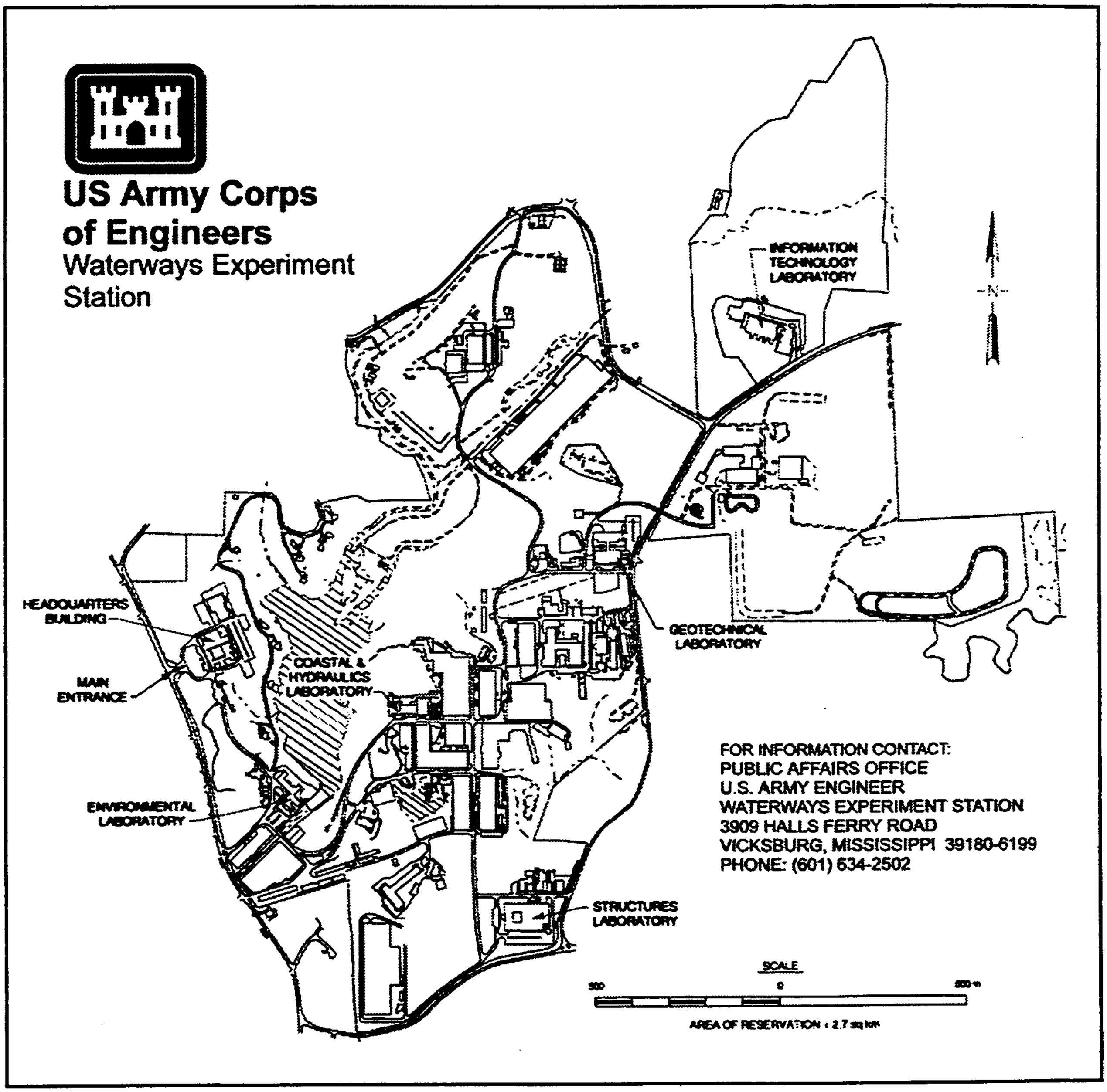
Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000



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Preface

This user's guide documents the features in the microcomputer version of the Arch Dam Stress Analysis System (ADSAS). ADSAS is primarily the trial load method of analysis. ADSAS was initially developed in the mid-1970's by engineers at the U.S. Bureau of Reclamation to run on a mainframe computer. With recent advances in computer technology, the Corps of Engineers adapted ADSAS for use on a microcomputer.

ADSAS is an engineering tool for the design and analysis of arch dams. It is not a substitute for sound engineering judgment. Although it has been used for the solution of many problems and has given satisfactory results, a potential user of the ADSAS computer program has the responsibility for its proper application to a proposed problem and the correctness of the data preparation. The user of this guide and of the ADSAS computer program should already have: (1) a knowledge of general structural analyses; (2) a specific knowledge of arch dams including the knowledge required to determine critical load combinations; (3) a general computer proficiency; and (4) the capability of recognizing and interpreting the results from ADSAS. Assistance in all of these areas should be provided by experienced engineers.

This guide was compiled and written by the Headquarters, U.S. Army Corps of Engineers (HQUSACE), sponsored Computer Aided Structural Engineering (CASE) Arch Dam Task Group. Task group members during the development of this guide were:

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]
feet	0.3048	meters
foot-pounds (force)	1.35518	meter-newton
kips (force)	4.448222	kilo-newton
pounds	4.535924	kilograms
pounds (force) per cubic foot	0.157087	kilo-newton per cubic meter
pounds (force) per square foot	47.88026	Pascal
pounds (force) per square inch	6.894757	kilo-Pascal

[1] To obtain Celsius © temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9) (F-32). To obtain Kelvin (K) readings use: K = (5/9) (F-32) + 273.15.

1 Introduction

This chapter provides an overview of the Arch Dam Stress Analysis System (ADSAS) program, a computerized version of the trial load method of analyzing arch dams. ADSAS was developed over many years, beginning in the mid-1970's, by engineers at the U.S. Bureau of Reclamation (USBR). It has been widely used in designing and analyzing arch dams. This user's guide and the ADSAS computer program contain terminology which may not be common to all engineers or may have different meanings than those used by other arch dam designers. Therefore, definitions of the terms as they apply to this guide and to the ADSAS computer program are furnished in Appendix A.

The ADSAS program assumes linear elastic behavior for the entire dam, although it does have the capability to do a crack analysis. The assumption of linear elastic behavior means that the dam is assumed to support the computed tensile stresses both within the concrete mass and across the monolith joints without cracking or joint opening. The evaluation of tensile stresses resulting from a linear elastic analysis of arch dams is discussed in EM 1110-2-2201, "Arch Dam Design."

It is also important to note that ADSAS views arch dams **looking upstream**. This methodology will require most engineers of dams to revise their view of dams since it is more common practice to identify "left" and "right" from a viewpoint looking downstream.

Trial Load Method

The ADSAS program is based on the trial load method of analysis. A complete description of the theory of the trial load method can be found in USBR publications (1938, 1977a), and Ghanaat (1993). Only a brief overview will be presented in this chapter.

As the name implies, the trial load method is a method of trial in distributing the load between the arches and cantilevers until the deflections of the common points are in agreement. The trial load method divides the structure into 1-ft-wide arch and cantilever elements. Applied loads are split between these arch and cantilever elements, and the deformations of each element are determined. The deformations included in an ADSAS analysis are: (a) radial deflections; (b) tangential deflections; and (c) horizontal and vertical rotations. The deformations at the intersections of the arch and cantilever elements are compared, and the loads are adjusted until a final distribution of the loads is found which causes equal or near equal deformation at the intersections of the elements. The procedure requires several iterations of load adjustments to reduce secondary effects to a minimum.

Once the estimated distribution of load between horizontal (arches) and vertical (cantilever) elements has been determined, the resulting arch, cantilever, and principal stresses are calculated. Stresses are calculated at the upstream and downstream faces of the dam at the intersection of the arch and cantilever elements and at the arch quarter points.

Appendix B provides the general organization of ADSAS and a summary of the steps ADSAS uses to accomplish the process discussed above.

While the trial load method is not considered to be as accurate as the finite element method, ADSAS can produce results that compare favorably with those of a finite element analysis with a properly defined mesh. For dams that fit the ADSAS format, the trial load method does have an advantage over the finite element method in that the models can be constructed with input taken directly from the layout drawings. In addition, the computation time for ADSAS is usually much shorter than that with a finite element program. Also, changes or modifications in the arch dam layout can be made with a minimum number of changes to the input file. These qualities make ADSAS a logical choice for performing preliminary stress analysis during the layout process.

Layout Process

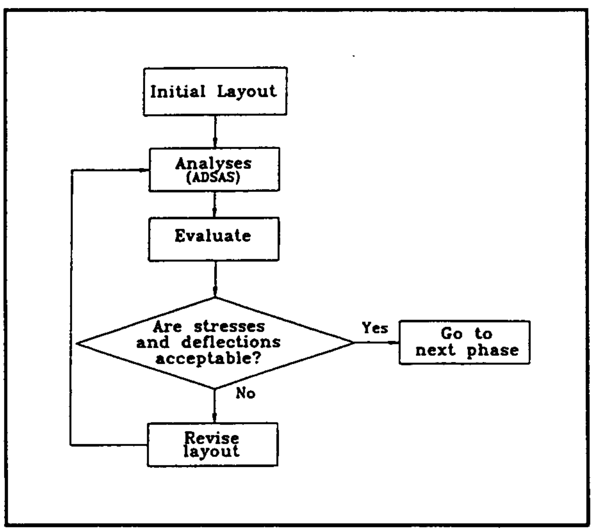

Figure 1-1. Flow chart for the arch dam design process

As shown in Figure 1-1, the process of designing an arch dam begins by making an initial layout based on parameters identified in Chapter 5 of EM 1110-2-2201. This initial layout can be analyzed using ADSAS to compute stresses and deformations for each of the load cases. If the calculated stresses are found to be unacceptable according to the criteria in EM 1110-2-2201, the geometry is modified in an attempt to improve those stresses. The new geometry is analyzed and the new stresses and deformations are evaluated for each load case. This iterative process is continued until an acceptable stress distribution is achieved with a minimum volume of concrete.

Input Requirements and File Structure

As noted earlier, ADSAS was initially developed in the mid-1970's. Like most programs written in that time frame, the ADSAS program was written when input files were read using card readers. As a result, the lines in the input file are still referred to as "cards." Hereafter in this user's guide, the word "card(s)" will be used and refers to certain lines of the input file. In addition, the data on the cards are in a fixed field format. This makes it critical that the data be organized carefully to avoid errors in the analysis. As a means of checking the input, ADSAS performs geometry checks and echoes the input values with descriptors in the output file.

It is also critical that the cards be placed in the proper order within the input file. The cards must be arranged in the sequence of analytical operations performed by ADSAS.

The input data required for ADSAS include sufficient geometric parameters to define the dam, material properties, and loading conditions. In addition, the extent of the analysis performed by ADSAS and the type and amount of output are controlled by the user by setting "flags" on certain control cards.

Running ADSAS

ADSAS will run on most IBM-compatible computers with DOS version 3.0 or later. It currently will not run under Windows. ADSAS is not compatible with some memory drivers and managers such as HIMEM.SYS and EMM386.EXE.

To run the microcomputer version of ADSAS the input data must be contained in a file called *ADSAS.DAT*. The program is executed by typing *ADSASE* and pressing the ↵**Enter** key. The output is contained in the file *ADSAS.OUT*.

Organization of This User's Guide

The chapters herein can be divided into several parts as described below:

a. General data requirements (Chapters 2-5).

b. Modeling techniques (Chapter 6).

c. Special layouts and analyses (Chapter 7).

d. Detailed description of the input cards (Chapter 8).

e. Guidance in interpreting ADSAS output data (Chapter 9).

The first part describes the general data requirements. In many cases, the location of information in an ADSAS input file changes depending on the design requirements. In addition, there are numerous "flags" which tell ADSAS where the data can be found in the input file, what type of analysis is to be performed, and what tables to include in the printout. A general description of the various options is presented in Chapters 2 through 5.

Chapter 6 provides some general guidance on modeling techniques including grid selection. Chapter 7 contains some special layout capabilities in ADSAS.

Chapter 8 provides the detailed description of the data required for each of the input cards. As noted earlier, the ADSAS computer program uses a fixed field format for all input data. It is critical that the data be properly placed on each card and that changes to the cards during subsequent layouts be made carefully. Most of the problems that occur in using ADSAS are in accidentally typing or shifting data out of its specified field (column) when making hurried changes between layout runs.

Chapter 9 includes some guidance in interpreting the ADSAS output. The output file from ADSAS can be very large and may appear cryptic to a user who is not familiar with the trial load method. The information in Chapter 9 is not intended as guidance on how to evaluate an arch dam. It is included in this guide only to help the user understand the difference between terms like "TAL/TO" and "TAR/TO" in the ADSAS printout. Guidance on arch dam criteria can be found in numerous other publications.

Also included herein are example files (Appendix C) and error messages (Appendix D). These appendixes should, hopefully, help the user in developing an input file for ADSAS and locating input errors. Most of the input files shown in Appendix C are taken from actual projects; but the files have been modified to demonstrate several of the various features in ADSAS. Appendix E is an index of the ADSAS input cards and their location in the user's manual.

Limitations

ADSAS is limited to 4 free cantilevers and a total of 144 arch/cantilever intersection points. This number does not include the intersection points with the abutment or foundation. For example, 11 arches and 2 free cantilevers produce 143 intersection points. Ten arches and 4 free cantilevers produce 140 intersection points.

There are several geometric limitations in the current version of ADSAS. ADSAS can only accept one-, two-, or three-centered layout(s). The line of centers for the dam must fall in a straight line. For three-centered layouts, the outer segments must be parallel to the inner segment. And ADSAS cannot accept filets and should not be used to model multiple-arch dams.

ADSAS can perform a pseudostatic analysis (seismic coefficient) and a response history analysis. However, response history analyses using ADSAS are not generally recommended, and the details of how to perform these analyses are not included in this guide. If a dynamic analysis is needed, it is usually preferable to use the finite element method.

In addition, no preprocessing or postprocessing capabilities currently exist within the ADSAS program.

Units of Measure

The following are the standard units used in ADSAS:

a. All elevations (el), stations, and distances are in feet (ft).

b. Material unit weights are in pounds per cubic foot (pcf).

c. Modulus of elasticity of the concrete and the deformation modulus of the foundation are in pounds per square inch (psi).

d. Hydrostatic and silt pressures are in pounds per cubic foot (pcf).

e. Temperatures are in degrees Fahrenheit (°F).

f. Moments are in foot-pounds (ft-lb).

g. Thrusts, shear, and resultant forces are in pounds (lb).

h. The final stresses are in pounds per square inch (psi). Computed stresses prior to the principal stresses are in pounds per square foot (psf).

i. Radial and tangential deflections are in feet (ft).

j. Twist rotations are in radians (rad).

2 Control and Title Cards

ADSAS uses numerous “flags” to control the type of analysis and the amount of output from the analysis. There are also flags that tell ADSAS where in the input deck and in what format the material properties and geometry will be included. These flags are contained on the control cards at the beginning and at the end of every ADSAS input file. Figure 2-1 shows the typical control cards used in each ADSAS run. Once the user has set these control cards for a particular dam or layout, they will not normally change from run to run.

```
- MASTERIO 111011111
- 1  0     ADSAS Test Problem           16       01
- 2  0     011011101
- 3  0     30100000000    3.0     .2   5.6  150.    2.5     .2    .0    .0
  4  0      6700.    7165.    7165.   6700.    7165.
  3  1       34.427    17.227   221.1513  174.6713  375.0          .0    3  1
  5  1 1 1   7165.0            .0       772.0     6874.069     825.0
  5  1 2 1   6950.0            .0       947.3946  6893.103     950.0
  5  1 2 2   7165.0            .06        .0        .0           .0
  5  1 3 1   7000.0            .0       846.4621  6598.577     700.0
  5  1 3 2   7041.622          .7         .0        .0           .0
  5  1 3 3   7100.0            .0      -421.5882  7548.229    -883.4174
  5  1 3 4   7160.0            .5888      .0        .0           .0
  5  1 3 5   7165.0            .0         .0        .0           .0
  5  1 4 1   7103.008          .0      1289.338   6544.889    1100.0
  5  1 4 2   7160.0            .5888      .0        .0           .0
  5  1 4 3   7165.0            .0         .0        .0           .0
  6  1           .0      12.0         .0        .0        .0        .0
  7  110000 6700.0     .0     .0     .0     .0     .0    .0   .0   .0
  7  100000 6790.0   44.350 44.350  .0     .0    -1.5    .0   .0   .0
  7  100000 6865.0   48.125 48.125  .0     .0    -1.5    .0   .0   .0
  7  100000 6940.0   49.600 49.600  .0     .0    -1.5    .0   .0   .0
  7  100000 7015.0   50.250 50.250  .0     .0    -2.0    .0   .0   .0
  7  100000 7090.0   51.625 51.625  .0     .0    -4.5    .0   .0   .0
  7  100000 7165.0   54.875 54.875  .0     .0   -15.0    .0   .0   .0
- 1  2             1  1  111  1
- 1  4                1                                      1
- 1  3           1           1  1   1      1 1       1
- 10005               1                      2       11111
- 1  10     1            1
  *ENDFILE
```

Figure 2-1. Control cards for a typical ADSAS run. The arrows (“-”) indicate the cards containing control and title data

In addition to the control cards, a project description can be included in the file. This chapter briefly describes the control and title cards and their general purpose. The detailed explanation of the control cards and all other cards used by ADSAS can be found in Chapter 8.

The **MASTERIO card** is the master input/output card. This card controls the type of analysis being performed by ADSAS. The available types include: a geometry and abutment analysis; an arch analysis; a cantilever analysis; various adjustments; and a stress analyzer. In most cases, all of the various analyzers within ADSAS should be run with each ADSAS analysis. Therefore, the **MASTERIO card** should always remain identical to that shown in Figure 2-1.

The **1-0 card** is the second card shown in Figure 2-1 and is the title card. The **1-0 card** allows the user to input some identification for the dam. Shown in Figure 2-1 is a test problem with the indication that it is for study number 16, case number 01. For example, the study number could designate the number of layouts that have been considered, and the case number could be used to designate the loading combination. The identification number and case number are written on the output listing.

The **2-0 card** is an operational control card. It is used to tell ADSAS if normal setup is to be used or if a special, user-supplied setup will be furnished. It also establishes certain internal operations. The flag in column 11 is usually the only option that the user needs to change. All other control flags should be considered fixed to the values shown in Figure 2-1 and should not be changed. The **2-0 card** shown in Figure 2-1 has a "0" in column 11 which is for the normal setup. If a "1" is placed in column 11 of the **2-0 card**, then ADSAS will expect to read a **1-1 card** (see below).

The **3-0 card** contains three types of information. The first set (columns 11 through 22) are flags which tell ADSAS: the type of analysis being run; the types of loads to be included in the analysis; the type of layout (one-, two-, or three-centered); and the type of foundation properties (uniform versus variable). These flags are shown in the darker shaded area of the **3-0 card** in Figure 2-1. Also contained on the **3-0 card** are various concrete and foundation material properties, the seismic coefficient (for pseudostatic analysis), and the closure temperature. Descriptions of these other items are included in Chapters 3 and 5.

The **1-1 card** (not shown in Figure 2-1) controls a portion of the printout from ADSAS. It also controls where arch properties are computed (at cantilever intersections or at the arch quarter points). The **1-1 card** is not normally used and is only required when the flag in column 11 of the **2-0 card** is set to "1."

The **1-2 card** controls the abutment analysis within ADSAS. This includes options such as whether the user inputs Vogt's (1925) constants or ADSAS computes them. The **1-2 card** also controls the printing of various tables associated with the foundation such as the x and y coordinates of the contact surface.

The **1-3 card** controls the cantilever analysis within ADSAS. Like the other control cards it controls the amount of output for an ADSAS run. It can also tell ADSAS other items such as if additional cards should be read (e.g., the **3-3** and **4-3 cards**) and if the moment due to the dead weight of the concrete should be distributed between the arches and cantilevers.

The **1-4 card** controls the printing of various tables from the arch analysis within ADSAS.

In addition to controlling the printing of various tables, the **10005 card** controls the number of adjustment cycles. It also controls the units for the stresses (pounds per square inch versus tons per square meter). (Note: The zeros must be input for the **10005 card**.)

The **1-10 card** controls whether or not ADSAS will scan and print the maximum and minimum stresses from the stress analyzer.

The last card in the data file is the ***ENDFILE card**.

3 Material Properties

Concrete Properties

All concrete properties are included on the **3-0 card**. There are only four concrete material properties used in ADSAS: modulus of elasticity; Poisson's ratio; coefficient of thermal expansion; and unit weight. The default values for these properties are shown in Figure 3-1. The modulus of elasticity (E_c) is in million psi. The coefficient of thermal expansion (e) is in millionths per °F, and the unit weight (γ_c) is in pcf.

3	0	30100000000	3.0	0.2	5.6	150.	2.5	.2	.0	.0
			↑ E_c	↑ μ_c	↑ e	↑ γ_c				

Figure 3-1. Concrete material properties

Foundation Properties

Foundation properties are included on the **3-0 card** or on a combination of the **3-0** and **7-1 cards**. In ADSAS the foundation is approximated by a series of independent springs. The elastic constants of these springs are determined from the Vogt's flexibility coefficients of a semi-infinite isotropic foundation (USBR 1977a, Vogt 1925). The foundation stiffness (deformation modulus) can be modeled either as a single value for the entire foundation, or it can be varied by elevation and abutment. If the deformation modulus is uniform throughout the foundation, the modulus is included only on the **3-0 card**. Figure 3-2 shows the case where a single (uniform) deformation modulus has been used. The values shown in Figure 3-2 are the default values. A modulus greater than 7,000,000,000 psi will simulate a fixed foundation.

If the deformation modulus is variable between abutments and/or with elevation, a flag of 1 is set on the **3-0 card** and the varying moduli are included on the

```
3  0   30100000000   3.0   0.2  5.6  150.  3.0   0.2    .0   .0
             ↑                               ↑     ↑
            flag                             Er    μr
        for uniform
        deformation
          modulus
```

Figure 3-2. Example for case of uniform deformation modulus throughout foundation

7-1 cards. Figure 3-3 shows the case where the deformation modulus is varied by elevation and abutment.

```
          flag indicating
        variable deformation
              modulus
                 ↑
3   0   30100000031    3.0     0.2     5.6   150.0       0.2    .0    .0
                                                          ↑
                                                          μr
.       .
.       .
.       .
7   11  314.9606                                   4.3    1.7   1.7
7   15  324.0000   12.5    17.5                    4.3    1.9   2.0
7   10  357.2412   30.5    31.0                    4.1    2.0   2.2
7   10  403.1730   37.7    35.5                    4.8    2.0   2.2
7   10  449.1047   43.5    38.7                    4.9    2.2   2.5
7   10  495.0365   49.2    43.0                    4.5    2.4   2.9
7   10  540.9682   51.7    47.8                    3.9    2.6   3.0
7   10  567.2000   52.5    49.2                    2.6    2.8   3.0
7   10  587.2000   52.7    50.2                    5.4    3.0   3.0
                                                          ↑     ↑
                                                        left   right
                                                         Er     Er
                                                     (looking upstream)
```

Figure 3-3. Example of deformation modulus varying with elevation and between abutments

4 Defining the Geometry

A majority of the cards in the ADSAS input deck are used to define the geometry of the dam (Table 4-1 and Figure 4-1). The order shown in Table 4-1 is the same order as that in which the cards should appear in the ADSAS file. These cards are discussed in general terms in this chapter with a more detailed description given in Chapter 8.

Table 4-1
Cards Needed to Define the Geometry of an Arch Dam in ADSAS

Card	Description of Part of Geometry Defined
3-0	Column 20 flags the type of layout (1-, 2-, or 3- centered)
4-0	Elevation of top and bottom of dam and elevation of top of grout
3-1	Base of dam description
4-1	Base of dam description. (Auxiliary card for 2- or 3-centered layouts
5-1	Crown cantilever and line of centers descriptions
6-1	Top of dam description
7-1	Arch descriptions
8-1	Compound curvature description for 3-centered layouts
9-1	Compound angles for 3-centered layouts. [This card is only needed if the compound curvature angle ($\Phi_{cc_{il}}$) varies with elevation.]

Figure 4-1 shows a complete input file; the cards in the darker shaded area are those needed to define the dam geometry. Figures 4-2 through 4-11 show the various features of an arch dam and the ADSAS cards that contain the information on those features. In Figure 4-2, five different cards are used to describe the crown cantilever. Figure 4-3 gives an example of those cards. Figures 4-4 and 4-5 show the information needed for the lines of centers (LOC). Figures 4-6 and 4-7 show how the angles to the abutments are identified for single-centered and two-centered layouts. Figures 4-8 and 4-9 show how all angles for the three-centered layout are defined. Figures 4-10 and 4-11 show how the arch elevations are specified as well as the base of the crown cantilever and any free cantilevers.

```
MASTERIO  111011111
1   0     PORTUGUES DAM B-16 USUAL  B16SU1
2   0     011011101
3   0     30100000031     3.1     .16         155.0
4   0     314.9606  587.20    500.00          567.20
3   1     20.0000   20.0000   327.3338  249.8251  496.1260      -.01    11  2
4   1     327.3338  249.8251  1316.3360
5   1 1 1 388.2249   -0.11124
5   1 1 2 536.9039            346.0281    429.8502    376.4866
5   1 1 3 587.2000   0.29659
5   1 2 1 587.2000            969.4095    479.0967    963.4933
5   1 3 1 435.9022            495.5113    92.9699     395.0000
5   1 3 2 515.0000            -92.8411    1122.7453   -791.000
5   1 3 3 583.9000   1.20
5   1 3 4 587.2000   0.0
5   1 4 1 515.0000            879.5001    -44.2652    728.0000
5   1 4 2 583.9000   1.20
5   1 4 3 587.2000   0.0
5   1 5 1 435.9022            1315.7213   92.9699     395.0000
5   1 5 2 515.0000             727.3689   1122.7453   -791.000
5   1 5 3 583.9000   1.20
5   1 5 4 587.2000   0.0
5   1 6 1 515.0000            1699.7101   -44.2652    728.0000
5   1 6 2 583.9000   1.20
5   1 6 3 587.2000   0.0
6   1     0.0       12.0000
7   11    314.9606                              4.3        2.0  3.0
7   15    324.0000  12.5    17.5                4.3        2.0  3.0
7   10    357.2412  30.5    31.0                4.1        2.0  3.0
7   10    403.1730  37.7    35.5                4.8        2.0  3.0
7   10    449.1047  43.5    38.7                4.9        2.0  3.0
7   10    495.0365  49.2    43.0                4.5        2.0  3.0
7   10    540.9682  51.7    47.8                3.9        2.0  3.0
7   10    567.2000  52.5    49.2                2.6        2.0  3.0
7   10    587.2000  52.7    50.2                5.4        2.0  3.0
8   1     3 1       30.0    30.0
1   2           1   1   111      1
1   4               1                                             1
1   3          1           1    1     1         1 1       1
10005                1                           2         11111
1  10      1            1
*ENDFILE
```

Figure 4-1. Summary of data file. The darker shaded areas represent cards or parts of cards used to define the geometry for a three-centered arch dam

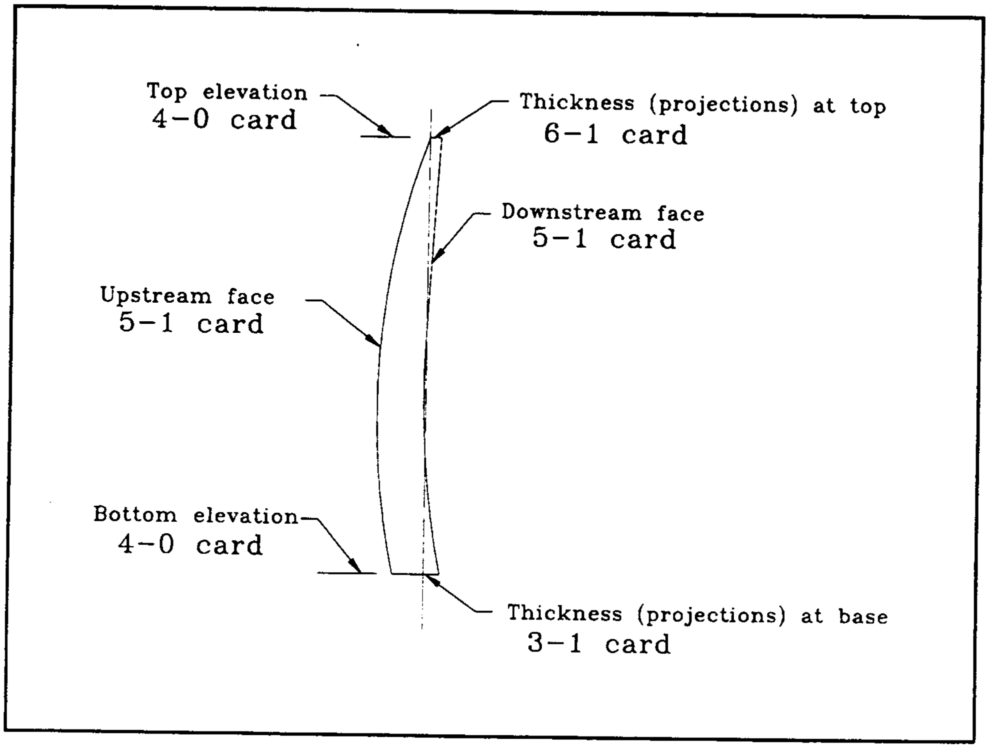

Figure 4-2. Sketch of section through the crown cantilever

```
Overall elevations (4-0 card)
4   0      314.9606  587.20    500.00          567.20
                ↑         ↑                         ↑
         base el.      crest el.            top of grout el.

Base definition (3-1 card)
3   1      20.00     20.00     327.3338  249.8251  496.1260    -.01   11  2
             ↑         ↑
        upstream & downstream projections from axis

Upstream face (5-1 cards)
5   1 1 1 388.2249    -0.11124
5   1 1 2 536.9039                346.0281   429.8502   376.4866
5   1 1 3 587.2000     0.29659
Downstream face (5-1 cards)
5   1 2 1 587.2000                969.4095   479.0967   963.4933
Crest (6-1 card)
6   1      0.0        12.00
            ↑          ↑
       upstream & downstream projections from axis
```

Figure 4-3. Cards required to define the crown cantilever

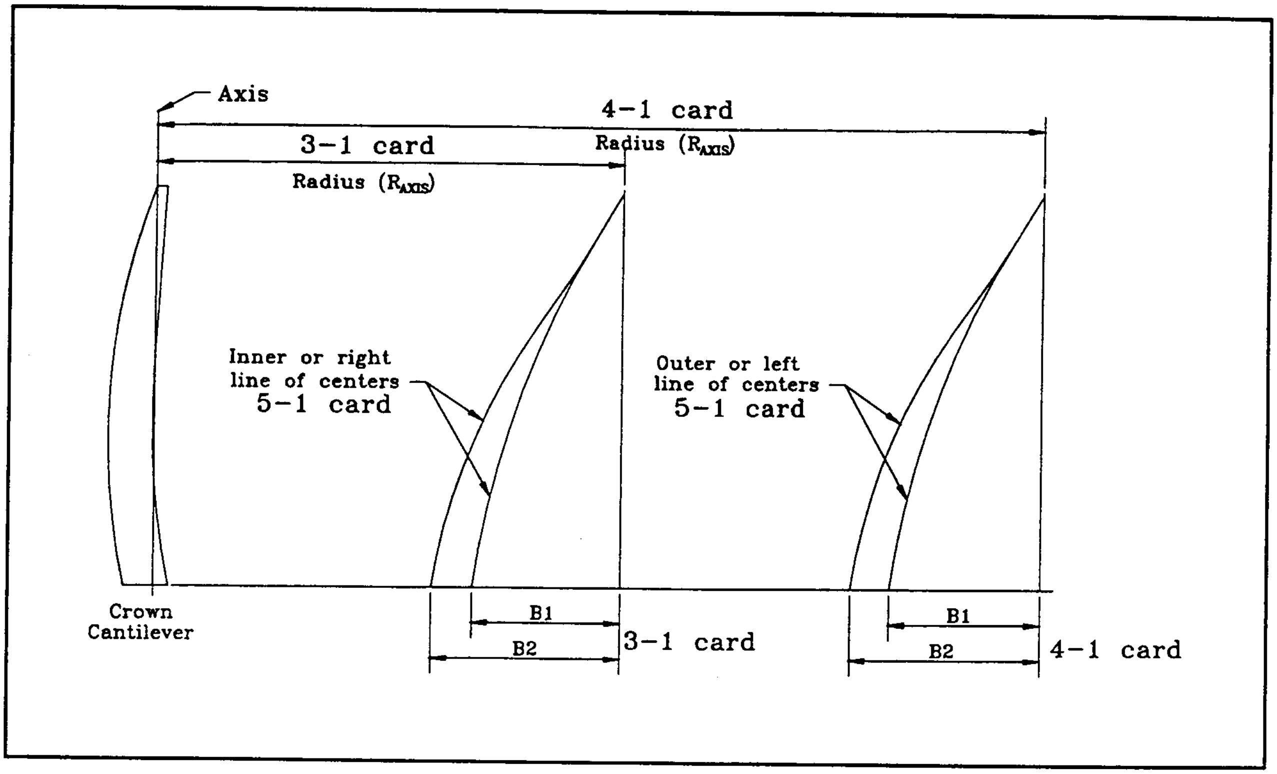

Figure 4-4. Sketch of the lines of centers

```
    Inner/right LOC's ⇒              B2         B1      Radius
                                     ↓          ↓          ↓
3   1      20.0000   20.0000    327.3338   249.8251   496.1260        -.01    11 2
4   1      327.3338  249.8251   1316.3360
              ↑         ↑          ↑
              B2        B1       Radius        ⇐ Outer/left LOC's
Inner/right intrados LOC's
5   1 3 1 435.9022                 495.5113    92.9699     395.0000
5   1 3 2 515.0000                 -92.8411    1122.7453   -791.0000
5   1 3 3 583.9000      1.20
5   1 3 4 587.2000      0.0
Inner/right extrados LOC's
5   1 4 1 515.0000                 879.5001    -44.2652    728.0000
5   1 4 2 583.9000      1.20
5   1 4 3 587.2000      0.0
Outer/left intrados LOC's
5   1 5 1 435.9022                 1315.7213   92.9699     395.0000
5   1 5 2 515.0000                  727.3689   1122.7453   -791.000
5   1 5 3 583.9000      1.20
5   1 5 4 587.2000      0.0
Outer/left extrados LOC's
5   1 6 1 515.0000                 1699.7101   -44.2652    728.0000
5   1 6 2 583.9000      1.20
5   1 6 3 587.2000      0.0
```

Figure 4-5. Cards required to describe the lines of centers

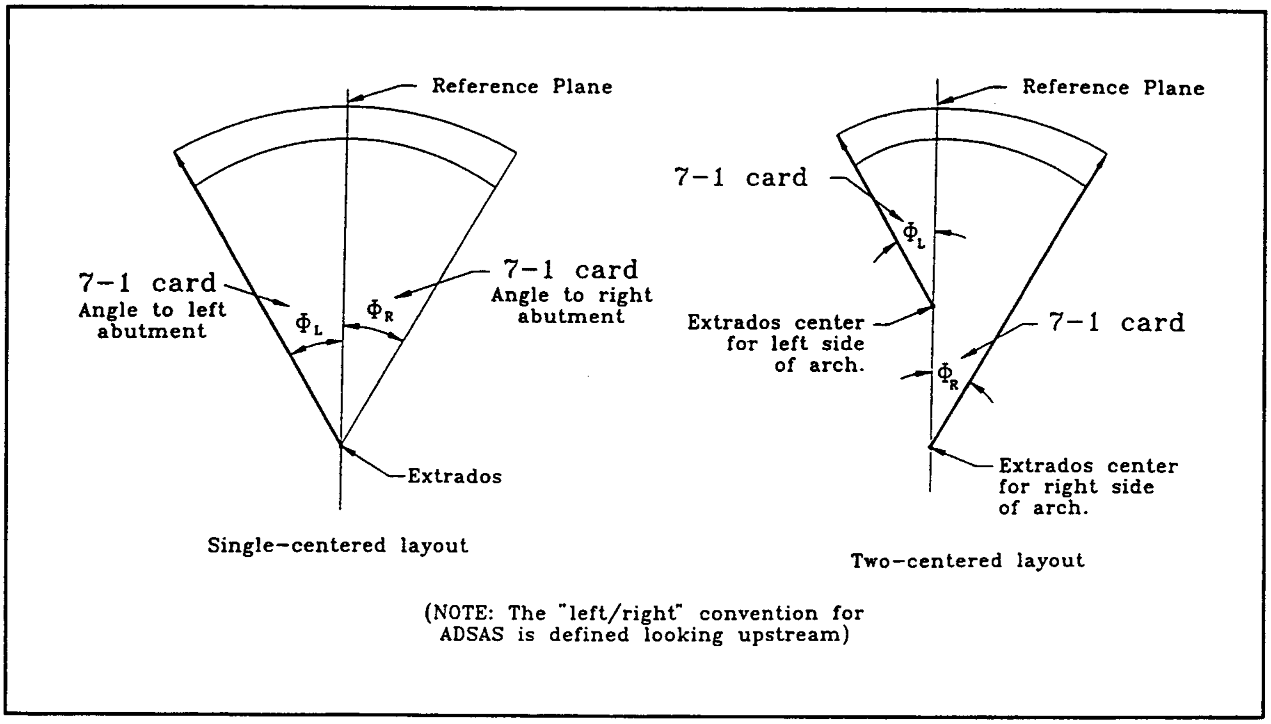

Figure 4-6. Plan view of angles to the abutments for single-centered and two-centered layouts

```
3   0      301000000010   3.5    0.16  5.5   155.0  0.0    0.20  0.0  50.0
                  ↑
              flag set
    for single-centered layout
.
.
.
7   110000 6700.0    .0     .0      .0     .0        .0    .0    .0    .0
7   100000 6790.0  44.350 44.350    .0     .0      -1.5    .0    .0    .0
7   100000 6865.0  48.125 48.125    .0     .0      -1.5    .0    .0    .0
7   100000 6940.0  49.600 49.600    .0     .0      -1.5    .0    .0    .0
7   100000 7015.0  50.250 50.250    .0     .0      -2.0    .0    .0    .0
7   100000 7090.0  51.625 51.625    .0     .0      -4.5    .0    .0    .0
7   100000 7165.0  54.875 54.875    .0     .0     -15.0    .0    .0    .0
             ↑        ↑      ↑
        elevation    ΦL     ΦR
```

Figure 4-7. Cards required to define angles to the abutments for single-centered and two-centered layouts

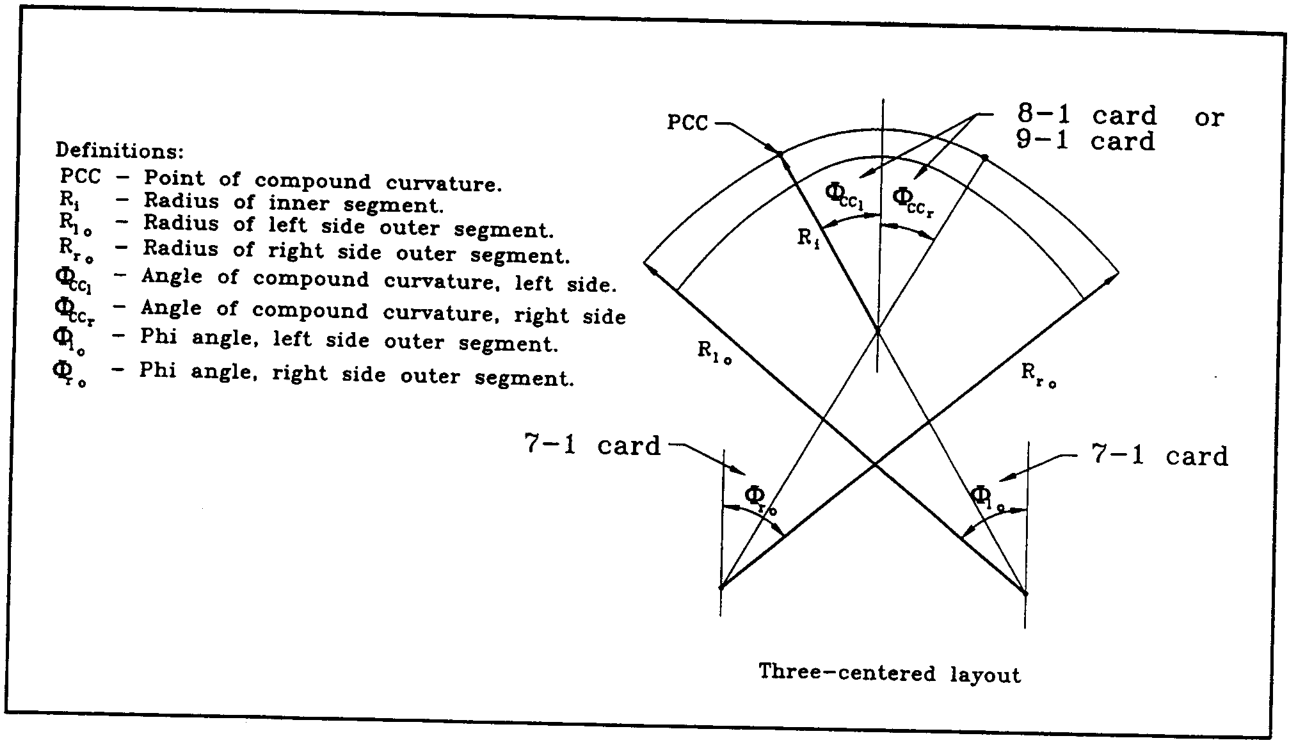

Figure 4-8. Plan view of angles in a three-centered layout

```
3   0      301000000310     3.5    0.16    5.5   155.0    0.0    0.20   0.0    0.0
                   ↑
           flag set for three-centered layout
.
.
.
7   11     314.9606                                          4.3              2.0  3.0
7   15     324.0000    12.5    17.5                          4.3              2.0  3.0
7   10     357.2412    30.5    31.0                          4.1              2.0  3.0
7   10     403.1730    37.7    35.5                          4.8              2.0  3.0
7   10     449.1047    43.5    38.7                          4.9              2.0  3.0
7   10     495.0365    49.2    43.0                          4.5              2.0  3.0
7   10     540.9682    51.7    47.8                          3.9              2.0  3.0
7   10     567.2000    52.5    49.2                          2.6              2.0  3.0
7   10     587.2000    52.7    50.2                          5.4              2.0  3.0
              ↑          ↑       ↑
          elevation      Φ       Φ      ⇐ Angle to abutment
                       left    right
8   1     3 1      30.0    30.0
                    ↑       ↑
                   Φcc     Φcc     ⇐ Angle of compound curvature
                   left    right
```

Figure 4-9. Cards required to define angles in a three-centered layout

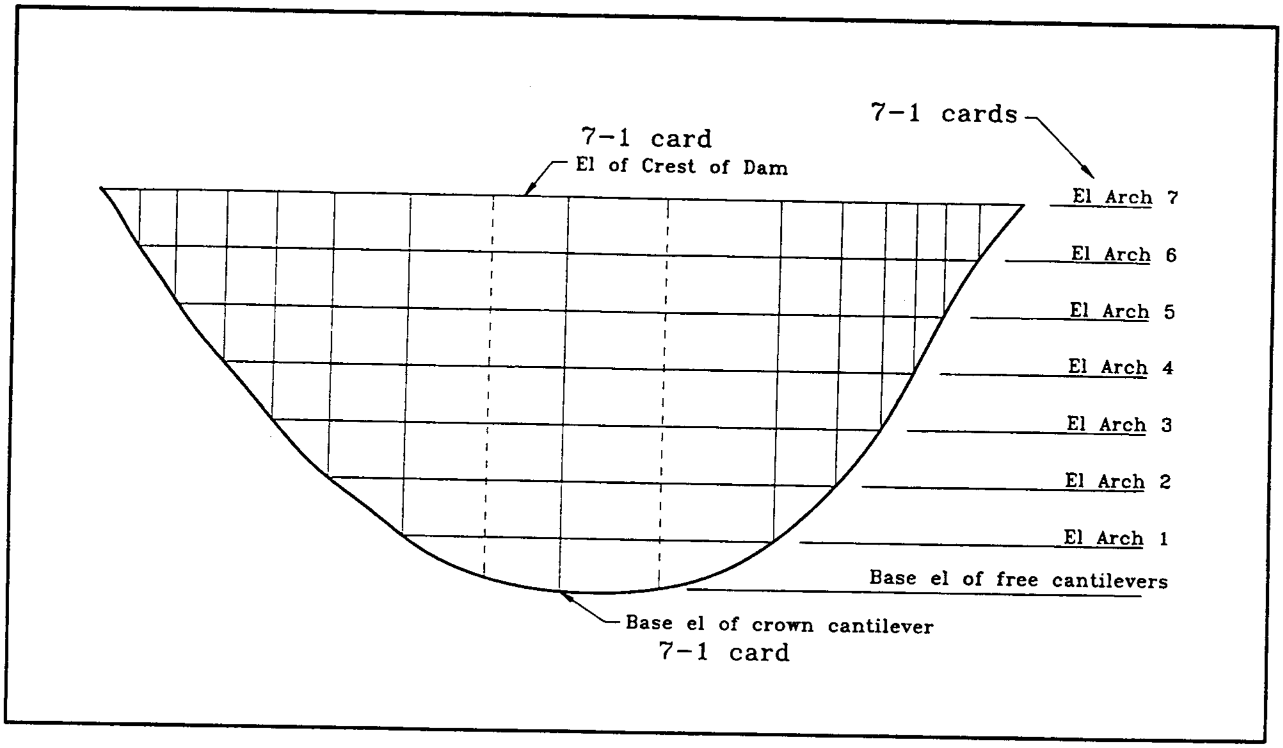

Figure 4-10. Developed profile showing arch elevations

Base of crown cantilever

7	11	314.9606			4.3	2.0	3.0
7	15	324.0000	12.5	17.5	4.3	2.0	3.0
7	10	357.2412	30.5	31.0	4.1	2.0	3.0
7	10	403.1730	37.7	35.5	4.8	2.0	3.0
7	10	449.1047	43.5	38.7	4.9	2.0	3.0
7	10	495.0365	49.2	43.0	4.5	2.0	3.0
7	10	540.9682	51.7	47.8	3.9	2.0	3.0
7	10	567.2000	52.5	49.2	2.6	2.0	3.0
7	10	587.2000	52.7	50.2	5.4	2.0	3.0

arch elevations   Crest of dam

Figure 4-11. Cards required to define arch elevations

5 Defining the Loads

ADSAS has the capability to include most of the normal loads associated with the analyses of arch dams. These loads include:

Gravity (dead weight)
Reservoir
Tailwater
Temperature (uniform and linear)
Silt
Ice
Earthquake
External Loads (initial load modifications)

ADSAS will include the above-listed loads in any combination specified by the user. EM 1110-2-2201 provides guidance for selecting applicable load combinations for arch dam analyses.

Gravity loads are included by the unit weight of concrete on the **3-0 card**. Also included on the **3-0 card** are a series of flags which tell ADSAS what temperature loads will be considered and if tailwater, silt, and ice loads are included in the analysis. Figure 5-1 shows an example of the **3-0 card**.

Reservoir loads are included as a reservoir level on the **4-0 card**. It should be noted that ADSAS may not run properly if the reservoir level is set below the base of the dam. For a condition with no reservoir (for example, the construction condition) the reservoir level should be set equal to the base of the crown cantilever. If no tailwater is included, it will be assumed to be at the base of the crown cantilever. Figure 5-1 also shows the reservoir and tailwater elevations included on the **4-0 card**.

Temperature Loads

Temperature loads can be very critical in the stress distribution for arch dams. While the temperature distribution through a concrete dam is nonlinear, for simplicity it is assumed to vary linearly between the upstream and downstream faces.

```
3-0 CARD

3   0   301111110000    3.0    .2    5.6   150.   2.5    .2    .0     .0
          ↑↑↑↑↑↑                          ↑
      flags set for                      unit
      uniform/linear                     weight
    temperature, tailwater,            of concrete
     silt, and ice loads

4-0 CARD

4   0     6700.    7165.   7165.   6730.   7165.
                             ↑       ↑
                           reser-  tail-
                            voir   water
                             el     el
```

Figure 5-1. Example of gravity, reservoir, and tailwater loads. Also flags have been set to read silt, ice, and temperature loads on separate cards

ADSAS accepts two types of temperature loads, uniform and linear as shown in Figure 5-2. The "uniform" temperature load is the difference between the average of the concrete face temperatures and the closure temperature (see Appendix A for closure temperature definition). The "linear" temperature load is the difference between the face temperatures.

Uniform temperature loads are applied as initial arch deformations and are called "02" loads in ADSAS terminology. Linear temperature loads are applied as initial deformations to both arches and cantilevers and are called "03" loads in ADSAS terminology. Normally, uniform and linear temperature loads are included in the **7-1 cards** as shown in Figure 5-3.

The temperatures shown in the **7-1 cards** are a function of ambient air, reservoir temperatures, solar radiation, dam thickness, and the concrete thermal properties. These temperature loads change by elevation but are assumed to be constant across the canyon. The temperatures can be estimated by several methods including the method described in a USBR monograph (USBR 1981). The computer program TEMPER (X8305) is based on the method shown in that monograph and provides a direct method to obtain the "02" and "03" temperature loads. A more refined temperature distribution can be obtained from a finite element heat flow model using any of a number of general purpose finite element programs.

In some very refined analyses or for extraordinary conditions, uniform and linear temperature loads can be assumed to vary throughout the dam, from the base to the crest and from abutment to abutment. These temperature loads are called "05" temperature loads in ADSAS terminology and are included in the **7-3**, **6-4**, and

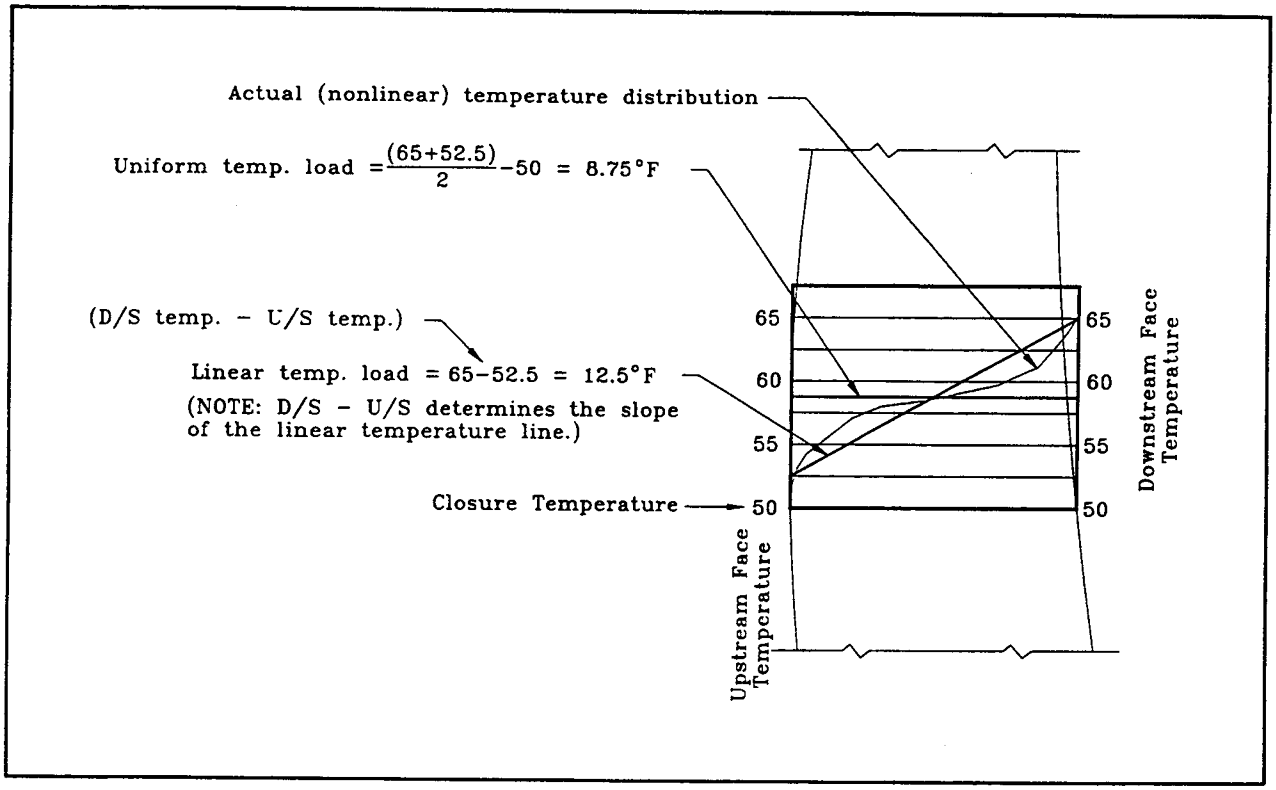

Figure 5-2. Uniform and linear temperature distributions assumed by ADSAS

```
3   0      30110000000   3.0        .2      5.6  150.0  2.5     .2     .0     .0
             ↑↑
          flags for
         uniform and
         linear temp.
            loads
.
.
.
7   110000    6700.0      .0        .0      .0    .0     .0    2.1     .0     .0
7   100000    6790.0    44.350    44.350    .0    .0    -1.5   3.2     .0     .0
7   100000    6865.0    48.125    48.125    .0    .0    -1.5   4.1     .0     .0
7   100000    6940.0    49.600    49.600    .0    .0    -1.5   4.2     .0     .0
7   100000    7015.0    50.250    50.250    .0    .0    -2.0   4.3     .0     .0
7   100000    7090.0    51.625    51.625    .0    .0    -4.5   4.6     .0     .0
7   100000    7165.0    54.875    54.875    .0    .0   -15.0   5.0     .0     .0
                                                         ↑      ↑
                                                   uniform   linear
                                                     temp.   temp.
                                                     load    load
```

Figure 5-3. Example of typical layout when both uniform and linear temperature loads are included

7-4 cards. If required, this type of temperature distribution for "05" loads can best be estimated by a three-dimensional finite element heat flow model.

Ice Loads

Ice load is included on the **13-3 card** as a force per linear foot across the dam. A value of 5,000 psf is typically assumed for ice load. Therefore, a 2-ft-thick ice layer would apply a 10,000 lb/lin ft foot load on the upstream face of the dam. The force is applied at the elevation of one-half the ice thickness below the reservoir surface. Figure 5-4 shows an example of a data file that includes ice loads.

```
 3   0     30100011000    3.0      0.2     5.6  150.0    2.5    0.2    0.0    0.0
                 ↑↑
                flags
             for ice and
            silt loadings
  .
  .
  .
  .
 13  3      10000.0      2.0       - ice loading
 14  3     85.0    85.0    6865.0  6700.0  6800.0  6700.0   - silt loading
                                                              on both faces
```

Figure 5-4. Example input for ice and silt loads

Silt Loads

Silt loads can be applied to either face of the dam. The loads are defined by pressure loads in pounds per cubic foot and the top and bottom elevations of the silt layer. Silt load data are input on the **14-3 card** as shown in Figure 5-4.

Earthquake Loads

ADSAS has the capability of performing a pseudostatic analysis by applying an acceleration, equal to a constant percentage of the gravitational constant, in the upstream-downstream direction. The inertia forces include concrete and Westergaard's added mass. A positive acceleration means the ground is moving upstream along the reference plane. Vertical and cross-canyon earthquake motions are not available in ADSAS. The inertia forces are resolved into radial and tangential components according to their angular distance from the reference plane. The reactions and deformations, computed internally, are applied as initial radial and tangential cantilever deflections. As such, the pseudostatic effects are superimposed on the static loadings with the stress reflecting static and pseudostatic load combinations.

It should be noted that in the pseudostatic analysis ADSAS does not change the concrete modulus of elasticity to account for dynamic conditions. If an increased modulus of elasticity for the concrete, or an increased deformation modulus for the foundation, is appropriate, the user must manually change these values to account for dynamic conditions. Figure 5-5 shows how to include the seismic coefficient in an ADSAS analysis.

```
 3   0     3010000000     3.0   .2   5.6   150.   2.5    .2   +0.1     0.0
                                                               ↑
                                                          earthquake
                                                            loading
```

Figure 5-5. Typical setup for pseudostatic loading

External Loads (Initial Load Modification)

Additional loads can be added to the ADSAS analysis through a set of **8-3 cards**. Load modifications can be added concentrated loads or could be reduction in loads to account for voids in the dam. If the **8-3 cards** are needed, the **1-3 card** must first indicate to ADSAS that the **3-3** and **4-3 cards** will be included in the data file. On the **3-3 card** a flag must be set indicating that the **8-3 cards** will be included (see Figure 5-6).

A separate **8-3 card** must be included for each arch/cantilever intersection point throughout the dam and at the base of the crown cantilever and any free cantilevers. Adding external loads to the data file will increase the number of cards by 50 to 150 cards depending on the number of arches and cantilevers. These cards are included by cantilever number beginning with the crown cantilever (cantilever 20) and working toward the left (cantilevers 21, 22, etc.) and then toward the right (cantilevers 19, 18, etc.). In this way all cards for a cantilever unit are grouped together and are in the same order that the program processes cantilevers. Figure 5-6 shows the sequence of flags needed to include the **8-3 cards** and shows an example of a few of the **8-3 cards**.

```
                                                              flag indicating that
                                                               3-3 and 4-3 cards
                                                                are to be read
                                                                      ↓
1   3           0            1   11    1           1  1 1  1     11

          flag indicating that
               8-3 card
            is to be read
                   ↓
3   3     3010010001000    2.5      0.2     5.5      150.0
4   3       6002.0    5781.0    6029.0   5730.0    6029.0      5730.0

       Cant                          Load modifications
        No.    El        moment        horizontal       vertical
         ↓      ↓          ↓               ↓               ↓
8  3   20   6029.0
8  3   20   6004.0
8  3   20   5954.0
8  3   20   5904.0
8  3   20   5854.0
8  3   20   5804.0  -2.5806500+005-2.1505000+004-3.2400000+002
8  3   20   5759.0  -3.0971480+006-1.0913100+005-9.0490000+003
8  3   20   5730.0  -7.8522030+006-1.9992200+005-2.5293000+004
8  3   21   6029.0
8  3   21   6004.0
8  3   21   5954.0
8  3   21   5904.0
8  3   21   5854.0
8  3   21   5804.0 -2.6772600.005-2.0927000+004-1.0580000+003
8  3   21   5759.0 -3.0979510.006-1.0535000+005-1.2356000+004
.      .
.      .
.      .
cantilevers 22 through 26 and 19 through 14 not shown
```

Figure 5-6. Typical setup for load modification cards

6 Modeling Techniques for Arch Dams

As noted in Chapter 1, ADSAS is limited to a maximum of 144 arch/cantilever intersection points. This is not considered a severe limitation since usually six arches and two free cantilevers are adequate to obtain reasonable results. In this type of grid, the six arches will produce 10 cantilevers (the top arch has no cantilever). With the crown cantilever and the two free cantilevers, the resulting grid produces only 48 intersection points (Figure 6-1).

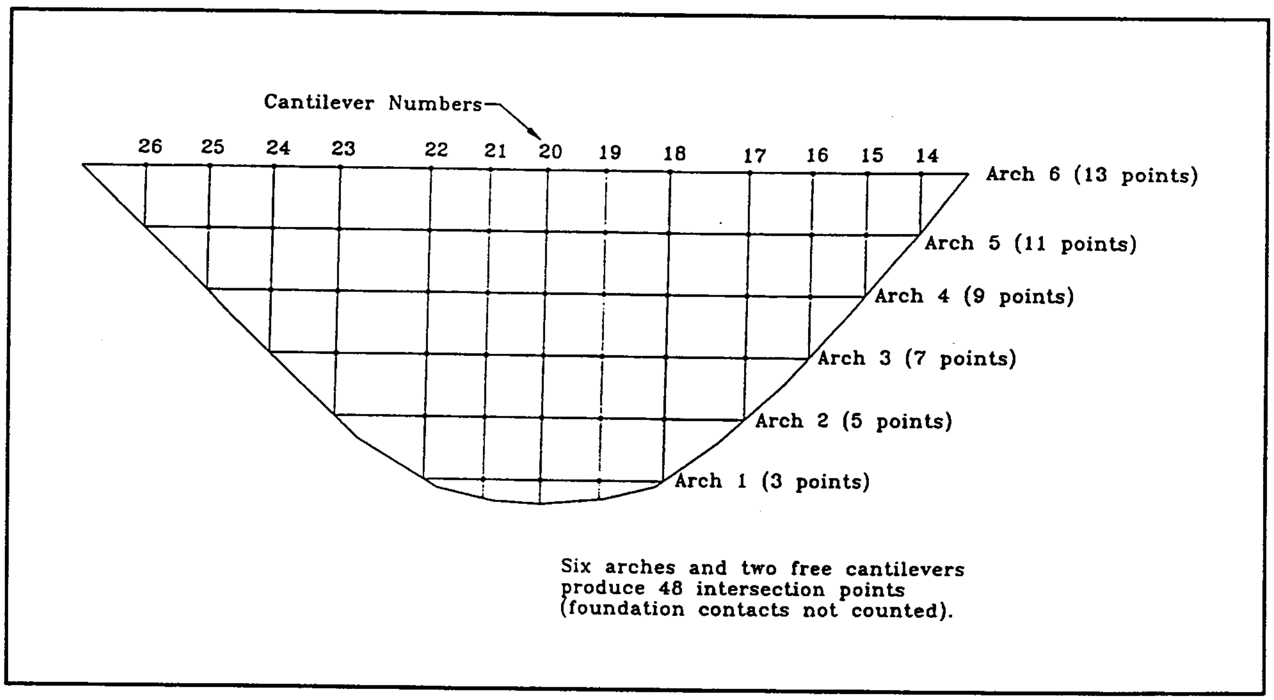

Figure 6-1. Typical layout for ADSAS analysis

Grid Selection—Elevations of Arches

Selection of arch elevations for a normal arch dam begins by selecting the top and bottom arches. The crest of the dam will always be the top arch. If a spillway is located along the crest of the dam, then the next arch below the crest of the dam should be located at the spillway crest as shown in Figure 6-2. For convenience the lowest arch is usually the lowest topographic contour but no higher than about 15 percent of the structural height. As a first estimate of the vertical spacing of the remaining arches, the difference between the elevation at crest of the dam (or spillway crest) and the lowest arch elevation is divided by four or five. The result establishes an even spacing between the top and bottom arches. The number of arches, the spacing, and/or the elevation of the lowest arch is usually adjusted so that the final spacing is in multiples of 5 or 10 ft. It may also be convenient to set the arches at elevations that correspond to contour lines.

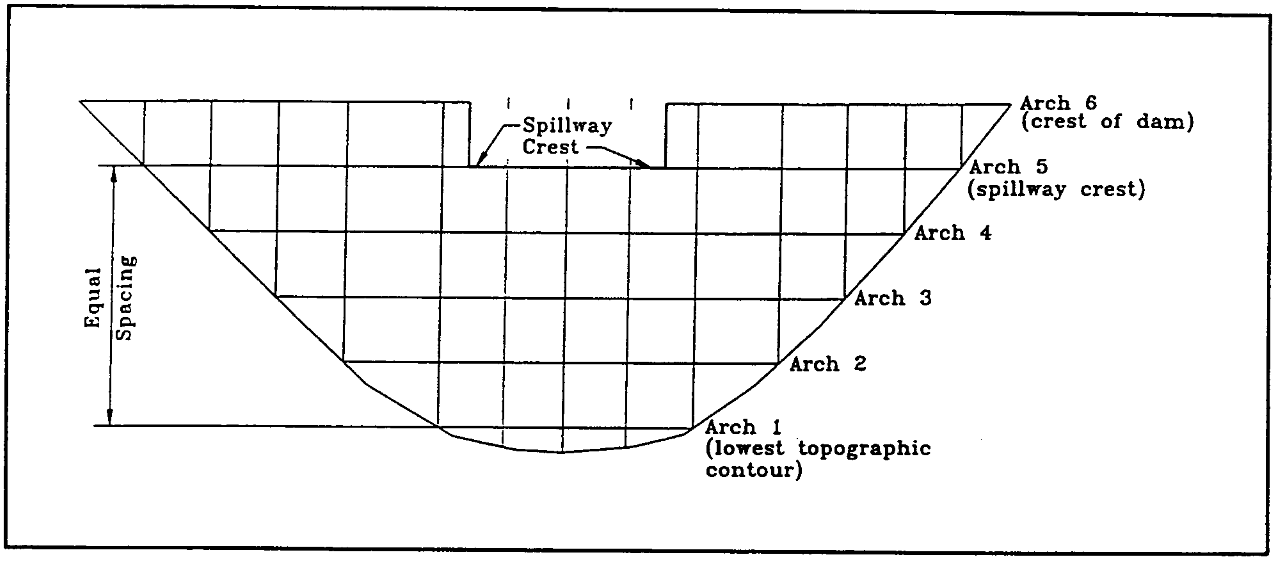

Figure 6-2. Typical layout of arches with spillway at top of dam

Grid Selection—Cantilevers

The crown cantilever is always located at the maximum section (maximum dam height). With the exception of the top arch, ADSAS automatically locates additional cantilevers at the ends of each arch. Cantilevers are numbered by ADSAS looking upstream. The crown cantilever is always numbered 20. The left-side cantilevers are sequentially numbered 21, 22, 23, etc. The right-side cantilevers are sequentially numbered 19, 18, etc., as shown in Figure 6-3.

The cantilever spacing generated from the automatic placement at arch elevation will usually give noticeably unequal spaces between the cantilevers next to the crown cantilevers. This unequal spacing can be improved by adding "free cantilevers" to the layout. Free cantilevers are cantilevers added by the designer and are

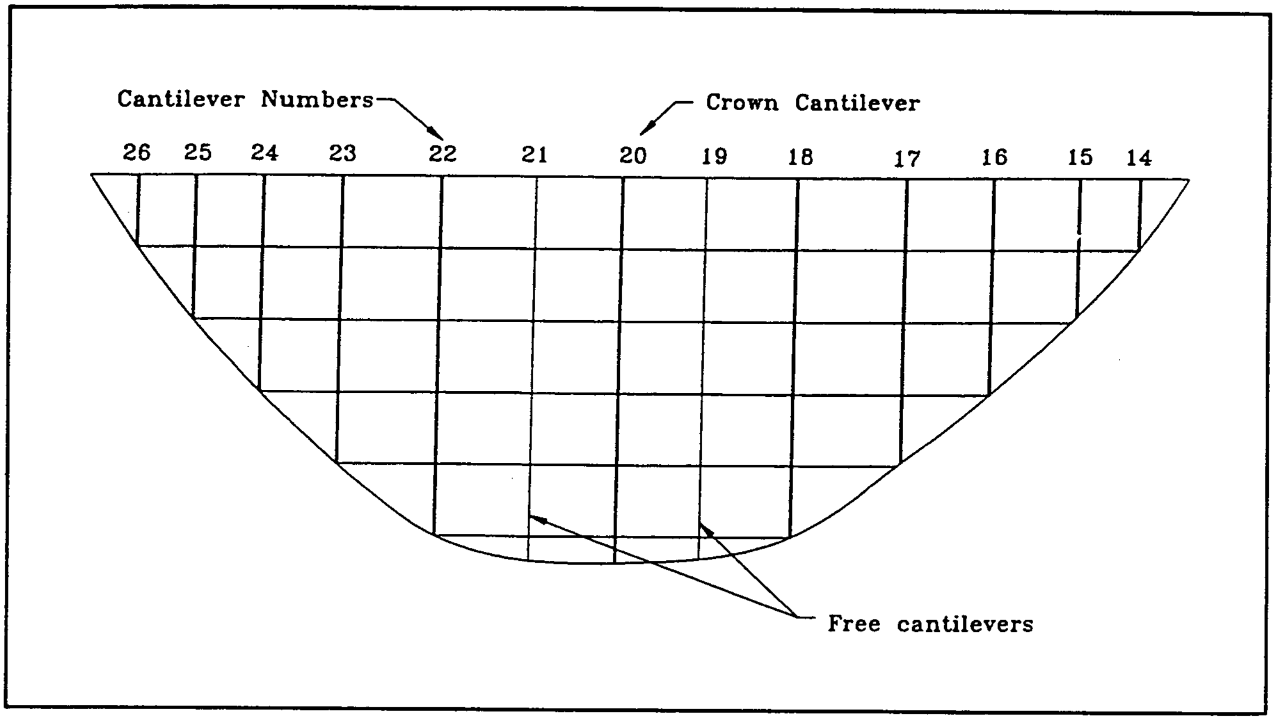

Figure 6-3. Cantilever numbering (looking upstream) and location of free cantilevers

not based on an arch. Up to two free cantilevers can be placed on each side of the crown cantilever and are set between the crown cantilever and the abutments of the lowest arch. Their base elevation must be above the crown cantilever base elevation and below the first arch elevation.

Adding one or two free cantilevers on each side of the crown cantilever is always recommended. Analyses with no free cantilevers may produce abnormal stress distributions along the lower arch abutments.

For single-centered and two-centered layouts the free cantilevers on opposite sides of the crown cantilever are not required to have the same base elevation. However, for three-centered arches, the free cantilevers on each side must come in pairs and their base elevations must be identical.

For two-centered layouts it is sometimes convenient to have one free cantilever on the short side and two on the long side as noted in Figure 6-4.

On highly irregular foundations, such as shown in Figure 6-5 where equally spaced arches cause a gap in the cantilever spacing, an additional arch may be added which will generate a cantilever in this gap. The additional arch will also generate a closely spaced cantilever on the short side (right side) of the dam. The additional arch and cantilevers should only have a negligible effect on the stresses in the adjacent arches and cantilevers. The stresses on the left abutment where the cantilevers are closely spaced should not change noticeably.

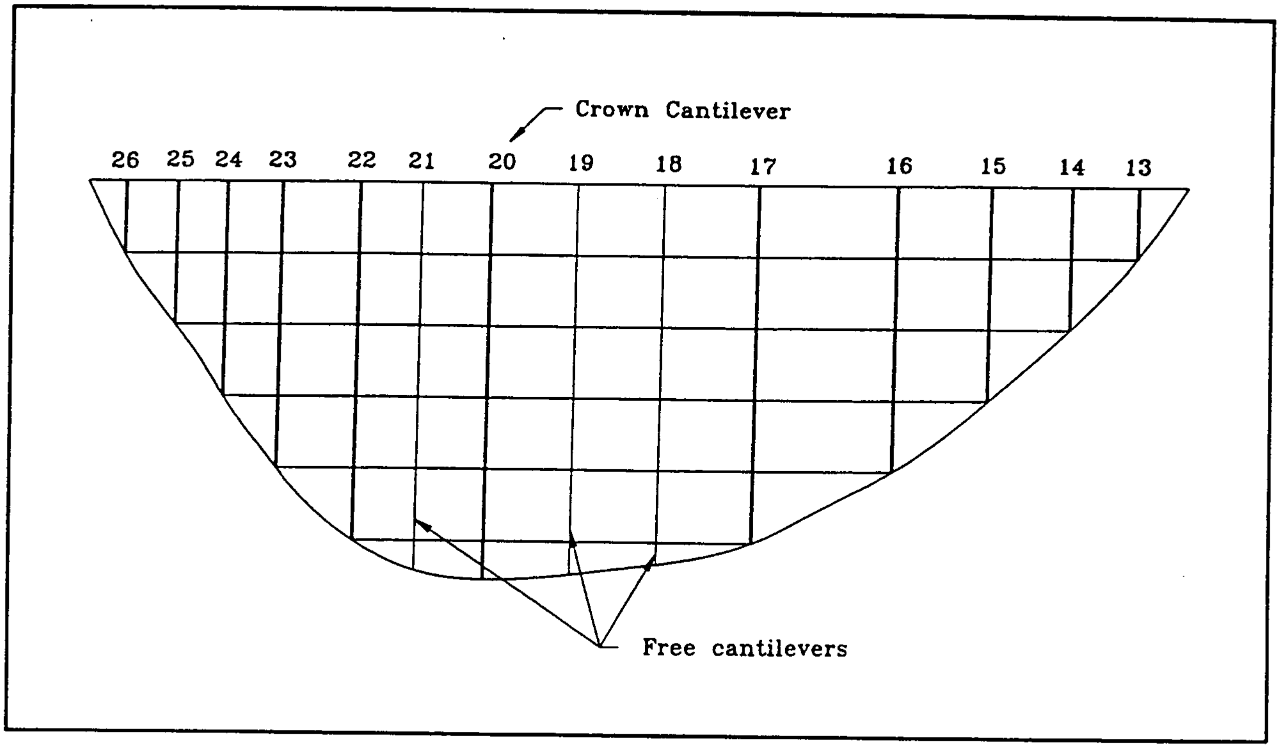

Figure 6-4. Free cantilevers for two-centered layout at highly unsymmetrical site

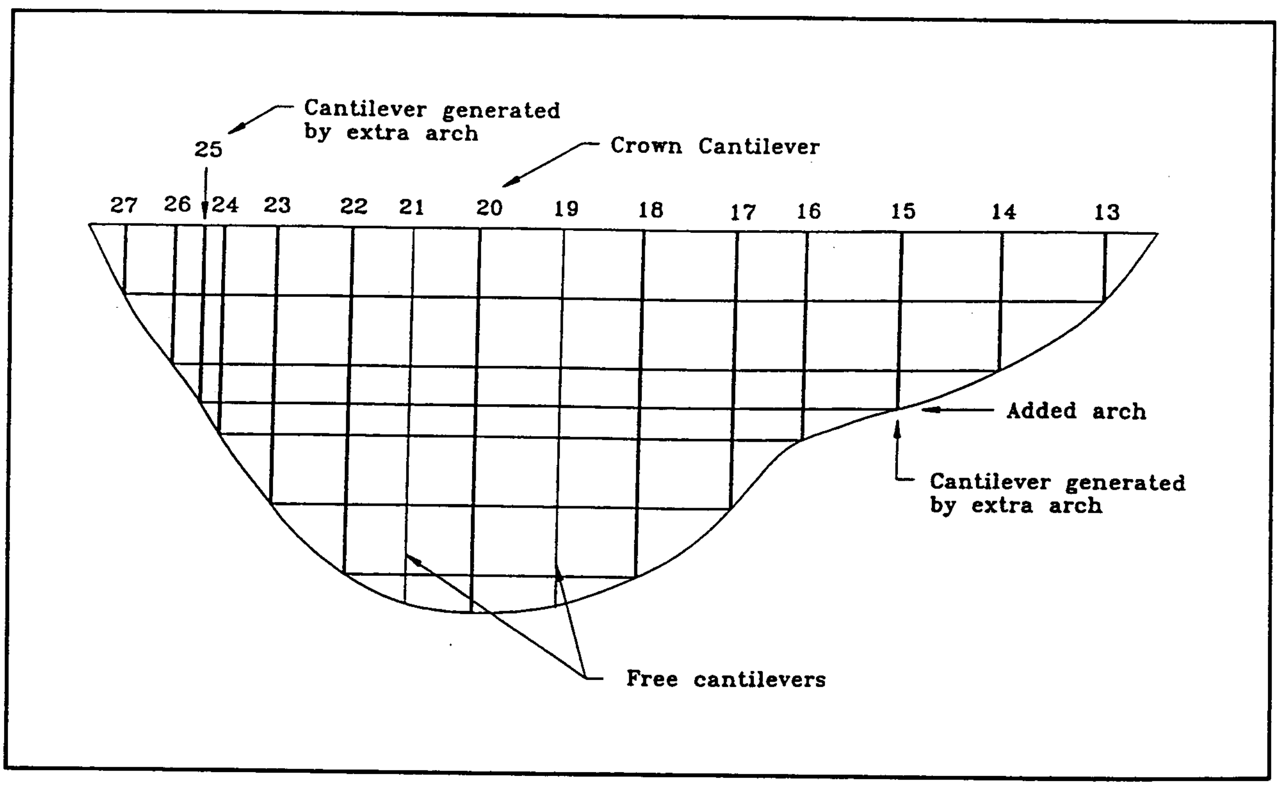

Figure 6-5. Adding an additional arch at a highly irregular site

7 Modeling Special Features and Layouts

ADSAS has the capability to model special features such as pads and thrust blocks and can model special layouts such as gravity dams or straight tangents at the ends of single-centered arch dams. This chapter discusses a few of these special features and layouts.

Straight Gravity Dam

Under certain conditions ADSAS can be used to analyze the three-dimensional effects of a straight gravity dam. This type of analysis is only valid for estimation of stresses; overturning and sliding stability are not included in the results. In addition, uplift is not considered in the analysis. Uplift must be considered separately.

To use ADSAS to model a straight gravity dam, the straight crest is approximated with a circular surface having a 999,999-ft radius. The geometric difference between the actual flat face and idealized curved face is negligible. For a 500-ft-long gravity dam, the maximum difference between the chord and the rise at the center of the curvature is 0.03 ft.

The data required are the same as those for an arch dam: crown cantilever description and cross-canyon dimensions, material properties, loads, and load combinations. Angles to the abutments of the arches (beams) are computed from the equation:

$$A = \frac{57.296 * L}{R} \tag{7-1}$$

where

A = the angle (deg)

L = the straight line distance from the crown cantilever to the abutment (ft)

R = the axis radius (999,999 ft)

Figure 7-1 shows the card setup for the analysis of a straight gravity dam.

```
3  0     30100000  01      3.0     .16         150.0
                    ↑
             Single Center

3  1        0.0      168.0       0.0         0.0     999999.0     -.01  12 4
                                                         ↑
                                              999,999-ft Radius

5  1 1 1    2404.0          0.0      ← Upstream face
5  1 2 1    2404.0        -0.75      ← Downstream face
5  1 3 1    2404.0          0.0      ← Intrados
5  1 4 1    2404.0          0.0      ← Extrados
6  1        0.0      15.0
7  11      2200.0                                     7.0          3.0  3.0
7  16      2225.0   0.0087  0.0085                    8.0          3.0  3.0
7  10      2250.0   0.0110  0.0101                    9.5          3.0  3.0
7  10      2280.0   0.0142  0.0119                   13.5          3.0  3.0
7  10      2310.0   0.0159  0.0133                   16.0          3.0  3.0
7  10      2340.0   0.0171  0.0146                   20.9          3.0  3.0
7  10      2358.0   0.0182  0.0151                   24.5          3.0  3.0
7  10      2380.0   0.0190  0.0154                   27.4          3.0  3.0
7  10      2404.0   0.0226  0.0179                   27.6          3.0  3.0
             ↑        ↑       ↑
        Elevation   Left    Right
                    Angle   Angle
                    (Φl)    (Φr)
```

Figure 7-1. Card deck for analysis of a straight gravity dam

Straight Tangents on Arch Dams

The same approximation used for gravity dams can also be applied to single plane of centers arch dams that have straight tangents on the upper portion of either abutment (Figure 7-2). To model this, the three-centered arch option is used. The single plane of centers is used to define the inner segment and the straight tangents are defined by the outer segments. Each of the outer segments will have a radius of 999,999 ft. Angles of compound curvature (**8-1 cards**) are measured from the reference plane to the abutments or to the beginning of the straight tangents. Phi

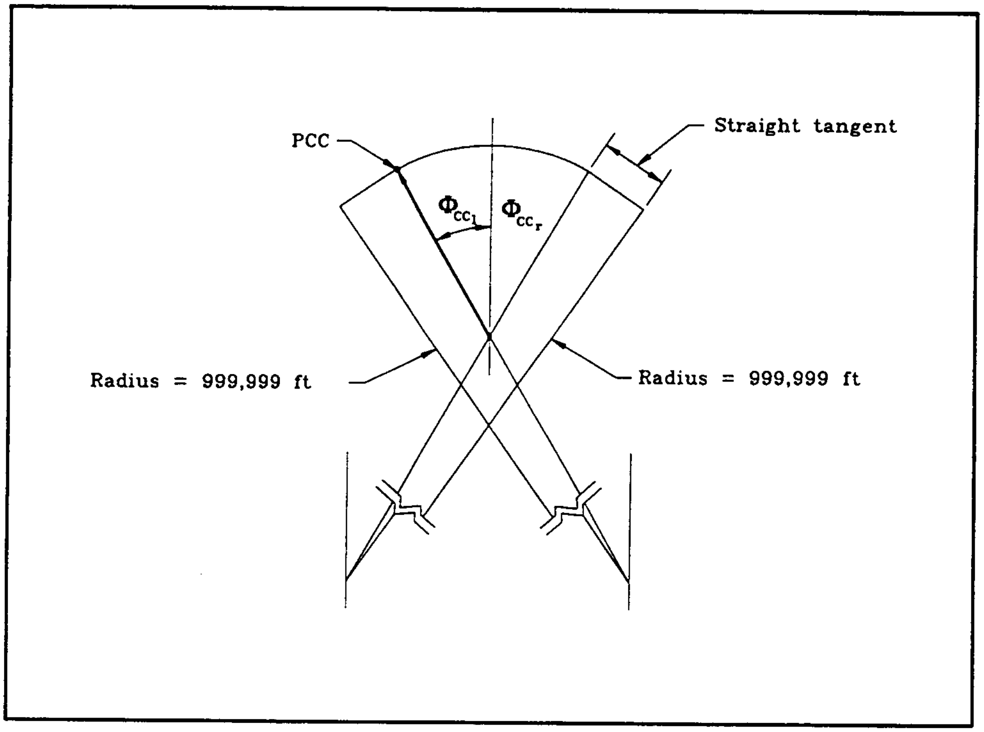

Figure 7-2. Single-centered dam with straight tangents

(ϕ) angles to the abutment (**7-1 cards**) for arches that contain straight tangents are the sum of the angles of compound curvature plus angular equivalent to the tangent lengths. This angular equivalent is computed by the same equation as that used for straight gravity dams (Equation 7-1).

Abutment Pads

Pads represent a rapid increase in thickness near the abutments. They are added to provide a better distribution of stresses on the foundation, much like a spread footing. Abutment pads can be included in ADSAS with three-centered layouts only. Figures 7-3 and 7-4 give a general description of abutment pads and the cards used to define them.

Abutment pads should not be confused with other types of restitution concrete where weak foundation material is replaced with concrete in order to provide a more symmetrical or uniform site. The abutment pads discussed in this guide are restricted to providing additional thickness along the abutment contact. The description of abutment pads in ADSAS does not extend below the dam/foundation contact (arch/cantilever intersection).

The **10-1, 11-1,** and **12-1 cards** are used to provide the pad geometry and the vertical and horizontal extent on an arch dam as follows:

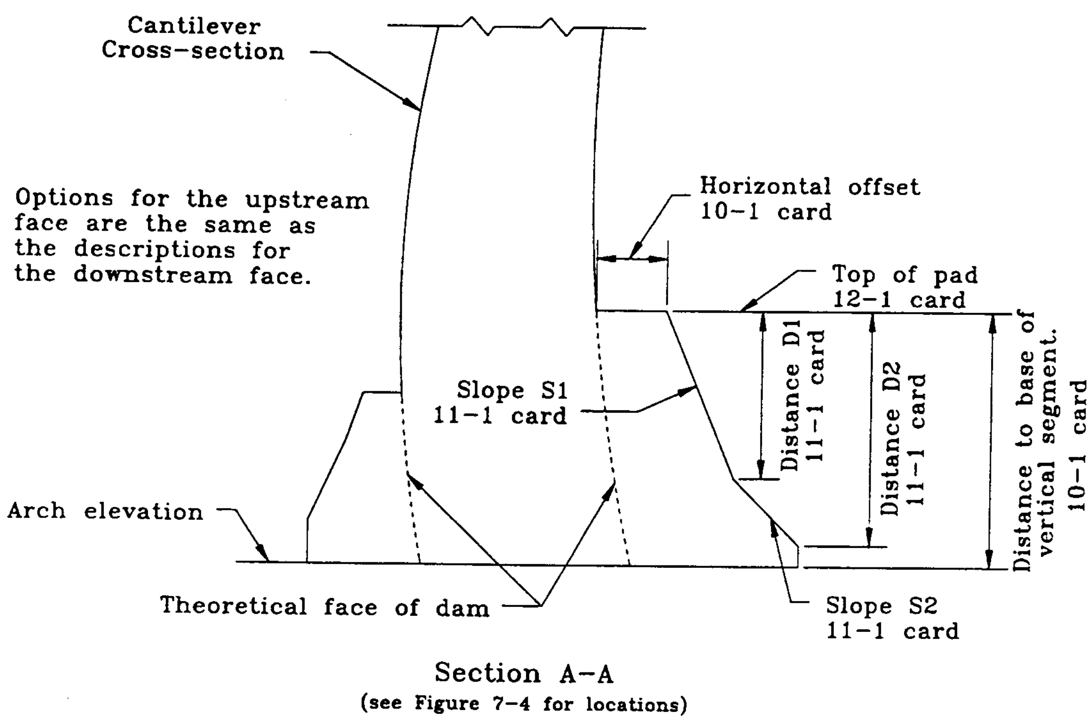

Figure 7-3. Schematic of pad descriptions

a. The **10-1 card** is the heading card. It controls the number of **11-1 cards** for either or both faces and defines the top horizontal offset (berm) and maximum extent of the vertical segment on either face.

b. The **11-1 cards** describe each sloping line segment on each face. The upstream face is given first, followed by the downstream face. Data begin at the highest line segment.

c. The **12-1 cards** define the top elevation of the pad on each cantilever and the distances (arc lengths) in from the abutment of each arch. The number and order of the **12-1 cards** are identical to the number and order of the **7-1 cards** used in the input file. The top of pad must not be set at an arch-cantilever elevation intersection but must be moved at least 1 ft above the arch and to the left or right of the cantilever.

Figure 7-5 shows the plan and section views of the pads designed by the Bureau of Reclamation for Auburn Dam (USBR 1977b). Figure 7-6 shows the **10-1, 11-1,** and **12-1 cards** used to describe the Auburn Dam pads.

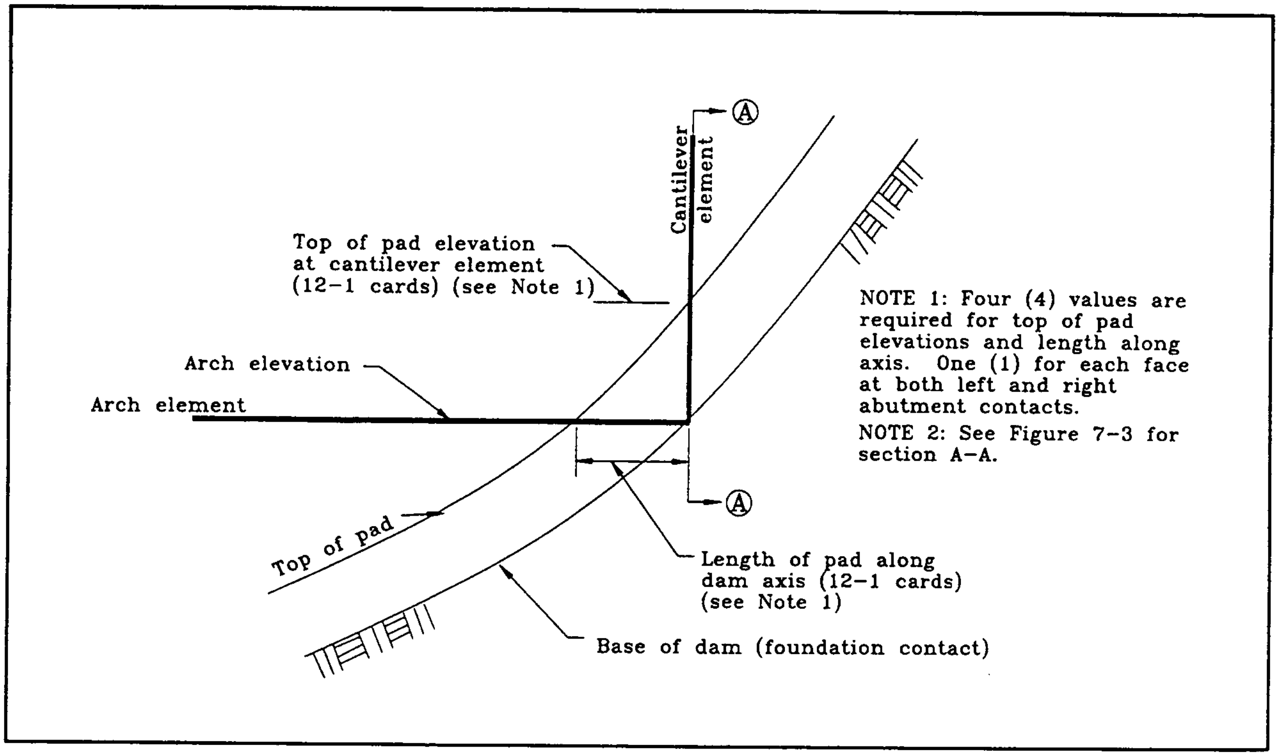

Figure 7-4. Pad elevation and arc length descriptions

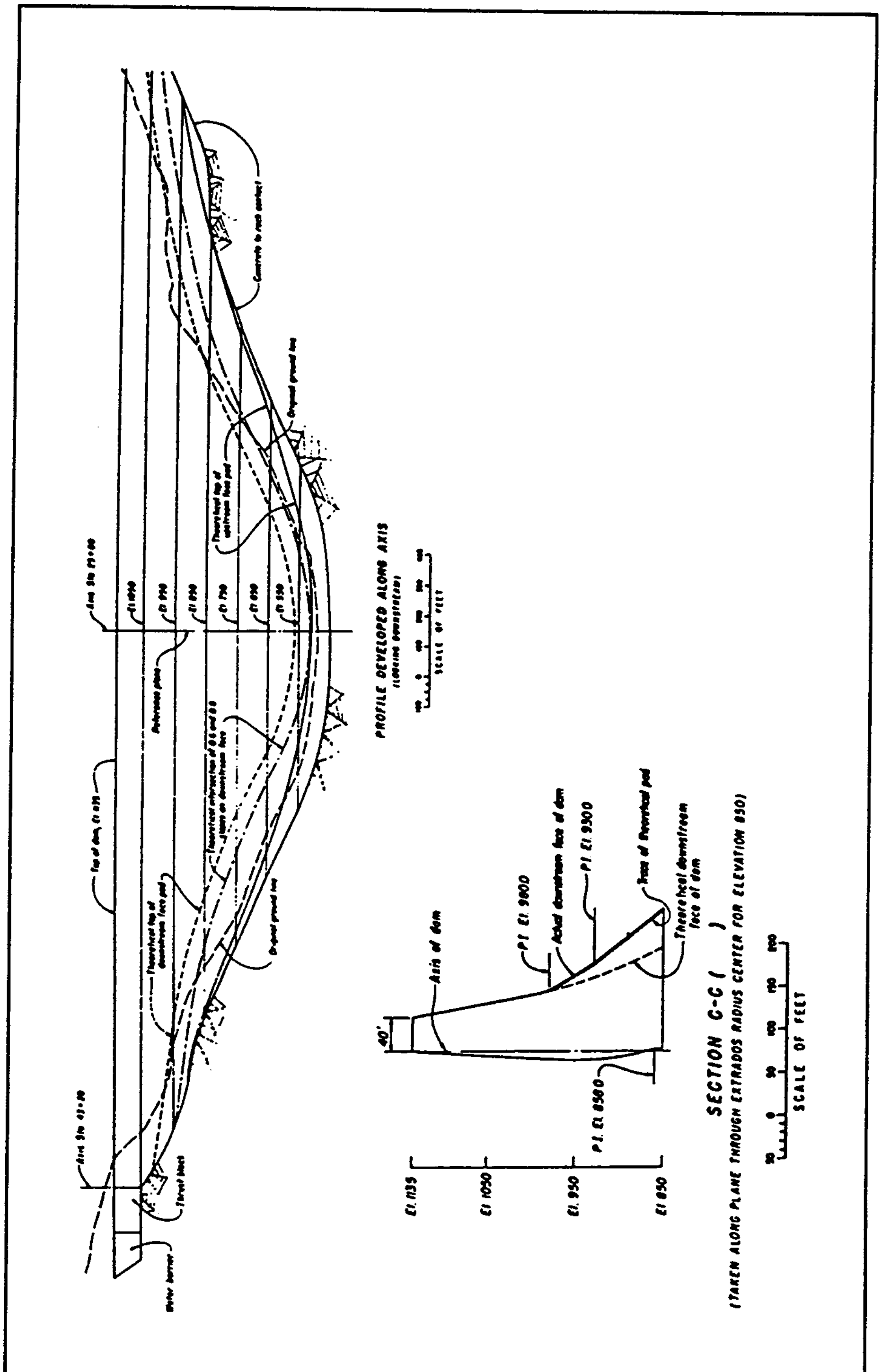

Figure 7-5. Example of abutment pads designed for Auburn Dam (USBR 1977b)

```
10-1 card
10  1    1    0      2       0.0        0.0        100.0       0.0
              ↑      ↑        ↑          ↑           ↑          ↑
            upstr  dnstr    horiz      horiz      vertical    vertical
            face   face     offset     offset     segment     segment
            # of lines      upstr      dnstr      upstr       dnstr
             segments       face       face       face        face

11-1 cards
11  1    1    2           50.0       0.6
11  1    2    2          200.0       0.8
         ↑    ↑            ↑          ↑
       line  dnstr         d1         S1
     segment face          d2         S2

                                                   Left   Left   Right  Right
12-1 cards                                         U/S    D/S    U/S    D/S
12     450.0      0.     0.     0.     0.          505.   565.   510.   565.
12     472.5      0.     0.     0.     0.          535.   613.   536.   612.
12     550.0    190.   560.   228.   563.          605.   720.   598.   734.
12     650.0    103.   398.    78.   418.          685.   832.   680.   830.
12     750.0     75.   420.    44.   444.          774.   917.   771.   904.
12     850.0     35.   480.    34.   424.          858.   980.   862.   950.
12     950.0     16.   593.     0.   328.          955.  1055.     0.   998.
12    1050.0      0.   268.     0.     0.            0.  1081.     0.     0.
12    1135.0      0.     0.     0.     0.            0.     0.     0.     0.
         ↑      length of pad (from abutment       Top elevation of pad beginning
         el     contact to edge of pad as          on left side (upstr and dnstr)
                measured along dam axis)           and right side (upstr and dnstr)
```

Figure 7-6. Cards used to define the abutment pads for Auburn Dam

8 Card Order and Details

The input file for ADSAS is a fixed field format and, as a result, is very structured. It is critical that the user follow the instructions on each card.

The cards are arranged according to the various segments or "analyses" within ADSAS. Most of the cards in ADSAS are designated by a pair of numbers. The second number on each card designation identifies the segment of the program to which it belongs. For example, the **1-0 card** is the first card in "segment" zero. Likewise the **4-3 card** is the fourth card in "segment" three.

To make it easier to locate the card descriptions in this guide the cards are arranged by segment number. Within each segment the cards are listed by card number. With a few exceptions, this is the same sequence in which they will occur in the ADSAS data file. The exceptions include the arch segment (segment 4) which comes before the cantilever segment (segment 3) in the data file. In addition, within segment 3, the cards for ice and silt loads (the **13-3** and **14-3 cards**) come before the "05" temperature cards (the **7-3 cards**) and the load modification cards (the **8-3 cards**).

Card Order

The following is a summary of the cards listed in the order in which they should be included in the input deck. Examples of various input decks are shown in Appendix C.

MASTERIO Card - Master control card.

Basic Information Cards

1-0 card	Study identification
2-0 card	Primary operational controls
3-0 card	Procedural controls and basic constants for the study
4-0 card	Elevations for the study
5-0 card	Comment cards (optional)

Geometry Segment

1-1 card	Input/output control card for the geometry program (optional, depending on controls set in the **2-0 card**)
3-1 card	Geometric data at the base of the dam
4-1 card	Auxiliary geometric data card (if needed)
5-1 card	Description of upstream and downstream face of crown cantilever and all intrados and extrados line of centers (LOC)
6-1 card	Geometric data at the top of the dam
7-1 card	Arch description cards containing the abutment angles, temperature loads, and variable foundation deformation moduli
8-1 card	Layout card (for three-centered dam only)
9-1 card	Compound angles (for three-centered dam only)
10-1 card	Pad description (for layouts with pads)
11-1 card	Pad line segment description (for layouts with pads)
12-1 card	Pad elevations and length descriptions (for layouts with pads)

Abutment Segment

1-2 card	Input/output control card for the abutment analysis program (optional, depending on controls set in the **2-0 card**)

Arch Segment

1-4 card	Input/output control card for the arch analysis program
6-4 card	"05" temperature loads
7-4 card	"05" temperature loads

Cantilever Segment

1-3 card	Input/output control card for the cantilever analysis program
3-3 card	Cantilever program heading card #1 (optional depending on controls in **1-3 card**)
4-3 card	Cantilever program heading card #2 (optional depending on controls in **1-3 card**)
13-3 card	Ice loading
14-3 card	Silt loading
7-3 cards	For "05" temperature loading only
8-3 cards	For initial force modification only

Complete Adjustment

1-5 card	Input/output control card for the complete adjustment program

Stress Analyzer

1-10 card	Stress analyzer controls

Card Details

The following pages include (1) details of each card in the input deck, (2) an example of each card, and (3) sketches of various features identified in the cards.

More detailed definitions and illustrations for many of the input parameters may be found in the USBR manual (USBR 1977a).

MASTERIO Card - Master Control Card (Figure 8-1)

Columns 1-8. Always set as: MASTERIO

Note: For a standard ADSAS analysis, set columns 11, 12, 13, 15, 16, 17, 18, and 19 to 1. Set column 14 to 0.

Column 11. Geometry program and abutment analysis program

Column 12. Arch analysis program

Column 13. Cantilever analysis program

Column 14. Set to 0

Column 15. Complete adjustment program (data organization)

Column 16. Complete adjustment program (write equations)

Column 17. Complete adjustment program (solve equations)

Column 18. Complete adjustment program (compute stresses)

Column 19. Stress analyzer program

```
MASTERIO  111011111
```

Figure 8-1. Example of MASTERIO card

1-0 Card - Study Identification Card (Figure 8-2)

Column 1.	Set to 1
Column 5.	Set to 0
Columns 11-40.	Name of dam or project
Columns 41-44.	Study number. Optional entry. This number may include any combination of alphabetic and numeric characters. Each layout is usually considered a study.
Columns 51-52.	Case number. Optional entry. Only numeric characters can be used. Case numbers usually correspond to the various load combinations

```
 1   0     ADSAS Test Problem              16        01
                 ↑                          ↑         ↑
            problem ID/name              study      case
                                         number    number
```

Figure 8-2. Example of 1-0 card

2-0 Card - Operational Control Card (Figures 8-3 and 8-4)

Column 1. Set to 2

Column 5. Set to 0

Column 11. Input/output control (IOC) for geometry program (see Figures 8-3 and 8-4)
Set to 0 for normal setup.
Set to 1 to override normal setup by reading the input/output **1-1 card**.

Column 12. IOC for arch program
Set to 0 for normal setup.
Set to 1 to override normal setup by reading the input/output **1-2 card**.

Column 13. Set to 1 - For the mainframe version of ADSAS this flag controlled binary tape output. For PC version it must be set to 1.

Column 14. Set to 1 - Number of copies of the geometrical statistics page. If set to 0, three copies will be printed.

Column 15. Inactive

Column 16. Set to 1.

Column 17. Set to 1 - If set to 0, ADSAS will expect user-provided abutment constants.

Column 18. Set to 0.

Column 19. Set to 1.

```
2   0       011011101
            ↑
          flag
       for normal
          run.
```

Figure 8-3. Example of typical 2-0 card

2-0 Card

```
2   0     111111101        ← 2-0 card
           ↑
         flag
    to override normal
setup and read 1-1 card

1   1                  1       1       ← 1-1 card
```

Figure 8-4. The 2-0 card with override set

3-0 Card - Heading Card (Figure 8-5)

Column 1.	Set to 3.
Column 5.	Set to 0.
Column 11.	Analysis indicator (usually set to 3) Set to 1 for crown analyses. Set to 3 for complete analyses.
Column 12.	Always set to 0.

(Columns 13-18 are load indicators - Set to 0 if the load is not included. Set to 1 if the load is included.)

Column 13.	**Uniform temperature load** (02). These loads are included on the 7-1 card.
Column 14.	**Linear temperature load** (03). These loads are included on the 7-1 card.
Column 15.	Combination of 02 and 03 loadings (05). If this loading is desired, then columns 13 and 14 must be set to "0" and the **6-4**, **7-4**, and **7-3 cards** must be included.
Column 16.	**Tailwater** load.
Column 17.	**Silt** load (if set to 1, then a **14-3 card** must be included).
Column 18.	**Ice** load (if set to 1, then a **13-3 card** must be included).
Column 20.	Set to 0 for single-centered dam; set to 1 for two-centered dam; set to 3 for three-centered dam.
Column 21.	Type of **deformation modulus.** Set to 1 for variable deformation moduli (varies with elevation and/or between abutments). Variable deformation moduli are provided on **7-1 cards**. Set to 0 if a constant deformation modulus is used and is provided on this card (see columns 52-58).
Column 22.	**Stage construction** analysis. Set to 1 if this is a stage construction analysis (stage construction studies require a **15-3 card**). Set to 0 if this is not a stage construction analysis.

Columns 26-32. **Modulus of elasticity of concrete** divided by 10^6 in psi (E_c) (default is 3.0).

Columns 33-38. **Poisson's ratio for the concrete** (μ_c) (default is 0.2).

Columns 39-44. **Coefficient of thermal expansion**, per degree Fahrenheit multiplied by 10^6 (e_c) (default is 5.6).

Columns 45-51. **Unit weight of concrete** in pounds per cubic foot (γ_c) (default is 150 pcf).

Columns 52-58. **Deformation modulus of the foundation rock** divided by 10^6 in psi (E_r) (default is 3.0). If set to a value larger than 7,000 an infinitely rigid abutment will be assumed (i.e., a fixed foundation restraint).

Columns 59-64. **Poisson's ratio for the rock** (μ_r) (default is 0.2).

Columns 65-69. Ratio of acceleration of **earthquake** to acceleration of gravity (g). If left blank, Zanger's type of earthquake loading will not be applied.
[Note: (+) is ground motion upstream and dam inertia downstream. (-) is ground motion downstream and dam inertia upstream.]

Columns 70-75. Grouting (closure) temperature in degrees Fahrenheit (T_c) (used for summary print only and is not used in any calculations, i.e., this temperature is not subtracted from the uniform and linear temperatures).

3	0	301000000300	3.0	0.2	5.6	150.0	2.5	0.2	0.1	0.0
			↑	↑	↑	↑	↑	↑	↑	↑
		control flags	E_c	μ_c	e_c	γ_c	E_r	μ_r	g	T_c

Figure 8-5. Example of 3-0 card

4-0 Card - Elevation Card (Figures 8-6 and 8-7)

Column 1.	Set to 4.
Column 5.	Set to 0.
Columns 11-19.	Base elevation of the crown cantilever.
Columns 20-28.	Crest elevation of the dam as defined on the plane of centers.
Columns 29-37.	Reservoir water surface elevation (must not be set to zero). A minimum reservoir elevation should be set to 1 ft above the crown cantilever base elevation. Maximum overtopping is limited to 50 ft above crest elevation. Overtopping can only be used with one- and two-centered layouts. **Overtopping cannot be used with three-centered layouts.**
Columns 38-46.	Tailwater surface elevation. If left blank, tailwater will be set to the base elevation.
Columns 47-55.	Elevation of the top of grout. This must be set to an arch elevation. The default is the crest of the dam.
Columns 56-64.	Elevation of the top of concrete (only required for stage construction analysis). This must correspond to an arch elevation.
Columns 65-73.	Elevation of the bottom of concrete (only required for stage construction analysis). This must correspond to an arch elevation.

```
4    0      6700.     7165.     7165.     6700.     7165.
              ↑         ↑         ↑         ↑         ↑
            base      top of    reser     tail      top of
           of dam      dam      voir      water     grout
```

Figure 8-6. Example of 4-0 card

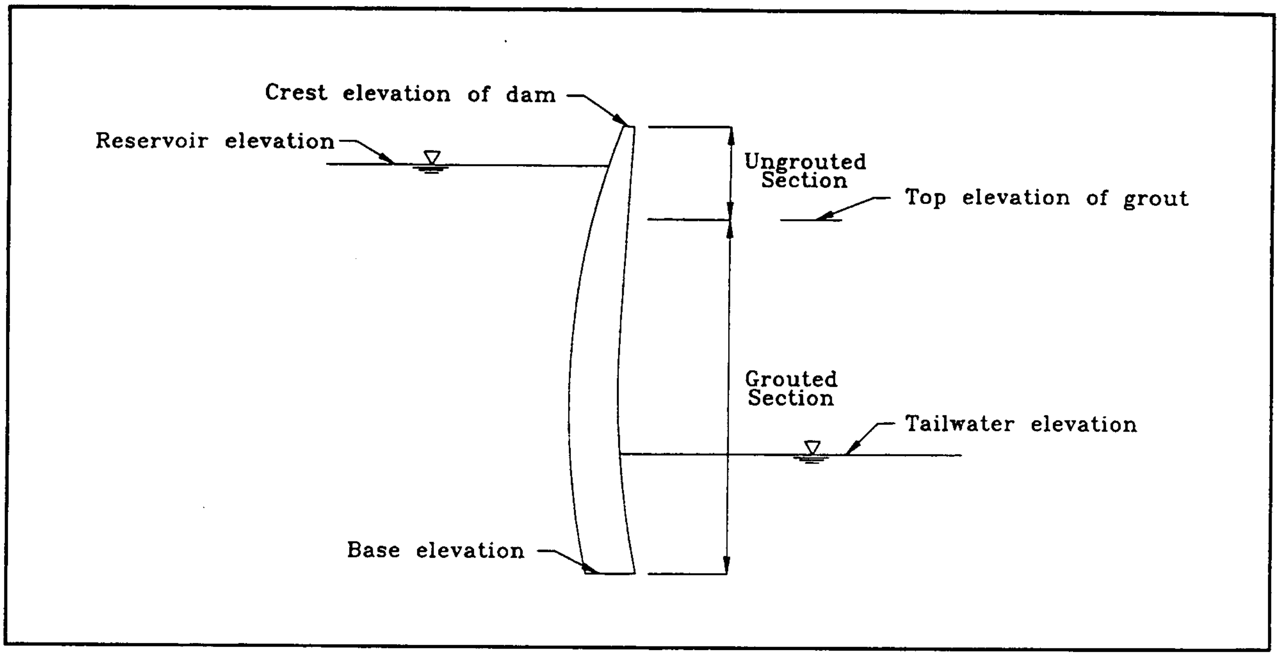

Figure 8-7. Sketch of items on 4-0 card

5-0 Card - Comment Cards (Figure 8-8)

These are optional cards that can be used to print comments at the top of each page of the output. These cards are intended to supplement the information contained on the **1-0 card**.

Two lines of comments can be printed with a maximum of 264 characters. Text for the comments is input through four **5-0 cards**. Any number up to four cards may be used. **These cards should be inserted directly after the 4-0 card.**

Each **5-0 card** can contain up of 66 characters. The first two **5-0 cards** will contain the 132 characters needed for the first comment line. An additional two **5-0 cards** are required for the second set of 132 characters. Thus, four cards are required to provide the maximum 264 characters. (See the example below.)

> *Note: Since column 1 in the printout is sometime used to control operation of some printers, it is always advisable to place a blank in position 1 (i.e., nothing should be placed in column 11 on either the first or third 5-0 cards).*

All **5-0 cards** have the same format.

Column 1.	Always set as 5.
Column 4.	Card number (1 through 4).
Column 5.	Can be set as either zero or blank.
Columns 11-76.	Comments.

The following rules may be used to help center a comment on a line:

a. If the comment is less than 119 characters, use the following rule:

$$c = 70 - n/2 \qquad (8\text{-}1)$$

where

c = the card column at the start of the comment

n = the number of characters in the comment (if n is odd, subtract one from it)

b. If the comments exceed 119 characters, start the comment in column 12.

```
5  1
5  2
5  3                                     STANDARD TEST PROBLEM FOR THE ARCH DAM
5  4            STRESS ANALYSIS SYSTEM OVERLAY TAPE
```

Figure 8-8. Example of 5-0 card. Note that this example will insert two lines in output file. The first line will be blank. The second line will read "STANDARD TEST PROBLEM...OVERLAY TAPE."

1-1 Card - Input-Output Control Card (Figure 8-9)

*(Note: The **1-1 card** is only needed when column 11 of the **2-0 card** is set to 1)*

Column 1. Set to 1.

Column 5. Set to 1.

(Columns 11-70 control when a specific input is provided or when a specific output format (table) is required. A value of "1" indicates that the option will be performed. A value of "0" or a blank indicates that the option will not be performed. Columns 11 through 33 are applicable to all geometries (one-, two-, or three-centered dams). Columns 34 through 40 are exclusively for layouts with pads. Columns 41 though 70 are specifically for three-centered dams.)

All Layouts

The following are the operational options for the one- or two-centered geometry program. The number of the option corresponds to an operational control digit.

Column 12. Print plane of centers data (Figure 9-2).

Column 13. Print table of areas of arches (area in the horizontal plane). This table is used to compute the dam volume (Figure 9-6).

Column 17. Print cantilever geometric properties (Figure 9-4).

Column 20. Print tables of the geometric properties of the abutments (Figure 9-5).

Column 23. Print table of controls, phi (ϕ) angles and temperature loads (Figure 9-2).

Column 24. Print tables of geometric properties of the arches (Figure 9-3).

Layouts with Pads

Column 34. Summary print of cantilever properties.

Column 36. Print geometric properties of cantilevers with pads (standard geometric properties table).

Column 40. Controls whether or not to include a pad in the description of the geometry, and prints input data for pad.

0 = no pad.

1 = includes pad.

Three-Centered Layouts

Column 41. Print tables of data by elevation (plane of centers, radii, coordinates, and points of compound curvature (PCC) angles) - only for three-centered geometry.

Column 42. Print table of data by cantilever number (base angles and elevations, also the type indicators) - only for three-centered geometry.

```
 1  1    1    1     1
```

Figure 8-9. Example of 1-1 card

1-1 Card

3-1 Card - Geometric Data at the Base of the Dam (Figures 8-10 through 8-12)

Column 1.	Set to 3.
Column 5.	Set to 1.
Columns 11-20.	Upstream projection at the base (USP) from axis.
Columns 21-30.	Downstream projection at the base (DSP) from axis.

Note: The data in columns 31-60 are for: (1) both sides of a single-centered layout; (2) the left side for a two-centered layout; or (3) the inner line of centers for a three-centered layout.

Columns 31-40.	Distance from axis center to the intrados line of centers at the base elevation (B2) (Figure 8-11).
Columns 41-50.	Distance from axis center to the extrados line of centers at the base elevation (B1) (Figure 8-11).
Columns 51-60.	Axis radius (Figure 8-11).
Columns 61-70.	Station at the crown of the arches. The default is 1000. A positive value causes stationing to increase from left to right (looking downstream). A negative value will cause stationing to increase from right to left (looking downstream).
Columns 71-73.	Number of voussoirs (Vi) per section on the lowest arch (from Table 8-1). Voussoirs are the number of sections between adjacent cantilevers (Figure 8-12). As the thickness decreases from base to crest the number of voussoirs within each section decreases by Delta V.
Columns 74-76.	Change in voussoirs per section for each arch above the lowest arch (Delta V) is noted in Table 8-1 for establishing values for Vi and Delta V.

3	1	20.0000	20.0000	327.3338	249.8251	496.1260	-.01	11	2
		↑	↑	↑	↑	↑	↑	↑	↑
		USP	DSP	B2	B1	Axis	Station	Vi	ΔV

Figure 8-10. Example of 3-1 card

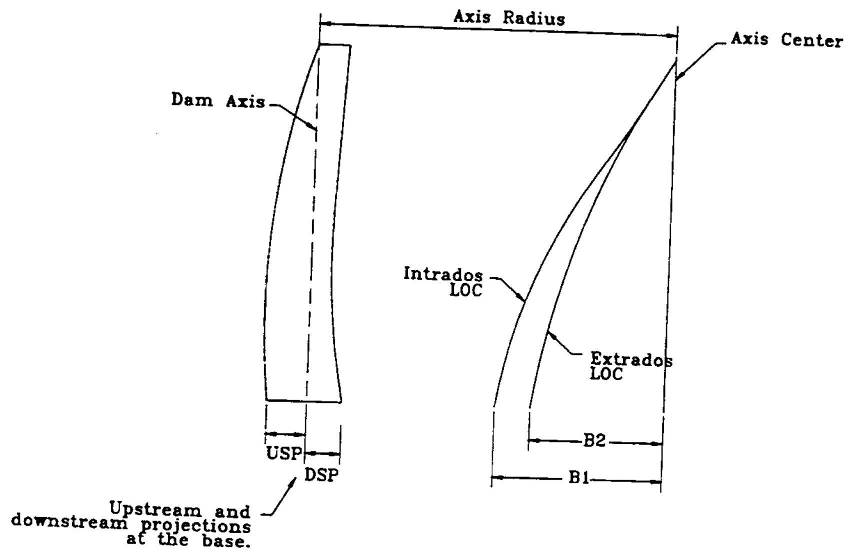

Figure 8-11. Features identified on the 3-1 card

Table 8-1
Selection of Vi and Delta V

No. of Arches	Vi	Delta V
4	12	4
5	11	3
6	11	2
7	12	2
8	12	2
9	9	1
10	10	1
11	11	1
12	12	1

Note: The guide does not apply to three-centered arches. When using a three-centered arch, 12 voussoirs/section are used on all arches sections.

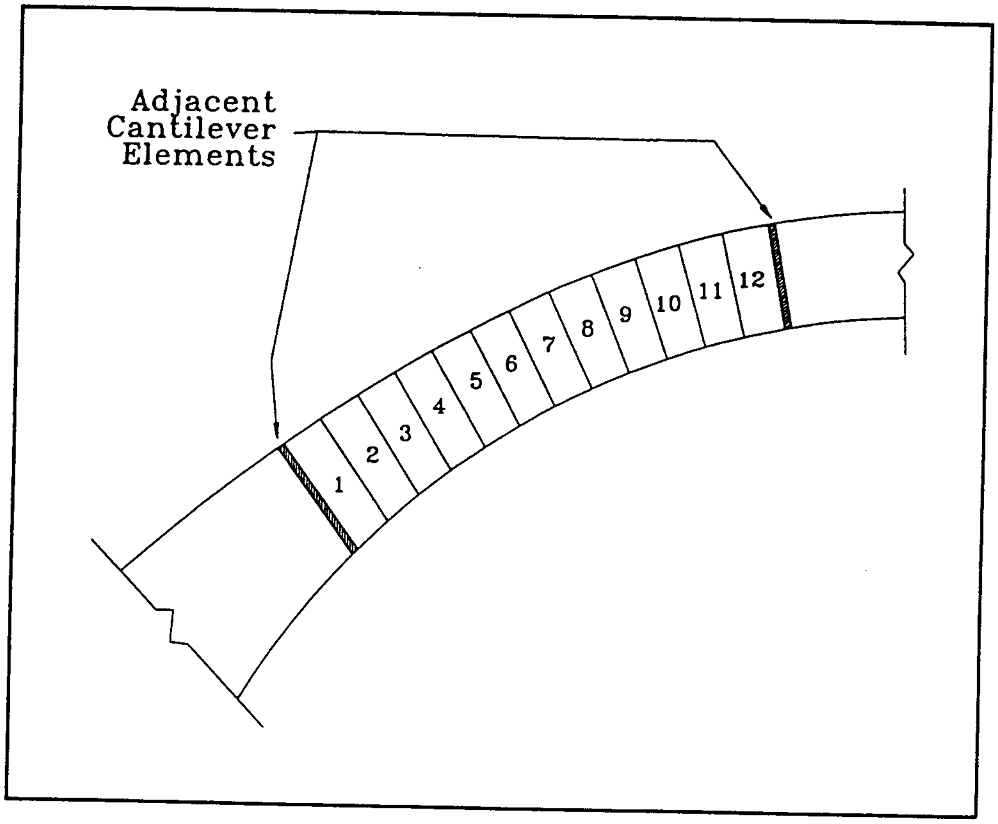

Figure 8-12. Typical arch section showing 12 voussoirs between adjacent cantilever elements

4-1 Card - Auxiliary Geometric Data at Base of Dam
(Figures 8-13 and 8-14)

Data required only for two- and three-centered layouts.

Column 1.	Set to 4.
Column 5.	Set to 1.
Columns 11-20.	Distance from axis center to the intrados line of centers at the base elevation (B2).
Columns 21-30.	Distance from axis center to the extrados line of centers at the base elevation (B1).
Columns 31-40.	Axis radius.

```
4   1     327.3338  249.8251  1316.3360
```

Figure 8-13. Example of 4-1 card

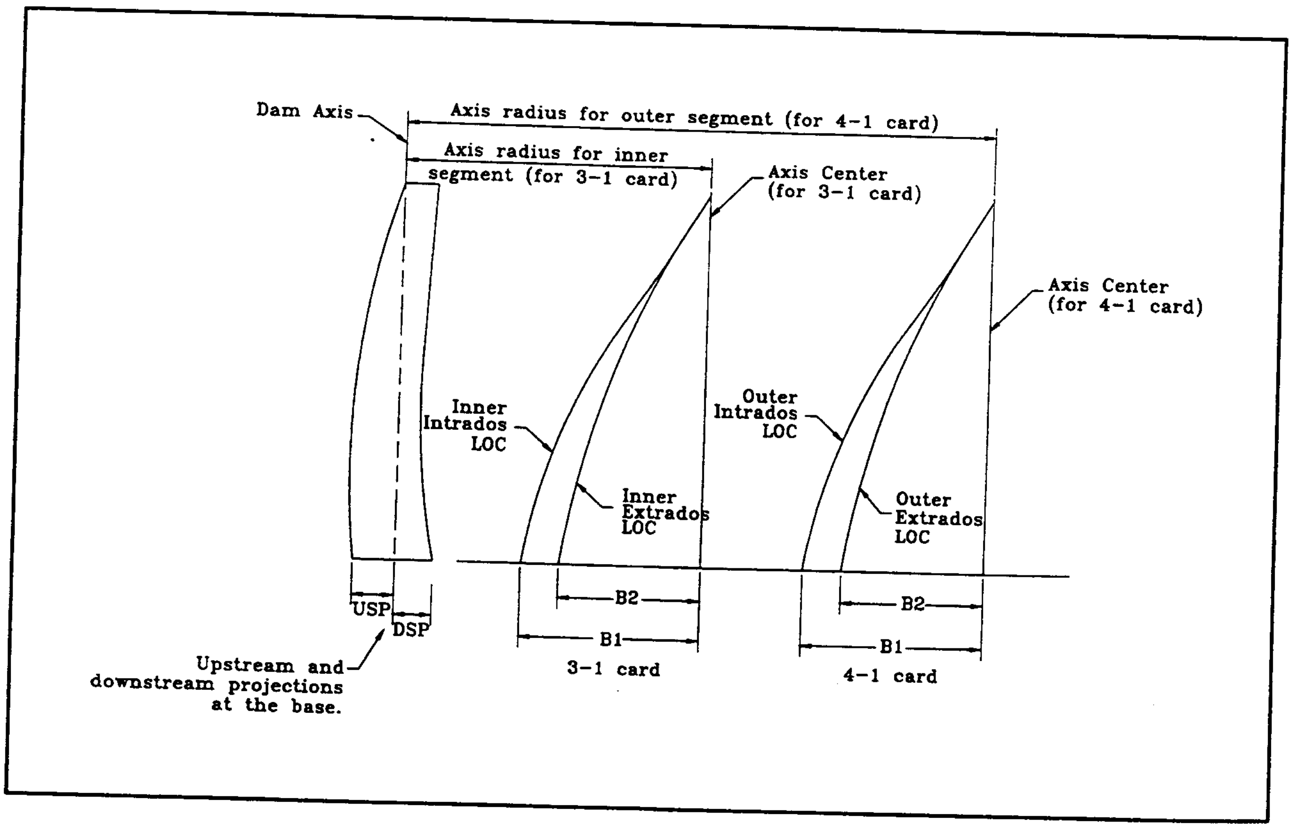

Figure 8-14. Features defined by 4-1 card

4-1 Card

5-1 Card - Plane of Centers Description (Figures 8-15 through 8-23)

For three-centered arch dams, one plane of centers describes the left and right "center" arcs from the crown cantilever to the points of compound curvature (PCC). The second plane describes the "outer" left and right arcs from the PCC to the abutment contacts at each elevation.

Column 1.	Set to 5.
Column 5.	Set to 1.
Column 7.	Line numbering: 1 = upstream face 2 = downstream face 3 = intrados LOC (see Note) 4 = extrados LOC (see Note) 5 = intrados LOC (see Note) 6 = extrados LOC (see Note)

Note: Lines 3 and 4 describe the line of centers for the single-centered layout. They also describe the line of centers for the left side of a two-centered layout or the inner line of centers for a three-centered layout. Lines 5 and 6 are only needed for a two-centered or a three-centered layout. For a two-centered layout, lines 5 and 6 describe the line of centers for the right side of the dam. For a three-centered geometry lines 5 and 6 describe the line of centers for the outer portion. See Figure 8-15.

Columns 8-9.	Segment number starts with 1 for the **lowest segment** in the line; each segment after that is numbered in ascending order.
Columns 11-22.	Maximum elevation of each segment.
Columns 23-34.	Slope of straight line segment. Slopes are positive according to standard geometric convention; +X is downstream, +Y is vertical A line segment is indicated to be straight when the value of the radius, entered in columns 59-70, is 0.
Columns 35-46.	Horizontal distance of center of circle to the axis of the dam. A positive distance is measured downstream from the axis of the crown section.
Columns 47-58.	Elevation of center of circle.

Columns 59-70. Radius is filled in only for a circular line segment. The sign given to the radius indicates the side of the circle relative to the coordinate;

+ is left or upstream,
- is right or downstream.

The next few pages show how the **5-1 cards** are used to define each face. In each case, the figure of the dam shows the details of the face being defined. Immediately after the figure of the dam is the corresponding input line for the **5-1 card.**

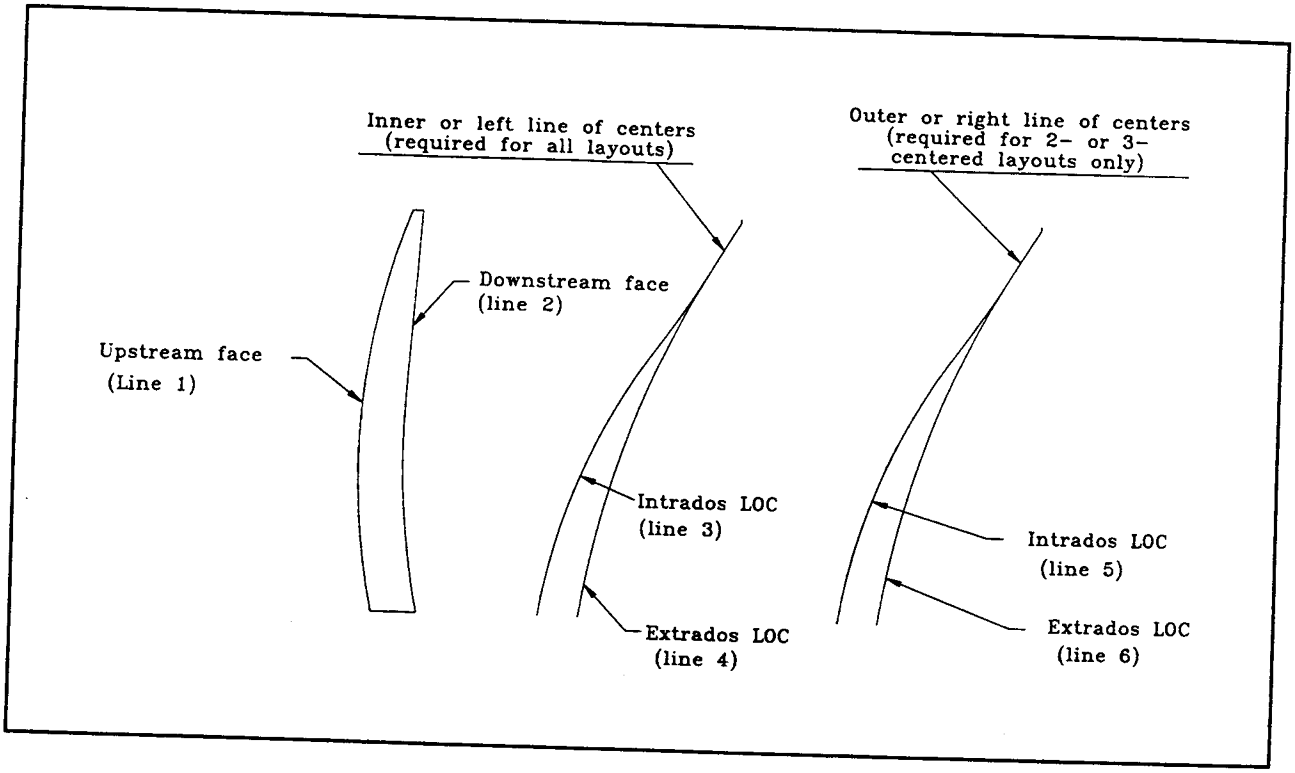

Figure 8-15. Features defined by 5-1 card

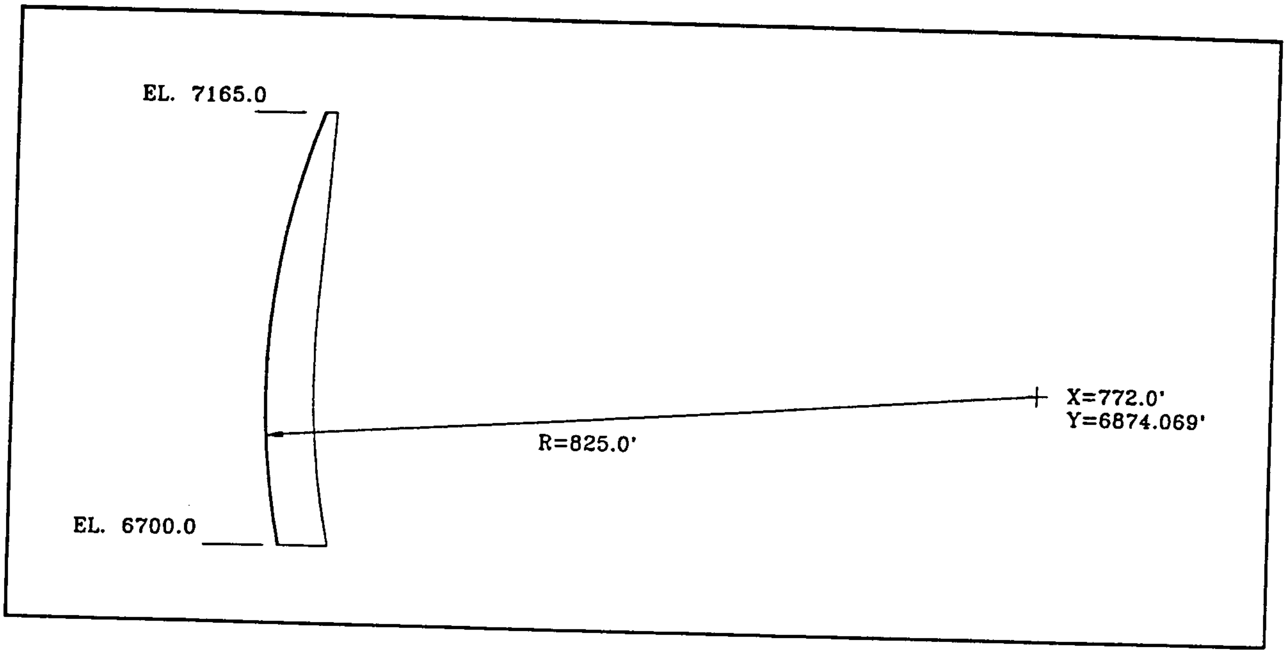

Figure 8-16. Example of definition for upstream face

```
5   1 1 1   7165.0          .0      772.0     6874.069    825.0
```

Figure 8-17. The 5-1 card defining the upstream face

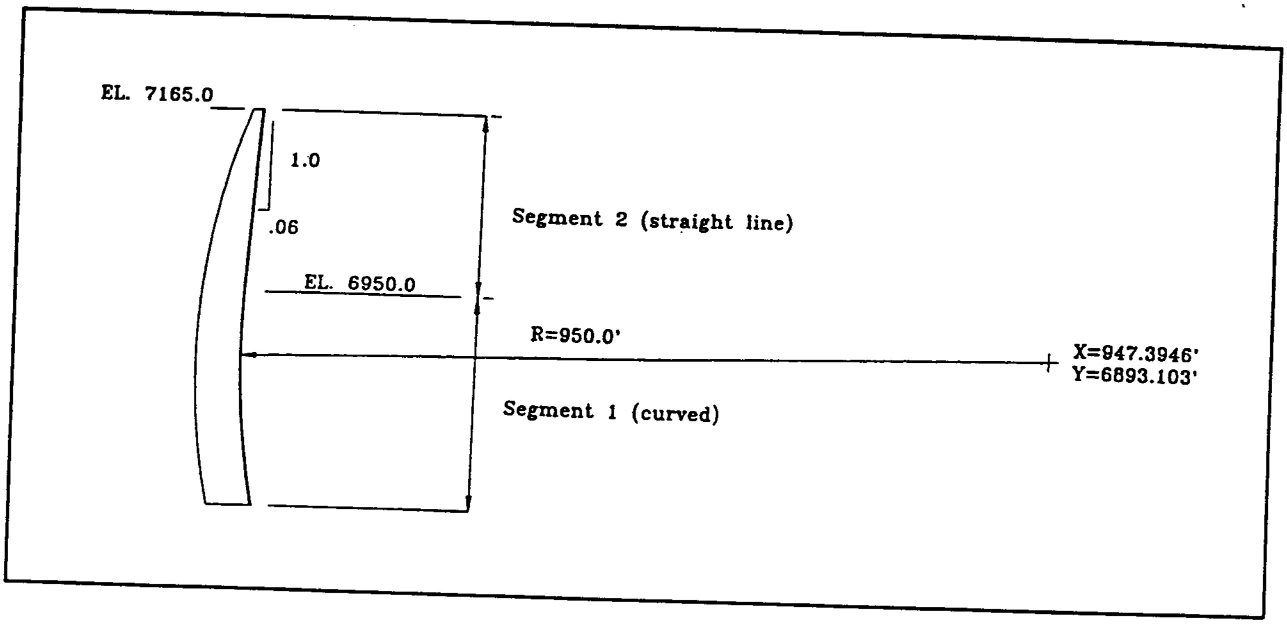

Figure 8-18. Features defined on the downstream face

```
5    1 2 1    6950.0             .0        947.3946    6893.103     950.0
5    1 2 2    7165.0             .06             .0          .0        .0
```

Figure 8-19. The 5-1 cards that define the downstream face

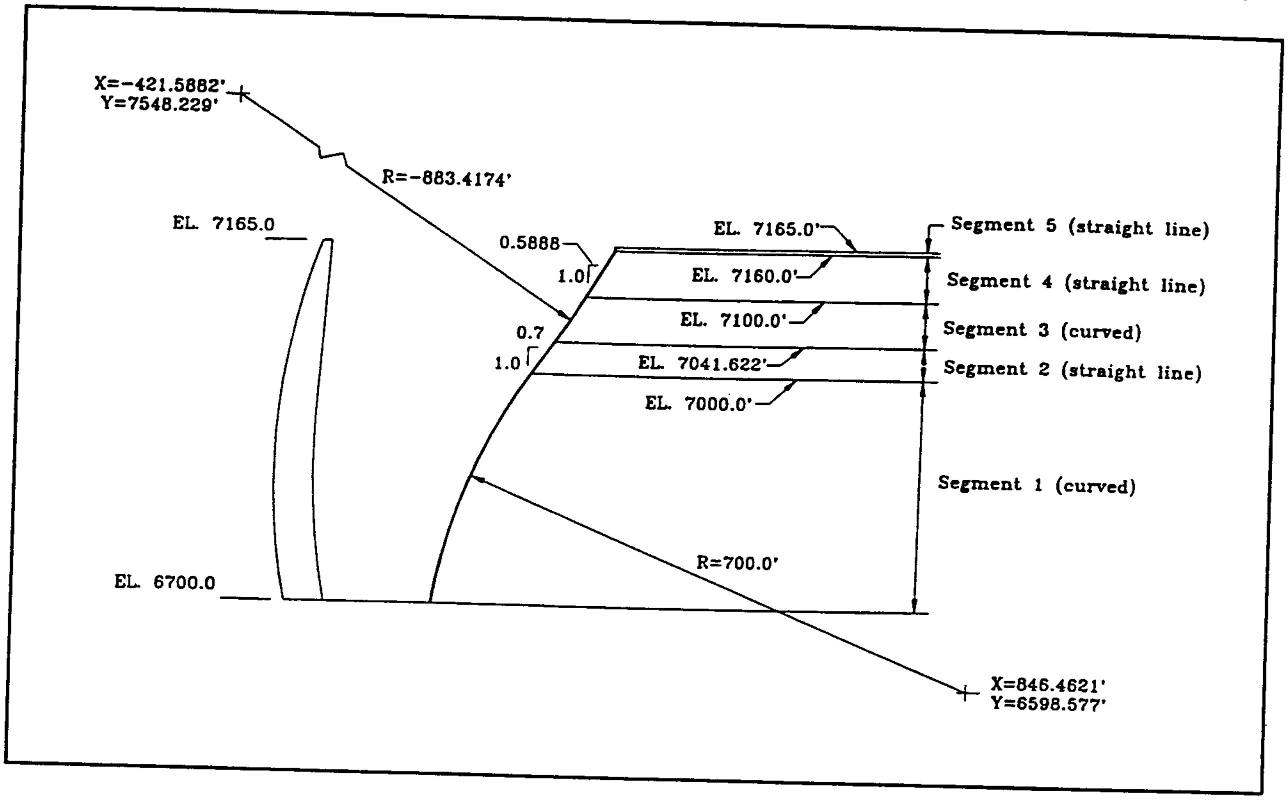

Figure 8-20. Example of intrados line of centers

5	1	3	1	7000.0	.0	846.4621	6598.577	700.0
5	1	3	2	7041.622	.7	.0	.0	.0
5	1	3	3	7100.0	.0	-421.5882	7548.229	-883.4174
5	1	3	4	7160.0	.5888	.0	.0	.0
5	1	3	5	7165.0	.0	.0	.0	.0

Figure 8-21. The 5-1 cards used to define intrados line of centers

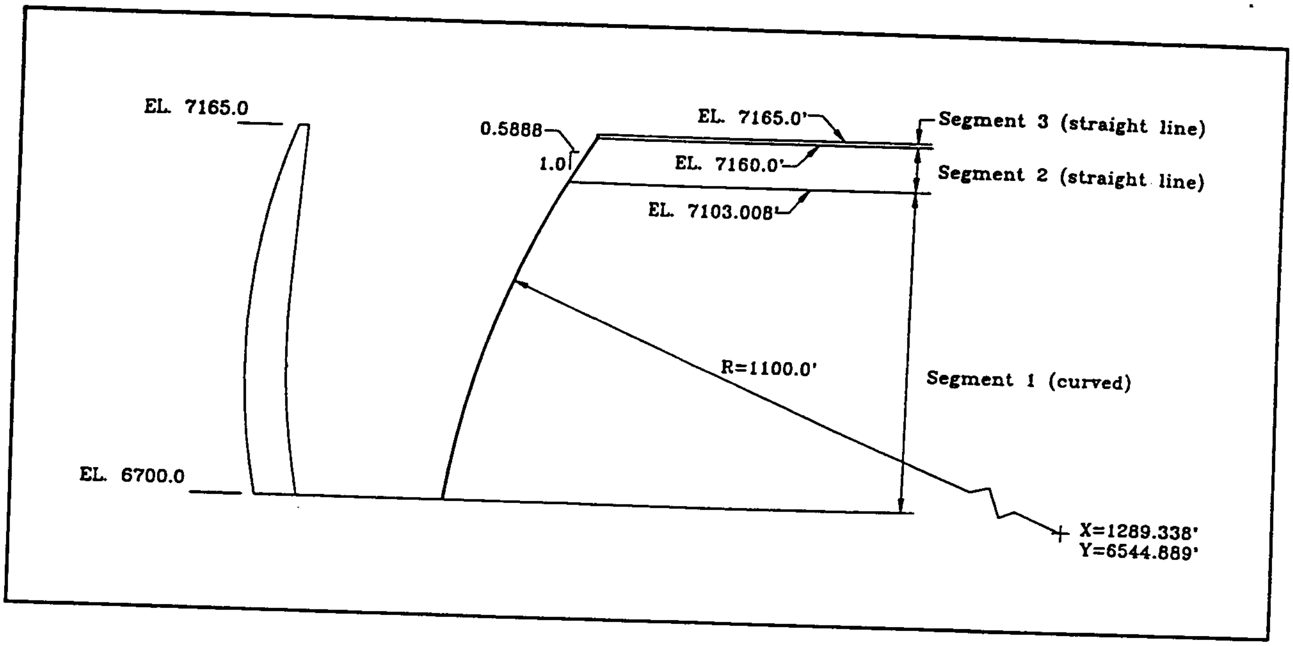

Figure 8-22. Example of extrados line of centers

5	1	4	1	7103.008	.0	1289.338	6544.889	1100.0
5	1	4	2	7160.0	.5888	.0	.0	.0
5	1	4	3	7165.0	.0	.0	.0	.0

Figure 8-23. The 5-1 cards used to define extrados line of centers

6-1 Card - Geometric Data at Top of Dam (Figures 8-24 and 8-25)

Column 1.	Set to 6.
Column 5.	Set to 1.
Columns 11-21.	Upstream projection (USP) at the crest from axis (usually zero).
Columns 22-32.	Downstream projection (DSP) at the crest from axis.

Data for: (1) line of centers for a single-centered dam; (2) left-side lines of centers for a two-centered dam; or (3) inner line of centers for a three-centered dam.

Columns 33-43.	Distance from axis center to the intrados line of centers at the crest (B2). Usually set to zero.
Columns 44-54.	Distance from axis center to the extrados line of centers at the crest (B1). Usually set to zero.

Data for right-side lines of centers, or outer lines if three-centered, at the crest. Required only when two or three planes of centers are used.

Columns 55-65.	Distance from axis center to the intrados line of centers at the crest (B2). Usually set to zero.
Columns 66-76.	Distance from axis center to the extrados line of centers at the crest (B1). Usually set to zero.

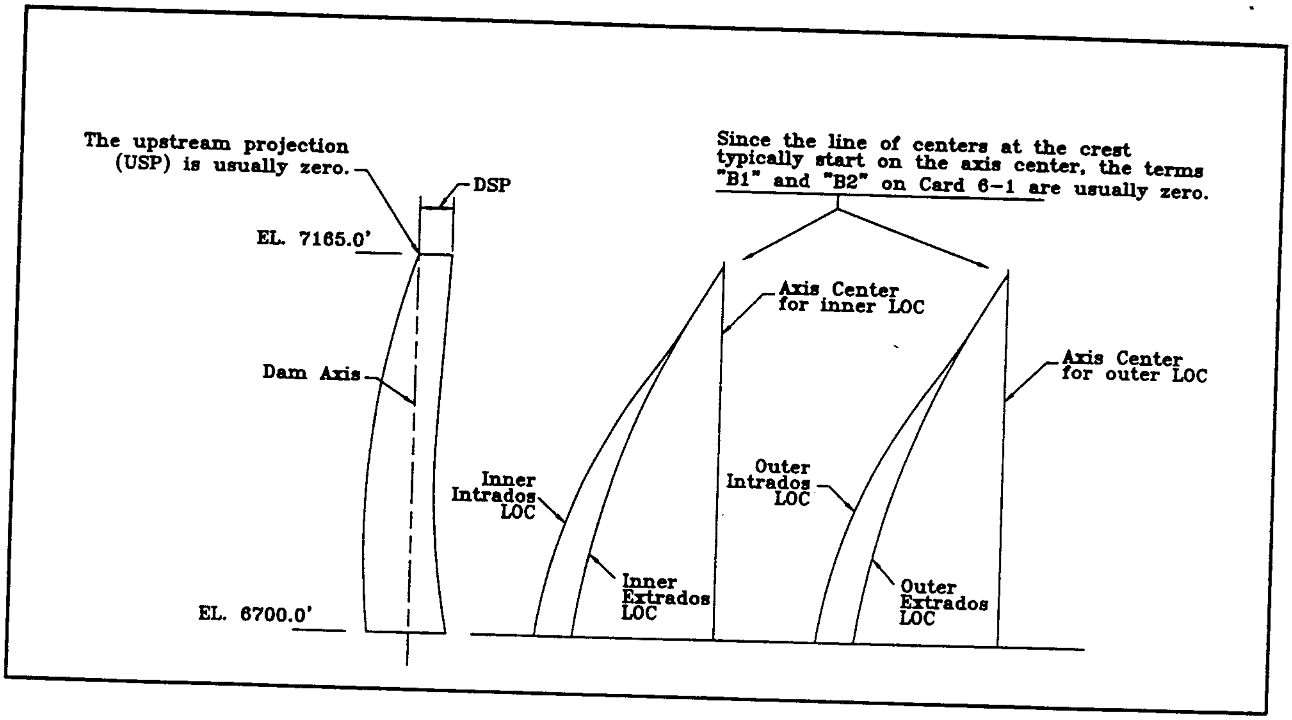

Figure 8-24. Top of dam descriptions

6	1	0.0	12.0	0.0	0.0	0.0	0.0
		↑ USP	↑ DSP	↑ B2	↑ B1	↑ B2	↑ B1
						2-centered and 3-centered dams only	

Figure 8-25. Typical 6-1 card used to describe the top of dam

7-1 Card - Angles and Controls for Arch Description
(Figures 8-26 through 8-30)

Column 1. Set to 7.

Column 5. Set to 1.

Column 6. Procedural control (see Figure 8-26).

- 0 - An arch element will be placed at this elevation with cantilevers based at both abutments.
- 1 - Base elevation of the crown cantilever (no arch at this elevation).
- 2 - Base elevation of a free cantilever on the left side (no arch at this elevation).
- 4 - Base elevation of a free cantilever on the right side (no arch at this elevation).
- 5 - Base elevation of free cantilevers on both sides (no arch at this elevation).
- 6 - Angles provided at this elevation only to aid in the computation of the volume of concrete (do not use for ungrouted elevations).
- 7 - Base elevation of a thrust block or other break point in the abutment used to correctly define angle Ψ (see additional descriptions for column 7).

Procedure controls 6 and 7 are used solely to better define the angle psi (Ψ) at the abutment for profiles with irregularities or dams with thrust blocks that cannot be sufficiently well defined with normal arches. Angle Ψ is used in computation of arch and cantilever foundation constants and is the weighted average of the two adjacent arch lengths with the arch in question.

Column 7. Supplementary procedure control.

- 0 - Not used.
- 1 - Break point is on the left abutment at this elevation.
- 2 - Break point is on the right abutment at this elevation.

3 - Break point is on both abutments at this elevation.

Column 8. Vertical adjustment control.

0 - Sloping abutment on both sides.

1 - Vertical abutment on the left side.

2 - Vertical abutment on the right side.

3 - Vertical abutment on both sides.

Note: If a thrust block starts at an arch elevation, that arch abutment is not vertical.

Column 10. Adjustment control.

0 - Cantilever based at this elevation will be adjusted.

1 - Cantilever based at this elevation will not be adjusted.

Columns 11-21. Elevation of arch.

Columns 22-28. Left-side phi angle (ϕ_L) looking upstream. All angles are positive. Phi (ϕ) angles are measured as shown in Figures 8-27 and 8-28. The phi (ϕ) angle for each side is measured from the reference plane to the abutment end of the arch. For full-radial abutments, the abutment point for phi (ϕ) measurement is the midpoint of the abutment thickness. For half-radial abutments, i.e., abutments with the downstream half radial to the axis center and the upstream half converging toward the extrados center, the approximated abutment radial line is located such that the arch area excluded equals the arch area included as shown in Figure 8-29.

Columns 29-35. Right-side phi angle (ϕ_R) looking upstream. The angles are measured the same as for ϕ_L discussed in columns 22-28.

Columns 50-55. Uniform temperature load (02). The uniform temperature loads are differences between the expected arch temperature and the closure temperature. A positive load is one where the temperature in the arch is above the closure temperature. The 02-type of temperature load is constant from abutment to abutment for each arch elevation. (See Figure 5-2.)

Columns 56-61. Linear temperature load (03). The linear temperature load indicates the expected differences in temperature between downstream and upstream faces at an elevation. A positive load is one where the temperature on the upstream face is lower than that on the downstream face. The 03-type of temperature load is constant from abutment to abutment for each arch elevation and is applied to arches and cantilevers. If expected, the 03- temperature cannot be set to zero. (See Figure 5-2.)

Columns 62-66. Modulus of elasticity of rock in pounds per square inch divided by 10^6 on the left side. Input only when a variable modulus is desired.

Columns 67-71. Modulus of elasticity of rock in pounds per square inch divided by 10^6 on the right side. Input only when a variable modulus is desired.

The value of the variable modulus is increased one elevation by the program for right-side three-centered layouts only.

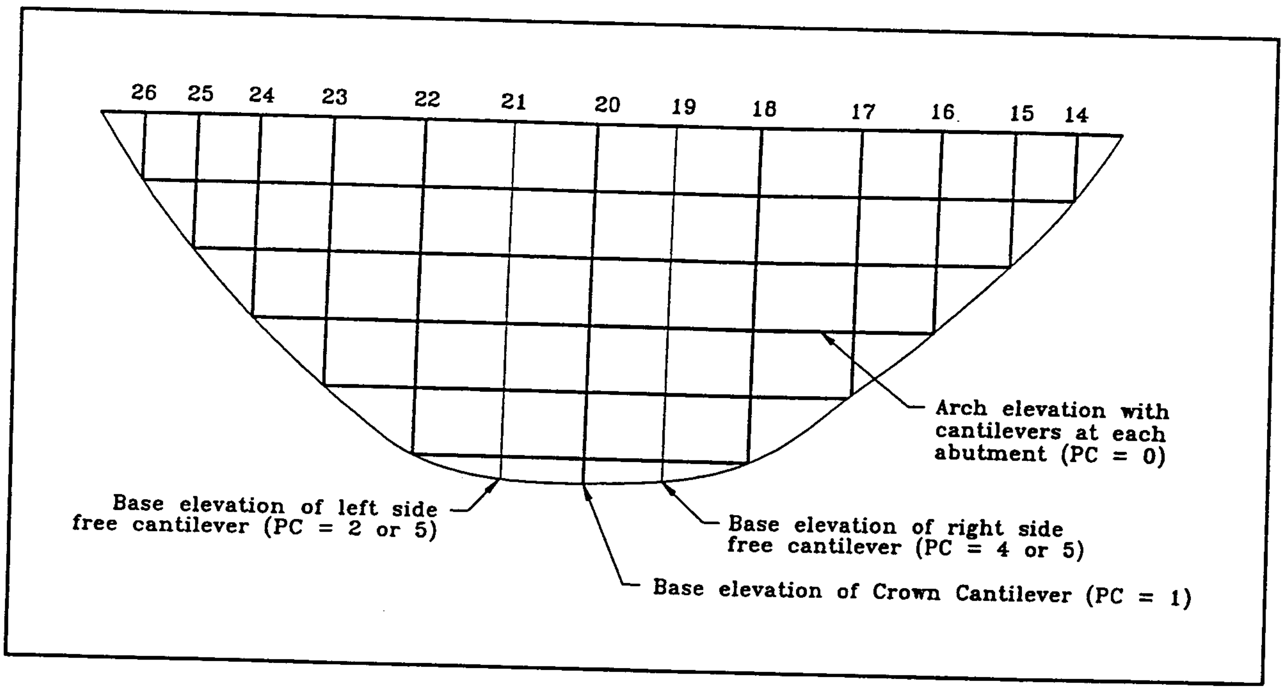

Figure 8-26. Description of the procedural control (PC) values in column 6 of the 7-1 card. Sketch shows the normal symmetrical arch dam (looking upstream)

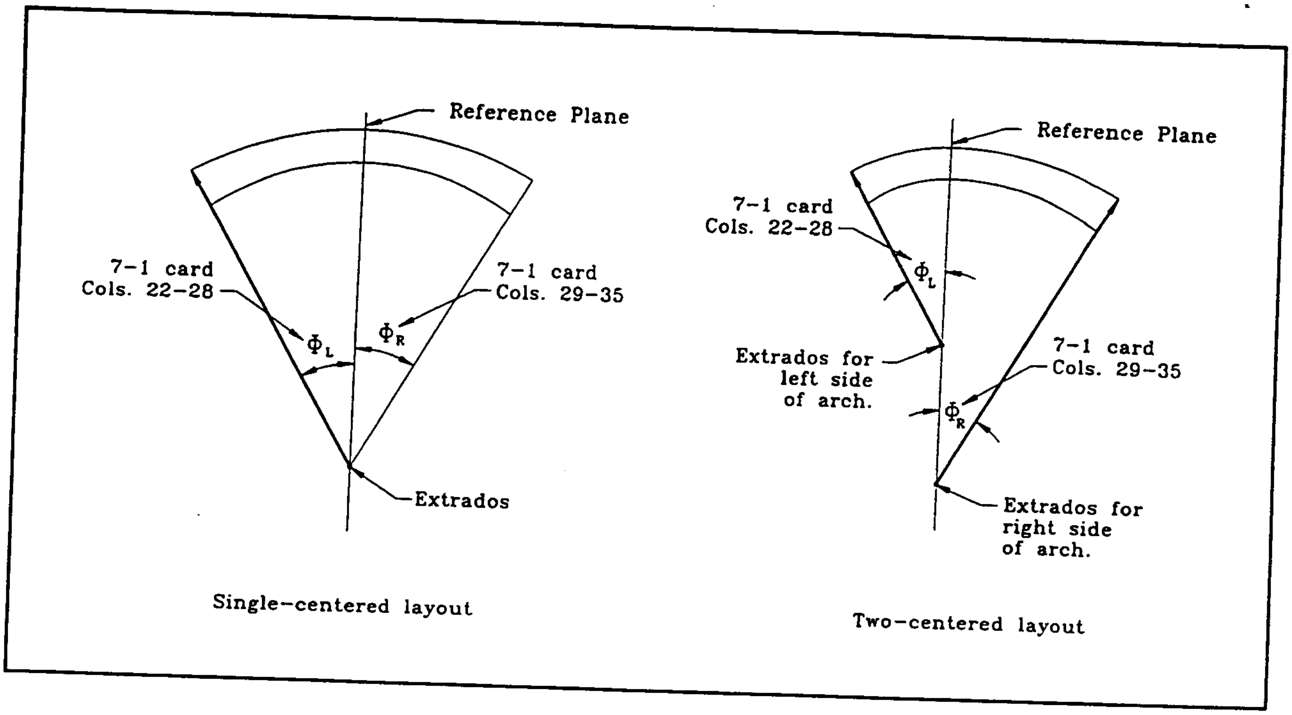

Figure 8-27. Definition for phi (ϕ) angle measurements for single- and two-centered layouts for 7-1 cards

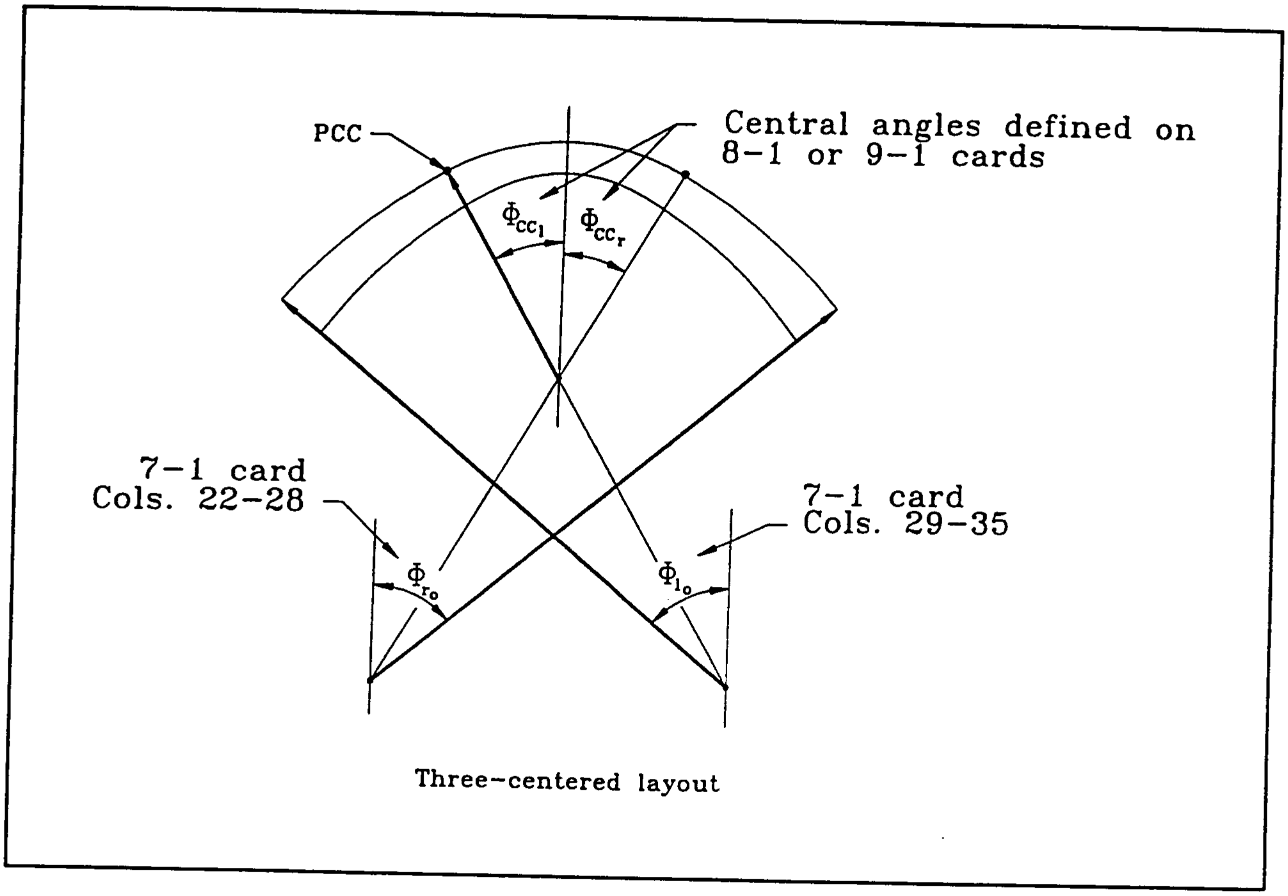

Figure 8-28. Definition for phi (ϕ) angle measurements for three-centered layouts for 7-1 cards

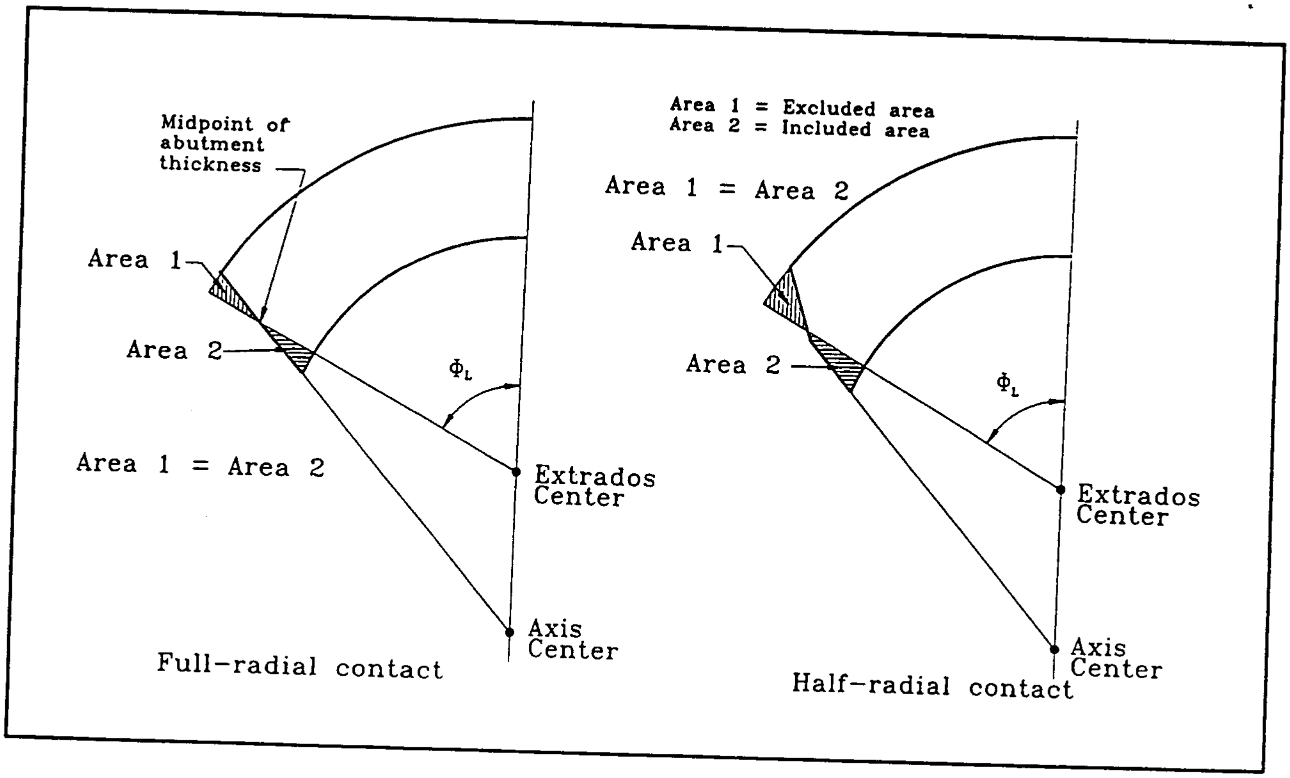

Figure 8-29. Measurement of phi (ϕ) angles for full-radial and half-radial abutment contacts

7	1100	0	6700.0	.0	.0	.0	2.1	1.7	1.7
7	1000	0	6790.0	44.350	44.350	-1.5	3.2	1.9	2.0
7	1000	0	6865.0	48.125	48.125	-1.5	4.1	2.0	2.2
7	1000	0	6940.0	49.600	49.600	-1.5	4.2	2.0	2.2
7	1000	0	7015.0	50.250	50.250	-2.0	4.3	2.2	2.5
7	1000	0	7090.0	51.625	51.625	-4.5	4.6	2.6	3.0
7	1000	0	7165.0	54.875	54.875	-15.0	5.0	2.8	3.0
			↑	↑	↑	↑	↑	↑	↑
			el	**Φ_L**	**Φ_R**	**02**	**03**	**E_r**	**E_r**
						temp. loads		**left**	**right**

Figure 8-30. Example of 7-1 cards

7-1 Card

8-1 Card - Heading for Three-Centered Geometry Program
(Figures 8-31 and 8-32)

Column 1. Set to 8.

Column 5. Set to 1.

Column 11. Compounding indicator has four possible settings (reference Figure 8-32):

1 - Use if angle Φ_{CCu} is constant by elevation, and downstream point of curvature (PCC_d) is determined by where a radial line from upstream point of curvature (PCC_u) cuts through the downstream face.

2 - Same as "1" except Φ_{CCu} varies by elevation. This option requires a **9-1 card** for each arch elevation.

3 - Use if Φ_{CCu} is constant by elevation and if Φ_{CCd} is equal to Φ_{CCu}.

4 - Same as "3" except Φ_{CCu} varies by elevation. This option requires a **9-1 card** for each arch elevation.

Column 13. Inputs information that the angles of compound curvature on the right side are the same or not the same as those on the left side.

0 - Angles are the same.

1 - Angles are different.

Column 15. Inputs whether or not the top arch has a uniform thickness.

0 - Uniform thickness.

1 - Nonuniform thickness. (If not uniform, additional information must be placed in columns 36-55).

Columns 20-25. The angle to the point of compound curvature on the **left side** of the upstream face is constant.

Columns 26-31. The angle to the point of compound curvature on the **right side** of the upstream face is constant and not equal to the angle on the left side (check column 13).

Columns 36-45.	Thickness (in ft) of the left abutment of the top arch. Input only if top arch is not of uniform thickness (check column 15).
Columns 46-55.	Thickness (in ft) of the right abutment of the top arch. Input only if top arch is not of uniform thickness (check column 15).

```
Example 1: equal angles and uniform thickness
8    1        3 0 0     30.0  30.0

Example 2: different angles and variable thickness
8    1        3 1 1     30.0  25.0       16.0        15.0
```

Figure 8-31. Examples of 8-1 card

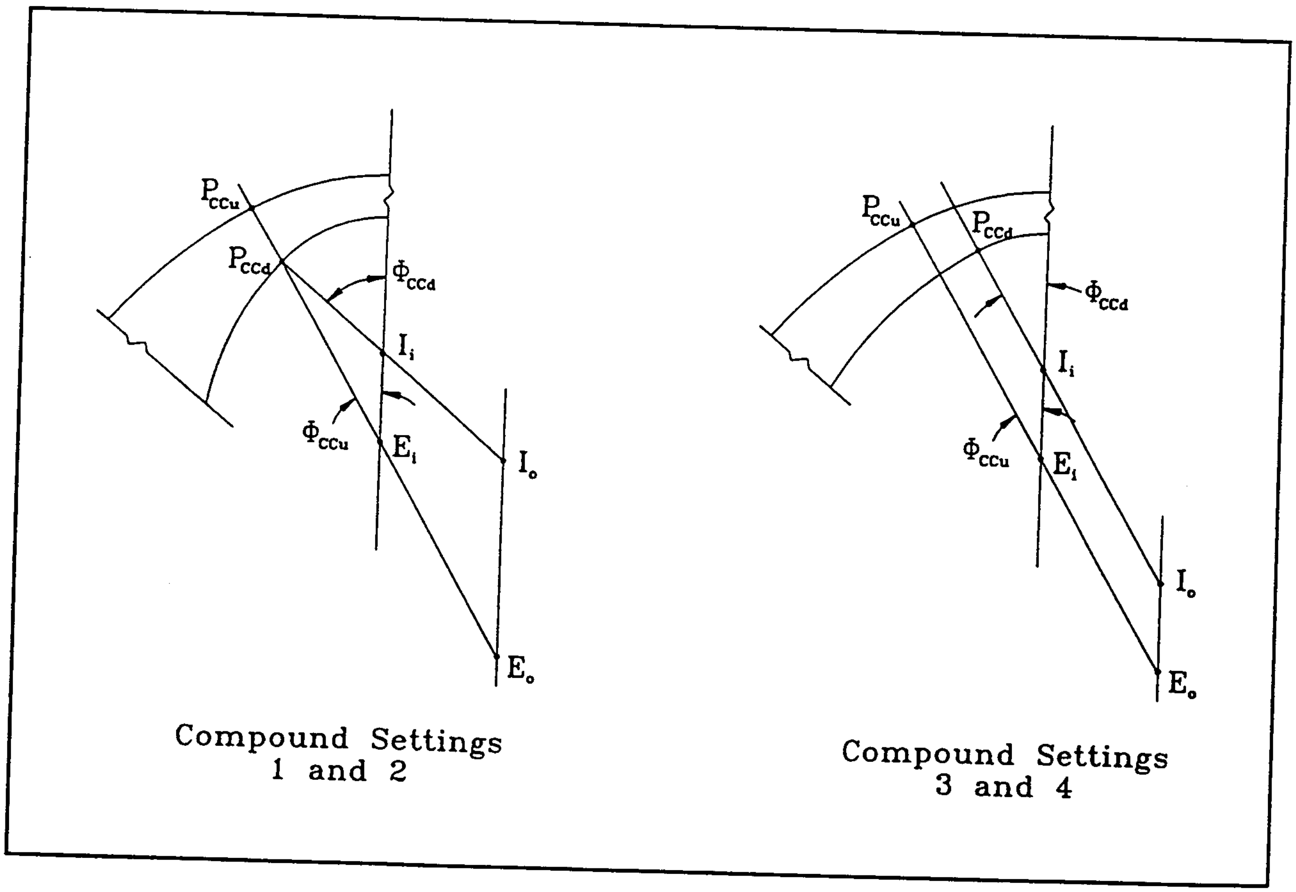

Figure 8-32. Compounding indicators for column 11 of 8-1 card

9-1 Card - Compounding Angles Three-Centered Arch Dam (Figure 8-33)

Note: This card is only required when Φ_{CCu} *and* Φ_{CCd} *vary with elevation as defined on the* ***8-1 Card****.*

Column 1.	Set to 9.
Column 5.	Set to 1.
Columns 11-20.	Elevation in same order as the **7-1 cards.**

The next set of values sets the angles of compounding (angle phi) for the left and right sides of the upstream and downstream faces. Measured about the extrados center for the upstream face, and about the intrados center for the downstream face (see Figure 8-32).

Columns 21-30.	Upstream face - left side.
Columns 31-40.	Upstream face - right side.
Columns 41-50.	Downstream face - left side.
Columns 51-60.	Downstream face - right side.

9	1	6700.0	.0	.0	.0	.0
9	1	6790.0	15.0	12.0	17.0	14.0
9	1	6865.0	16.0	13.0	18.0	15.0
9	1	6940.0	19.0	15.0	21.0	17.0
9	1	7015.0	21.0	17.0	23.0	19.0
9	1	7090.0	23.0	19.0	25.0	21.0
9	1	7165.0	25.0	21.0	27.0	23.0
		↑ el	↑ Φ_{ccu} Left side	↑ Φ_{ccu} Right side	↑ Φ_{ccd} Left side	↑ Φ_{ccd} Right side

Figure 8-33. Example of 9-1 cards

10-1 Card - Heading for Pad Description (Figures 8-34 and 8-35)

Concrete pads are additional concrete added to either face along the foundation contact. A pad acts as a spread footing to reduce the stresses along the contacts. Pads are described with straight line segments from the top of pad to the base and are defined on the cantilevers as shown in Figure 8-35. The maximum number of line segments is 17 per cantilever including arch elevations, top of pad elevations, and base elevation of each segment for each face. Horizontal offsets on either face provide a visible separation between the arch dam and the stiffer abutment pad. They also serve as an immediate increase in thickness for simulating the required approximation of the abutment rock stiffness.

Columns 1-2. Set to 10.

Column 5. Set to 1.

Column 10. Pad elevation index.

- 0 - Top of pad elevations are the same for the upstream and downstream faces.
- 1 - Top of pad elevations are different for the upstream and downstream faces.

Columns 14-15. Number of line segments used to describe pad on the upstream face (do not count the horizontal offset or the vertical segment at the base).

Columns 19-20. Number of line segments used to describe pad on the downstream face (do not count the horizontal offset or the vertical segment at the base).

Columns 26-32. Horizontal offset at top of the pad on the upstream face.

Columns 36-42. Horizontal offset at top of the pad on the downstream face.

Note: If a pad exists on a face and no line segments are given to describe the pad shape, a vertical segment at the base of the particular face must be given which exceeds any possible height of pad on that face.

Columns 46-52. Vertical segment at base of upstream face.

Columns 56-62. Vertical segment at base of downstream face.

```
10  1   1   2   2     5.0     10.0     100.0   50.0
```

Figure 8-34. Example of 10-1 cards

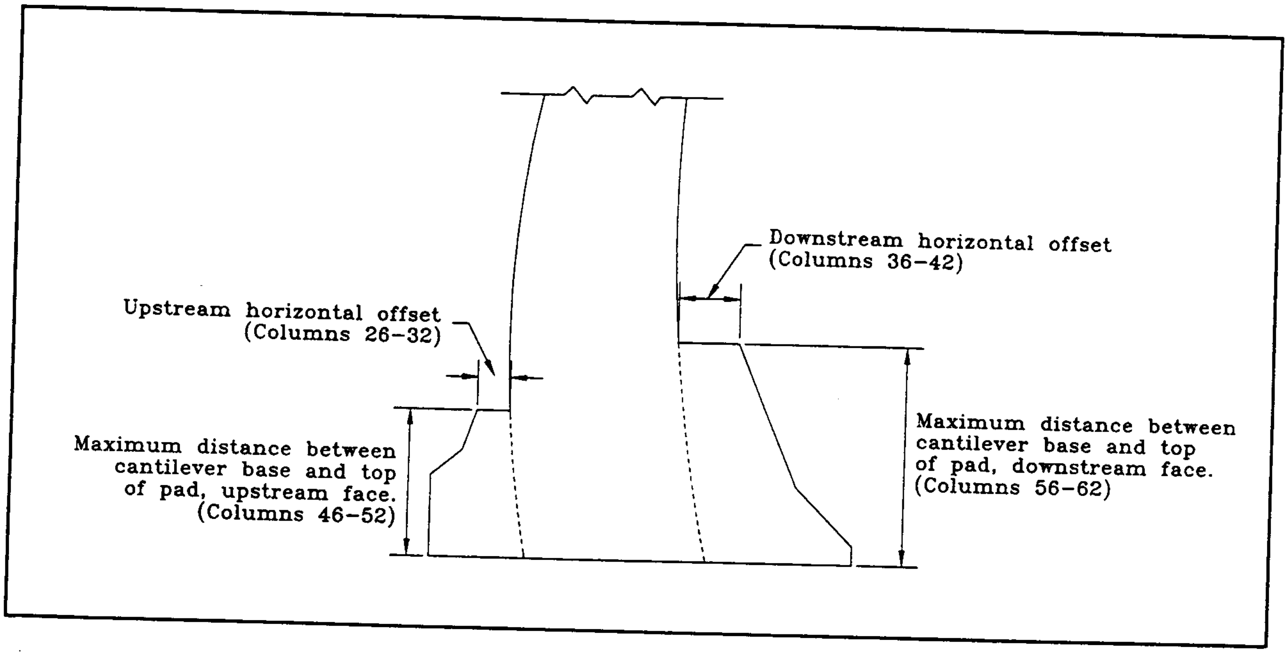

Figure 8-35. Pad features described on the 10-1 card

11-1 Card - Pad Line Segment Description
(Figures 8-36 and 8-37)

Columns 1-2.	Set to 11.
Column 5.	Set to 1.
Columns 9-10.	Segment number. Starting at 1 for each face (will be checked for increasing slope numbering from offset downward).
Column 15.	Face indicator. 1 = upstream face. 2 = downstream face.
Columns 26-32.	Distance from top of pad to the end of the line segment being considered.
Columns 36-42.	Slope of line segment (Slope = $\Delta X/\Delta Y$; positive slopes shown in Figure 8-37).

```
Upstream segments
11  1    1    1          10.0      0.45
11  1    2    1          50.0      0.60

Downstream segments
11  1    1    2          50.0      0.60
11  1    2    2         200.0      0.80
```

Figure 8-36. Examples of 11-1 cards

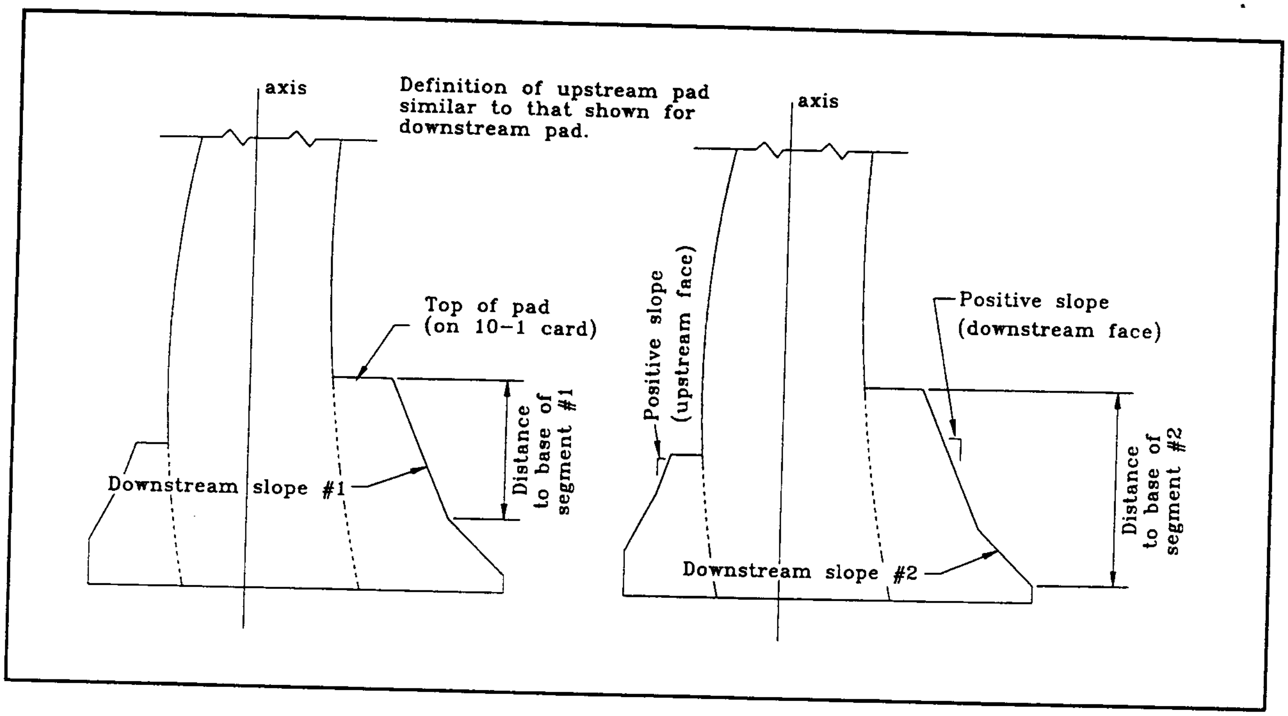

Figure 8-37. Pad features described on the 11-1 cards

12-1 Card - Pad Elevation and Length (Figures 8-38 and 8-39)

Columns 1-2.	Set to 12.
Columns 5-12.	Elevation of arch.
Columns 13-20.	Length of pad on left side of upstream face (LLUS).
Columns 21-27.	Length of pad on left side of downstream face (LLDS).
Columns 28-34.	Length of pad on right side of upstream face (LRUS).
Columns 35-41.	Length of pad on right side of downstream face (LRDS).
Columns 42-50.	Top elevation of pad on left side of upstream face (TLUS).
Columns 51-57.	Top elevation of pad on left side of downstream face if column 10 on the **10-1 card** is 1 (TLDS). Otherwise, leave blank.
Columns 58-64.	Top elevation of pad on right side of upstream face (TRUS).
Columns 65-71.	Top elevation of pad on right side of downstream face if column 10 on the **10-1 card** is 1 (TRDS). Otherwise, leave blank.

Note: Top of pad must not coincide with an arch-cantilever intersection; thus, move at least 1 ft away. Pad lengths are measured from abutment to pad on axis profile.

12	450.0	0.	0.	0.	0.	505.	565.	510.	565.
12	472.5	0.	0.	0.	0.	535.	613.	536.	612.
12	550.0	190.	560.	228.	563.	605.	720.	598.	734.
12	650.0	103.	398.	78.	418.	685.	832.	680.	830.
12	750.0	75.	420.	44.	444.	774.	917.	771.	904.
12	850.0	35.	480.	34.	424.	858.	980.	862.	950.
12	950.0	16.	593.	0.	328.	955.	1055.	0.	998.
12	1050.0	0.	268.	0.	0.	0.	1081.	0.	0.
12	1135.0	0.	0.	0.	0.	0.	0.	0.	0.

Figure 8-38. Example of 12-1 cards

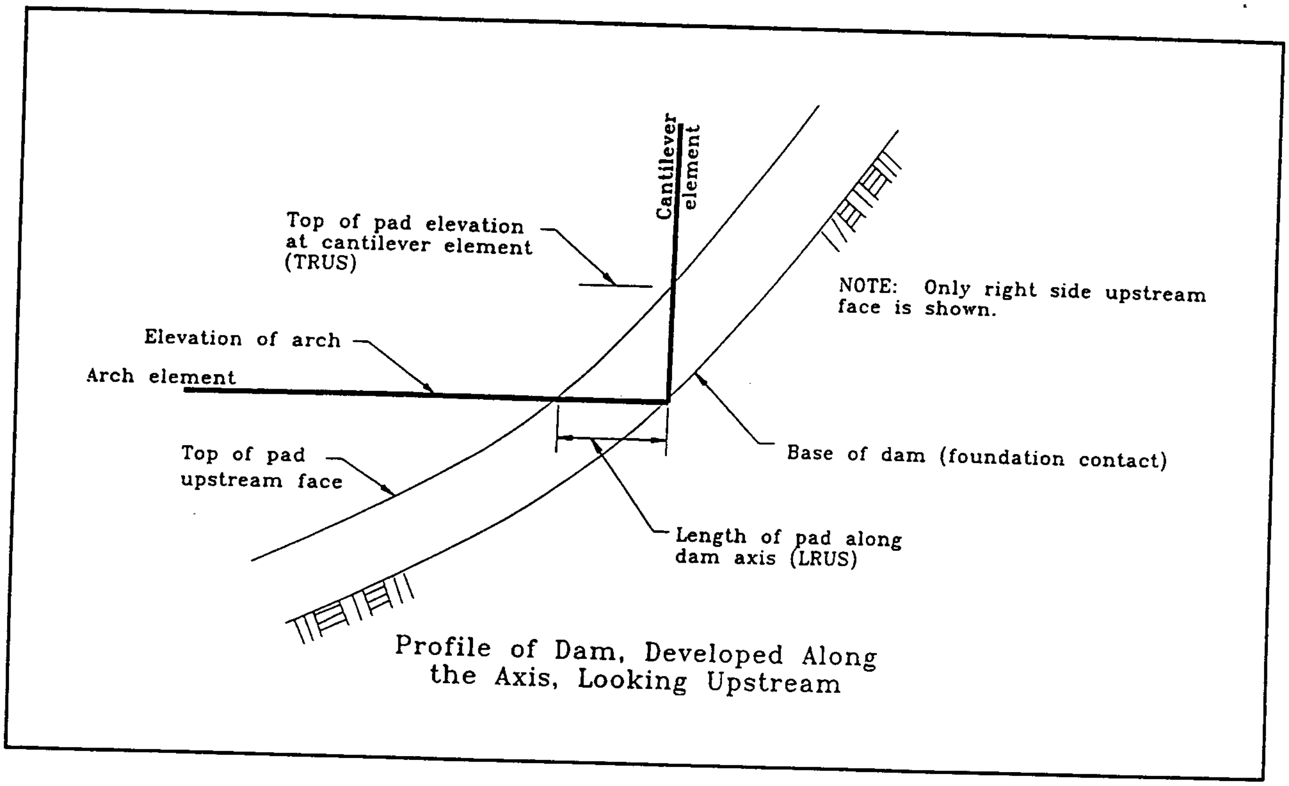

Figure 8-39. Pad features described on the 12-1 cards

1-2 Card - Abutment Controls (Figure 8-40)

*Note: The **1-2 card** is only needed when column 12 of the **2-0 card** is set to 1)*

Column 1.	Set to 1.
Column 5.	Set to 2.

The following is a list of operational options. The number of the option corresponds to an operational control digit. If this digit is set to 1, the indicated option will be performed; if set to 0 or blank, the option will not be performed.

Column 13.	b/a will be read instead of computed (normally set to 0). (Page 80, USBR 1977a.)
Column 15.	Read in Vogt's constants (normally set to 0). (Pages 74-82, USBR 1977a.)
Column 17.	Compute angle Ψ (normally set to 1).
Column 21.	Print the X and Y coordinates of the contact surface (Figure 9-6). (Page 80, USBR 1977a.)
Column 25.	Print Vogt's constants (Figure 9-7).
Column 26.	Print table of angle Ψ and functions of Ψ (Figure 9-7). Normally set to 1. (Pages 74-82, USBR 1977a.)
Column 27.	Print the abutment constants (Figure 9-8). (Pages 74-82, USBR 1977a.)
Column 33.	Controls procedure for computing gamma circle prime. (Page 81, USBR 1977a.) 0 - Use old method. 1 - Use revised method (revised 5/22/68). Normally set to 1.

```
1  2            1  1  111    1
```

Figure 8-40. Example of 1-2 card

1-3 Card - Cantilever Controls

Column 1.	Set to 1.
Column 5.	Set to 3.

The following is a the list of operational options for the cantilever program. The number of the option corresponds to an operational control digit. If this digit is set to 1, the indicated option will be performed; if set to 0 or blank, the option will not be performed.

Column 16.	Print of geometric properties and abutment constants of the cantilevers (Figure 9-4).
Column 27.	Print checking data from the earthquake over pressure routine.
Column 29.	Print a table of moments, shears, and weights due to external forces on the dam (Wc, Mc, Pres, Wvw, Mvw, Vcir, Vcit, Mci).
Column 32.	Print input data for dead-load stresses (for debugging purposes only).
Column 34.	Print summary of dead-load stresses (minimum stress for each elevation of concrete) for each cantilever (Figure 9-10).
Column 35.	Print a table of shears and moments due to ice loading.
Column 36.	Print checking data in the computation of moments and shears for horizontal water loading.
Column 40.	Print all radial initial information (moments, shears, and radial deflections) and forces for stress computations. If this control is set to 2, the edited version (less any pseudoarch elevation data) will also be printed.
Column 41.	Print all tangential initial information due to earthquake.
Column 42.	Print the summary of radial abutment information.
Column 43.	Print the tangential thrusts at the base of a cantilever (multiplied by tangent of angle psi (Ψ) times the ratio of R_{axis} to R_a) for each unit load on the cantilever.
Column 44.	Print a table of radial, tangential, and twist deflections at the top of the cantilever only due to each of the unit loads.

Column 47.	Print moments and shears due to horizontal water load.
Column 48.	Print radial deflections due to linear temperature loads and values of the temperature loads used.
Column 50.	Set to 1.
Column 52.	Set to 1.
Column 53.	Set to 0.
Column 55.	Controls whether or not the heading cards (the **3-3** and **4-3 cards**) are to be read. 0 - No. Don't read the **3-3** and **4-3 cards** 1 - Yes. Read the **3-3** and **4-3 cards** Normally set to 0.
Column 56.	Print vertical water forces on the previous stage removed from this stage.
Column 60.	Set to 1.
Column 61.	Print moments and shears due to tailwater loading.
Column 64.	Distribute the moment due to the weight of concrete between the arches and cantilevers.
Column 65.	Print silt loading check data (debugging).

For most analyses columns 16, 29, 34, 50, 52, and 60 should be set to 1.

```
  1   3            1            1   1               1 1      1
```

Figure 8-41. Example of the 1-3 card

3-3 Card - Cantilever Program Heading Card # 1 (Figure 8-42)

*Note: The **3-3 card** is needed only if column 55 on the **1-3 card** is set to 1.*

Column 1. Set to 3.

Column 5. Set to 3.

Column 11. Analysis indicator.
- 1 - Crown analysis
- 3 - Complete analysis

Normally set to 3.

Column 12. Symmetry indicator.
- 0 - nonsymmetrical shape
- 1 - symmetrical shape

Note: Columns 13-22 are load indicators. Set to 0 if the load is not included. Set to 1 if the load is included.

Column 13. **Uniform temperature** load (02).

Column 14. **Linear temperature** load (03).

Column 15. Combination of 02 and 03 loadings (05). Requires a series of **7-3 cards**.

Column 16. **Tailwater** load.

Column 17. **Ice** load (**13-3 card**).

Column 18. **Silt** load (**14-3 card**).

Column 19. Always set to 0.

Column 20. Initial load modifications (**8-3 cards**).

Column 21. Always set to 0.

Column 22. **Stage construction** (**15-3 card**).

Columns 27-33. **Modulus of elasticity of concrete** divided by 10^6 in psi (E_c). The default is 3.0.

Columns 37-42. **Poisson's ratio for concrete** (μ_c). The default is 0.2.

Columns 46-51.	**Coefficient of thermal expansion for concrete** per degree Fahrenheit multiplied by 10^6 (e_c). The default is 5.6.
Columns 55-63.	**Unit weight of concrete** in pounds per cubic foot (γ_c). The default is 150.
Columns 66-71.	Ratio of acceleration of **earthquake** to acceleration of gravity (g). If left blank Zanger's type of earthquake loading will not be applied.

3	3	301001000100	2.5	0.2	5.5	150.0	0.0
		↑	↑	↑	↑	↑	↑
		load indicators	E_c	μ_c	e_c	γ_c	g

Figure 8-42. Example of 3-3 card

4-3 Card - Cantilever Program Heading Card # 2 (Figure 8-43)

*Note: The **4-3 card** is needed only if column 55 on the **1-3 card** is set to 1.*

Column 1.	Set to 4.
Column 5.	Set to 3.
Columns 11-21.	Reservoir water surface elevation (must not be set to zero). A minimum reservoir elevation should be set to 1 ft above the crown cantilever base elevation. Maximum overtopping is limited to 50 ft above crest elevation. Overtopping can only be used with one- and two-centered layouts. **Overtopping cannot be used with three-centered layouts.**
Columns 22-32.	Tailwater surface elevation. If left blank, tailwater will be set to the base elevation.
Columns 33-43.	Elevation of the top of grout. This must be set to an arch elevation. The default is the top of the dam.
Columns 44-54.	Elevation of bottom of crown cantilever.
Columns 55-65.	Elevation of the top of concrete (only required for stage construction analysis). This must correspond to an arch elevation.
Columns 67-76.	Elevation of the bottom of concrete (only required for stage construction analysis). This must correspond to an arch elevation

```
4   3     6002.0     5781.0     6029.0     5730.0     6029.0     5730.0
```

Figure 8-43. Example of 4-3 card

7-3 Card - Format for 05 Temperature Loading (Figure 8-44)

*Note: The **7-3 cards** are only read if column 15 on the **3-0 card** is set to 1.*

Column 1.	Set to 7.
Columns 2-4.	Card number.
Column 5.	Set to 3.
Columns 8-9.	Cantilever number.
Columns 11-20.	Elevation of load. Elevations must be equal to the arch elevations (card 6-4)
Columns 21-31.	Temperature load (linear temperature variable by cantilever).

Note: The linear temperature load is the straight line difference between the upstream and downstream face temperatures at an elevation. A positive load is one where the temperature on the upstream face is lower than that on the downstream face.

Temperature load cards are positioned in the card deck from the top to bottom of each cantilever. Cards for each cantilever are placed beginning with the crown cantilever and working to the left (cantilevers 20, 21, 22, etc.) then to the right (cantilevers 19, 18, 17, etc.). All zero loads must be changed to a small value (example 0.01 °F).

```
3   0    30001011000      3.0       .2    5.6   150.     2.5    .2    0.1     .0
             ↑
    Column 15 flag indicating the "05" temperature loading will be used.
    (Note: Columns 13 and 14 are set to "0")

7   3    20 7165.0       5.0     (Note: A separate set of cards
7   3    20 7090.0       4.6      is needed for each cantilever.)
7   3    20 7015.0       4.3
7   3    20 6940.0       4.2
7   3    20 6865.0       4.1
7   3    20 6790.0       3.2
7   3    20 6700.0       2.1
         ↑    ↑           ↑
      cant.  el       temperature
     number
```

Figure 8-44. Example of the setup for the 7-3 cards

7-3 Card

8-3 Card - Initial Force Modification (Figure 8-45)

Note: Force modifications are based on a "per foot" basis (cantilever element width).

Column 1.	Set to 8.
Columns 2-4.	Card number.
Column 5.	Set to 3.
Columns 9-10.	Cantilever number.
Columns 11-18.	Elevation of forces. Elevations must agree with arch/cantilever intersections or with the base of the cantilever. Elevation check is 0.01 ft; if difference is less than 0.01, elevation is OK.
Columns 19-32.	Moment modification, in foot-pounds. This modification is read as an exponential number. The exponent must be right justified in the field as shown below. 21 29 ↓ ↓ +x.xxxxxxx+xxx
Columns 33-46.	Shear (horizontal) modification, in pounds. This modification is read as an exponential number. Exponent must be right justified in the field. 35 43 ↓ ↓ +x.xxxxxxx+xxx
Columns 47-60.	Weight (vertical) modification, in pounds. This modification is read as an exponential number. Exponent must be right justified in the field. 49 57 ↓ ↓ +x.xxxxxxx+xxx

Note: Cards are stacked by cantilever unit. The first card corresponds to crest elevation. Fill all spaces with numbers to avoid a space between number and exponent.

```
                                                            flag indicating that
                                                             3-3 and 4-3 cards
                                                              are to be read
                                                                    ↓
 1   3           0            1    11      1       1  1 1  1      11
          flag indicating that
                8-3 card
              is to be read
                    ↓
 3   3      30100100010000    2.5        0.2       5.5       150.0
 4   3       6002.0      5781.0      6029.0      5730.0     6029.0      5730.0


        Cant                        Load modifications
        No.   El         moment          horizontal    vertical
         ↓     ↓           ↓                  ↓            ↓
 8   3   20 6029.0
 8   3   20 6004.0
 8   3   20 5954.0
 8   3   20 5904.0
 8   3   20 5854.0
 8   3   20 5804.0 -2.5806500+005-2.1505000+004-3.2400000+002
 8   3   20 5759.0 -3.0971480+006-1.0913100+005-9.0490000+003
 8   3   20 5730.0 -7.8522030+006-1.9992200+005-2.5293000+004
 8   3   21 6029.0
 8   3   21 6004.0
 8   3   21 5954.0
 8   3   21 5904.0
 8   3   21 5854.0
 8   3   21 5804.0 -2.6772600.005-2.0927000+004-1.0580000+003
 8   3   21 5759.0 -3.0979510.006-1.0535000+005-1.2356000+004
 .       .
 .       .
 .       .
cantilevers 22 through 26 and 19 through 14 not shown
```

Figure 8-45. Example of the setup for the 8-3 cards

13-3 Card - Ice Load (Figure 8-46)

Columns 1-2. Set to 13.

Column 5. Set to 3.

Columns 12-21. Force/linear foot of ice loading (pounds per linear foot). For example, at 5,000 psf a 2-ft-thick sheet of ice would put a 10,000-plf load on the dam.

Columns 23-32. Thickness of ice (ADSAS sets the load positioned at one-half the thickness of the ice below the water surface).

```
13  3        10000.0     2.0
```

Figure 8-46. Example of 13-3 card

14-3 Card - Silt Load (Figure 8-47)

Columns 1-2.	Set to 14.
Column 5.	Set to 3.
Columns 11-18.	Horizontal pressure on the upstream face (pcf).
Columns 19-26.	Horizontal pressure on the downstream face (pcf).
Columns 27-34.	Top elevation of silt on the upstream face.
Columns 35-42.	Bottom elevation of silt on the upstream face.
Columns 43-50.	Top elevation of silt on the downstream face.
Columns 51-58.	Bottom elevation of silt on the downstream face.

```
14  3        85.0     85.0    6865.0  6700.0  6800.0  6700.0
```

Figure 8-47. Example of 14-3 card

1-4 Card - Arch Controls (Figure 8-48)

Column 1. Set to 1.

Column 5. Set to 4.

The following is a list of operational options for the Arch program. The number of the option corresponds to an operational control digit. If this digit is set to 1, the indicated option will be performed. If set to 0 or blank, the option will not be performed.

Column 16. Number of stages for stage construction.

Column 21. Print of uniform loads only.

Column 63. Controls printing of ID sheet at beginning of common output.
- 0 - Eliminate.
- 1 - Print.

Column 65. Control to omit note for end of job.
- 0 - Omit.
- 1 - Print.

Column 69. Always set to 1.

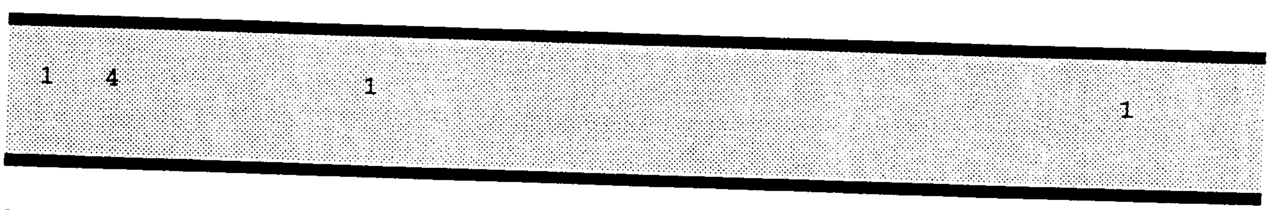

Figure 8-48. Example of 1-4 card

6-4 Card - Heading for Arch 05-Temperature Loads (Figure 8-49)

Column 1.	Set to 6.
Columns 2-4.	Card number.
Column 5.	Set to 4.
Columns 6-7.	Arch number. Lowest arch is No. 1.
Column 8.	Side indicator. 0 - Left side. 1 - Right side.
Columns 9-10.	Number of 05-temperature loads used (number of 7-4 cards). The number of temperature loads must be equal to the number of cantilever intersection points (card 7-3).

*Note: One **6-4 card** plus associated set of **7-4 cards** comprise 05-temperature load cards for each side of each arch.*

```
    arch number
       |
6   4 50 5 - Number of 7-4 cards to describe arch
        |      temperature
  Left side
```

Figure 8-49. Example of 6-4 cards

7-4 Card - 05-Temperature Loads Per Arch Section (Figure 8-50)

Column 1.	Set to 7.
Column 5.	Set to 4.
Columns 6-7.	Arch number. Lowest arch is No. 1.
Column 8.	Side indicator. 0 - Left side. 1 - Right side.
Columns 11-21.	Temperature load (02). List load at the abutment end of the section.
Columns 22-32.	Temperature load (03). List load at the abutment end of the section.

Note: One card for each section, starting at abutment section.

```
Left side of arch
6    4 50 5 - 6-4 card (see Figure 8-49)

 Arch No.           03 temperature
      ↓                 ↓
7    4 50    6.4        17.9
7    4 50    5.6        16.5
7    4 50    4.8        15.6
7    4 50    4.4        14.2
7    4 50    4.2        13.4
      ↑       ↖
 left side       02 temperature

Right side of arch
6    4 51 5
7    4 51    3.8        14.2
7    4 51    4.0        13.3
7    4 51    4.3        13.5
7    4 51    4.9        13.8
7    4 51    4.4        13.3
```

Figure 8-50. Example of 7-4 cards

1-5 Card - Complete Adjustment Controls (Figure 8-51)

Columns 1-5. Always set as 10005.

(The following is a list of operational options. Except as noted in the descriptions, if this digit in a column is set to 1, the indicated option will be performed. If it is set to 0 or left blank, the option will not be performed.)

Column 11. Controls print of execution time.

Column 17. Write out sizing parameters..

Column 22. Print individual execution times by subroutine.

Column 26. Controls which procedure to use to obtain the abutment load:

0 - Linear extrapolation.

1 - Equal to last load adjacent to abutment.

The matrix analyses of each individual adjustment omit the intersection of the arch and cantilever along the abutment because the abutment deformation is limited to the arch abutment deformation. The cantilever base deformation equals the arch abutment deformation by definition. For this reason, the arch abutment load is defined by one of two methods: (a) linear extrapolation from the two adjacent arch loads, or (b) equal to the next adjacent load. The normal procedure is by extrapolation. The second method, equal to the adjacent load, is used whenever the canyon profile is very irregular or narrow, thus not permitting good use of the free cantilevers. Selecting the second method occurs after the stress plots show severe stress oscillations along the abutment followed by assessment of the erratic transition of abutments loads.

Columns 50-51. Number of adjustment cycles. An adjustment cycle consists of one radial adjustment, one tangential adjustment, and one twist adjustment, in that order. One additional radial adjustment will always be performed. This option sets the number of iterative adjustment cycles necessary to reduce the secondary effects to a minimum. Normally 2 to 4 cycles are all that are required. If in doubt, the usual method is to make several analyses only changing the number of cycles and comparing the principal stresses along the abutment. If the stress differences are negligible, select the fewest cycles. Generally, iterating 10 or more cycles causes divergence of the analyses which show up as unbelievable stresses. Dams with irregular arch-cantilever grids should be checked for the best number of cycles.

Column 61. Print debugging information for the stress program. Nine tables that will be printed are:

a. Total radial shear force at the base of each cantilever (multiplied by Raxis/Ra and TAN in pounds per square inch).

b. Total radial bending moments on cantilevers.

c. Total tangential shear force on horizontal planes.

d. Shear stresses, Tau XZ in horizontal planes.

e. Cantilever stresses parallel to faces (in pounds per square foot).

f. Arch stresses parallel to faces (in pounds per square foot).

g. Shear stresses on rock planes.

h. Maximum horizontal shear stresses.

i. Total arch forces.

Column 62. Number of copies of normal stress print desired. It is assumed that at least one copy would always be required as these tables are the primary reason for running the programs. The tables printed are as follows:

a. Arch stresses (in pounds per square inch) at the upstream and downstream faces--both normal and parallel, as shown in Figure 9-26.

b. Cantilever stresses (in pounds per square inch) at the upstream and downstream faces--both normal and parallel, as seen in Figure 9-27.

c. Principal stresses (in pounds per square inch) at the abutment, as given in Figure 9-29.

Column 63. Number of copies of stresses tabulated in such a manner as to correspond roughly with their actual positions on the dam. Stress maps are very valuable in structural assessment of the applied loads. The maps provide a quick scan of the upstream and downstream cantilever stresses, as well as extrados and intrados arch stresses at intersections of the arches and cantilevers. The scan involves horizontal and vertical evaluation of stress consistency from intersection to the next intersection. Stress maps provide the cantilever and arch stresses, in pounds per square inch, in the plane tangent to the face, in their relative location, looking upstream, i.e., by elevation and station. The left- and right-side maps are printed such that the pages can be trimmed and matched producing one larger page with stresses on both sides. For example, note that the title "Cantilever Stresses Paral" is on one sheet and the remainder of the title "lel to the Face of the Dam" is on the companion listing. Elevations and stations are in feet. Tau is the maximum rock plane shear stress. Samples of the individual prints of the stress maps are shown in Figures 9-31 through 9-34.

Column 64. Controls whether or not principal stresses will be printed for all points on the dam (they are printed for abutment points) as a matter of course.

Column 66. Used to indicate in which units of measurement the stresses (arch, cantilever, and principal) should be displayed.

a. If set to 0 or 1, the units will be pounds per square inch.

b. If set to 2, the units will be metric tons per square meter.

Columns 71-72. Cohesion, concrete-to-rock, C/10 in pounds per square inch. Cohesion is used to compute the shear friction factors of safety along the abutment. These values are printed with the "resultant" tables. Unless changed, the default value is 300 psi.

Columns 73-74. (Tan ϕ) × 100. Tan ϕ is used in concert with cohesion. The default value is 1.0, unless otherwise changed.

(Note: For most analyses, set columns 11, 22, 51, 61, 62, 63, and 64 to 1.)

10005	1	2	1111

Figure 8-51. Example of 1-5 card

1-10 Card - Stress Analyzer Controls (Figure 8-52)

Column 1.	Set to 1.
Columns 4-5.	Set to 10.
Column 11.	Call cracking routines.
Column 12.	Scan all stresses for maximum and minimum values.
Column 23.	Print cantilever normal stresses.
Column 26.	Print maximum absolute arch stress for each arch.

(Note: For most analyses, set columns 12 and 26 to 1).

```
1  10      1             1
```

Figure 8-52. Example of 1-10 card

9 Interpretation of Results

This chapter includes some guidance in interpreting the ADSAS output. The output file from ADSAS can be very large and may appear cryptic to a user who is not familiar with the trial load method. Definitions and illustrative examples of terms shown in ADSAS output data may be found in Design Manual for Concrete Arch Dams (USBR 1977a). The information in this chapter is not intended as guidance on how to evaluate an arch dam. Guidance on arch dam criteria can be found in EM 1110-2-2201, "Arch Dam Design."

The first set of pages in the output file is an echo and a summary of the input data (Figure 9-1) and allows the user to quickly verify that the data have been read correctly. ADSAS also performs an internal geometry check and will provide warnings if the data are incorrect. For fatal errors, the program will print a brief description of the error.

After the program has determined that the geometry has been adequately defined, it computes the geometric properties of the arches and cantilevers. The amount of output from the program is determined by the flags set on the various input/output control cards. Figures 9-2 through 9-8 show some of the tables typically included in an ADSAS output file.

The remainder of the output file (Figures 9-9 through 9-35) includes the calculation of moments, forces, and deformations. These tables are used to evaluate the design and can also provide useful information to be used in other analyses. For example, information in table "RESOLUTION OF FORCES AND MOMENTS ON ABUTMENTS" (Figure 9-24) can be used in foundation stability analysis. In addition, the cantilever and arch deflection information (Figures 9-17 and 9-18) predicted by ADSAS can be compared with the measured deflection data for an existing dam.

Figure 9-36 shows the direction of positive loads, forces, moments, and movements. Figure 9-37 shows the direction of positive movements, forces, moments, and loads; and also shows direction of forces, moments, and movements due to positive loads. Both figures are from Design Manual for Concrete Arch Dams (USBR 1977a).

DESIGN CRITERIA

1. DATA WILL BE PREPARED FOR A COMPLETE ADJUSTMENT.
2. THE SHAPE WILL BE CONSIDERED NONSYMMETRIC.
3. TEMPERATURE LOADING IS UNIFORM ACROSS THE ARCH.
4. TEMPERATURE LOADING IS PRESENTED IN TABULAR FORM (SEE TABLE ON PAGE 1, LINK 1 OUTPUT).
5. THE GROUTING TEMPERATURE= 0.00 DEGREES FAHRENHEIT.
6. THE EFFECTS OF TAILWATER, UPLIFT, SILT AND ICE LOADING, IF ANY, ARE NOT INCLUDED.
7. NO EARTHQUAKE LOADING WILL BE APPLIED.
8. TWO LINES OF CENTERS WILL BE USED TO DESCRIBE THE DAM.
9. MODULUS OF ELASTICITY OF THE ROCK IS CONSTANT FROM TOP TO BOTTOM OF THE DAM.
10. EFFECTS OF THE CONSTRUCTION PROGRAM ARE NOT INCLUDED IN THIS STUDY.
11. PHYSICAL PROPERTIES OF THE CONCRETE

    A. YOUNGS MODULUS OF ELASTICITY= 3.000 MILLION POUNDS/SQUARE INCH.
    B. POISSONS RATIO= 0.200.
    C. COEFFICIENT OF THERMAL EXPANSION, 0.000005600 FOOT/FOOT/DEGREE FAHRENHEIT.
    D. UNIT WEIGHT OF CONCRETE= 150.00 POUNDS/CUBIC FOOT.

12. PHYSICAL PROPERTIES OF THE ABUTMENT ROCK

    A. YOUNGS MODULUS OF ELASTICITY= 2.500 MILLION POUNDS/SQUARE INCH.
    B. POISSONS RATIO= 0.200.

13. THE BASE ELEVATION OF THE DAM IS 6700.000.
14. THE TOP ELEVATION OF THE DAM (AS DEFINED ON THE PLANE OF CENTERS) IS 7165.000.
15. THE RESERVOIR WATER SURFACE ELEVATION IS 7165.000.
16. THE TAILWATER SURFACE ELEVATION IS 6700.000.
17. THE DAM IS GROUTED TO ELEVATION 7165.000.
18. THE ELEVATION OF TOP OF CONCRETE IS 7165.000.
19. THE ELEVATION OF BOTTOM OF CONCRETE IS 6700.000.

Figure 9-1. Summary of the design criteria from the input file

The data in the "PLANE OF CENTERS DATA" table in Figure 9-2 serve as a check on the values from the layout drawings. Note that the crest thickness is slightly less than the value on the **6-1 card**. The value shown in Figure 9-2 is calculated based on the definitions of the upstream and downstream faces. The values shown as "DOWNSTREAM LINE OF CENTERS" and "UPSTREAM LINE OF CENTERS" represent the distance of the line of centers from the axis center (the B1 and B2 values shown in Chapter 8, Figure 8-14). RE and RI represent the extrados and intrados radii, respectively, at each elevation.

The data in the "CONTROLS, PHI ANGLES AND TEMPERATURE LOADS" table in Figure 9-2 serve as a check on the data entered on the **7-1 cards**. CNTRL are controls defined in the **7-1 card**. The "PHI ANGLES TO THE WEDGE" part of the table is inactive and should be ignored.

In Figure 9-4 "RE/Raxis," "RO/Raxis," and "RD/Raxis" are ratios of radii necessary for accurate computation of properties in radial side horizontal cantilever sections which are "Area," "LG," and "I." "LG" is the distance from the upstream

PLANE OF CENTERS DATA

ELEV	THICKNESS	UPSTREAM PROJECTION	DOWNSTREAM PROJECTION	DOWNSTREAM LINE OF CNTRS	UPSTREAM LINE OF CNTRS	RE	RI
6700.0	51.65466	34.42737	17.22729	221.1514	174.6710	234.7563	136.6213
6790.0	51.71149	48.70544	3.00604	201.8560	158.0055	265.7000	170.1379
6865.0	50.76050	52.95013	-2.18964	175.8546	138.0541	289.8961	201.3351
6940.0	48.91412	50.36127	-1.44714	139.6274	112.2522	313.1091	236.8197
7015.0	43.87351	40.87360	2.99991	91.5008	80.1447	335.7289	280.4993
7090.0	31.74027	24.24036	7.49991	41.3051	41.0960	358.1443	326.1950
7165.0	11.99998	0.00006	11.99991	0.0000	-0.0007	375.0008	363.0001
				↑ B2	↑ B1		

CONTROLS, PHI ANGLES AND TEMPERATURE LOADS

ELEVATION	VERT ABUT CNTRL	WEDGE CNTRL	PROCEDURE CNTRL	ADJUSMENT CNTRL	SUPPL ABUT CNTRL	PHI ANGLES TO THE RADIAL ABUTMENT LEFT	PHI ANGLES TO THE RADIAL ABUTMENT RIGHT	PHI ANGLES TO THE WEDGE LEFT	PHI ANGLES TO THE WEDGE RIGHT	TEMPERATURE LOADS UNIFORM	TEMPERATURE LOADS LINEAR
6700.0	0	0	1	0	0	0.000	0.000	0.000	0.000	0.0	0.0
6790.0	0	0	0	0	0	44.350	44.350	0.000	0.000	-1.5	0.0
6865.0	0	0	0	0	0	48.125	48.125	0.000	0.000	-1.5	0.0
6940.0	0	0	0	0	0	49.600	49.600	0.000	0.000	-1.5	0.0
7015.0	0	0	0	0	0	50.250	50.250	0.000	0.000	-2.0	0.0
7090.0	0	0	0	0	0	51.625	51.625	0.000	0.000	-4.5	0.0
7165.0	0	0	0	0	0	54.875	54.875	0.000	0.000	-15.0	0.0
								Inactive	Inactive		

Figure 9-2. Tables summarizing plane of centers data, arch controls, and temperature loading

GEOMETRIC PROPERTIES OF THE LEFT SIDE OF ARCH 4 AT ELEVATION 7015.00

THIS IS A 4 SECTION ARCH WITH 4 ADJUSTED POINTS. THERE WILL BE 1 VOUSSOIRS PER SECTION.

THE AVERAGE THICKNESS OF THIS ARCH IS 45.55 FEET.
THE UNIFORM TEMPERATURE LOAD= -2.0 DEGREES
THE LINEAR TEMPERATURE LOAD= 0.0 DEGREES

STATION	CONTROL	RE	ANGLEPHI	THICKNESS
1266.99			50.25000	48.10400
1238.39	1	335.7289	45.13581	47.33420
1210.85	1	335.7289	40.13342	46.64288
1178.16	1	335.7289	34.10217	45.89859
1000.00	1	335.7289	0.00000	43.87351

GEOMETRIC PROPERTIES OF THE RIGHT SIDE OF ARCH 4 AT ELEVATION 7015.00

THIS IS A 4 SECTION ARCH WITH 4 ADJUSTED POINTS. THERE WILL BE 1 VOUSSOIRS PER SECTION.

THE AVERAGE THICKNESS OF THIS ARCH IS 45.55 FEET.
THE UNIFORM TEMPERATURE LOAD= -2.0 DEGREES
THE LINEAR TEMPERATURE LOAD= 0.0 DEGREES

STATION	CONTROL	RE	ANGLEPHI	THICKNESS
733.01			50.25000	48.10400
761.61	1	335.7289	45.13581	47.33420
789.15	1	335.7289	40.13342	46.64288
821.84	1	335.7289	34.10217	45.89859
1000.00	1	335.7289	0.00000	43.87351

Figure 9-3. Typical table of geometric properties of the arches

face to the centroid of the area, and "I" is the moment of inertia about the centroid. "Phi" (ϕ) is the angle, measured at the extrados center, from the reference plane to the cantilever station. "ANGLE BETA" (β) is the angle measured at the downstream face between radii from the extrados and intrados center.

Figure 9-9 is the printout of a standard summary of pertinent geometric values. Line 8 is the b/a ratio as defined in section 4-30 "Foundation Constants" (USBR 1977a).

GEOMETRIC PROPERTIES FOR CANTILEVER NUMBER 20

STATIONED AT 1000.00

THIS CANTILEVER IS NOT BASED ON AN ARCH
THIS CANTILEVER WILL BE ADJUSTED
THE UPSTREAM PROJECTION AT THE WATER SURFACE= 0.00006 WHICH IS AT ELEVATION 7165.0
THE DOWNSTREAM PROJECTION AT THE TAILWATER SURFACE= 0.00000 WHICH IS AT ELEVATION 6700.0

ELEVATION	US PROJ	THICKNESS	ANGLE BETA	PHI	AREA	LG	I	RE/RAXIS	RO/RAXIS	RD/RAXIS
6700.0	34.42737	51.65466	0.0000	0.0000	53.87217	24.7631	11917.480	1.1718540	1.0429300	0.9140050
6745.0	42.84125	51.85132		0.0000	56.07435	24.9282				
6790.0	48.70544	51.71149	0.0000	0.0000	57.15675	24.9266	12687.460	1.2244550	1.1053010	0.9861469
6827.5	51.68457	51.34698		0.0000	57.24984	24.8026				
6865.0	52.95013	50.76050	0.0000	0.0000	56.66674	24.5685	12130.090	1.2234690	1.1163550	1.0092410
6902.5	52.50995	49.95105		0.0000	55.47262	24.2239				
6940.0	50.36127	48.91412	0.0000	0.0000	53.73655	23.7663	10688.500	1.1916710	1.0985900	1.0055080
6977.5	46.49066	47.24057		0.0000	51.12724	23.0021				
7015.0	40.87360	43.87350	0.0000	0.0000	46.69125	21.4256	7477.403	1.1386230	1.0642240	0.9898258
7052.5	33.47333	38.72324		0.0000	40.46650	18.9802				
7090.0	24.24036	31.74026	0.0000	0.0000	32.53592	15.6248	2729.554	1.0725970	1.0250680	0.9775387
7127.5	13.10992	22.85983		0.0000	22.96775	11.3081				
7165.0	0.00006	11.99997	0.0000	0.0000	11.80797	5.9675	141.682	1.0000000	0.9840001	0.9680003

Figure 9-4. Table summarizing the cantilever properties

GEOMETRIC PROPERTIES AT THE ABUTMENT ON THE LEFT SIDE

ELEV	CON TRL	LENGTH	ARCH ABUTMENT	CANTILEVER THICKNESS	RAXIS/RA
6700.00	1	0.0000	51.6547	51.6547	0.9588375
6790.00	0	185.6522	66.9894	66.9894	1.0567280
6865.00	0	222.1773	65.3060	65.3060	1.0436960
6940.00	0	249.8812	59.4663	59.4663	1.0317520
7015.00	0	275.2045	48.1040	48.1040	1.0223900
7090.00	0	308.3981	31.8196	31.8196	1.0171410
7165.00	0	353.4103	12.0003	12.0003	1.0162590

GEOMETRIC PROPERTIES AT THE ABUTMENT ON THE RIGHT SIDE

ELEV	CON TRL	LENGTH	ARCH ABUTMENT	CANTILEVER THICKNESS	RAXIS/RA
6790.00	0	185.6522	66.9894	66.9894	1.0567280
6865.00	0	222.1773	65.3060	65.3060	1.0436960
6940.00	0	249.8812	59.4663	59.4663	1.0317520
7015.00	0	275.2045	48.1040	48.1040	1.0223900
7090.00	0	308.3981	31.8196	31.8196	1.0171410
7165.00	0	353.4103	12.0003	12.0003	1.0162590

Figure 9-5. Table of the geometric properties of the abutments

The table below line 8 compares selected parameters for this layout with those values predicted by empirical equations in EM 1110-2-2201 or in the Bureau of Reclamation's Engineering Monograph No. 36, "Guide for Preliminary Design of Arch Dams" (USBR 1977c).

In the last table in Figure 9-9, "GEOMETRIC PROPERTIES OF THE ARCHES," the ratios "TAL/TO" and "TAR/TO" are the ratios of the abutment to crown thicknesses. These thicknesses can be used for comparison with the values suggested in EM 1110-2-2201 or the USBR Engineering Monograph No. 36. "TAVE/RO" is the ratio of the average arch thickness to the radius at the average thickness of the crown cantilever. The "RISE CHORD" is the ratio of each arch rise to its chord length. These values can be helpful when comparing different layouts at the same site to determine whether the arch curvature has increased or decreased.

AREAS OF THE ARCHES

ELEVATION	AREA
6790.0	20904.
6865.0	24534.
6940.0	26087.
7015.0	24888.
7090.0	19593.
7165.0	8482.

THE VOLUME OF CONCRETE IN THE DAM = 351441. CUBIC YARDS.

X AND Y COORDINATES OF THE CONTACT AREA

X	Y
0.0000	12.00027
87.4706	31.81961
169.4877	48.10400
248.6475	59.46631
328.6006	65.30597
412.0218	66.98938
623.6215	51.65466
835.2212	66.98938
918.6423	65.30597
998.5955	59.46631
1077.7550	48.10400
1159.7720	31.81961
1247.2430	12.00027

Figure 9-6. Table of areas of the arches

TABULATION OF VOGTS CONSTANTS

B/A= 18.871980

POISSONS RATIO FOR THE ROCK= 0.20

C1= 5.4392 USED IN THE COMPUTATION OF ALFA PRIME (X = 18.9)

C2= 6.6483 USED IN THE COMPUTATION OF DELTA PRIME (X = 9.4)
C3= 2.1223 USED IN THE COMPUTATION OF BETA PRIME (X = 9.4)

C4= 2.5053 USED IN THE COMPUTATION OF GAMA C PRIME (X = 0.106)

C5= 2.6854 USED IN THE COMPUTATION OF GAMA PRIME (X = 18.9)

C6= 0.6651 USED IN THE COMPUTATION OF ALFA D PRIME (X = 18.9)

TABULATION OF ANGLE SI AND FUNCTIONS OF ANGLE SI FOR THE LEFT SIDE

ELEV	SI	TANGENT SI	SINE SI	COSINE SI
6700.00	89.43	99.97960000	1.00000000	0.00000000
6790.00	50.27	1.20327500	0.76907840	0.63915450
6865.00	23.18	0.42819320	0.39362550	0.91927090
6940.00	19.47	0.35351460	0.33330080	0.94282050
7015.00	21.31	0.39011240	0.36343620	0.93161910
7090.00	27.54	0.52137180	0.46231000	0.88671840
7165.00	34.17	0.67895450	0.56171840	0.82732850

TABULATION OF ANGLE SI AND FUNCTIONS OF ANGLE SI FOR THE RIGHT SIDE

ELEV	SI	TANGENT SI	SINE SI	COSINE SI
6790.00	50.27	1.20327500	0.76907840	0.63915450
6865.00	23.18	0.42819320	0.39362550	0.91927090
6940.00	19.47	0.35351460	0.33330080	0.94282050
7015.00	21.31	0.39011240	0.36343620	0.93161910
7090.00	27.54	0.52137180	0.46231000	0.88671840
7165.00	34.17	0.67895450	0.56171840	0.82732850

Figure 9-7. Summary of Vogt's constants and functions of psi (Ψ)

The information in Figure 9-10 can help evaluate various layouts during the design process. For example, each reshaping of the dam will change the reactions carried by each arch element. This means that Arch No. 5 will have a different set of reactions to a uniform 1-kip load. By comparing the radial deflections between

ARCH ABUTMENT CONSTANTS ON THE RIGHT SIDE

ELEV	ALFA (1-11)	ALFA2 (-11)	GAMA (-11)	BETA (-11)
6790.00	0.2434867	1.1266440	476.7775000	417.0155000
6865.00	0.3368809	2.3906450	685.7304000	557.0799000
6940.00	0.4127753	2.7616460	703.2972000	566.9522000
7015.00	0.6261470	3.3333160	694.9415000	562.2975000
7090.00	1.3860760	10.5377000	617.1459000	515.4984000

CANTILEVER ABUTMENT CONSTANTS ON THE RIGHT SIDE

ELEV	DELTA (-11)	GAMA CIRCLE (-11)	GAMA (-11)	ALFA (-11)	ALFA3
6790.00	0.3096016	530.2494000	606.2387000	0.2984726	1.7237700
6865.00	0.1505532	248.9609000	306.4552000	0.172881	0.4574762
6940.00	0.1505555	206.7899000	256.5203000	0.1759606	0.3560887
7015.00	0.2497368	224.2706000	277.1753000	0.2894222	0.5186477
7090.00	0.7350482	287.9043000	350.7715000	0.8243585	1.2622160
7165.00	6.4093520	355.6907000	425.8269000	6.9005700	4.9366420

Figure 9-8. Summary of abutment constants

GEOMETRICAL STATISTICS

1. HEIGHT OF DAM= 465.0 FEET (141.7M.).

2. A. CHORD LENGTH AT THE CREST= 613.4 FEET (187.0M.).
B. LENGTH ALONG AXIS AT THE CREST= 718.3 FEET (218.9M.).

3. A. SUBTENDED ANGLE AT THE CREST= 109.8 DEGREES.
B. AXIS RADIUS= 375.0 FEET (114.3M.).

4.

	THICKNESS	UPSTREAM PROJECTION	DOWNSTREAM PROJECTION
A. AT CREST	12.00 (3.66M.)	0.00 (0.00M.)	12.00 (3.66M.)
B. AT BASE	51.65 (15.74M.)	34.43 (10.49M.)	17.23 (5.25M.)

5. THE SLENDERNESS RATIO (TB/H)= 0.111.

6. THE LENGTH (ALONG AXIS) TO HEIGHT RATIO= 1.54.

7. THE VOLUME OF CONCRETE IN THE DAM= 351440.7 CUBIC YARDS (268852.1 CUBIC METERS).

8. LENGTH TO WIDTH RATIO OF THE IDEALIZED ABUTMENT CONTACT AREA (B/A)= 18.9.

THE CANYON SHAPE IS A

NARROW U

6 ARCHES AND 0 FREE CANTILEVERS
WILL BE ADJUSTED

AT 36 POINTS

COMPARISON OF THE ACTUAL PROPERTIES OF THIS DAM WITH THE PROPERTIES PREDICTED BY THE PRELIMINARY DESIGN CRITERIA

PROPERTY	ACTUAL	PREDICTED	PER CENT DIFFERENCE
BASE THICKNESS	51.65	47.93	7.2
CREST THICKNESS	12.00	12.01	-0.1
VOLUME	351441.	440490.	-20.2

THESE PREDICTIONS ARE
BASED ON CHORD LENGTHS OF

613.4 FEET AT ELEV 7165.
269.9 FEET AT ELEV 6770.

GEOMETRIC PROPERTIES OF THE ARCHES

ELEVATION	PHI LEFT	PHI RIGHT	CROWN THICKNESS	LEFT ABUT THICKNESS	RIGHT ABUT THICKNESS	TAL/TO	TAR/TO	AVERAGE THICKNESS	RE	TAVE/RO	RISE CHORD
7165.0	54.9	54.9	12.00	12.00	12.00	1.0000	1.0000	12.00	375.00	0.0325	0.2596
7090.0	51.6	51.6	31.74	31.82	31.82	1.0025	1.0025	31.77	358.14	0.0928	0.2418
7015.0	50.3	50.3	43.87	48.10	48.10	1.0964	1.0964	45.55	335.73	0.1452	0.2345
6940.0	49.6	49.6	48.91	59.47	59.47	1.2157	1.2157	53.33	313.11	0.1847	0.2310
6865.0	48.1	48.1	50.76	65.31	65.31	1.2866	1.2866	57.27	289.90	0.2165	0.2233
6790.0	44.3	44.3	51.71	66.99	66.99	1.2954	1.2954	59.35	265.70	0.2475	0.2038

Figure 9-9. Summary of geometric statistics

the original and revised layout the designer can determine how the reshaping affected the loads carried by the arches.

The data in the numbered columns in Figure 9-11 are as follows.

(1) Elevation of arches below top of dam.

(2) Concrete weight from top of dam down to elevation shown, in pounds; + is down.

UNIT ARCH DATA FOR THE LEFT HALF OF ARCH NO. 5 AT ELEVATION 7090.00

UNIFORM RADIAL LOAD TO BE USED FOR CROWN ANALYSIS OR FOR CHECKING

STATION	MOMENTS	THRUSTS	SHEARS	RADIAL DEFLECTION	TANGENTIAL DEFLECTION	ANGULAR DEFLECTION
1305.63	-0.12121000E+07	0.34879780E+06	-0.11803000E+05	-0.13340520E-03	-0.18936220E-02	-0.17339460E-04
1266.99	-0.78681200E+06	0.34754630E+06	-0.10693470E+05	-0.18132700E-02	-0.27611760E-02	-0.50030390E-04
1238.39	-0.49814800E+06	0.34669690E+06	-0.97787340E+04	-0.37870230E-02	-0.32492170E-02	-0.65735640E-04
1210.85	-0.24388800E+06	0.34594870E+06	-0.88280940E+04	-0.60603780E-02	-0.35486420E-02	-0.74512420E-04
1178.16	0.24626000E+05	0.34515860E+06	-0.76183910E+04	-0.89866020E-02	-0.36538910E-02	-0.77537360E-04
1000.00	0.72810860E+06	0.34308880E+06	0.00000000E+00	-0.19095140E-01	-0.32441660E-07	0.37107380E-09
	DATA FOR THE RIGHT HALF OF THE ARCH					
1000.00	0.72810860E+06	0.34308880E+06	0.00000000E+00	-0.19095140E-01	0.32441660E-07	-0.37107380E-09
821.84	0.24626000E+05	0.34515860E+06	-0.76183910E+04	-0.89866020E-02	0.36538910E-02	0.77537360E-04
789.15	-0.24388800E+06	0.34594870E+06	-0.88280940E+04	-0.60603780E-02	0.35486420E-02	0.74512420E-04
761.61	-0.49814800E+06	0.34669690E+06	-0.97787340E+04	-0.37870230E-02	0.32492170E-02	0.65735640E-04
733.01	-0.78681200E+06	0.34754630E+06	-0.10693470E+05	-0.18132700E-02	0.27611760E-02	0.50030390E-04
694.37	-0.12121000E+07	0.34879780E+06	-0.11803000E+05	-0.13340520E-03	0.18936220E-02	0.17339460E-04

Figure 9-10. Table of arch reactions to a uniform load of 1 kip

FORCES DUE TO CONCRETE AND VERTICAL WATER ON CANTILEVER 20

ELEVATION	WEIGHT DUE TO CONCRETE (X10)	MOMENT DUE TO CONCRETE (X100)	WATER PRES AT THE AXIS	WEIGHT DUE TO VERTICAL WATER	MOMENT DUE TO VERTICAL WATER (X10)	INERTIAL EFFECTS OF CONCRETE VCIR	VCIT	MCIR (X100)
7090.0	25540.	-14966.	4687.50	60937.6	45976.	0.	0.0	0.
7015.0	70745.	-64279.	9375.00	191528.4	172152.	0.	0.0	0.
6940.0	127921.	-133008.	14062.50	321663.5	294957.	0.	0.0	0.
6865.0	190226.	-158061.	18750.00	373049.8	360355.	0.	0.0	0.
6790.0	254505.	-52289.	23437.50	263455.8	230227.	0.	0.0	0.
6700.0	329954.	366714.	29062.50	-184555.8	-856142.	0.	0.0	0.
↑ (1)	↑ (2)	↑ (3)	↑ (4)	↑ (5)	↑ (6)	↑ (7)	↑ (8)	↑ (9)

Figure 9-11. Example of summary of concrete and vertical forces on a typical cantilever

(3) Radial moment of concrete weight about centroid, in foot-pounds; + is overturning upstream.

(4) Hydrostatic pressure at the elevation shown, in pounds per square foot.

(5) Weight of vertical water column on upstream face, in pounds.

(6) Moment of vertical water column about centroid, in foot-pounds.

(7) Horizontal concrete inertia force in the radial direction.

(8) Horizontal concrete inertia force in the tangential direction.

(9) Moment about elevation shown from the radial inertia force.

In Figure 9-12 the "DSDF" and "USUF" tables show the development of minimum stress on either face of each cantilever during construction from base to crest by arch elevations assuming each cantilever stands alone (note that positive values indicate compression and negative values indicate tension). When evaluating the stresses for this condition it is important to keep in mind that the concrete will not typically have reached its design strength.

MINIMUM DEAD LOAD STRESSES (IN PSI) FOR CANTILEVER 20

```
CELEV-    STRESSES COMPUTED WITH CONCRETE PLACED TO THIS ELEVATION.
D ELEV-   ELEVATION OF MINIMUM STRESS ON THE DOWNSTREAM FACE.
DSDF-     MINIMUM STRESS ON THE DOWNSTREAM FACE.
DSUF-     STRESS ON UPSTREAM FACE AT ELEVATION OF MINIMUM DOWNSTREAM STRESS.
W ELEV-   ELEVATION OF WATER REQUIRED TO REDUCE TENSION ON THE DOWNSTREAM FACE TO ZERO.
D WEIGHT-WEIGHT AT ELEVATION OF MINIMUM STRESS ON THE DOWNSTREAM FACE.
D MOMENT-MOMENT AT ELEVATION OF MINIMUM STRESS ON THE DOWNSTREAM FACE.
U ELEV-   ELEVATION OF MINIMUM STRESS ON THE UPSTREAM FACE.
USUF-     MINIMUM STRESS ON THE UPSTREAM FACE.
USDF-     STRESS ON DOWNSTREAM FACE AT ELEVATION OF MINIMUMUPSTREAM STRESS.
U WEIGHT-WEIGHT AT ELEVATION OF MINIMUM STRESS ON THE UPSTREAM FACE.
U MOMENT-MOMENT AT ELEVATION OF MINIMUM STRESS ON THE UPSTREAM FACE.
```

C ELEV	D ELEV	DSDF	DSUF	W ELEV	D WEIGHT	D MOMENT	U ELEV	USUF	USDF	U WEIGHT	U MOMENT
7165.	6700.	-149.	954.	6797.	0.32995E+07	0.36671E+08	6940.	-40.	383.	0.12792E+07	-0.13301E+08
7090.	6700.	-210.	947.	6809.	0.30441E+07	0.38436E+08	6940.	21.	250.	0.10238E+07	-0.72122E+07
7015.	6700.	-233.	856.	6813.	0.25921E+07	0.36178E+08	6940.	46.	104.	0.57176E+06	-0.18168E+07
6940.	6700.	-183.	669.	6804.	0.20203E+07	0.28314E+08	6865.	73.	80.	0.62305E+06	-0.21977E+06
6865.	6700.	-84.	424.	6780.	0.13973E+07	0.16872E+08	6790.	103.	51.	0.64279E+06	0.18215E+07
6790.	6700.	4.	184.	0.	0.75448E+06	0.59781E+07	6700.	184.	4.	0.75448E+06	0.59781E+07

Figure 9-12. Table of cantilever dead load stresses

The moment and dead weight in Figure 9-12 can help evaluate the stability of the cantilever during construction. This can be done by calculating the eccentricity (moment/weight) to see if the resultant remains within the base.

In Figure 9-13 the numbered columns show:

(1) Elevations, in feet.

(2) Cantilever load, in kips, removed from the initial load by arch action.

(3) Cantilever deflection, in feet. (+ is toward the right side looking upstream.)

(4) Arch deflection, in feet. (+ is toward the right side looking upstream.)

CANTILEVER NO 19 TANGEN ADJUSTMENT NO 2

ELEVATION	CANTILEVER LOAD	DEFLECTIONS CANTILEVER	DEFLECTIONS ARCH	DIFFERENCE
7165.00	0.2602	0.021509400	0.021509000	0.000000404
7090.00	2.1352	0.022096880	0.022096860	0.000000022
7015.00	-0.6431	0.023335080	0.023335080	0.000000006
6940.00	-4.7794	0.023752950	0.023752940	0.000000007
6865.00	-7.8335	0.021667490	0.021667480	0.000000007
6790.00	-10.8876	0.015724850		
↑ (1)	↑ (2)	↑ (3)	↑ (4)	

Figure 9-13. Typical list of cantilever tangential deflection

Figure 9-14 lists the following information:

Left side (looking upstream):

(1) Arch length, in feet.

TANGEN ADJUSTMENT NO 2
ARCH AT ELEVATION 7165.00
ARCH LOADS, DEFLECTIONS, AND LENGTHS

LEFT ABUTMENT TO CROWN				RIGHT ABUTMENT TO CROWN			
LENGTH	STATION	LOAD	DEFLECTION	LENGTH	STATION	LOAD	DEFLECTION
0.00	1359.16	-0.155	-0.001464	0.00	640.84	-0.155	0.001464
52.67	1305.63	-0.669	-0.009058	52.67	694.37	-0.668	0.009058
90.70	1266.99	-1.039	-0.014432	90.70	733.01	-1.039	0.014431
118.84	1238.39	-1.053	-0.017799	118.84	761.61	-1.054	0.017798
145.93	1210.85	-0.725	-0.020164	145.93	789.15	-0.725	0.020164
178.11	1178.16	-0.260	-0.021510	178.11	821.84	-0.260	0.021509
353.41	1000.00	0.000	-0.000001	353.41	1000.00	0.000	-0.000001
↑	↑	↑	↑	↑	↑	↑	↑
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)

Figure 9-14. Typical list of arch tangential deflections

(2) Station along axis, in feet.

(3) Arch load, in kips.

(4) Arch deflection, in feet.

Right side (looking upstream):

(5) Arch length, in feet.

(6) Station along axis, in feet.

(7) Arch load, in kips.

(8) Arch deflection, in feet.

The term "abutment" used in this table is used as an indication of the side.

The following information is shown in the numbered columns of Figure 9-15:

(1) Elevation, in feet.

(2) Cantilever load, in foot-kips, is the load removed from the initial load by arch action.

CANTILEVER NO 19 TWIST ADJUSTMENT NO 2

	CANTILEVER	DEFLECTIONS		
ELEVATION	LOAD	CANTILEVER	ARCH	DIFFERENCE
7165.00	0.3008	0.000474556	0.000474557	-0.000000001
7090.00	8.4400	0.000466037	0.000466037	0.000000000
7015.00	18.1530	0.000450624	0.000450624	0.000000000
6940.00	90.0378	0.000411588	0.000411588	0.000000000
6865.00	202.8872	0.000312872	0.000312872	0.000000000
6790.00	315.7366	0.000166405		
↑	↑	↑	↑	
(1)	(2)	(3)	(4)	

Figure 9-15. Typical list of the cantilever twists (rotations)

(3) Rotation, in radians. (+ is counterclockwise.)

(4) Rotation, in radians. (+ is counterclockwise.)

Figure 9-16 shows:

Left side (looking upstream):

(1) Arch length, in feet.

(2) Station along axis, in feet.

(3) Arch load, in foot-kips.

(4) Arch rotation, in radians.

Right side (looking upstream):

(5) Arch length, in feet.

(6) Station along axis, in feet.

(7) Arch load, in foot-kips.

(8) Arch rotation, in radians.

The term "abutment" used in this table is used as an indication of the side.

TWIST ADJUSTMENT NO 2
ARCH AT ELEVATION 7165.00
ARCH LOADS, DEFLECTIONS, AND LENGTHS

LEFT ABUTMENT TO CROWN				RIGHT ABUTMENT TO CROWN			
LENGTH	STATION	LOAD	DEFLECTION	LENGTH	STATION	LOAD	DEFLECTION
0.00	1359.16	21.911	0.000014	0.00	640.84	21.917	-0.000014
52.67	1305.63	12.552	-0.000061	52.67	694.37	12.556	0.000061
90.70	1266.99	5.796	-0.000201	90.70	733.01	5.799	0.000201
118.84	1238.39	-0.018	-0.000311	118.84	761.61	-0.014	0.000310
145.93	1210.85	-3.225	-0.000403	145.93	789.15	-3.214	0.000403
178.11	1178.16	-0.312	-0.000475	178.11	821.84	-0.301	0.000475
353.41	1000.00	-0.004	0.000000	353.41	1000.00	-0.004	0.000000
↑ (1)	↑ (2)	↑ (3)	↑ (4)	↑ (5)	↑ (6)	↑ (7)	↑ (8)

Figure 9-16. Typical list of arch twist (rotations)

Figure 9-17 shows:

(1) Elevation, in feet.

(2) Cantilever load, in kips per square foot, is the load removed by arch action.

(3) Deflection, in feet. (- is downstream.)

CANTILEVER NO 19 RADIAL ADJUSTMENT NO 3

ELEVATION	CANTILEVER LOAD	DEFLECTIONS CANTILEVER	DEFLECTIONS ARCH	DEFLECTIONS DIFFERENCE
7165.00	-0.4620	-0.042856070	-0.042819530	-0.000036545
7090.00	-4.3408	-0.043282600	-0.043278760	-0.000003837
7015.00	-9.0093	-0.040648590	-0.040646340	-0.000002250
6940.00	-14.4118	-0.033953170	-0.033951640	-0.000001535
6865.00	-15.9133	-0.022961380	-0.022960940	-0.000000438
6790.00	-15.3376	-0.009762060		
↑ (1)	↑ (2)	↑ (3)	↑ (4)	

Figure 9-17. Typical list of cantilever radial deflections

(4) Deflection, in feet. (- is downstream.)

Figure 9-18 shows:

Left side (looking upstream):

(1) Arch length, in feet.

(2) Station along axis, in feet.

(3) Arch load, in kips per square foot.

(4) Arch deflection, in feet.

Right side (looking upstream):

(5) Arch length, in feet.

(6) Station along axis, in feet.

(7) Arch load, in kps per square foot.

(8) Arch deflection, in feet.

The term "abutment" used in this table is used as an indication of the side.

RADIAL ADJUSTMENT NO 3
ARCH AT ELEVATION 7165.00
ARCH LOADS, DEFLECTIONS, AND LENGTHS

LEFT ABUTMENT TO CROWN				RIGHT ABUTMENT TO CROWN			
LENGTH	STATION	LOAD	DEFLECTION	LENGTH	STATION	LOAD	DEFLECTION
0.00	1359.16	0.436	0.000191	0.00	640.84	0.435	0.000191
52.67	1305.63	0.462	-0.001148	52.67	694.37	0.462	-0.001136
90.70	1266.99	0.482	-0.007871	90.70	733.01	0.482	-0.007843
118.84	1238.39	0.257	-0.016424	118.84	761.61	0.257	-0.016383
145.93	1210.85	0.516	-0.027379	145.93	789.15	0.516	-0.027327
178.11	1178.16	0.462	-0.042881	178.11	821.84	0.462	-0.042820
353.41	1000.00	0.405	-0.103381	353.41	1000.00	0.405	-0.103381
↑ (1)	↑ (2)	↑ (3)	↑ (4)	↑ (5)	↑ (6)	↑ (7)	

Figure 9-18. Typical list of radial arch deflections

MOMENTS,THRUSTS,AND SHEARS AT ARCH POINTS DUE TOTAL LOADS
(PRINTED FROM LEFT ABUTMENT TO RIGHT ABUTMENT LOOKING UPSTREAM)

ARCH NUMBER 1 AT ELEVATION 7165.00

STATION	MOMENT	THRUST	SHEAR
1359.16	38473.	289674.	30273.
1305.63	-200233.	271081.	13935.
1266.99	-212841.	239596.	5740.
1238.39	-210082.	210367.	-859.
1210.85	-158348.	186014.	-4716.
1178.16	-73918.	169793.	-4126.
1000.00	276350.	145955.	-2.
821.84	-74303.	169758.	-4111.
789.15	-158548.	185991.	-4701.
761.61	-210140.	210353.	-848.
733.01	-212776.	239585.	5747.
694.37	-200020.	271068.	13944.
640.84	39025.	289651.	30288.

Figure 9-19. Summary of moments, thrusts, and shears in arches

Figure 9-20 shows:

(1) Elevation, in feet.

(2) Radial bending moments, in foot-pounds per foot of axis, of live load carried by the arches.

(3) Radial bending moments, in foot-pounds per foot of axis, from differential cantilever torque.

(4) Radial bending moments, in foot-pounds per foot of axis, from initial cantilever live loads and concrete weight.

(5) Net radial cantilever bending moments per foot of axis, in foot-pounds. This is the sum of the ABC columns which are the cantilever moments used to compute face stresses.

* TOTAL MOMENT OF CANTILEVER(M),ONE FOOT WIDE AT THE AXIS,
ABOUT CENTER OF GRAVITY OF HORIZONTAL SECTION

DEFINITIONS
A = SUMMATION OF RADIAL BENDING MOMENTS DUE RADIAL CANTILEVER LOADS
B = RADIAL BENDING MOMENTS DUE TO TWIST EFFECTS
C = RADIAL BENDING MOMENTS DUE TO CONCRETE AND INITIAL LOAD

.
.
.
.

CANTILEVER NO 19

ELEVATION	A	B	C	MOMENT
7165.00	0.	0.	0.	0.
7090.00	5165852.	-129026.	-5090979.	-54154.
7015.00	37232150.	829501.	-38242060.	-180412.
6940.00	125785700.	4334045.	-126673100.	3446680.
6865.00	300691100.	9316602.	-296232500.	13775230.
6790.00	572810600.	15529360.	-571533200.	16806640.
↑	↑	↑	↑	↑
(1)	(2)	(3)	(4)	(5)

Figure 9-20. Summary of cantilever moments

Figure 9-21 shows:

(1) Elevation, in feet.

(2) Reciprocal of cantilever area, in square feet.

(3) Distance from upstream face to centroid divided by moment of inertia.

(4) Distance from downstream face to centroid divided by moment of inertia.

(5) Tangential shear, in kips per foot of elevation (see Figure 9-37 for meaning of sign convention).

(6) Cantilever twisting moment (torque), in foot-pounds per foot of elevation (see Figure 9-37 for meaning of sign convention).

(7) Shear stresses, in pounds per square foot, on the upstream and downstream faces.

```
                *SHEAR STRESSES(TXZ) IN HORIZONTAL PLANES OF CANTILEVER ELEMENTS
                               (ACTING IN TANGENTIAL DIRECTION)
DEFINITIONS
  AC = AREA OF HORIZONTAL CANTILEVER SECTION
  LG = DISTANCE FROM UPSTREAM FACE TO CENTER OF GRAVITY OF HORIZONTAL CANTILEVER SECTION
  IC = MOMENT OF INERTIA OF HORIZONTAL CANTILEVER SECTION
  T = THICKNESS OF DAM IN RADIAL DIRECTION
  VTA = TOTAL HORIZONTAL TANGENTIAL SHEAR FORCE
  MTW = TOTAL TWISTING MOMENT ON HORIZONTAL CANTILEVER SECTION
                   .
                   .
                   .
                   .
                   .
```

CANTILEVER NO 19

ELEVATION	1/AC	LG/IC	(T-LG)/IC	VTA	MTW	SHEAR STRESS POUNDS/SQ.FT. UPSTREAM	SHEAR STRESS POUNDS/SQ.FT. DOWNSTREAM
7165.00	0.08468789	0.04211793	0.04257699	0.	0.	0.	0.
7090.00	0.03117524	0.00580093	0.00598324	-90453.	-220469.	4099.	1501.
7015.00	0.02131040	0.00272251	0.00285902	-146570.	-544268.	4605.	1567.
6940.00	0.01774720	0.00187096	0.00199568	62979.	-4408982.	7131.	-9917.
6865.00	0.01626780	0.00152632	0.00165251	546631.	-12405410.	10042.	-29393.
6790.00	0.01577456	0.00135433	0.00149115	1244546.	-18056380.	4822.	-46557.
↑ (1)	↑ (2)	↑ (3)	↑ (4)	↑ (5)	↑ (6)	↑ (7)	↑ (7)

Figure 9-21. Shear stresses in the horizontal planes

Figure 9-21 is useful to explain tension along the toe, which is caused by torque and not flexure. The shear stress downstream face of (7) is mitigated by shifting the cantilever base upstream; the optimum amount is the eccentricity calculated by dividing (6) by (5) at the base elevation.

Figure 9-23 shows:

(1) Elevation, in feet.

ARCH STRESS PARALLEL TO FACES
STRESSES PRINTED FROM LEFT ABUTMENT TO RIGHT ABUTMENT LOOKING UPSTREAM

ARCH NUMBER 1 AT ELEVATION 7165.00

			ARCH FORCES				TAN		ARCH STRESSES (PSF)	
STATION	1/AREA	C/I	MOMENT	THRUST	SHEAR	BETA	PHID	TXZD	EXTRADOS	INTRADOS
1359.16	0.083332	0.041665	38473.	289674.	30273.	0.000084	0.000000	0.	25742.	22536.
1305.63	0.083332	0.041665	-200233.	271081.	13935.	0.000084	0.000000	0.	14247.	30932.
1266.99	0.083332	0.041666	-212841.	239596.	5740.	0.000075	0.000000	0.	11098.	28834.
1238.39	0.083332	0.041666	-210082.	210367.	-859.	0.000068	0.000000	0.	8777.	26284.
1210.85	0.083333	0.041666	-158348.	186014.	-4716.	0.000061	0.000000	0.	8903.	22099.
1178.16	0.083333	0.041666	-73918.	169793.	-4126.	0.000053	0.000000	0.	11069.	17229.
1000.00	0.083334	0.041667	276350.	145955.	-2.	0.000000	0.000000	0.	23678.	648.
821.84	0.083333	0.041666	-74303.	169758.	-4111.	0.000053	0.000000	0.	11050.	17242.
789.15	0.083333	0.041666	-158548.	185991.	-4701.	0.000061	0.000000	0.	8893.	22105.
761.61	0.083332	0.041666	-210140.	210353.	-848.	0.000068	0.000000	0.	8774.	26285.
733.01	0.083332	0.041666	-212776.	239585.	5747.	0.000075	0.000000	0.	11100.	28831.
694.37	0.083332	0.041665	-200020.	271068.	13944.	0.000084	0.000000	0.	14255.	30922.
640.84	0.083332	0.041665	39025.	289651.	30288.	0.000084	0.000000	0.	25763.	22511.

Figure 9-22. Summary of arch stresses parallel to faces

* CANTILEVER STRESSES PARALLEL TO FACE

DEFINITIONS
PHIU = SLOPE UPSTREAM EDGE OF CANTILEVER MAKES WITH VERTICAL
PHID = SLOPE DOWNSTREAM EDGE OF CANTILEVER MAKES WITH VERTICAL
BETAD = ANGLE BETWEEN RE AND RI AT THE DOWNSTREAM FACE IN DEGREES
PU = NORMAL PRESSURE AT UPSTREAM FACE OF DAM
PD = NORMAL PRESSURE AT DOWNSTREAM FACE OF DAM
CW = TOTAL WEIGHT OF CANTILEVER, INCLUDING VERTICAL WATER LOAD
CM= TOTAL MOMENT OF CANTILEVER

CANTILEVER NO 19

ELEVATION	1/AC	LG/IC	(T-LG)/IC	BETAD	PHIU	PHID	PU	PD	CW	CM	CANTILEVER STRESSES POUNDS/SQ.FT. UPSTREAM	DOWNSTREAM
7165.00	0.08469	0.04212	0.04258	0.0001	0.00000	0.00000	0.	0.	0.	0.	0.	0.
7090.00	0.03118	0.00580	0.00598	0.0186	0.19387	0.02562	4688.	0.	300936.	-54154.	9232.	9712.
7015.00	0.02131	0.00272	0.00286	1.3007	0.09242	0.06782	9375.	0.	830236.	-180412.	17268.	18288.
6940.00	0.01775	0.00187	0.00200	4.0618	-0.00027	0.09692	14063.	0.	1461790.	3446680.	32391.	19384.
6865.00	0.01627	0.00153	0.00165	7.1146	-0.08635	0.16557	18750.	0.	2066556.	13775230.	54911.	12407.
6790.00	0.01577	0.00135	0.00149	10.3795	-0.16787	0.22862	23438.	0.	2551228.	16806640.	64121.	20012.
↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)

Figure 9-23. Cantilever stresses parallel to faces

(2) Reciprocal of the cantilever area, in square feet.

(3) Section modulus measured from the upstream face to the cantilever centroid.

(4) Section modulus measured from the downstream face to the cantilever centroid.

(5) The horizontal angle on the downstream face, in degrees, between a line to the extrados center and the intrados center.

(6) The tangent the slope on the upstream face makes with the vertical. (+ is dipping upstream.)

(7) The tangent the slope on the downstream face makes with the vertical. (+ is dipping downstream.)

(8) The reservoir hydrostatic pressure on the axis, in pounds per square foot.

(9) The tailwater hydrostatic pressure on the axis, in pounds per square foot.

(10) The total weight of the cantilever, including vertical water pressure, in pounds.

(11) The total moment of the live loads distributed to the cantilevers plus the dead load, in foot-pounds.

(12) Cantilever stress parallel to the upstream face, in pounds per square foot.

(13) Cantilever stress parallel to the downstream face, in pounds per square foot.

"PHIU" and "PHID" are useful in assessing the increase in resolving the normal stresses to stresses parallel to the plane of the face. The normal stress is multiplied by $SEC^2 \phi$ to compute the increase; note that Tau-XZ is also resolved to the plane of the face.

Figure 9-24 shows:

(1) Elevation, in feet. These elevations begin at the left side (looking upstream) crest contact and proceed down to the crown cantilever base and up to the right side (looking upstream) crest.

(2) The resultant of forces, in pounds, in the XY (horizontal) plane. (+ is toward the abutment.)

(3) The angle, in degrees, the resultant makes with the tangent (x-direction). (+ is rotation toward the upstream.)

(4) The resultant of forces, in pounds, in the XZ plane (vertical plane in the tangent direction). (+ is toward the abutment.)

(5) The angle, in degrees, the resultant dips from the horizontal. (+ is dipping from the horizontal into the abutment.)

(6) The resultant from the vertical and radial forces, in pounds.

(7) The angle of the resultant from horizontal, in degrees. (+ is dipping downstream.)

```
                                        RESOLUTION OF FORCES AND MOMENTS ON ABUTMENTS
     DEFINITIONS
       R-XY,R-XZ,R-YZ,R-XYZ = RESULTANT FORCES ON A ONE FOOT WIDE FOUNDATION.
       A-XY,A-XZ,A-YZ,A-XYZ = ANGULAR LOCATIONS OF FORCES,I.E.,A-XY IS THE ANGLE MEASURED FROM X(TANGENTIAL)
                              TOWARD Y(RADIAL). (+)A-XY IS UPSTREAM. A-XZ,A-YZ, AND A-XYZ ARE THE DIPS OF
                              THE RESULTANTS. (+) IS DOWNWARD.
       ECC = ECCENTRICITY OF R-XYZ FROM THE CENTER OF THICKNESS ON THE FOUNDATION. (+) IS UPSTREAM.
       Q = SHEAR FRICTION FACTOR OF SAFETY ALONG THE PLANE OF THE ABUTMENT. Q1 IS IN THE RADIAL DIRECTION
           ( + IS UPSTREAM), Q2 IS IN THE DIRECTION NORMAL TO RADIAL( + IS DOWN).
   NOTE - THE ELEVATIONS ARE LISTED SEQUENTIALLY DOWN THE RIGHT SIDE OF THE DAM AND THEN UP THE LEFT SIDE
   LOOKING UPSTREAM.


ELEVATION      XY PLANE             XZ PLANE             YZ PLANE            XYZ PLANE           ECC          Q
               R        A           R        A           R        A          R        A                    Q1      Q2

*** WARNING IN DC0850***
 7165.00     240943.   5.970     239637.   0.000      25058.   0.000     240943.   0.000      0.134     24.644   -4.588
 7090.00    1534525.   0.582    1536482.   2.950      80610.  78.846    1536561.   2.950     -2.242    132.954   -3.243
 7015.00    2641976.  -6.194    2632888.   3.975     338455.  32.631    2648272.   3.952     -7.730    -11.699   -4.250
 6940.00    3317245. -12.087    3283889.   8.972     863008.  36.402    3356547.   8.777    -11.789     -6.023   -6.993
 6865.00    3449426. -18.028    3531574.  21.754    1689026.  50.798    3689401.  20.779    -12.544     -4.296  -52.171
 6790.00    2643742. -27.446    3620586.  49.608    3014781.  66.160    3820139.  46.207     -5.431     -3.860 -112.286
 6700.00    1570680.  90.000    3114826.  90.000    3488435.  63.240    3488435.  63.240     -4.065      2.412  121.636
 6790.00    2643742. -27.446    3620581.  49.608    3014780.  66.160    3820136.  46.207     -5.431     -3.860 -112.284
 6865.00    3449415. -18.028    3531567.  21.754    1689019.  50.799    3689391.  20.779    -12.544     -4.296  -52.172
 6940.00    3317241. -12.087    3283883.   8.972     863015.  36.402    3356544.   8.777    -11.789     -6.023   -6.993
 7015.00    2641974.  -6.193    2632887.   3.975     338448.  32.632    2648270.   3.952     -7.729    -11.700   -4.250
 7090.00    1534534.   0.582    1536492.   2.951      80622.  78.848    1536571.   2.951     -2.242    132.951   -3.243
*** WARNING IN DC0850***
 7165.00     240961.   5.966     239656.   0.000      25045.   0.000     240961.   0.000      0.132     24.657   -4.587
    ↑           ↑        ↑          ↑        ↑           ↑        ↑          ↑        ↑          ↑          ↑        ↑
   (1)         (2)      (3)        (4)      (5)         (6)      (7)        (8)      (9)        (10)       (11)     (12)
```

Figure 9-24. Resolution of forces and moments on abutments

(8) The resultant of forces in the X, Y, and Z directions, in pounds.

(9) The angle from R-XY (horizontal) of the R-XYZ resultant in the vertical plane, in pounds. (+ is dipping downstream.)

(10) The eccentricity of the resultant from the abutment mid-thickness, in feet. (+ is upstream.) Eccentricity is the arch and cantilever moments resolved in a plane normal to the abutment divided by the resultant.

(11) The shear friction factor of safety based on an assumed cohesion of 300 psi acting on a 1-ft-wide by abutment thickness area plus the normal force and tan phi equal one. The sum is divided by the radial component of the resultant. (+ is upstream.) This local shear friction factor has no real meaning to the arch dam stability but only serves to provide an intuitive feeling for the relative effects of sliding stability around the dam perimeter.

(12) The sliding stability in the direction normal to Q1. (+ is down.) The driving force is the resultant component normal to the radial component from Q1.

* SHEAR STRESSES ON ROCK PLANE AT U.S. AND D.S. FACES
(ACTING IN RADIAL DIRECTION)

DEFINITIONS
BETA = TANGENT OF ANGLE BETWEEN RE AND RI AT THE DOWNSTREAM FACE
PHI = SLOPE OF FACE CANTILEVER MAKES WITH VERTICAL
TZY = HORIZONTAL CANTILEVER SHEAR STRESS ACTING IN RADIAL DIRECTION ON A HORIZONTAL PLANE(POUNDS/SQ.FT.)
TXY = HORIZONTAL ARCH SHEAR STRESS ACTING IN RADIAL DIRECTION ON A VERTICAL RADIAL PLANE
TRY = TYZ*SIN(SI)+TXY*COS(SI)
SI = ANGLE A TANGENT TO AN ABUTMENT POINT MAKES WITH THE VERTICAL

CANTILEVER	PHIU	PHID	BETA	TZYU	TZYD	TXYU	TXYD	SI	TRYU	TRYD
15	0.03743	0.17616	0.00050	-147.	1574.	116.	-14.	0.48060	35.	715.
16	0.00185	0.21334	0.03114	-15.	3378.	23.	5386.	0.37195	16.	6246.
17	-0.05611	0.17746	0.08837	909.	4471.	-782.	13855.	0.33980	-434.	14553.
18	-0.11274	0.21020	0.14118	2921.	8220.	-1297.	22591.	0.40457	-43.	24003.
19	-0.16787	0.22862	0.18316	6642.	11999.	-809.	25579.	0.87740	4591.	25577.
20	-0.21530	0.20720	0.00000	-1636.	20161.	0.	0.	1.56079	-1636.	20160.
21	-0.16787	0.22862	0.18316	6642.	11999.	-809.	25579.	0.87740	4591.	25577.
22	-0.11274	0.21020	0.14118	2921.	8218.	-1297.	22591.	0.40457	-42.	24002.
23	-0.05611	0.17746	0.08837	909.	4470.	-782.	13855.	0.33980	-434.	14553.
24	0.00185	0.21334	0.03114	-15.	3378.	23.	5386.	0.37195	16.	6245.
25	0.03743	0.17616	0.00050	-147.	1574.	116.	-14.	0.48060	35.	715.

Figure 9-25. Shear stresses on rock plane at faces

Figure 9-26 shows:

(1) Station along the axis, in feet.

(2) Extrados stress normal to the extrados radius, in pounds per square inch; (+) is compression.

(3) Intrados stress normal to the extrados radius, in pounds per square inch.

(4) Extrados stress in the plane parallel to the face, in pounds per square inch.

(5) Intrados stress in the plane parallel to the face, in pounds per square inch.

(6) Maximum shear stress along the abutment, in pounds per square inch.

STRESSES(PSI) FOR ARCH NO 1 AT ELEVATION 7165.00
STRESSES PRINTED FROM LEFT ABUTMENT TO RIGHT ABUTMENT LOOKING UPSTREAM

STATION	NORMAL TO RE		PARALLEL TO FACES		TXYM
	EXTRADOS	INTRADOS	EXTRADOS	INTRADOS	MAX.
1359.16	179.	157.	179.	157.	-26.
1305.63	99.	215.	99.	215.	
1266.99	77.	200.	77.	200.	
1238.39	61.	183.	61.	183.	
1210.85	62.	153.	62.	153.	
1178.16	77.	120.	77.	120.	
1000.00	164.	5.	164.	5.	
821.84	77.	120.	77.	120.	
789.15	62.	154.	62.	154.	
761.61	61.	183.	61.	183.	
733.01	77.	200.	77.	200.	
694.37	99.	215.	99.	215.	
640.84	179.	156.	179.	156.	-26.
↑	↑	↑	↑	↑	↑
(1)	(2)	(3)	(4)	(5)	(6)

Figure 9-26. Summary table for arch stresses

Arch stresses are computed at each face both normal to a line radial to the extrados and resolved into the tangent to the curve of each face. The resolution includes shear stresses and water pressure where appropriate. Normal stresses are computed from the equation $H/A \pm Mc/I$.

Figure 9-27 shows:

(1) Elevation, in feet.

(2) Vertical stresses at the upstream face of the horizontal section through cantilevers, in pounds per square inch.

(3) Vertical stresses at the downstream face of the horizontal section through cantilevers, in pounds per square inch.

(4) Stresses, in pounds per square inch, in the plane tangent to the upstream face.

(5) Stresses, in pounds per square inch, in the plane tangent to the downstream face.

Maximum rock plane shear is the maximum shear stress in the plane of the abutment caused by resolution of both arch and cantilever shear stresses acting on that plane. Cantilever stresses are computed normal to the horizontal section and in the plane tangent (parallel) to the face. Stresses parallel to the face include the shear component Tau-XZ in the resolution of forces.

STRESSES(PSI) FOR CANTILEVER NO 19

	VERTICAL STRESSES		PARALLEL STRESSES	
ELEVATION	US FACE	DS FACE	US FACE	DS FACE
7165.00	0.	0.	0.	0.
7090.00	63.	67.	64.	67.
7015.00	119.	126.	120.	127.
6940.00	225.	132.	225.	135.
6865.00	379.	75.	381.	86.
6790.00	438.	105.	445.	139.
↑ (1)	↑ (2)	↑ (3)	↑ (4)	↑ (5)

Figure 9-27. Summary table of cantilever stresses

PRINCIPAL STRESSES (PSI) ON CANTILEVER 19

AT THE UPSTREAM FACE					AT THE DOWNSTREAM FACE				
			ALPHA				ALPHA		
ELEV	PI	P2	DEG	MIN	P1	P2	DEG	MIN	ELEV
7165.0	0.	77.	0	0	0.	120.	0	0	7165.0
7090.0	60.	294.	7	11	67.	404.	1	46	7090.0
7015.0	119.	328.	8	47	127.	537.	1	29	7015.0
6940.0	291.	298.	34	18	124.	642.	-7	52	6940.0
6865.0	398.	89.	-13	29	13.	760.	-17	5	6865.0
6790.0	447.	-118.	-3	27	-62.	785.	-26	50	6790.0

Figure 9-28. Principal stress by cantilever

Figure 9-29 shows:

(1) Elevation, in feet.

(2) P1 is the major principal stress, in pounds per square inch, on the upstream face. (+ is compression.)

(3) P2 is the minor principal stress, in pounds per square inch, on the upstream face. (+ is compression.)

(4) ALPHA is the angle, in degrees and minutes, of the direction the major principal stress, P1, makes as measured from the vertical. (+) ALPHA is clockwise on the left side looking upstream and counterclockwise on the right side looking upstream as shown in Figure 9-25.

(5) CANT NO is the cantilever number where 20 is the crown cantilever; numbers greater than 20 are on the left side, and numbers less than 20 are on the right side.

(6) Major principal stress, P1, on the downstream face, in pounds per square inch.

(7) Minor principal stress, P2, on the downstream face, in pounds per square inch.

(8) ALPHA is the angle P1 makes with the vertical, in degrees and minutes. (+ is clockwise on the left side and counter-clockwise on the right side.)

(9) Elevation, in feet.

PRINCIPAL STRESSES (PSI) PARALLEL TO THE FACES AT THE ABUTMENTS

LEFT ABUTMENT (LOOKING UPSTREAM)

AT THE UPSTREAM FACE						AT THE DOWNSTREAM FACE				
			ALPHA		CABT			ALPHA		
ELEV	P1	P2	DEG	MIN	NO	P1	P2	DEG	MIN	ELEV
7165.0	0.	179.	0	0	26	0.	157.	0	0	7165.0
7090.0	57.	232.	7	7	25	54.	538.	0	15	7090.0
7015.0	180.	-9.	-33	42	24	99.	784.	-5	24	7015.0
6940.0	243.	-84.	-18	14	23	100.	880.	-9	10	6940.0
6865.0	328.	-94.	-11	-11	22	60.	884.	-76	57	6865.0
6790.0	447.	-118.	-3	-3	21	-62.	785.	-26	50	6790.0
6700.0	147.	0.	0	0	20	705.	0.	0	0	6700.0

RIGHT ABUTMENT (LOOKING UPSTREAM)

AT THE UPSTREAM FACE						AT THE DOWNSTREAM FACE				
			ALPHA		CABT			ALPHA		
ELEV	P1	P2	DEG	MIN	NO	P1	P2	DEG	MIN	ELEV
7165.0	0.	179.	0	0	14	0.	156.	0	0	7165.0
7090.0	57.	232.	7	7	15	64.	538.	0	15	7090.0
7015.0	180.	-9.	-33	42	16	99.	784.	-5	24	7015.0
6940.0	243.	-84.	-18	14	17	100.	880.	-9	10	6940.0
6865.0	328.	-94.	-11	-11	18	60.	884.	-76	57	6865.0
6790.0	447.	-118.	-3	-3	19	-62.	785.	-26	50	6790.0
↑ (1)	↑ (2)	↑ (3)	↑ (4)		↑ (5)	↑ (6)	↑ (7)	↑ (8)		↑ (9)

Figure 9-29. Principal stresses parallel to the faces at the abutments

As shown in Figure 9-30, P2 is 90° from P1. To make all ALPHA values positive, ALPHA is subtracted from 90°, and the stress values of P1 and P2 are reversed.

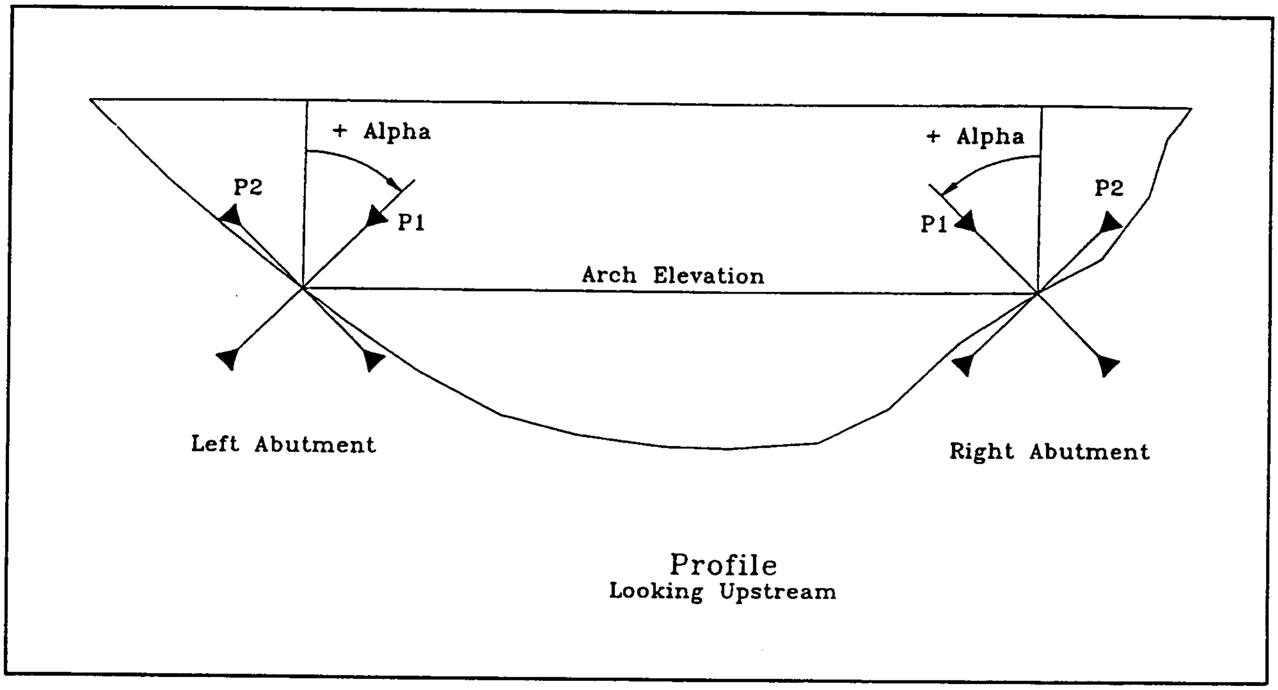

Figure 9-30. Schematic of principal stress orientation of each face along the abutment

CANTILEVER STRESSES PARAL
LOOKING

ELEV	STA	1305.63	1266.99	1238.39	1210.85	1178.16	1000.00
	TAU	0.					
7165.	U	0.	0.	0.	0.	0.	
	D	0.	0.	0.	0.	0.	0.
	TAU	-13.					
7090.	U	60.	75.	66.	66.	64.	47.
	D	64.	50.	62.	64.	67.	90.
		TAU	48.				
7015.		U	122.	142.	130.	120.	60.
		D	106.	90.	109.	127.	211.
			TAU	103.			
6940.			U	211.	243.	225.	142.
			D	123.	101.	135.	277.
				TAU	167.		
6865.				U	312.	381.	356.
				D	143.	86.	196.
					TAU	178.	
6790.					U	445.	614.
					D	139.	54.
						TAU	140.
6700.						U	147.
						D	705.

Figure 9-31. Left-side cantilever stresses

LEL TO THE FACE OF THE DAM
UPSTREAM

821.84	789.15	761.61	733.01	694.37	
				0.	TAU
0.	0.	0.	0.	0.	
0.	0.	0.	0.	0.	
				-13.	TAU
64.	66.	66.	75.	60.	
67.	64.	62.	50.	64.	
			48.	TAU	
120.	130.	142.	122.		
127.	109.	90.	106.		
		103.	TAU		
225.	243.	211.			
135.	101.	123.			
	167.	TAU			
381.	312.				
86.	144.				
178.	TAU				
445.					
139.					

Figure 9-32. Right-side cantilever stresses

ARCH STRESSES PARALLEL
LOOKING

ELEV	STA	1359.16	1305.63	1266.99	1238.39	1210.85	1178.16	1000.00
	TAU	-26.						
7165.	E	179.	99.	77.	61.	62.	77.	164.
	I	157.	215.	200.	183.	153.	120.	5.
		TAU	-14.					
7090.		E	229.	181.	197.	233.	290.	526.
		I	538.	572.	543.	489.	403.	74.
			TAU	50.				
7015.			E	49.	121.	209.	323.	765.
			I	778.	715.	638.	537.	128.
				TAU	106.			
6940.				E	-52.	82.	264.	885.
				I	861.	763.	632.	200.
					TAU	159.		
6865.					E	-78.	106.	919.
					I	814.	696.	145.
						TAU	179.	
6790.						E	-116.	669.
						I	612.	72.

Figure 9-33. Left-side arch stresses

```
TO THE FACE OF THE DAM
UPSTREAM


  821.84    789.15     761.61     733.01     694.37     640.84

                                                         -26.        TAU
     77.       62.        61.        77.        99.      179.
    120.      154.       183.       200.       215.      156.

                                                -14.      TAU
    290.      233.       197.       181.       229.
    403.      489.       543.       572.       538.

                                     50.       TAU
    323.      209.       121.        49.
    537.      638.       715.       778.

                          106.       TAU
    264.       82.       -52.
    632.      763.       861.

               159.       TAU
    106.       -78.
    696.       814.

    179.       TAU
   -116.
    612.
```

Figure 9-34. Right-side arch stresses

```
  MAX-MIN ARCH STRESSES
            STRESSES (PSI)
ELEVATION    MAX     MIN
 7165.       215.      5.
 7090.       572.     74.
 7015.       776.     49.
 6940.       885.    -52.
 6865.       919.    -78.
 6790.       669.   -116.

THE OVERALL MAX-MIN VALUES WERE
MAX-  919.           MIN- -116.


  MAX-MIN CANTILEVER STRESSES
CANTILEVER           STRESSES(PSI)
  NUMBER             MAX      MIN
    15                62.  69444.
    16               122.     49.
    17               210.     62.
    18               310.     64.
    19               438.     63.
    20               676.     46.
    21               438.     63.
    22               310.     64.
    23               210.     62.
    24               122.     49.
    25                62.  69444.

OVERALL MAX-MIN STRESSES(PSI)
MAX= 676.            MIN=   46.


  MAX-MIN PRINCIPAL STRESSES
   PSI  ELEV. CANT.  FACE
   919. 6865.   20             US
  -118. 6790.   21             US
```

Figure 9-35. Summary of maximum and minimum arch, cantilever, and principal stresses

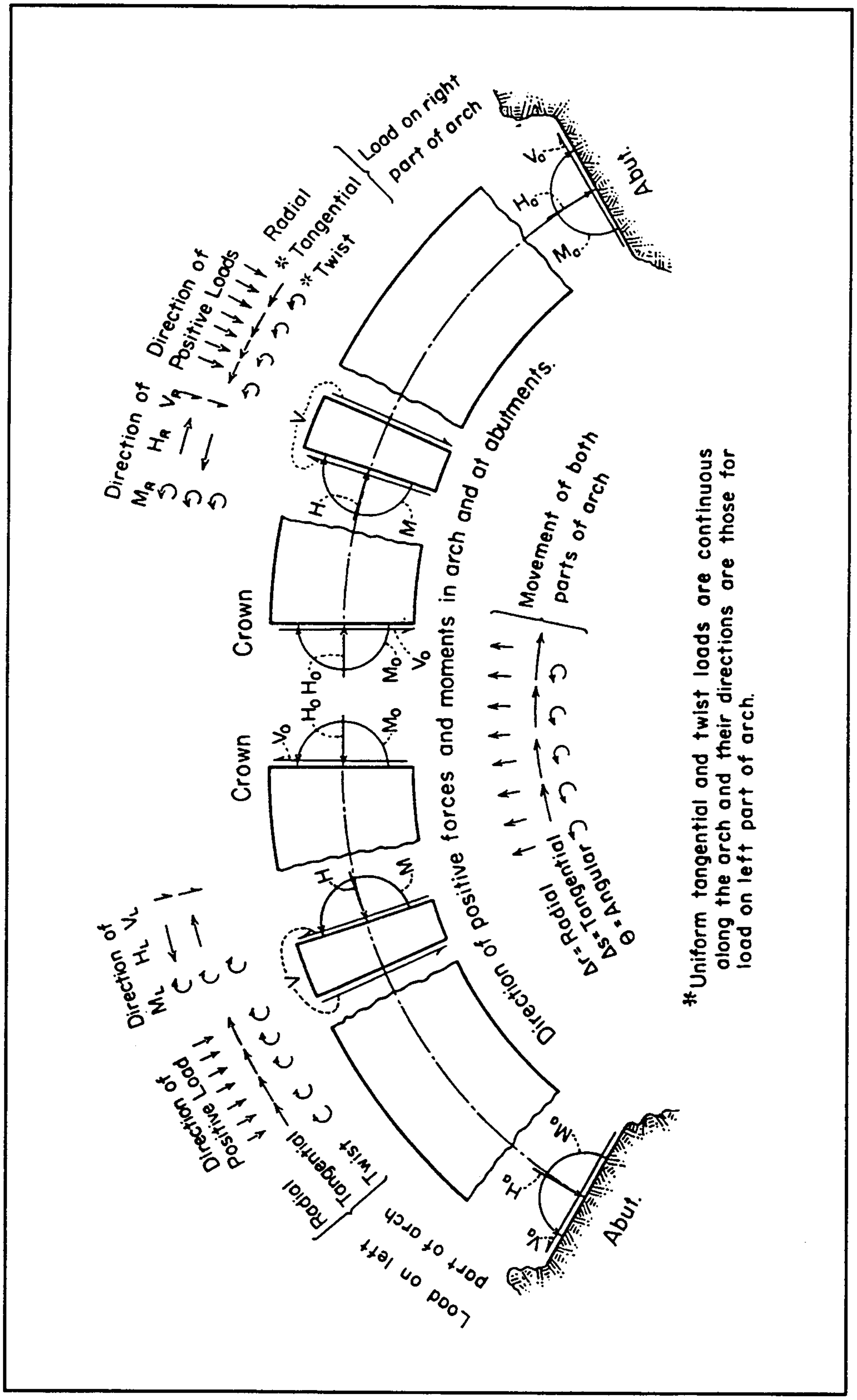

Figure 9-36. Direction of positive loads, forces, moments, and movements (USBR 1977a)

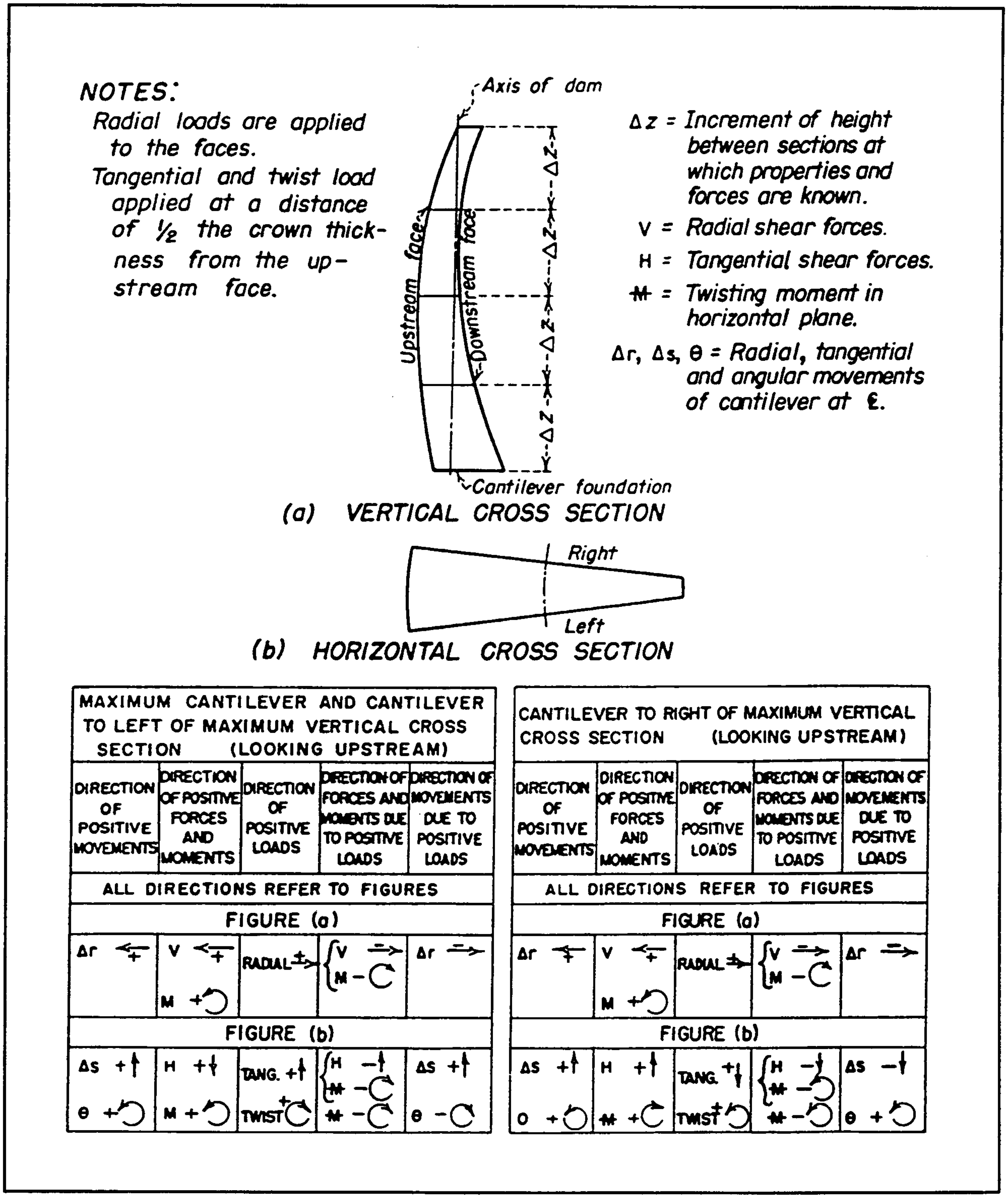

Figure 9-37. Direction of positive movements, forces, moments, and loads; and direction of forces, moments, and movements due to positive loads (USBR 1977a)

References

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Appendix A Definitions

Concrete arch dam terminology is not common to all engineers and is not universal. The terms used in this guide are defined below and are furnished to provide a clearer understanding of their use in the hopes of avoiding ambiguity.

Abutment - In ADSAS terms, the abutments are considered to be the rock supporting the arch elements. This is in contrast to the foundation, which is considered to support the cantilever elements.

Angle of compound curvature (Φ_{cc}) - In three-centered arch dams, the angle measured at the extrados center and located at the limit of the center segment is called the Φ_{cc}. The inner and outer circular arcs are compounded at that angle. Angles may be different on the left and right side.

Arch (Arch unit) - Arch (or arch unit) refers to a portion of the dam bounded by two horizontal planes, 1 ft apart. Arches may have uniform thickness or may be designed so that their thickness increases gradually on both sides of the reference plane (variable thickness arches).

Axis - Vertical reference surface, curved in plan and coincident with the extrados at the crest elevation. The three-centered arch dam's axis has three separate cylindrical surfaces.

Axis center - Vertical line(s) downstream from the axis representing the loci of centers for the axis.

Axis radius - Radius (or radii) of axis is equal to extrados radius (or radii) at crest elevation.

Base - Bottom surface of cantilever vertical element resting on foundation.

Cantilever (Cantilever unit) - Cantilever (or cantilever unit) is a portion of the dam contained between two vertical radial planes, 1 ft apart at the axis.

Central angle - Angle at extrados center formed by lines extended to arch abutments at the crest.

Closure temperature - The temperature at which there is no temperature stress in the dam. This is also referred to as the stress-free temperature condition. Typically the temperature at which the monolith joints are grouted. Also referred to as the grouting temperature.

Crest - The highest point of the dam capable of carrying loads by arch or cantilever action.

Crown cantilever - The maximum vertical section. The "crown" cantilever is so-named because it is the location of all the arch crowns.

Deformation modulus - The modulus of deformation of the rock mass. The deformation modulus will vary with the rock type and with the rock quality (RQD, joint spacing, joint orientation, etc.).

Double curvature - Arch dams which are curved vertically as well as horizontally.

Downstream projection - The horizontal distance from the axis to the downstream face (intrados).

Extrados - Curved upstream surface of horizontal arch elements.

Foundation - In ADSAS terms, the foundation is considered to be the rock supporting the cantilever elements. This is in contrast to abutment, which is considered to support the arch elements.

Free cantilever - A free cantilever is one which has no corresponding arch at its base. As such, its base is free to deflect independently of any arch deflections.

Intrados - The concave downstream surface of horizontal arch elements.

Line of centers (LOC) - The vertical reference line which describes the radii for each face of the various arch elements.

Reference plane - The plane which passes though the line of centers and both faces of the crown cantilever

Section - The part of the arch bounded by adjacent cantilever elements.

Single-center layout - A layout in which the upstream and downstream arch faces are each described by one center. If the upstream and downstream faces are described by the same center, then the arch will have a uniform thickness. If the upstream and downstream faces are described by different centers, then the arch will be of variable thickness.

Single curvature - Layouts in which only the arches are curved; i.e., the cantilevers are not curved.

Structural height - Vertical distance from crest of dam to base of maximum section.

Thickness - Horizontal distance between the upstream and downstream faces of the dam on line normal to the extrados or intrados.

Thickness, uniform - Arches which have a uniform or constant thickness between abutments at any given elevation.

Thickness, variable - Arches in which the thickness increases from the crown cantilever to each abutment. A variable thickness layout will increase the arch stiffness and spread the load from the arches to the abutment rock.

Three-center layout - A layout in which each arch face is described by three centers. Typically in a three-centered layout, there are three circular arch segments; a short radius segment and two long radii segments. Thus, each face approximates an ellipse.

Top arch - The highest arch which is capable of transferring load into the abutments.

Two-center layout - A layout in which each arch face is described by two centers; one for the left side and the other for the right side. Both centers are located on the reference plan. This shape is typically used for nonsymmetrical sites.

Upstream projection - Horizontal distance from the axis to the upstream face (extrados).

Voussoirs - Each section of an arch is divided into segments called voussoirs. Voussoirs are equal width sections of different thickness that provide better approximation of flexibility of variable thickness arches.

Appendix B
ADSAS Organization

ADSAS is the computerized version of the trial load method of analyzing arch dams. In ADSAS the following three primary load distribution adjustments between the arches and cantilevers are performed: (a) radial deflections, (b) tangential deflections, and (c) horizontal and vertical rotation. Each primary adjustment produces secondary movements that affect the other two deformations. The total procedure to arrive at acceptable deformations requires several cycles of radial, tangential, and twist adjustments until the differential deformations between successive cycles become sufficiently small. At that time, the solution process is complete and the total loads are used to compute stresses. The following summarize the steps used in ADSAS:

a. Compute the geometric properties of each arch and cantilever.

b. Compute the moments, forces, and deformations created by an applied unit load on each arch and cantilever at their common nodes of intersection.

c. Reorganize the data into a logical form within the computer.

d. Write out the stiffness matrix for each adjustment.

e. Solve each stiffness matrix for the live loads.

f. Iterate each adjustment until the secondary effects have been minimized and a load distribution between arches and cantilevers produces equal deformation at common nodes.

These loads are used to compute forces, moments, and stresses on each arch and cantilever face. A unit load is 1 kip placed at a node linearly reducing to zero at each of the adjacent nodes (see Figure B-1).

In ADSAS, abutment movement is not directly computed in the matrix solutions. At each abutment the cantilever deformation is set equal to the arch deformation. An exception to this is for the crown cantilevers and the free cantilevers whose foundation movements are computed from the distributed load and a linear extrapolation of loads at arches 1 and 2.

ADSAS is organized into what are called "links," which are distinct steps in the computer:

a. **Links 0 and 1** read the input data, check for errors on input, and compute the arch and cantilever geometric structural parameters.

b. **Link 2** computes the unit foundation deformations for each arch and cantilever.

c. **Link 3** (cantilever program) computes:

(1) Cantilever load effects which consist of moments, shears, and deformations from the initial loads.

(2) Radial, tangential, and twist reactions and deformations for each unit load of 1 kip peaking at each selected elevation on each cantilever.

d. **Link 4** (arch program) computes:

(1) Arch load effects which consist of deformations from uniform temperatures.

(2) Radial, tangential, and twist deformations from the moment, thrust, and shears from each unit load of 1 kip peaking at all cantilever intercepts on each arch and the abutment.

e. **Link 5** reorganizes the data generated in links 3 and 4.

f. **Link 6** writes out the arch and cantilever unit data and initial loads into matrix-type equations and partially solves the matrices. A standard equation/load matrix is formed for each primary solution of radial, tangential, and twist effects.

g. **Link 7** cycles the partial solutions until there is sufficient reduction in primary and secondary effects on the radial, tangential, and twist adjustments. Secondary effects are the unbalancing of deformations in the remaining two matrices due to the solution of the first matrix. For example, the radial solution will unbalance the tangential, twist arch, and cantilever deformations; the tangential solution will unbalance the radial and twist; and the twist will unbalance the radial and tangential deformation. This sequence is an adjustment cycle that is recycled several times until the change in secondary deflections is minimal.

h. **Link 8** uses the load distribution from link 7 to compute arch and cantilever moments, thrusts, weights, and shears for horizontal, vertical, and principal stresses.

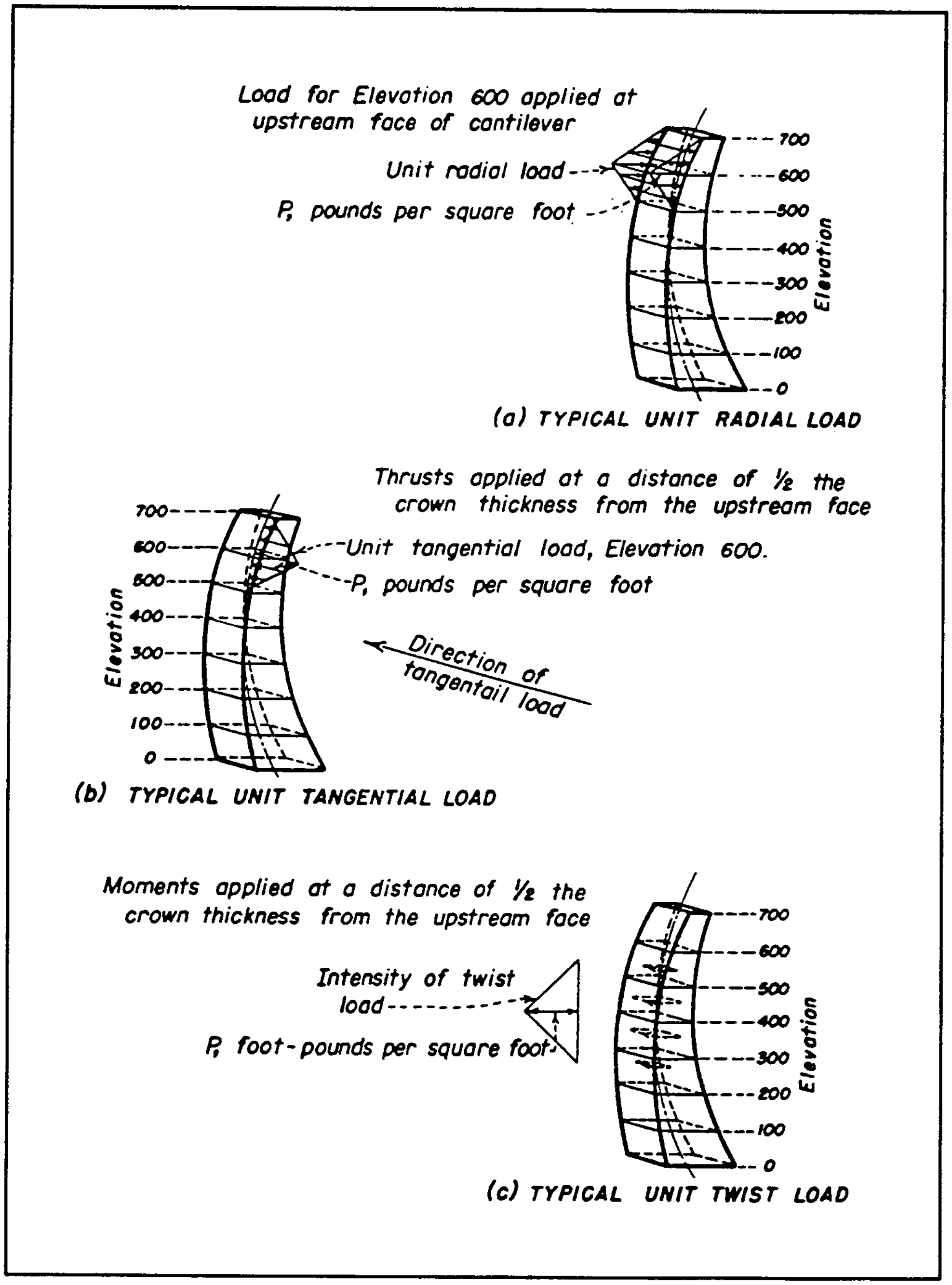

Figure B-1. Typical unit cantilever loads (USBR 1977a)

Appendix C
Example Input Files

This appendix contains layout drawings and input files for three arch dams and one gravity dam. These examples are illustrations of preliminary layouts and not necessarily the final design layout of the dams. These examples were selected only to demonstrate how an ADSAS input file is developed from the layout drawings.

Each example contains a plan view, developed profile, section along the reference plane, and the input file (Figures C-1 through C-16). The single-centered arch dam and the gravity dam have uniform thickness at each elevation while the two-centered and three-centered arch dams have a variable thickness in the lower arches. Included in the single-centered arch dam is a 2-ft-thick ice load (**13-3 card**). With the exception of the two-centered arch dam, all the examples have a spillway in the center of the dams. In the ADSAS input file these spillways are simulated by selecting the grout elevation equal to the crest of the spillway.

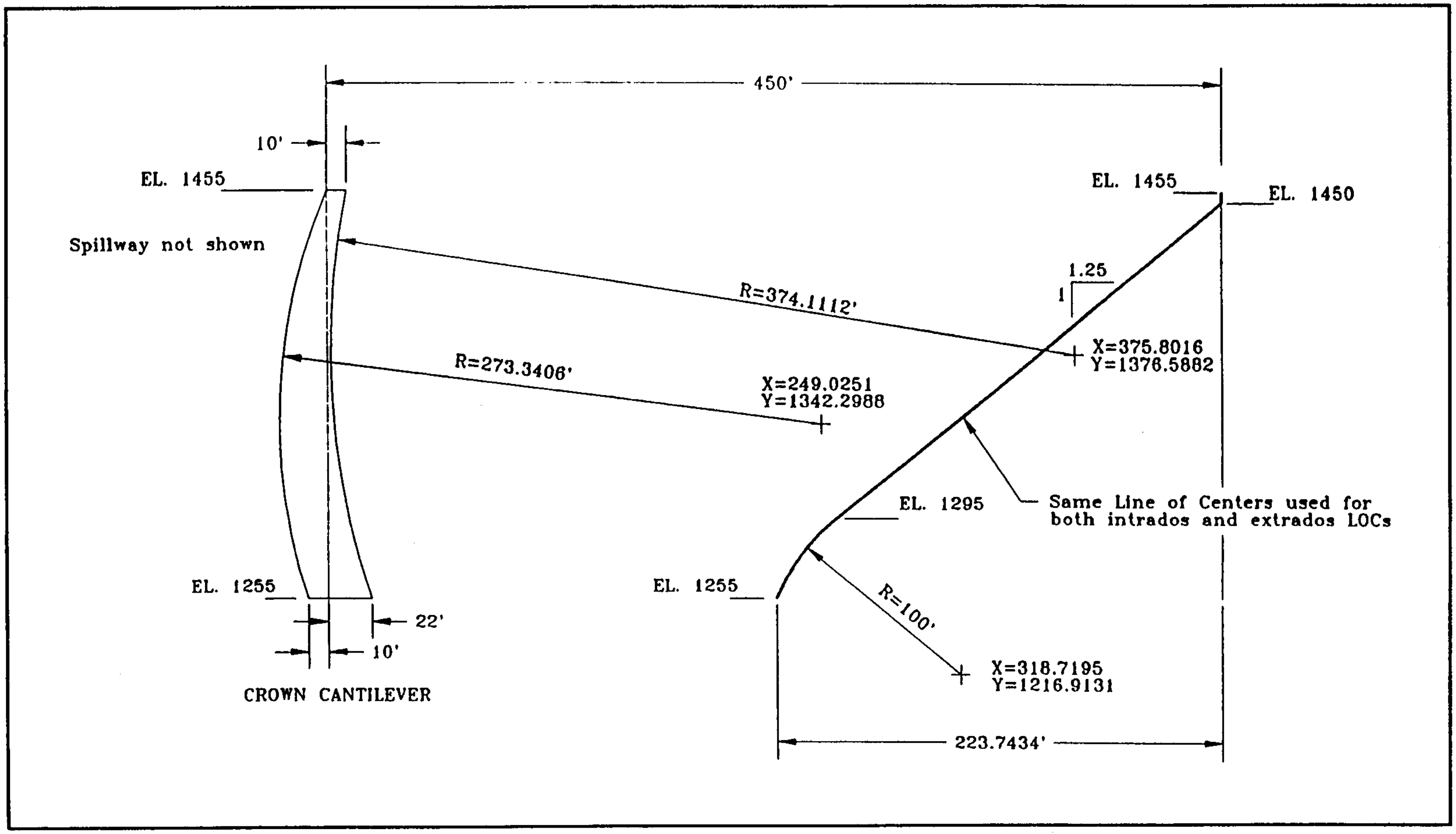

Figure C-1. Crown cantilever and line of centers for a single-centered arch dam

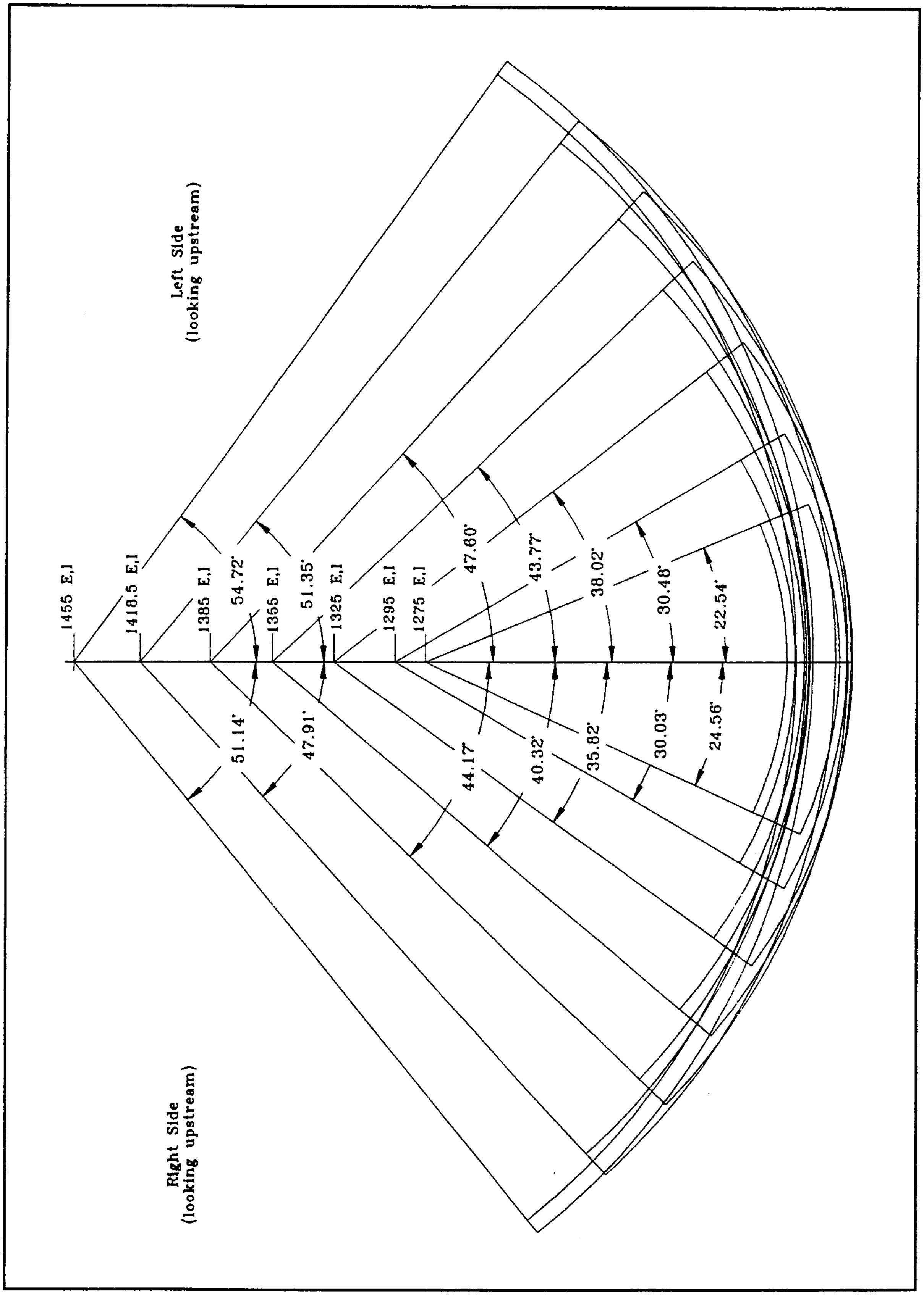

Figure C-2. Plan view of the single-centered example

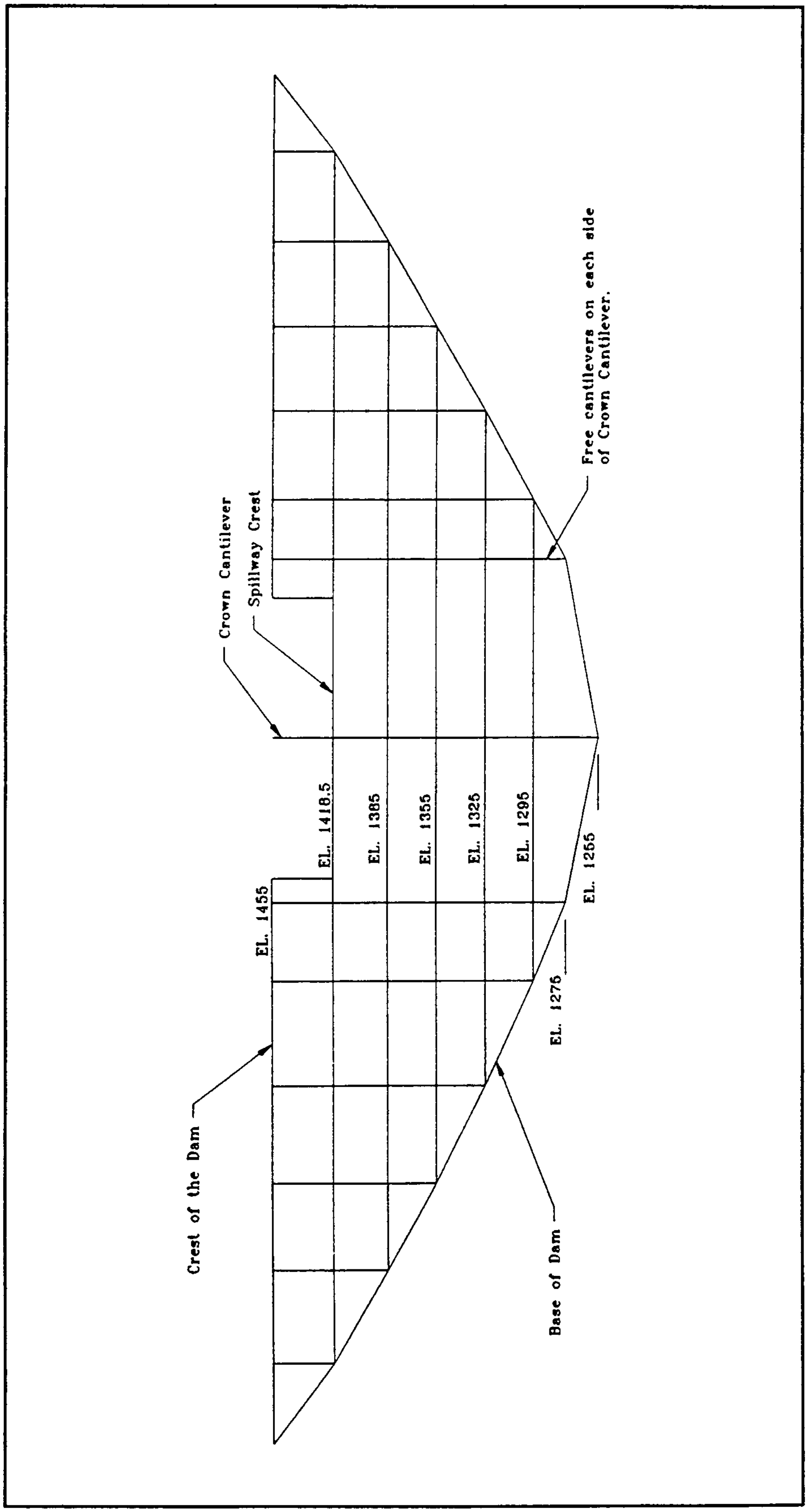

Figure C-3. Developed profile for the single-centered arch dam

```
MASTERIO  111011111
1   0     SINGLE-CENTERED DAM
2   0     011011101
3   0     30100101001      3.0    .16         150.0
4   0      1255.0   1455.0   1361.0  1270.0    1418.5
3   1       10.0      22.0      223.7434  223.7434  450.0       -.01    11  2
5   1 1 1    1455.0                 249.0251    1342.2988   273.3406
5   1 2 1    1455.0                 375.8016    1376.5882   374.1112
5   1 3 1    1295.0                 318.7195    1216.9131   100.0
5   1 3 2    1450.0       1.25
5   1 3 3    1455.0       0.0
5   1 4 1    1295.0                 318.7195    1216.9131   100.0
5   1 4 2    1450.0       1.25
5   1 4 3    1455.0       0.0
6   1         0.0     10.0
7   11      1255.0                                -9.60      3.0  3.0
7   15      1275.0    22.54  24.56                -9.82      3.0  3.0
7   10      1295.0    30.48  30.03               -10.04      3.0  3.0
7   10      1325.0    38.02  35.82               -10.78      3.0  3.0
7   10      1355.0    43.77  40.32               -12.17      3.0  3.0
7   10      1385.0    47.60  44.17               -13.96      3.0  3.0
7   10      1418.5    51.35  47.91               -16.42      3.0  3.0
7   10      1455.0    54.72  51.14               -20.44      3.0  3.0
1   2           1   1   111     1
1   4               1                                             1
1   3          1            1    1     0         1 1       1
13  3      10000.0    2.0
10005                                             2         1111
1  10      1             1
*ENDFILE
```

Figure C-4. Input file for the single-centered arch dam example

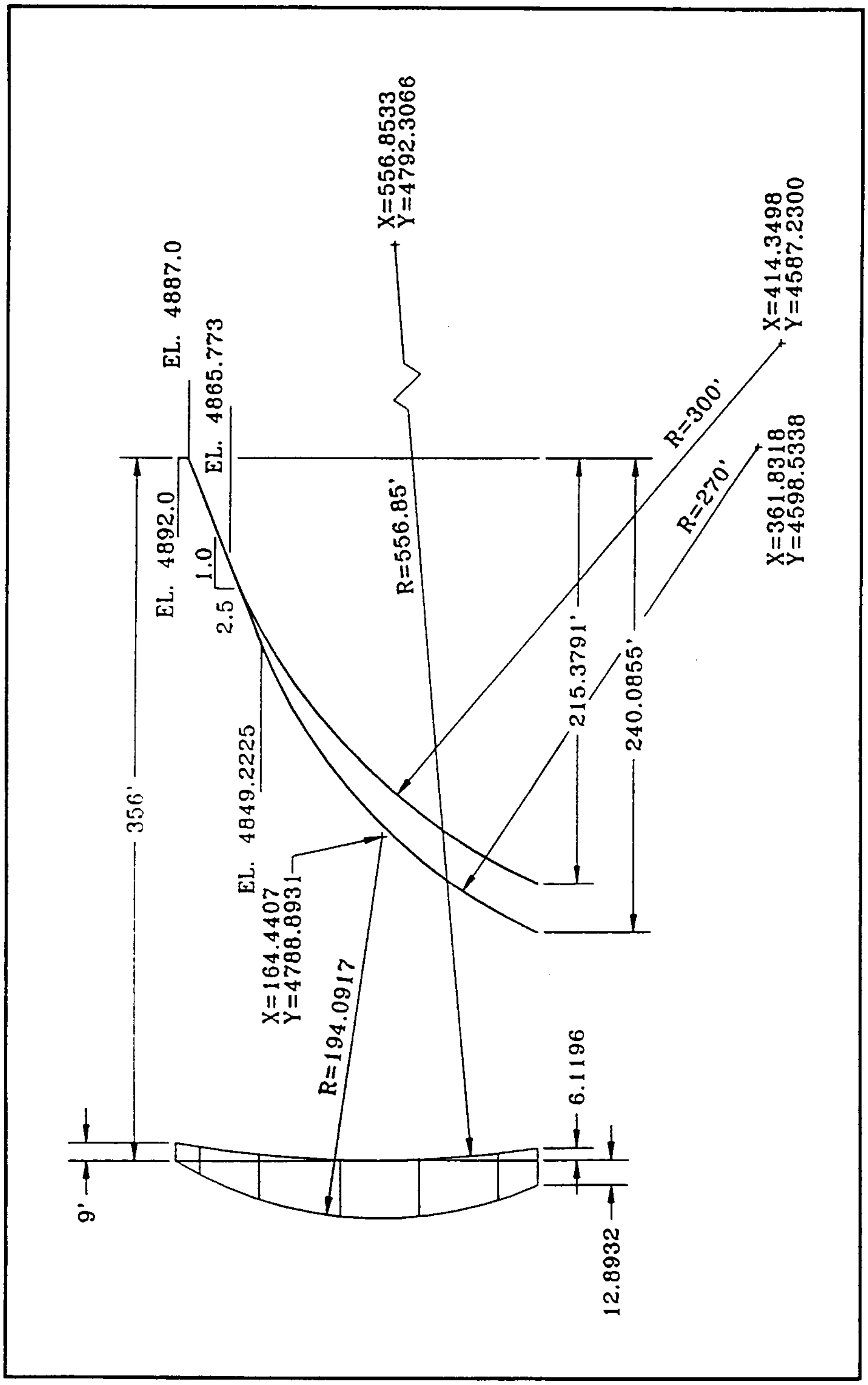

Figure C-5. Crown cantilever and left-side line of centers for the two-centered arch dam example

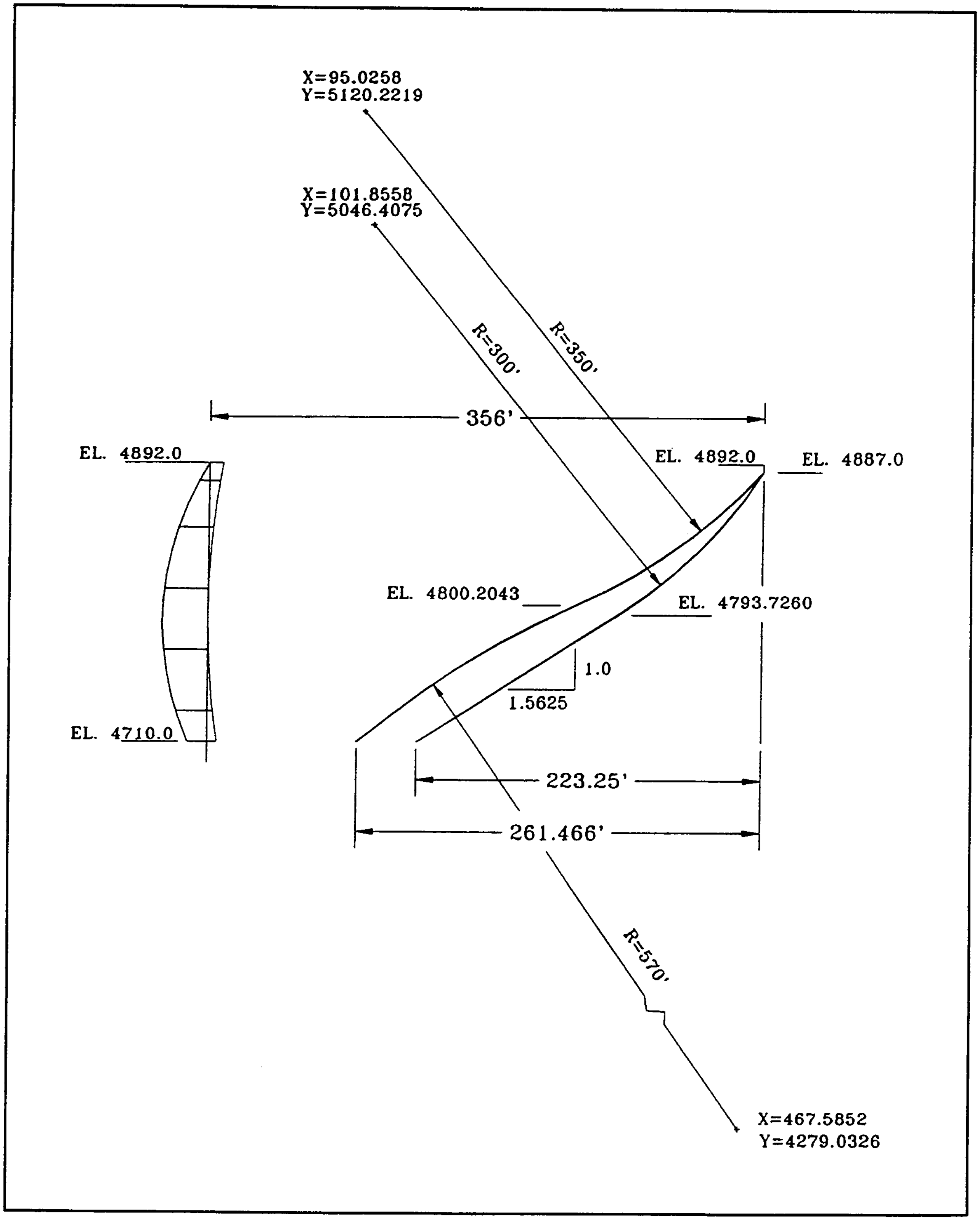

Figure C-6. Right-side line of centers for the two-centered arch dam example

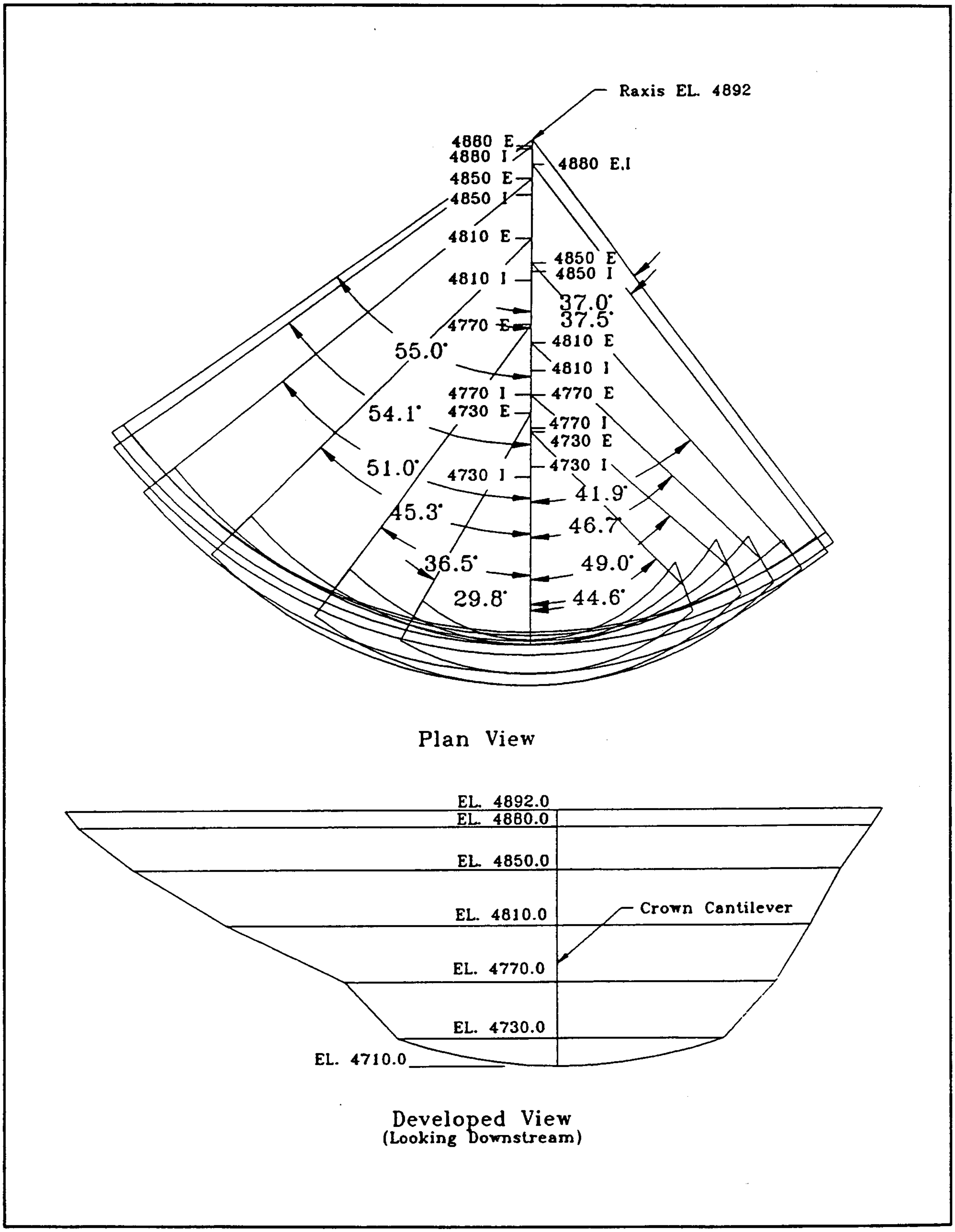

Figure C-7. Plan view and developed profile for the two-centered arch dam example

```
MASTERIO  111011111
1   0     TWO-CENTERED LAYOUT       11
2   0     011011101
3   0     30110000 1000    3.0    .20   5.5  150.0   2.0    .20
4   0     4710.0    4892.0   4882.0     0.    4892.0
3   1       12.8932   6.1196    240.0855  215.3791  356.0        -.01 11 2
4   1       261.466   223.25    356.0
5   1 1 1   4892.                    164.4407   4788.8931    194.0917
5   1 2 1   4892.                    556.8500   4792.3066    556.8500
5   1 3 1   4849.2225                361.8318   4598.5338    270.000
5   1 3 2   4887.       2.500                                  0.0
5   1 3 3   4892.         0.0                                  0.0
5   1 4 1   4865.7730                414.3498   4587.2300    300.000
5   1 4 2   4887.       2.500                                  0.0
5   1 4 3   4892.         0.0                                  0.0
5   1 5 1   4800.2043                467.5852   4279.0326    570.000
5   1 5 2   4887.                     95.0258   5120.2219   -350.000
5   1 5 3   4892.         0.0                                  0.0
5   1 6 1   4793.7260   1.5625                                 0.0
5   1 6 2   4887.                    101.8558   5046.4075   -300.000
5   1 6 3   4892.         0.0                                  0.0
6   1         0.        9.0       0.0        0.0        0.0        0.0
7   11     4710.                                  0.0  20.0
7   10     4730.      44.6   29.8                 0.0  20.0
7   10     4770.      49.0   36.5                 3.4  16.6
7   10     4810.      46.7   45.3                 7.6  12.4
7   10     4850.      41.9   51.0                11.7   8.3
7   10     4880.      37.5   54.1                15.9   4.1
7   10     4892.      37.0   55.0                20.0   0.1
1   2           1   1   111     1
1   4               1                                    1   1
1   3          1           1    1              1 1      1
10005                                          2        1111
1  10      1             1
*ENDFILE
```

Figure C-8. Input file for the two-centered arch dam example

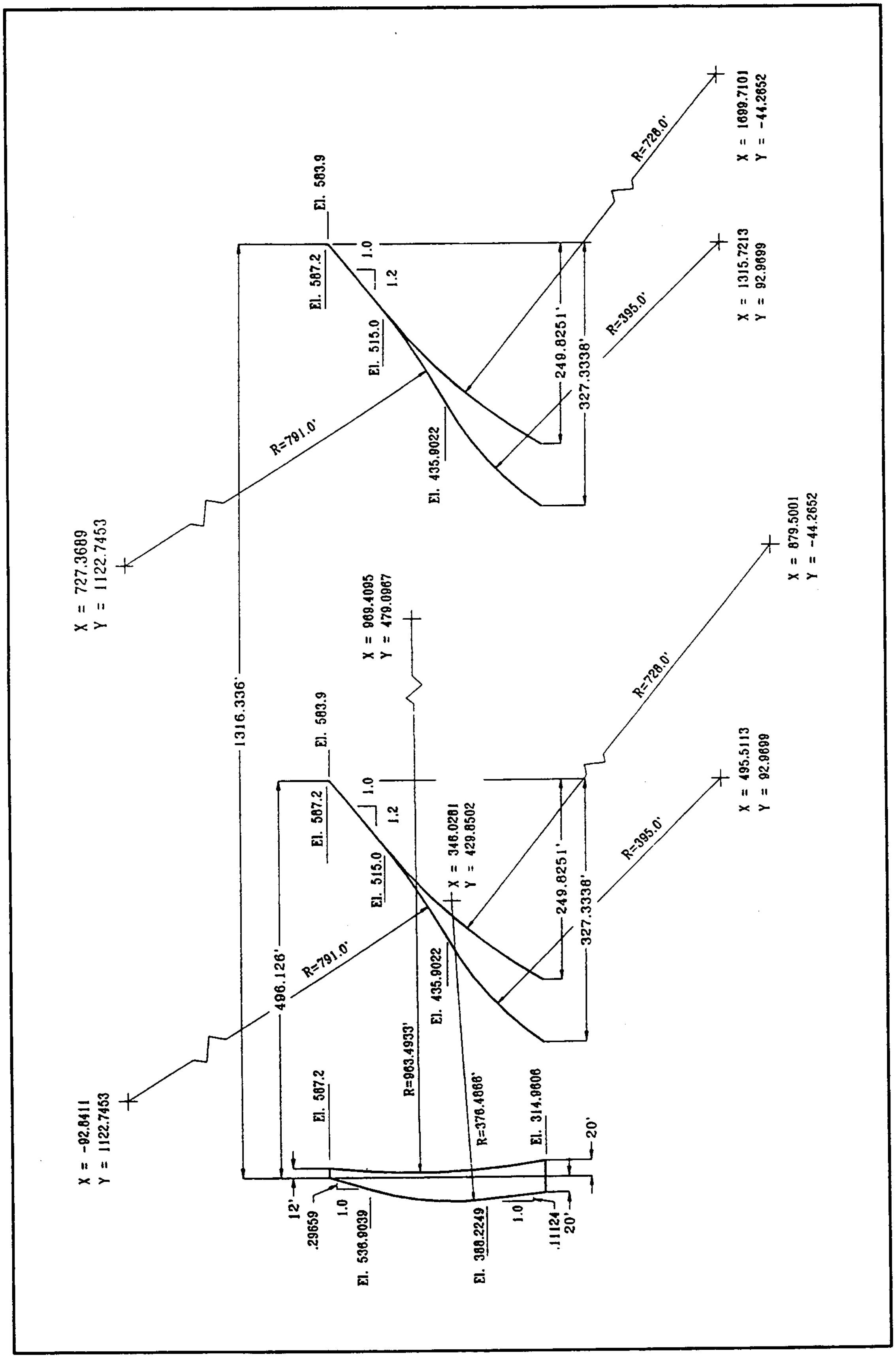

Figure C-9. Crown cantilever and line of centers for a three-centered arch dam

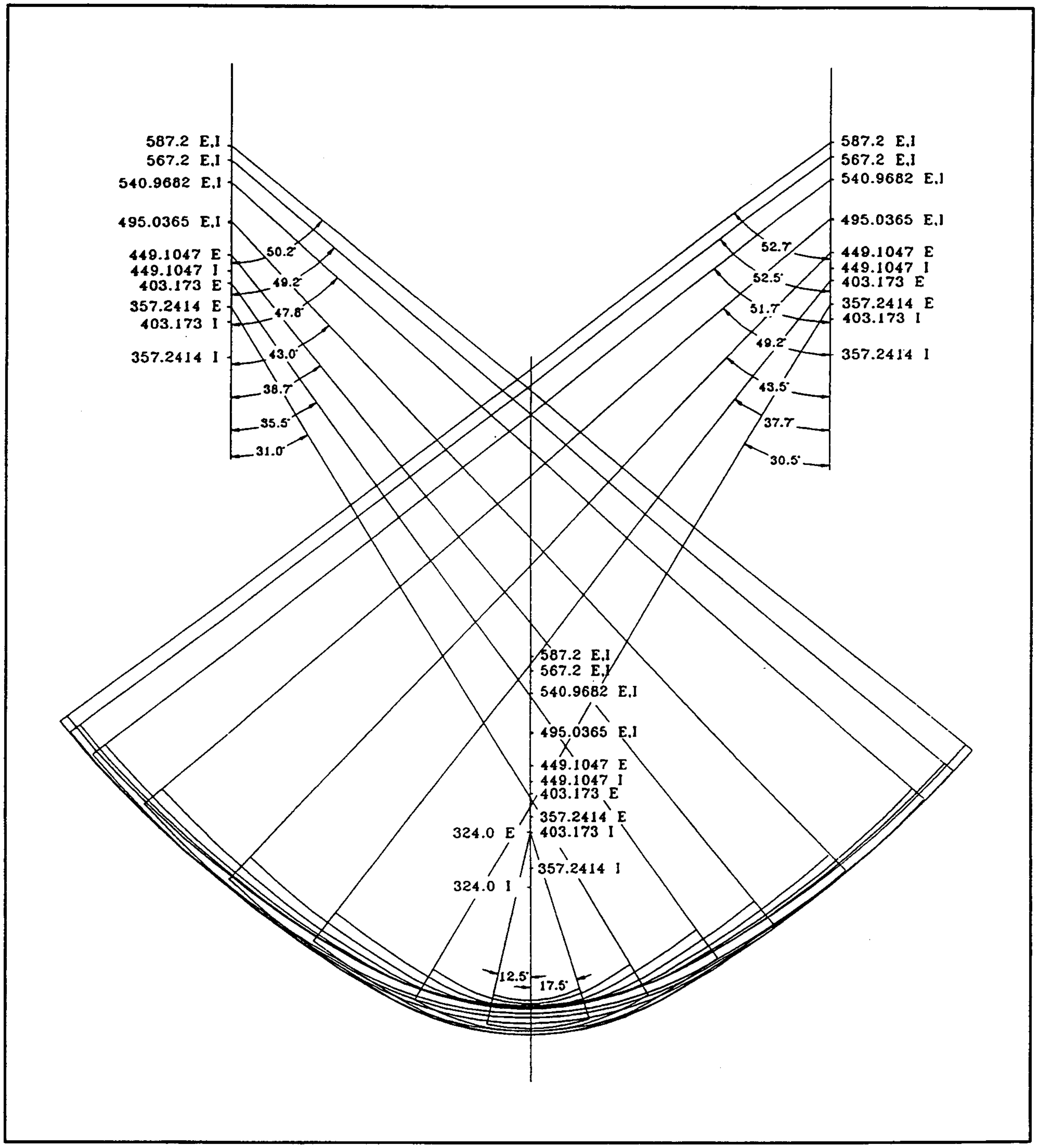

Figure C-10. Plan view for the three-centered arch dam example

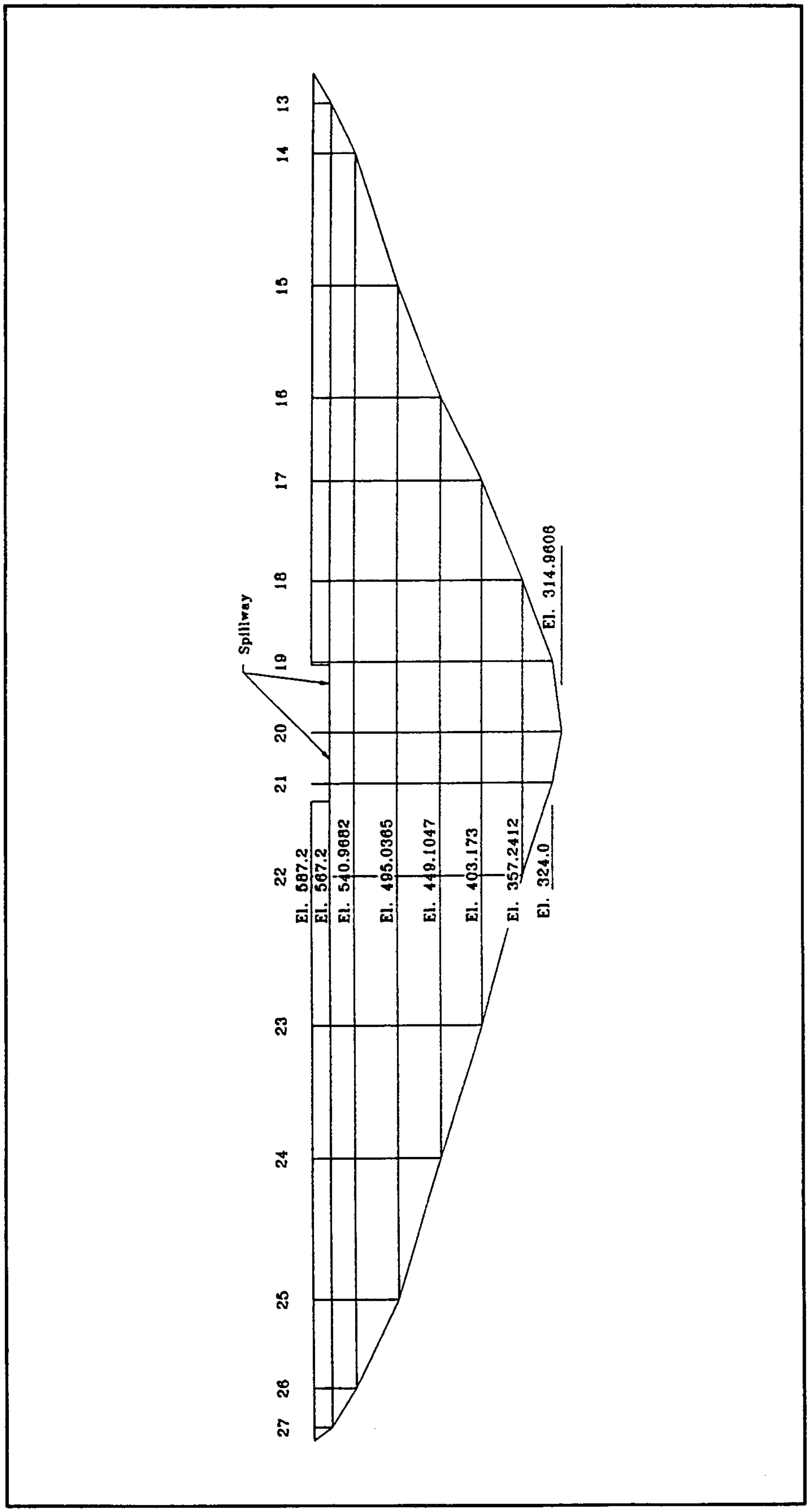

Figure C-11. Developed profile along axis of the three-centered arch dam example

```
MASTERIO  111011111
1   0     Three-Centered Dam
2   0     011011101
3   0     30100000031     3.1      .16         155.0
4   0     314.9606  587.2     500.0          567.20
3   1     20.0      20.0      327.3338  249.8251  496.1260       -.01   11  2
4   1     327.3338  249.8251  1316.3360
5   1 1 1 388.2249    -0.11124
5   1 1 2 536.9039                 346.0281    429.8502    376.4866
5   1 1 3 587.2       0.29659
5   1 2 1 587.2                    969.4095    479.0967    963.4933
5   1 3 1 435.9022                 495.5113    92.9699     395.0
5   1 3 2 515.0                    -92.8411    1122.7453   -791.0
5   1 3 3 583.9       1.20
5   1 3 4 587.2       0.0
5   1 4 1 515.0                    879.5001    -44.2652    728.0
5   1 4 2 583.9       1.20
5   1 4 3 587.2       0.0
5   1 5 1 435.9022                 1315.7213   92.9699     395.0
5   1 5 2 515.0                     727.3689   1122.7453   -791.0
5   1 5 3 583.9       1.20
5   1 5 4 587.2       0.0
5   1 6 1 515.0                    1699.7101   -44.2652    728.0
5   1 6 2 583.9       1.20
5   1 6 3 587.2       0.0
6   1     0.0       12.0
7   11    314.9606                               4.3        2.0  3.0
7   15    324.0     12.5   17.5                  4.3        2.0  3.0
7   10    357.2412  30.5   31.0                  4.1        2.0  3.0
7   10    403.1730  37.7   35.5                  4.8        2.0  3.0
7   10    449.1047  43.5   38.7                  4.9        2.0  3.0
7   10    495.0365  49.2   43.0                  4.5        2.0  3.0
7   10    540.9682  51.7   47.8                  3.9        2.0  3.0
7   10    567.2     52.5   49.2                  2.6        2.0  3.0
7   10    587.2     52.7   50.2                  5.4        2.0  3.0
8   1     3 1     30.0  30.0
1   2          1   1   111     1
1   4              1                                                1
1   3         1            1    1      1        1 1       1
10005                                            2        1111
1  10     1             1
*ENDFILE
```

Figure C-12. Input file for the three-centered arch dam example

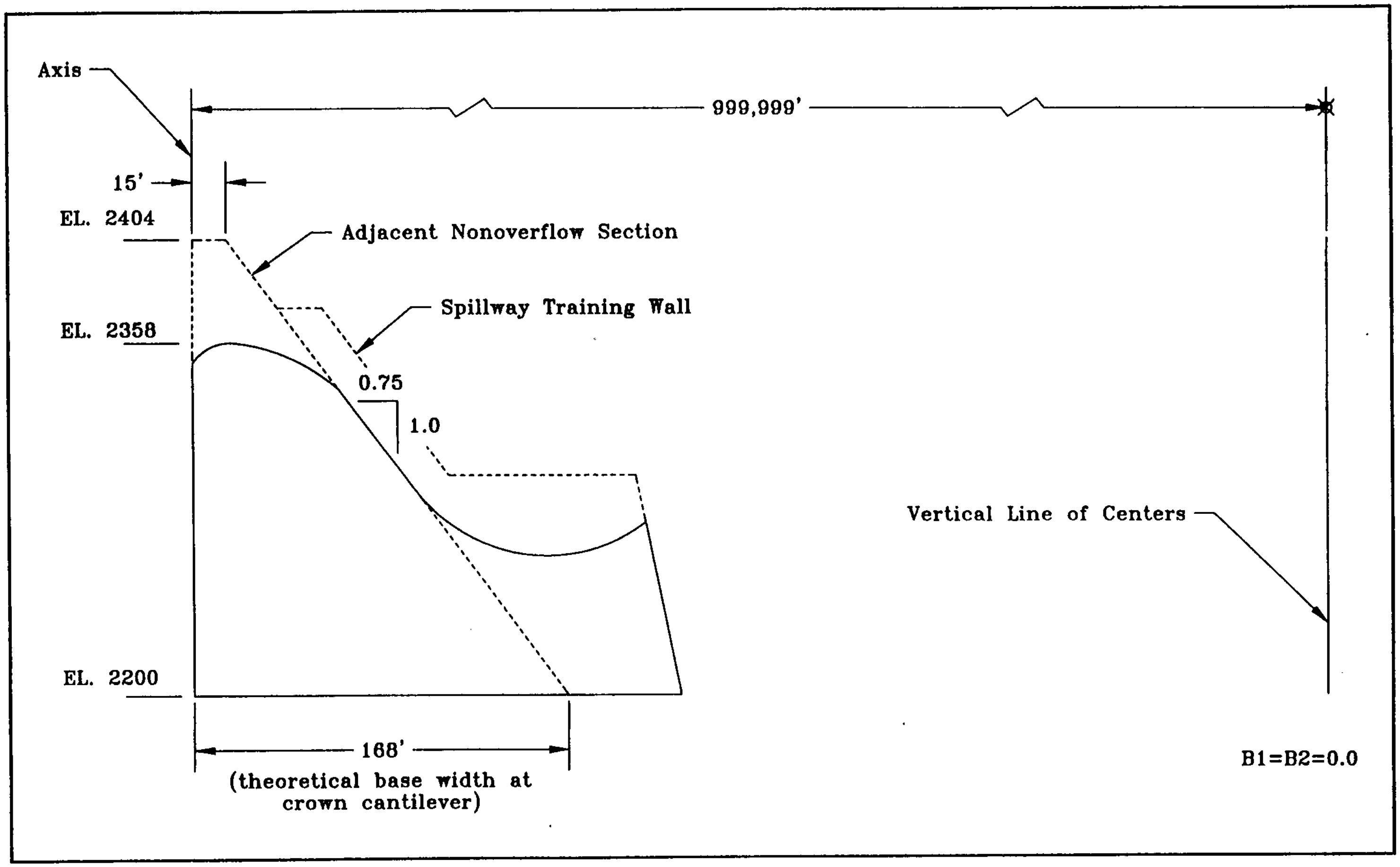

Figure C-13. Crown cantilever and reference plan for a gravity dam

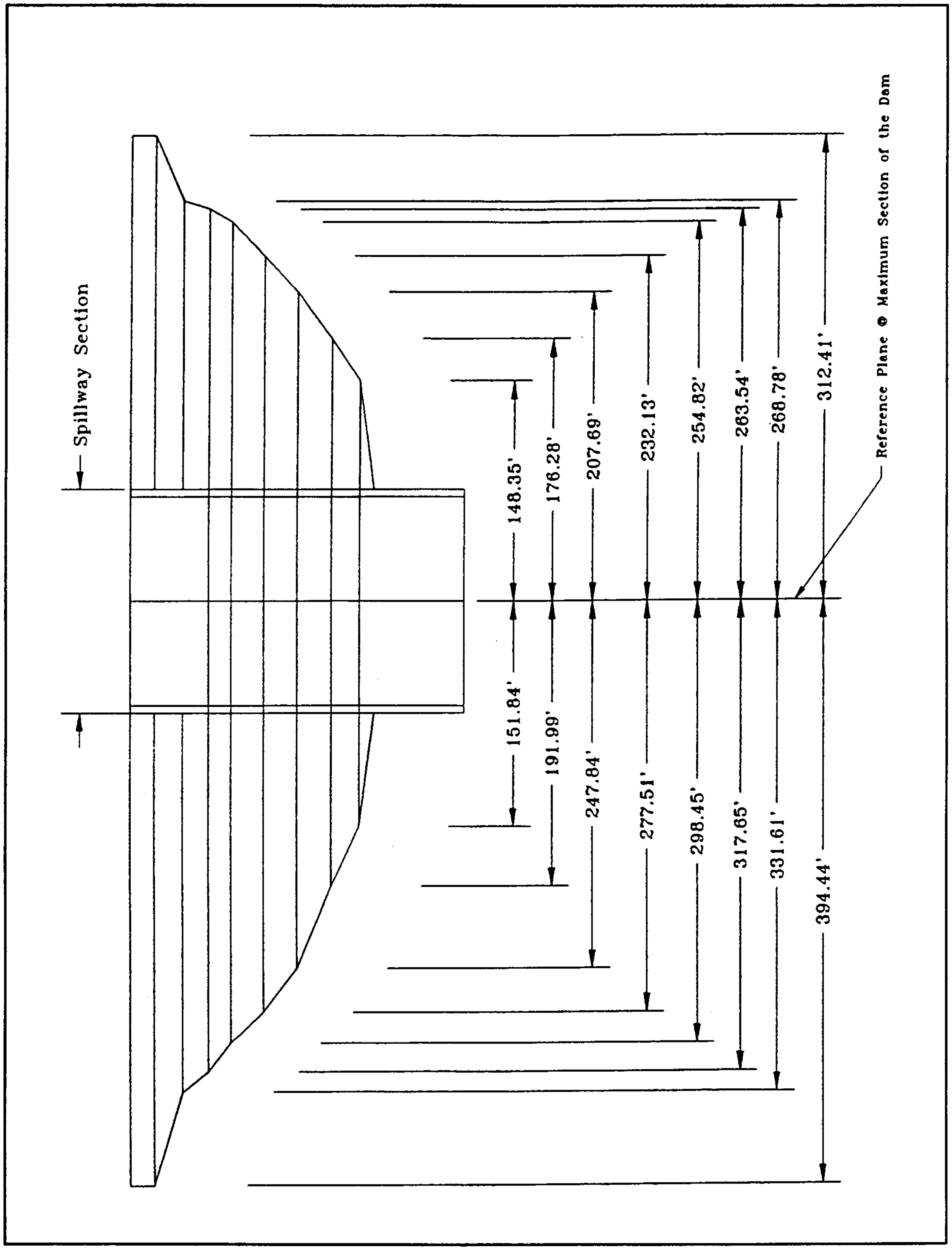

Figure C-14. Plan view for the gravity dam example

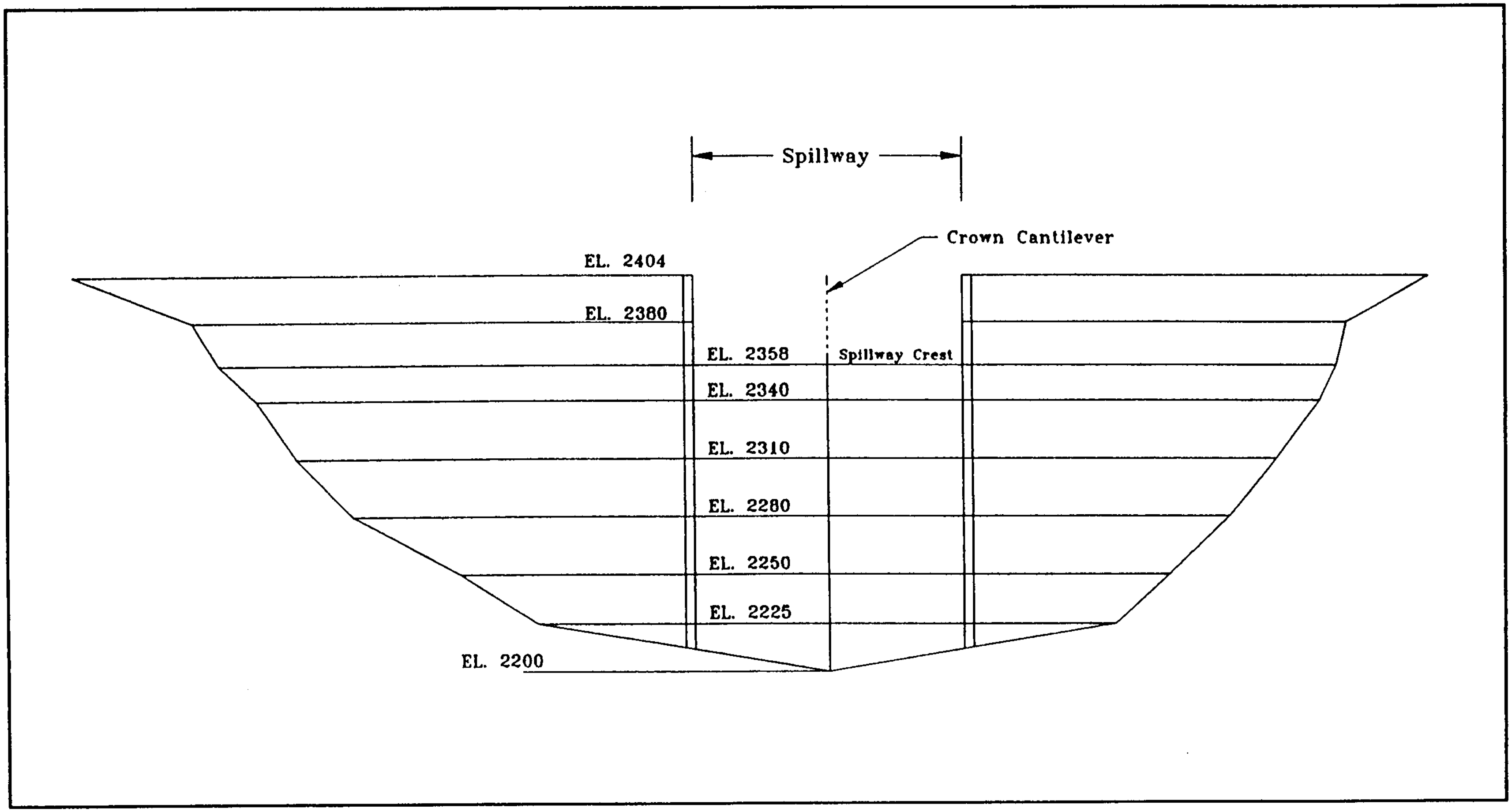

Figure C-15. Developed profile along axis of the gravity dam example

```
MASTERIO  111011111
1   0     Gravity Dam Example
2   0     011101101
3   0     30100000001      3.0     .16        150.0
4   0      2200.0   2404.0   2205.0              2358.0
3   1       0.0      168.0         0.0      0.0     999999.0      -.01    12   4
5   1 1 1    2404.0        0.0
5   1 2 1    2404.0       -0.75
5   1 3 1    2404.0        0.0
5   1 4 1    2404.0        0.0
6   1       0.0      15.0
7   11     2200.0                                   7.0         3.0  3.0
7   16     2225.0   0.0087 0.0085                   8.0         3.0  3.0
7   10     2250.0   0.0110 0.0101                   9.5         3.0  3.0
7   10     2280.0   0.0142 0.0119                  13.5         3.0  3.0
7   10     2310.0   0.0159 0.0133                  16.0         3.0  3.0
7   10     2340.0   0.0171 0.0146                  20.9         3.0  3.0
7   10     2358.0   0.0182 0.0151                  24.5         3.0  3.0
7   10     2380.0   0.0190 0.0154                  27.4         3.0  3.0
7   10     2404.0   0.0226 0.0179                  27.6         3.0  3.0
1   2          1   1   111      1
1   4              1                                                 1
1   3         1            1    1              1 1       1
10005                                            2        1111
1  10     1             1
*ENDFILE
```

Figure C-16. Input file for the gravity dam example

Appendix D
Error Messages

Most of the error checking in the ADSAS computer program is primarily concentrated on verifying that the data input contains the correct information and is in the proper order. ADSAS also checks for unrealistic deformation. If such deformations are detected, the analysis will be aborted. Also, a number of diagnostic prints will be turned on, and the computations of unit deformations repeated in order that the cause of the problem might be more easily detected.

If an error is detected, ADSAS will generally print an explanatory message before it aborts the run. In some cases, it will simply refer to the error by a number. A list of the numbered errors follows.

Error Messages for Geometry Program (Links 0 and 1)

Stop Number	Explanation
2	Type 7 card (elevations) was not read when expected.
6	Checking data for the top of the dam was not read when expected. (Program expects a 6 in Column 1. This card follows the group of cards with 5 in Column 1).
7	While scanning the plane of centers data, a discontinuity or a discrepancy with checking data which exceeded 0.5 ft was found (10 ft at the base of the line of centers).
9	Procedure control on the first elevation card (type 7) was not 1 (indicating that this elevation is the base of the crown cantilever).
15	While doing a table lookup on the table of crown elevations, using the grout elevation as the search argument, it was found that the grout elevation exceeds all entries in the crown elevation table.
21-26	A type 5 card was not read when expected. (Program expects a 5 in Column 1.) The second digit indicates the line number which was being processed at the time of failure.
31-36	The wrong line number was read on a type 5 card. The line number is placed in Column 7. The second digit indicates the line number being processed at time of failure.
41-46	The segment numbers seem to be out of order on the major line whose number is the second digit. The segment numbers are placed in Columns 8 and 9.
51-56	The elevation on the segment cards for the major line (whose number is the second digit) does not ascend.
61-64	There are too many line segments on the major line whose number is the second digit. There is a limit of 10.
71-76	A maximum elevation for a line segment exceeds the elevation which defines the top of the dam.

Error Messages for Abutment Program (Link 2)

Stop Number	Explanation
1	IOC card not identified by "1" in column 1.
2	Link number was not "2" in column 5.

Error Messages for Cantilever Program (Link 3)

Stop Number	Explanation
2	A problem occurred while reading card input.
3	IOC card not identified by -1- in Column 1.
15	The elevation of the top of concrete as read in from Columns 33-43 of the second heading card exceeds the highest defined elevation on the crown cantilever.
16	The list of crown elevations exceeds 50 items.
26	Special data card for ice load was not identified by -13- in Columns 1 and 2.
28	Link number was not -3- on IOC card (entered in Column 5).

Error Messages for Arch Program (Link 4)

Stop Number	Explanation
7	IOC card not identified by "1" in column 1.
8	Link number was not "4" in column 5.

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13. ABSTRACT *(Maximum 200 words)*

The Arch Dam Stress Analysis System (ADSAS) is a computerized version of the trial load method of analyzing arch dams. ADSAS assumes linear elastic behavior for the entire dam, i.e. the dam is assumed to support the computed tensile stresses within the concrete mass and across the monolith joints without cracking or opening the joints. Although the trial load method is not considered to be as accurate as the finite element method, ADSAS can produce results that compare favorably with those of the finite element analysis with a properly defined mesh. For dams that fit the ADSAS format, input can be taken directly from the layout drawings, and changes or modifications to the dam layout can be made a minimum of changes to the input file. Thus, ADSAS is a logical choice for performing a preliminary stress analysis during the layout process.

This user's guide for ADSAS describes general requirements for the input file, provides guidance on modeling techniques, and cites some special layout capabilities. It gives detailed descriptions of the data required for each of the input cards, which are an integral part of ADSAS. Some guidance in interpreting the data output is given. Appendixes include sample files and error messages.

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