# DYNAMIC PROGRAMMING OPTIMIZATION: A WATER DISTRIBUTION SYSTEM DESIGN

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## ABSTRACT

*A computation technique based on the dynamic programming approach using the interactive Fortran language has been developed. The computerized design procedure can be used to obtain optimal design for single source water or other compressed fluid systems with a finite number of diverging branches and loops. Pumping effect on a single source system cannot be optimized, however, the developed procedure does allow quick evaluation of many alternate pumping pressures. Similarly, multiple source network with converging branches can only be evaluated by the repeated use of the computerized procedure.*

*Dynamic programming has been proved to be very powerful for the analysis and design of a water network. From an engineer's point of view, this approach can be used to design any conceptual water network with little limitation.*

# CONTENTS



# FIGURES

TABLES

# INTRODUCTION

Fluid transport systems guide fluid flow sequentially from one conduit to the next. Close relationships exist between these adjacent conduits. Based on these relationships, the designer selects the most economical configuration to meet the system requirement. Large numbers of nonlinear relationships complicate this design problem. Past approaches to the solution of this type of problem include linearizing the problem by Dajani et al. (1972) and Goda and Ogura (1967), solving the simultaneous equations by the Hardy Cross method (Morris 1963; Voyles and Wilke 1962), using analog computers or electric analyzers to evaluate alternate designs (Kozobkov et al. 1965), developing special formulas for selecting pipeline diameter by Downs and Tait (1953; Culver 1954 and 1955; Kennedy and Strieve 1964; Luce 1955; Pietrkowski 1952; and Voyles and Wilke 1962). All of these efforts depend on over-simplification which prevents the achievement of an overall optimum design. Wong and Larson (1968) and Larson and Ree (1971) studied the problem of delivering petroleum gas through a tree-structure network. Their work is probably the first documented effort in the application of dynamic programming to optimize the operation of a fluid transport system with a known configuration. Operating pressure differences between pumping stations were their decision variables. The problem of arriving at an optimal configuration for a fluid transport system was not considered. Recently, Liang (1971) developed an optimization procedure based on dynamic programming which selects an optimal system design. Each pipe segment of a system was treated as a dynamic programming stage. *The total heads at the inlet and outlet of each segment of pipe are the input and output state variables* of each stage. The *pipe diameter* is the *decision variable* of each stage. The sum of all cost phases, which includes pipe material cost, power cost, and wasted water cost of all stages, was used as a criterion for measuring the overall system effectiveness. However, the head loss due to sudden expansion or contraction between two adjacent pipe segments of different diameters was not accounted for. This omission may affect the accuracy of the final result, as the head loss in junctions could be significant compared to the head loss in pipes, especially when the length of pipe segments between junctions is shorter than 1000 times the diameter of the pipe.

The computation method developed by Liang (1971) was relatively inefficient and inflexible. The optimization (or computation) was performed on a computer in a batch fashion, which permits no communication between the designer and the computer once the calculation is started. This inflexibility has at least the following disadvantages:

1. Allowable pressure range, pipe length, etc., for each segment of the pipe of the entire fluid distribution system under design must be preselected before starting calculation. Knowledge gained in the selection of the earlier stage cannot be used as a guideline for selection of later stages. This forces designers to adopt very wide trial pressure ranges which result in superfluous computation time as well as computer memory.
2. Psychologically, the batch process puts pressure on the designer by requiring all correct assumptions and input data before the computerized design process starts. The result is revealed only after the completion of the computing process. When a program is designed to solve problems as complex as the fluid distribution system, a minor error could mean a lot of wasted money and time. Designers naturally feel pressured when no recourse is provided to make minor changes during the optimization process.

The method of checking compatible relationships between the inlet and the outlet total heads of a pipe segment, as well as the dynamic programming (DP) stage in Liang's computer program (1971), can be improved. Since the allowable maximum and minimum total heads permitted at both inlet and outlet are preselected, the desired resolution interval that divides the pressure range between the maximum and minimum heads into a series of equally spaced values of pressure head can be obtained. Then each outlet total head, together with each available pipe size can be tested and an attempt can be made to find a matched or compatible inlet total head. The trial and error process in finding the matched inlet and outlet total head requires a great deal of time since the head loss in pipe is greatly affected by flow rate. The flow rate, however, is a function of the total head difference between inlet and outlet and pipe size. The interaction between these variables makes this trial and error approach a time consuming process.

In this study, an improved method of finding the relation between inlet and outlet total heads was developed. The Moody diagram was stored as an array in computer memory for pipe friction coefficient searching. In order to obtain accurate values of the friction coefficient, a large amount of computer memories to store the many discrete values from the Moody diagram was required as well as a great deal of search time to find the value being searched. The speed of finding the pipe friction coefficient can be improved and the computer memory storage needs can also be reduced by using a different method. A modified program of the IBM FORTRAN SSP program, RTMJ, is suitable for this purpose. This program can search the value of the friction coefficient by means of the Mueller-S iteration method of successive bisections and inverse parabolic interpolation, which starts at two preselected initial bounds. This method will save time in comparison to the direct chart searching method. Finally, the DP approach adapted in this study was limited only to the design of sequential or serially connected conduit systems. An extension to nonserial conduit systems is definitely needed.

## DEVELOPMENT OF THE MATHEMATICAL MODEL

### Structure of a Fluid System

A single source fluid network system consists mainly of a power source (one flow inlet) and one or more outlets. Between inlets and outlets, there exist some branch pipelines and loops. Each loop is formed by several branch pipeline can also have its own branch pipelines and a loop can be a sub-loop of another loop. A complex fluid network resembles very much a net. Figure 1 is a schematic drawing of a fluid network, consisting of many loops and branch pipelines, with each pipeline having similar features. Pipelines are constructed with many serially connected pipe segments and are subject to the following restrictions:

1. Each pipe segment may use different diameter pipes with, at most, one discharge outlet near the end as shown in Figure 2a. The discharge rate from each outlet depends upon the discharge pressure at the discharge outlet and its size. Pipelines may use 0-90° elbow segments, Figure 2b, to change flow direction.
2. No discharge outlet on an elbow segment is allowed. Flow with more than a 90° direction change can be facilitated by installing more than one elbow.

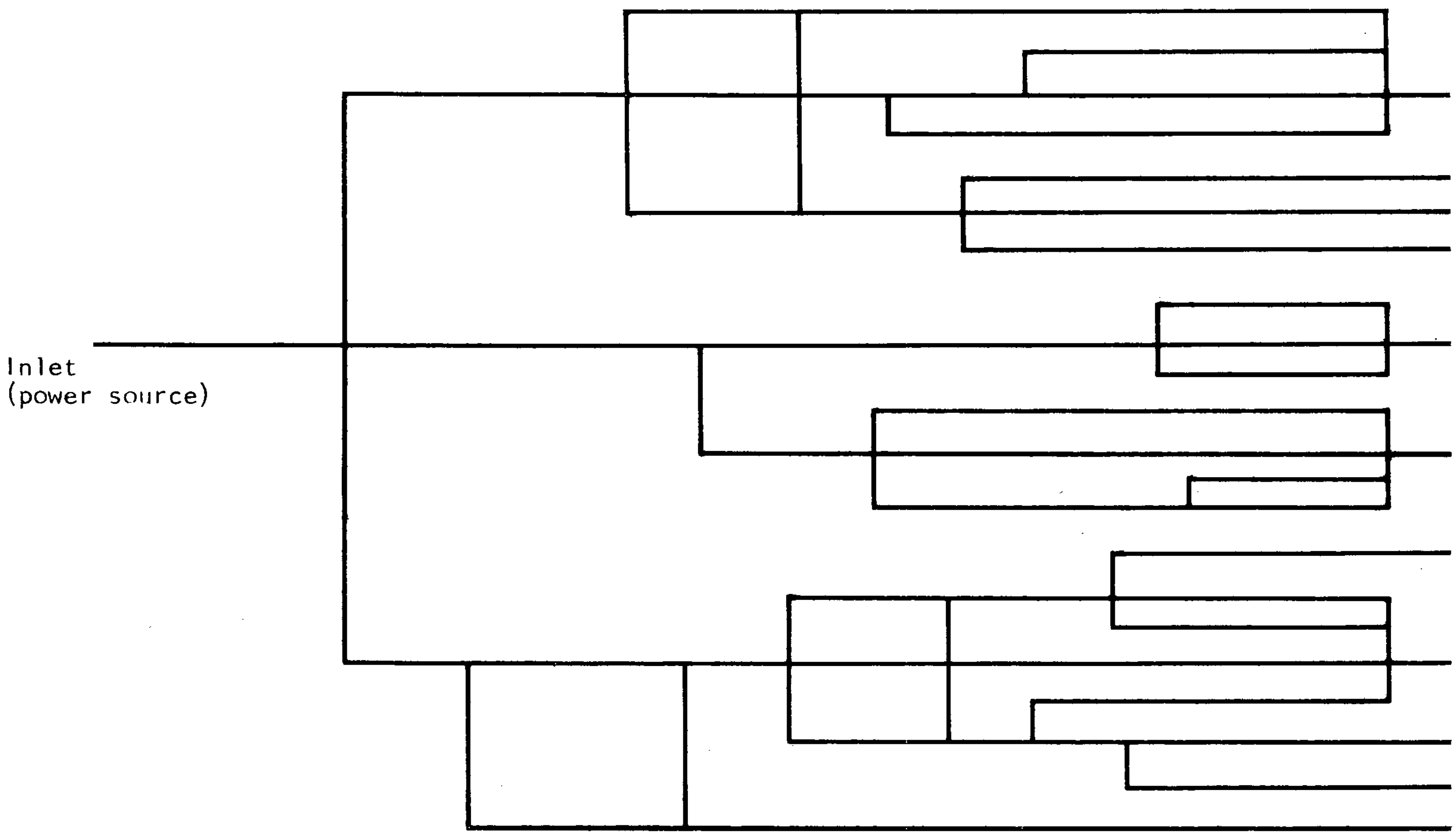



FIGURE 1. FLUID NETWORK DIAGRAM

3. Either sudden change of diameter or gradual change of diameter type of connections between two adjacent pipes of different diameters is accomplished by installing connectors as shown in Figures 2e and 2f. Two segments of pipes having the same diameter are connected directly, without a connector between them.
4. Two or three pipelines may branch out from, or merge to, a pipeline by adding a tee, Figure 2c, or cross joint fitting, Figure 2d. A series of tee and/or cross joint fittings can be used to handle more than three branch or merge pipelines at the same point; however, there are no discharge outlets on tee or cross joint fittings. Both tee and cross joints have the same diameter inlets as well as outlets.

An example of a fluid network is shown in Figure 3.

## Transformations and Constraints

In fluid systems where fluid flows sequentially from one conduit to another, quantified relationships exist between the adjacent conduit segments. The design of this type of system can be readily solved by the use of dynamic programming. A segment of pipe, elbow, tee or cross, in a fluid network can be treated as a dynamic programming stage. The inlet and outlet total head in a segment of pipe corresponds to the input and output state variables of a dynamic programming stage, while the pipe diameter corresponds to the dynamic programming decision variable. The DP return function of a stage refers to the total cost of using this pipe. The transformation equation between the input and output state variables can be established by investigating the hydraulic relationship between the inlet and outlet total head of a pipe. Figure 4 shows the corresponding relation between a dynamic programming stage and a pipe segment in which $X_i$ represents the input and $X_{i-1}$ the output state variables of Stage $i$, $D_i$ being the decision variable, and $r_i$ the stage return.

The transformation equations for state variables $X_i$, $X_{i-1}$ and the decision variable $D_i$ used by Liang (1971) was first modified by adding expansion or contraction loss due to diameter change between two adjacent segments of pipes. The pressure head loss in the pipe junction caused by the change of pipe sizes can be expressed in terms of velocity head, Equation 1. The head loss in sudden type connector change depends upon the ratio of cross section areas of inlet to outlet. Loss in gradual-change type connector is

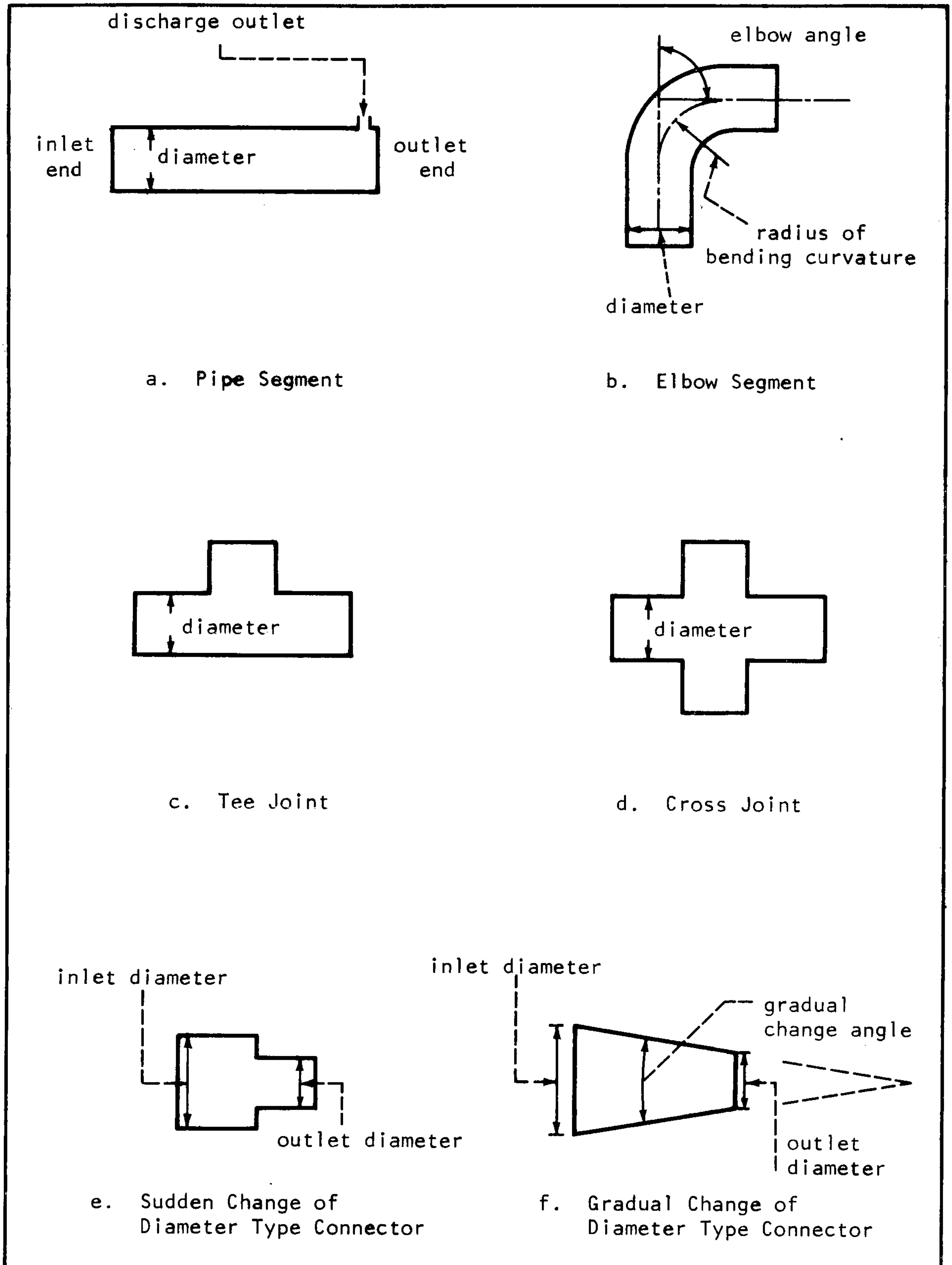



FIGURE 2. DIFFERENT PARTS FOR CONSTRUCTING A FLUID NETWORK

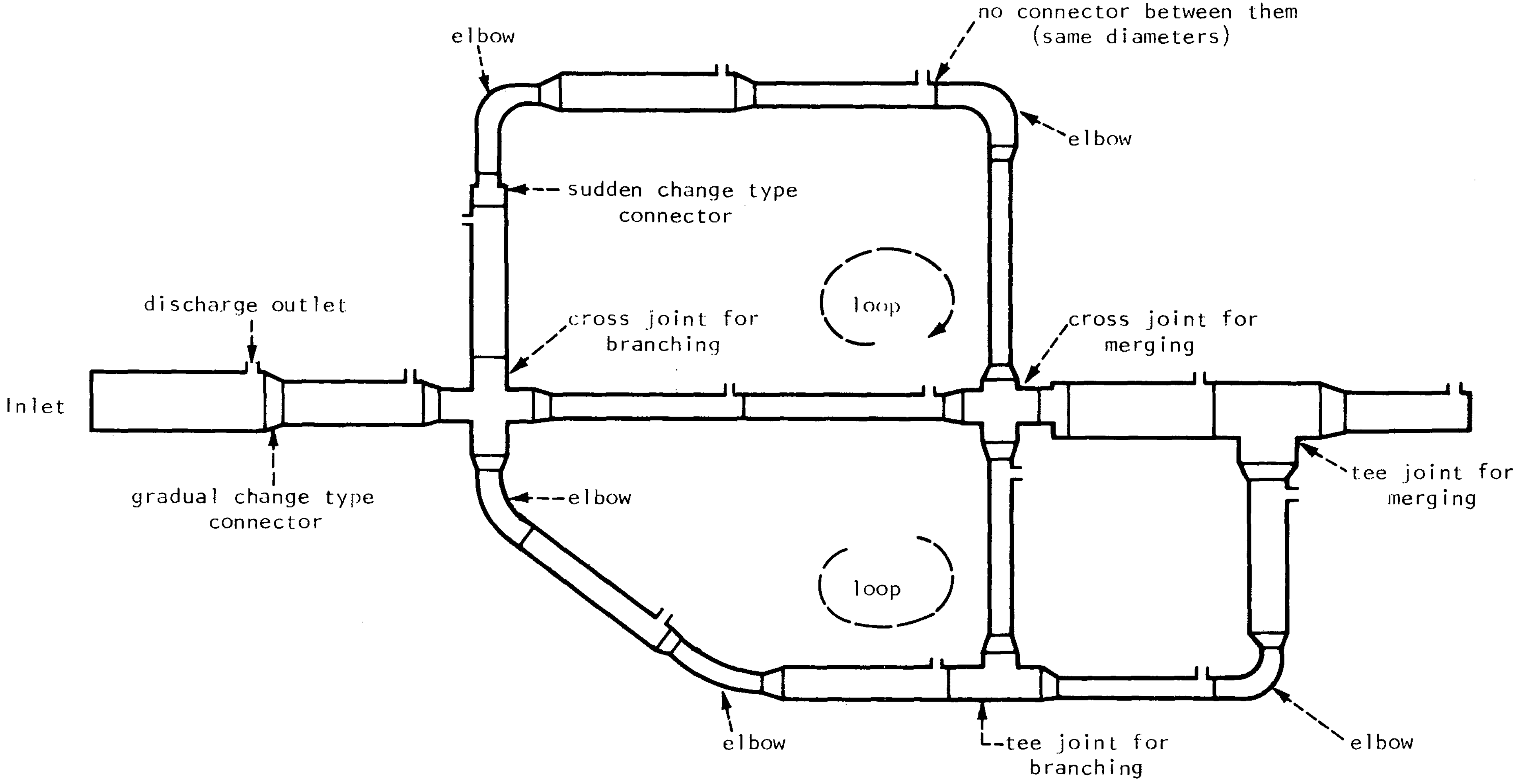



FIGURE 3. CONNECTION DIAGRAM OF A FLUID NETWORK

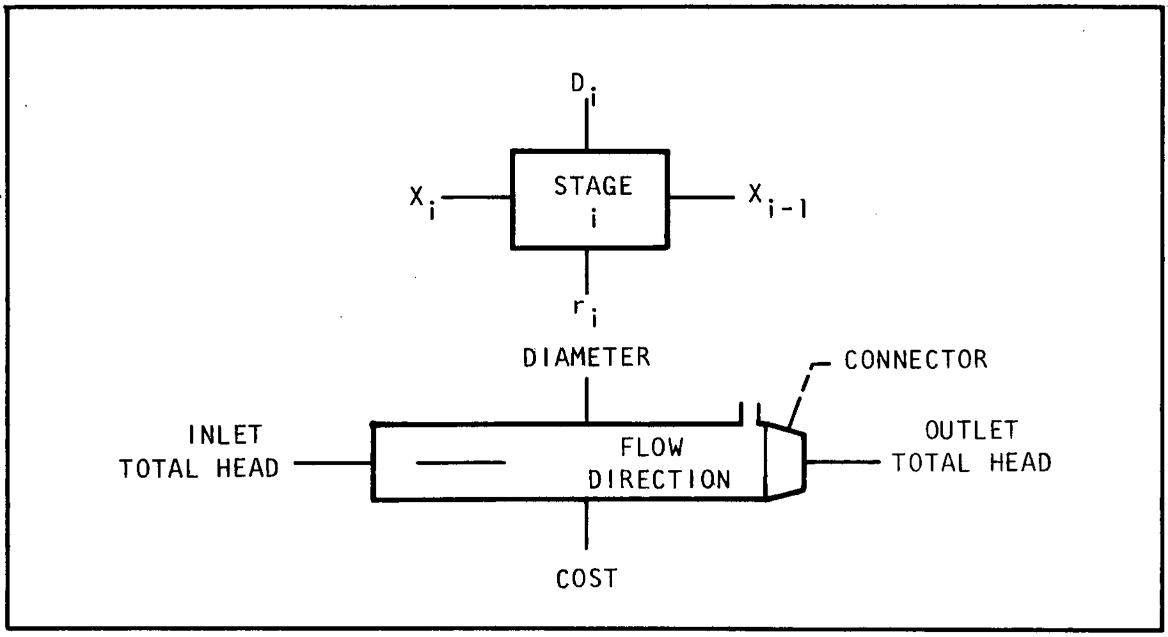



FIGURE 4. CORRESPONDING RELATIONS BETWEEN A DYNAMIC PROGRAMMING STAGE AND A SEGMENT OF PIPE

affected by both the gradual change in angle and the area ratio. The loss coefficient, CL, in a sudden change or gradual change type connector can be found from curves in Albertson, Barton, and Simons (1964). The loss then can be calculated by using the following relation:

$$\text{Loss} = (V_{i-1})(CL) \tag{1}$$

where $V_{i-1}$ = velocity head of the ith stage outlet, in psi, and
CL = loss coefficient

The general transformation, $X_{i-1} = t_i(X_i, D_i)$, between the inlet and outlet pressure of a fluid, such as water being transported through a segment of pipe, can be expressed as

$$\begin{aligned} X_{i-1} &= X_i - 0.0252 \frac{f_i \cdot H_i \cdot Q_i^2}{(D_i/12)^5} - V_{i-1} \cdot CL_i \\ &= X_i - 6270.5664 \frac{f_i \cdot H_i \cdot Q_i^2}{D_i^5} - V_{i-1} \cdot CL_i \end{aligned} \tag{2}$$

where $X_i$ = inlet total head of the ith stage, in psi,
$X_{i-1}$ = outlet total head of the ith stage and inlet total head of (i-1)th stage (a pipe and the connector attached to its

outlet end together are treated as one stage), in psi,

$f_i$ = friction coefficient of the ith stage, dimensionless,

$H_i$ = length of the ith stage, in feet,

$Q_i$ = flow rate in the ith stage, in cfs,

$D_i$ = diameter of the ith stage, in inches,

$V_{i-1}$ = velocity head of the ith stage at outlet, in psi, and

$CL_i$ = head loss coefficient due to change of diameters, dimensionless.

The term $V_{i-1}$ multiplied by $CL_i$ in Equation 2 is the head loss in the connector between stage i and stage i-1. The resistance coefficient of the ith stage, $f_i$, can be found by solving the following equation (Albertson, Barton, and Simons 1964):

$$\frac{1}{\sqrt{f_i}} = 1.14 - 2 \log\left(\frac{e}{D_i} + \frac{9.35}{R_i\sqrt{f_i}}\right) \tag{3}$$

where e = pipe roughness, in feet and

$R_i$ = Reynolds number for the ith stage, dimensionless.

The Reynolds number can be expressed as

$$R_i = \frac{48\ Q_i}{\pi\nu\ D_i} \tag{4}$$

where $\nu$ = fluid kinematic viscosity, in square feet per second ($1.21 \times 10^{-5}$ for water at 60° F).

Equation 3 is valid for $R \geq 4000$. For cases where $R_i < 2000$, Equation 3 should be replaced by the following relation:

$$f_i = \frac{64}{R_i}$$

The flow rate through the ith pipe, $Q_i$, is the sum of $Q_{i-1}$ and $q_i$ which are the flow rates of the (i-1)th pipe, and the discharge rate from the ith discharge outlet respectively. That is,

$$Q_i = Q_{i-1} + q_i \tag{5}$$

For fixed discharge orifice size, the discharge rate is usually proportional to the square root of the discharge head. The proportional constant discharge coefficient can be determined experimentally. For this study, a value of 0.0033754 cu ft/sec/sq ft of psf was used. Thus, the discharge rate from the ith pipe, in cubic feet per second, can be expressed as

$$q_i = 0.0033754 \sqrt{(PD_i)\ 144.0}$$

$$= 0.0033754 \sqrt{(X'_{i-1} - Z_i - V'_{i-1})\ 144.0}$$

where $PD_i$ = pressure head at discharge outlet, in psi
$X'_{i-1}$ = total head at discharge outlet, in psi
$Z_i$ = elevation head at discharge outlet, in psi
$V'_{i-1}$ = velocity head at discharge outlet, in psi.

The relation between the heads, flow and discharge rate in a pipe are shown graphically in Figure 5. The transformation, $Q_i = F_i(Q_{i-1}, X_{i-1}, X_i)$, can be explicitly expressed as

$$Q_i = 0.0033754 \sqrt{(X'_{i-1} - Z_i - V'_{i-1})\ 144.0} + Q_{i-1}$$

The variable, $V'_{i-1}$, can be obtained from the following expression

$$V'_{i-1} = \left(\frac{4Q_{i-1}}{\pi(D_i/12)^2}\right)^2 / [2g \cdot (33.9 \text{ ft of water/atmosphere}) \cdot (14.7 \text{ psi/atmosphere})] \quad (8)$$

$$= 225.8\ Q_{i-1}{}^2/D_i{}^4$$

where g = acceleration of gravity which is equal to 32.2 ft/sec$^2$
$X'_{i-1}$ = the outlet total head of the ith stage before subtraction of head loss due to change of pipe size.

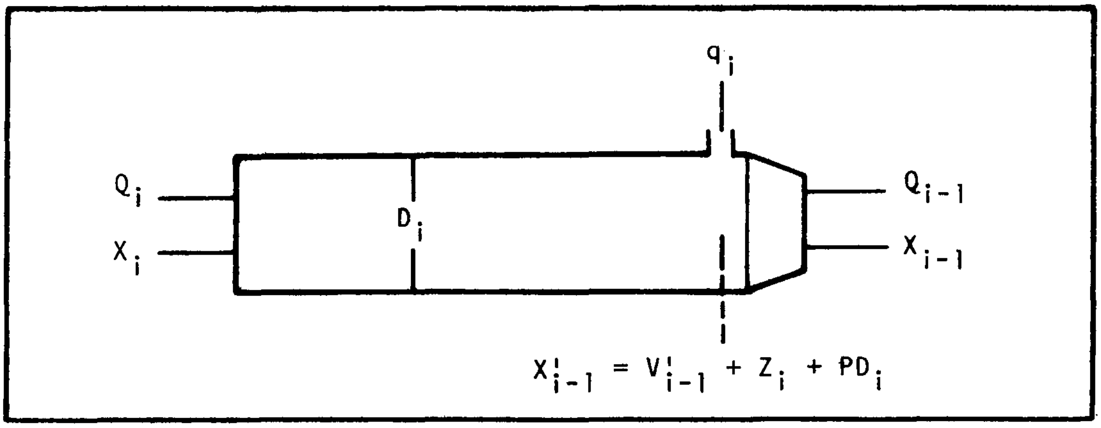



FIGURE 5. HEADS AND FLOW RELATIONS IN A PIPE

By modifying Equation 2, $X_{i-1}$ can be obtained as follows:

$$X'_{i-1} = X_{i-1} + V_{i-1}\, CL_i$$
$$= X_i - 6270.5664\, \frac{f_i \cdot H_i \cdot Q_i^2}{D_i^5} \tag{9}$$

The term, $Z_i$,, expressed in psi, can be converted from feet of water by simply multiplying a constant 0.433 psi/ft of water.

The head loss within the elbow, caused by changing the direction of flow, can also be expressed in terms of velocity head Equation 1 as

$$X_{i-1} = X_i - V'_{i-1} \cdot CB_i - V_{i-1} \cdot CL_i \tag{10}$$

where, $CB_i$, the loss coefficient due to change of flow direction, is a function of elbow angle and the ratio of the radius of the bending curvature to the elbow diameter. The values of CB can be approximated from the curve in Albertson, Barton, and Simons (1964). The term $V'_{i-1} \cdot CB_i$, in Equation 10 is the loss within the elbow and $V_{i-1} \cdot CL_i$, the loss within the connector between the ith and (i-1)th stage. A corresponding relation diagram between an elbow and a dynamic programming stage is shown in Figure 6. Since no discharge is allowed in this case, $Q_i$ is equal to $Q_{i-1}$.

When two or more pipelines branch out from one pipeline or merge with another pipeline, head loss again occurs at the junction. A tee or a cross joint is usually used. Energy loss caused by a tee or a cross joint fitting has not been described exactly by any simple relation. However, the flow is quite similar to a sudden expansion or contraction (Albertson, Barton, and Simons 1964) and a change in flow direction. The transformation of a tee or cross joint then can be approximated by

$$X_{i-1} = X_i - (V_i - V'_{i-1})\, CJ_i - V_{i-1} \cdot CL_i \tag{11}$$

The head loss coefficient, $CJ_i$, due to branching or merging (tee or cross) can be determined from the curves which were used for determining the loss associated with sudden expansion or contraction of pipe size. This approximation makes the tees and crosses much easier to handle. However, some inaccuracy must be tolerated by the designer in order to solve the problem within a reasonable time. The term, $(V_i - V'_{i-1})\, CJ_i$, in Equation 11 is the head loss within a tee or a cross and $V_{i-1} CL_i$, the loss within the connector between the ith and (i-1)th stage. A corresponding

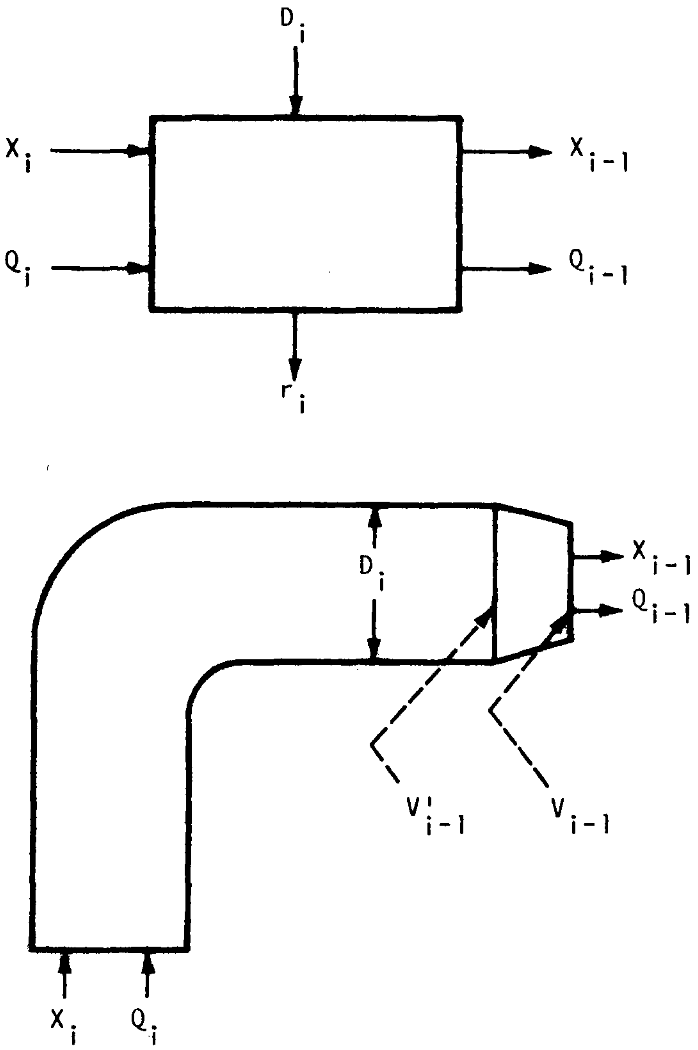



FIGURE 6. CORRESPONDING RELATIONS BETWEEN A DYNAMIC PROGRAMMING STAGE AND AN ELBOW

relation between a dynamic programming stage and a tee or a cross is shown in Figure 7. Other relationships between Q or X besides Equation 11 are:

$$X_{i-1} = X_{i-1,1} \qquad (12a)$$

$$Q_i = Q_{i-1} + Q_{i-1,1} \quad \text{tee joint for branching} \qquad (13a)$$

and

$$X_i = X_{i,1} \qquad (12b)$$

$$Q_{i-1} = Q_i + Q_{i,1} \quad \text{tee joint for merging} \qquad (13b)$$

$$X_{i-1} = X_{i-1,1} = X_{i-1,2} \qquad (12c)$$

$$Q_i = Q_{i-1} + Q_{i-1,1} + Q_{i-1,2} \quad \text{cross joint for branching} \qquad (13c)$$

$$X_i = X_{i,1} = X_{i,2} \qquad (12d)$$

$$Q_{i-1} = Q_i + Q_{i,1} + Q_{i,2} \quad \text{cross joint for merging} \qquad (13d)$$

## Stage Returns and the System Effectiveness

The overall measure of system effectivenss, or design effectiveness, in this study is cost which includes:

1. $\sum_{i=1}^{N} C_{Pi}$ = cost of pipes, elbows, tees, and crosses, in dollars per year;

2. $\sum_{i=1}^{N} C_{ei}$ = cost of energy put into fluid, in dollars per year;

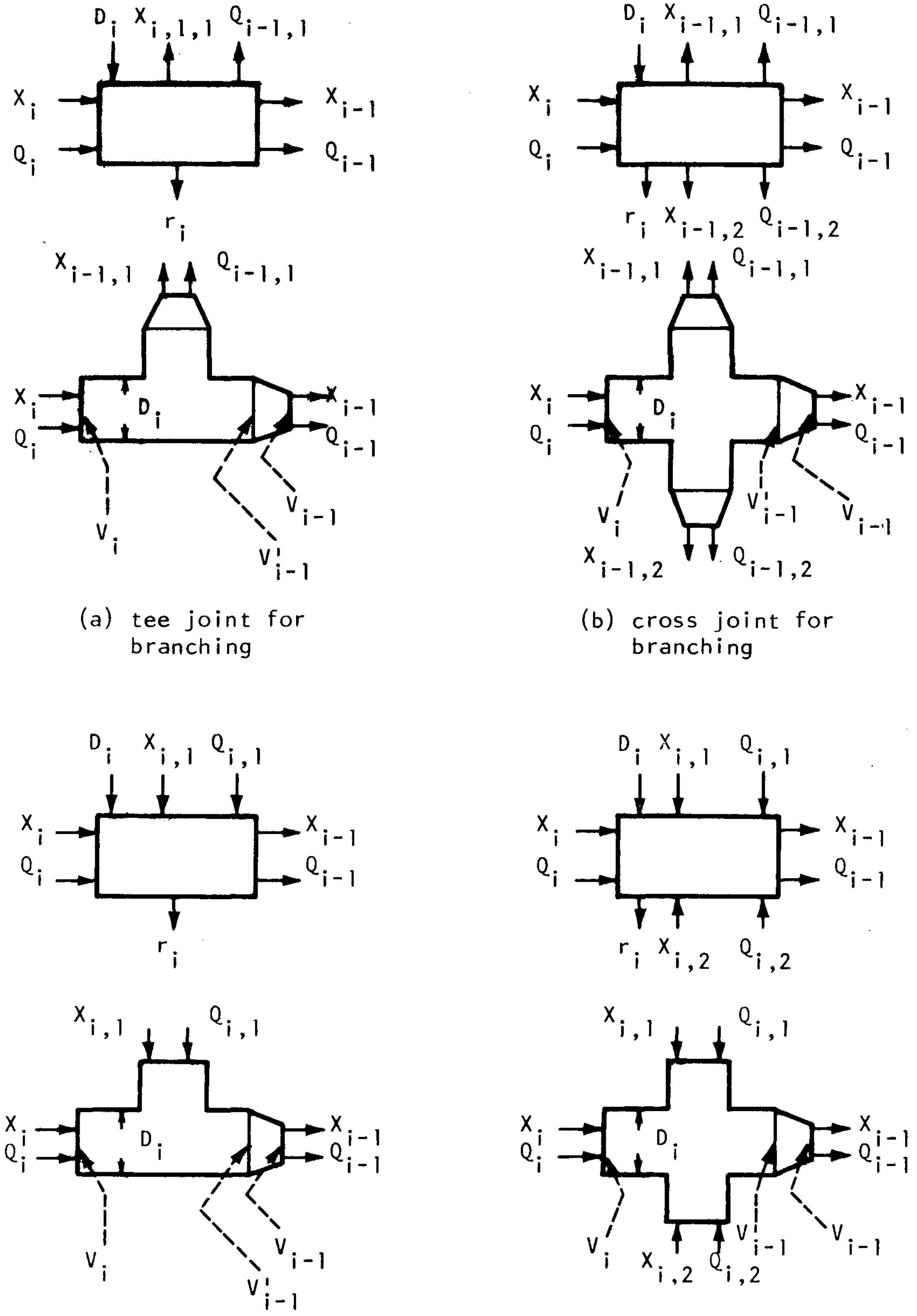
3. $\sum_{i=1}^{N} C_{wi}$ = wasted water cost due to discharge exceeding the design requirement.

For every individual conduit segment or dynamic programming stage, the terms $C_{pi}$, $C_{ei}$, $C_{wi}$ can be expressed as

$$C_{pi} = (H_i \overline{C_{di}} + C_{ci}) \left[\frac{1}{L} + \frac{(1 - S)I}{2 \times 100}\right] \qquad (14a)$$

$$C_{ei} = \left[0.262 \ \overline{C_e} \ Q_i \ T \ \frac{(X_i - X'_{i-1})}{E}\right] + \left[0.262 \ \overline{C_e}(Q_i - Q_{i-1}) T \ \frac{X'_{i-1}}{E}\right] + \left[0.262 \ \overline{C_e} \ Q_{i-1} \ T \frac{(X'_{i-1} - X_{i-1})}{E}\right] \qquad (15a)$$

$$C_{wi} = 3600 \ T[0.0033754 \ \sqrt{(X'_{i-1} - Z_i - V'_{i-1} - P_i) \ 144.0}\ ] \cdot \overline{C_w} \qquad (16)$$




(a) tee joint for branching

(b) cross joint for branching

(c) tee joint for merging

(d) cross joint for merging

FIGURE 7. CORRESPONDING RELATIONS BETWEEN A DYNAMIC PROGRAMMING STAGE AND A TEE JOINT OR A CROSS JOINT

and for elbows, tees, or crosses,

$$C_{pi} = (C'_{di} + C_{ci}) \left[\frac{1}{L} + \frac{(1 - S) I}{2 \times 100}\right] \quad (14b)$$

$$C_{ci} = 0.262\ C_e\ Q_i\ T\ \frac{(X_i - X_{i-1})}{E}$$

$$C_{wi} = 0 \quad (15b)$$

where

$H_i$ = length of the ith pipe, in feet

$\bar{C}_{di}$ = unit cost in dollars per foot of the ith pipe with a diameter of d in.

$C_{ci}$ = cost of connectors either sudden change type or gradual type between the ith and (i-1)th stage in dollars; this term will be the cost of all connectors if a tee or a cross is used.

$C'_{di}$ = cost of an elbow, a tee, or a cross in dollars with size d in.

L = life of the fluid network, in years

S = salvage value of conduits, as a fraction of the original cost

I = annual interest, as a percentage

$\bar{C}_e$ = unit power cost, in dollars per horsepower-hour

T = usage of the system in annual hours

E = conversion efficiency from electrical or other power source to water power, in decimals

$P_i$ = desired pressure head of the ith stage, in psi

$\bar{C}_w$ = water cost, in dollars per cubic foot

The measure of effectiveness, C, as the sum of cost items of all pipe segments may be expressed as

$$C(X_i, D_i, X_0, X_{01}, \ldots, X_{0L} \text{ for } i=1,\ldots,N) = \sum_{i=1}^{N} (C_{pi} + C_{ei} + C_{wi}) \quad (17)$$

where

$D_i$ = size of pipe, elbow, tee, or cross of the ith stage and $X_0, X_{01}, X_{02}, \ldots, X_{0L}$ are final states of each branchline.

Then, a fluid system design problem can be looked upon as

$$\text{Minimize } C(X_i, D_i, X_0, X_{01}, \ldots, X_{0L} \text{ for } i=1,\ldots,N) = \sum_{i=1}^{N} (C_{pi} + C_{ei} + C_{wi})$$

subject to $X_{i-1} = t_i(X_i, D_i)$

$Q_i = F_i(Q_{i-1}, X_{i-1}, X_i)$ for discharge stage

$Q_i = \sum_j Q_{(i-1)j}$ for elbow and tee, or cross in branching (18)

$$Q_{i-1} = \sum_j Q_{ij} \qquad \text{for tee or cross in merging}$$

The function, $C(X_i, D_i, X_o, X_{01}, \ldots, X_{0L}$ for $i=1,\ldots,N)$, is nondecreasing and also decomposable in the DP sense, therefore, dynamic programming techniques can be applied readily in optimizing the problem.

## Dynamic Programming Optimization of a Fluid Network

The use of the dynamic programming technique in the modeling and optimization of a general fluid network can be illustrated by an example shown in Figure 8. Each branchline of the loops with many segments of pipes can be optimized separately by following the serial-type optimization procedure. The optimizations that need to be obtained at all stages are:

1. For Stages 1 through M of the branch pipeline 1

$$f_{11}\ (X_{11}) = \underset{D_{11}}{\text{Max}}\ r_{11}(X_{ii}, D_{11}) \quad \text{for Stage 1 and}$$

$$f_{m1}\ (X_{m1}) = \underset{D_{m1}}{\text{Max}}\ \left\{ r_{m1}(X_{m1}, D_{m1}) + f_{m-1,1}[t_{m1}(X_{m1}, D_{m1})] \right\} \text{ for}$$

$$m = 2,\ldots,M \tag{19}$$

2. For Stages 1 through M of the branch pipeline 2

$$f_{12}(X_{12}) = \underset{D_{12}}{\text{Max}}\ r_{12}, D_{12}) \quad \text{for Stage 1 and}$$

$$f_{m2}(X_{m2}) = \underset{D_{m2}}{\text{Max}}\ \left\{ r_{m2}(X_{m2}, D_{m2}) + f_{m-1,2}[t_{m2}(X_{m2}, D_{m2})] \right\} \text{ for}$$

$$m = 2,\ldots,M \tag{20}$$

3. For Stages 1 through j-1 of the main pipeline

$$f_1(X_1) = \underset{D_1}{\text{Max}}\ r_1(X_1, D_1) \quad \text{for Stage 1 and}$$

$$f_n(X_n) = \underset{D_n}{\text{Max}}\ \left\{ r_n(X_n, D_n) + f_{n-1}[t_n(X_n, D_n)] \right\} \quad \text{for}$$

$$n = 2,\ldots,j-1 \tag{21}$$

where $r_i$ = measure of effectiveness attributed to the ith conduit, i.e., the cost in this study, $C(X_i, D_i, X_0)$

4. For the merging Stage j

$$f_j(X_j) = \underset{D_j}{\text{Max}}\ \left\{ r_j(X_j, D_j) + f_{j-1}[t_j(X_j, D_j)] \right\} \tag{22}$$

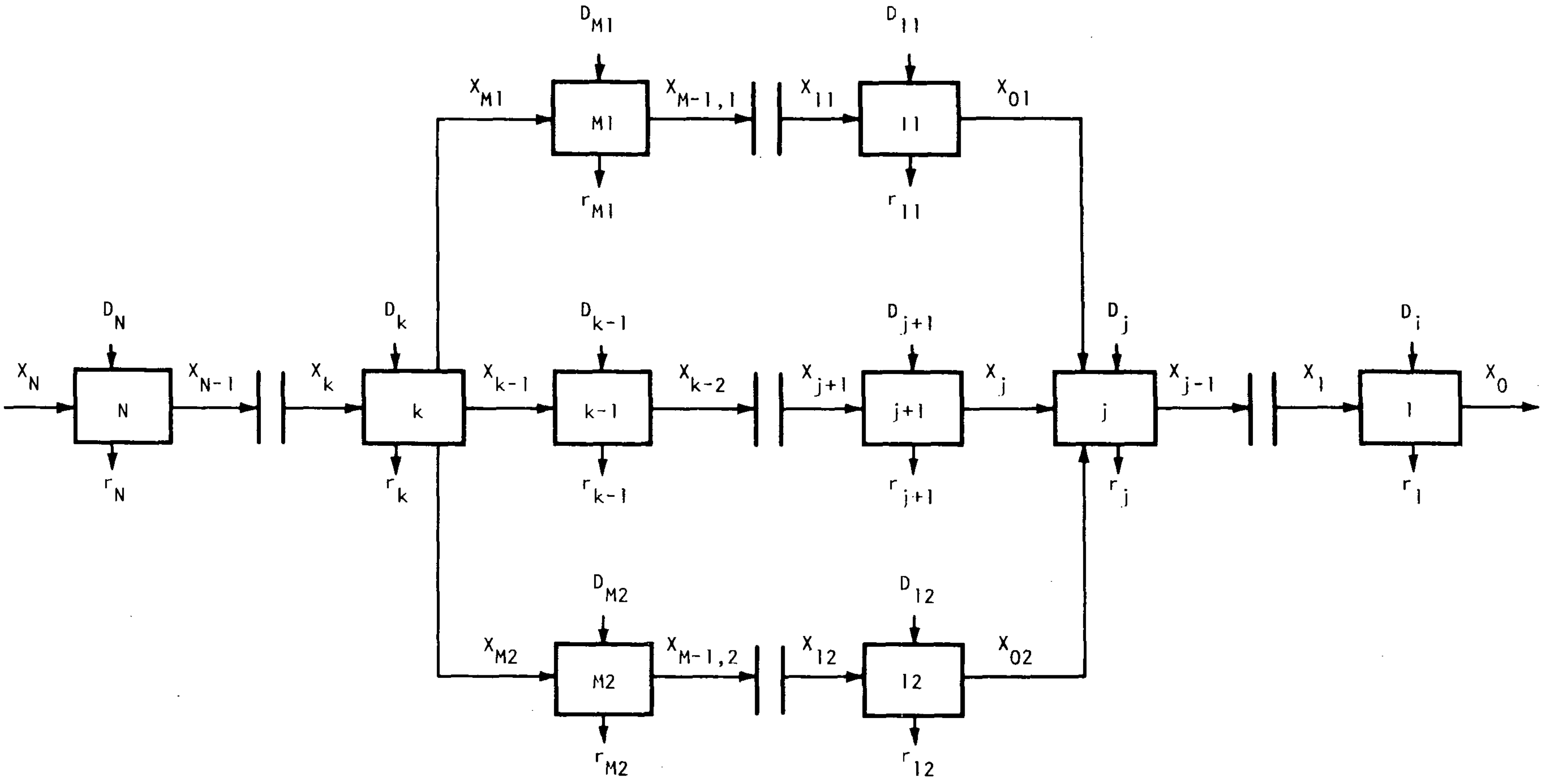



FIGURE 8. FLUID NETWORK SYSTEM

The principle of merging is that same input pressure must occur in each branch at Stage j, thus

$$X_j = X_{01} = X_{02}$$

5. For Stages j+1 through k-1 of the main pipeline

$$f_n(X_n) = \underset{D_n}{\text{Max}} \left\{ r_n(X_n, D_n) + f_{n-1}[t_n(X_n, D_n)] \right\} \text{ for} \qquad (23)$$

$$n = j+1, \ldots, k-1$$

Each branchline and mainline from Stages k-1 to -j are so optimized that its optimal return is expressed as a function of the input total heads of stages M2, M1, and k-1, respectively. These optimal returns can be combined at Stage k. The remainder of the optimization, from k through N, can be carried out as a serial pipeline.

6. For the diverging Stage k,

$$f_{k+M1+M2}(X_k) = \underset{D_k}{\text{Max}} \left\{ r_k(X_k, D_k) + f_{k-1}[t_k(X_k, D_k)] + f_{M1}[t_k(X_k, D_k)] + f_{M2}[t_k(X_k, D_k)] \right\} \qquad (24)$$

7. For the remaining Stages k+1 through N

$$f_{n+M1+M2}(X_n) = \underset{D_n}{\text{Max}} \left\{ r_n(X_n, D_n) + f_{(n-1)+M1+M2}[t_n(X_n, D_n)] \right\}$$

$$n = k+1, \ldots, N \qquad (25)$$

The terms, $f_{M1}$, $f_{M2}$ which appear in the equation for $f_{k+M1+M2}$ can be thought of as representing an absorption of the diverging branches into the main serial system. The principle of this absorption is that same output pressure must occur in each branch at Stage k with transformation $t_k$, thus,

$$t_k(X_k, D_k) = Y_k = X_{k-1} = X_{M1} = X_{M2} \ . \qquad (26)$$

Then the optimal returns from the branches, including Stages 1 through k-1 of the main branch, as a function of $Y_k$ is

$$f_{(k-1)+M1+M2}(Y_k) = \underset{Y_k = X_{k-1} = X_{M1} = X_{M2}}{\text{Max}} [f_{k-1}(X_{k-1}) + f_{M1}(X_{M1}) + f_{M2}(X_{M2})] \qquad (27)$$

Once $f_{(k-1)+M1+M2}(Y_k)$ has been determined, it is combined with the Stage k return as follows:

$$f_{k+M1+M2}(X_k) = \text{Max}\ \{r_k(X_k,D_k) + f_{(k-1)+M1+M2}[t_k(X_k,D_k)]\} \qquad (28)$$

After Stage N, this main pipeline can absorb other branches or can be absorbed into other main pipelines as a branch. Thus, the term "main" used here is relative as each pipeline can be the mainline or a branch to other pipelines and is dependent entirely upon its relative position to other pipelines in the whole system. Other loops, or loops within another loop, can be optimized by the identical procedures described above. Equations (19) to (28) can be used repeatedly in the design of a complete network; in other words, this optimization procedure is general enough for a general fluid network of any configuration. The repeated use of this procedure will finally lead to the optimal design.

## COMPUTER ASSISTED OPTIMIZATION PROCEDURES

A dynamic programming modeling of the diverging branch type fluid network can be programmed and optimized on a digital computer. The DP optimization procedure used is a final state problem and backward recursive approach (Luce 1955). The final state variable is the desired discharge pressure head and its range at the last stage of each branch pipeline of the network. Once this pressure head, its permissable range of variation, and the elevation at the discharge point are given, the feasible total pressure head range at this point can be calculated. Then, many alternate inlet total heads of this stage can be derived for the different pipe sizes. The total number of inlet heads depends on the selected inlet pressure resolution interval which, in turn, depends on design accuracy and network complexity. A desired range of the total inlet head must be selected to eliminate infeasible inlet heads and to keep calculations manageble. The resolution interval and pressure range also determine the number of total pressure heads necessary at the next upstream stage outlet. After calculating the head loss in stage junction, pipe or elbow, a set of total inlet heads are generated. Some inlet heads are not within the desired total head range specified by the design; some have discharge heads exceeding the desired limits, or some have the same values or very closed values. Designs which have the same inlet total head but higher costs than other designs and the designs which have total heads or discharge heads outside the range are considered infeasible designs which are eliminated from this stage. This stage elimination makes it unnecessary to evaluate all possible system designs and still reach the overall optimum design. Without eliminating the infeasible value of the state variables, the number of alternate or possible values will exceed the storage capacity of any computer memory after a few stages of calculations. Application of dynamic programming for more complex problems is made possible because of this approach.

The range of resolution interval is selected by the designer. Broad intervals save more computer time and memory but obtain less accurate results and vice versa. The designer must decide on this matter. For preliminary design, low resolution or broad intervals probably should be used until the final design stage is reached.

The outlet total head of a stage is the input state variable or inlet head of the next downstream stage. This procedure is executed repeatedly until a tee or cross is reached.

After all branches of a tree or cross have been analyzed with the optimization procedure, these branches will be brought together. Only the total heads which are common to all branches are used. If a loop is formed, the total inlet head of each branch at merging point should also be identical. Again, it probably will be very difficult to find identical total head at each branch. A slight difference of total heads among branches must be allowed in order to achieve an optimal solution. The allowable tolerance of this difference can be specified by the designer, and it should be as small as possible in order to obtain accurate results. Two or three branches can be absorbed into one pipeline through a tee or cross. The outlet total head of a tee or cross is the input head of the next downstream stage following a tee or a cross. The optimization procedure repeats along a pipeline until another joint of branch is reached. Then all branches are absorbed. This procedure is repeated up to the last upstream stage of the whole system.

The flow rate, discharge rate, and the cost of each stage for a given input state variable and decision variable are also computed by using the transformation between input and output state variables during the optimizing process.

The available energy range for the whole network at the inlet will eliminate the computed total heads outside the range at the final stage. Then, among all feasible total heads, the one with the lowest cost is the optimal cost of the system. The total head corresponding to the optimal cost will be selected as the input total head of the whole network. Search for the optimal design with the lowest cost is conducted from upstream to downstream stages, just opposite to the optimization process. Figure 9 shows a diagram of the optimal design searching.

## CHARACTERISTICS OF THE INTERACTIVE COMPUTER PROGRAMS

Since the batch processed computer program (Liang 1971) provided no flexibility for human interaction, an interactive type program was adopted for this study. An interactive program using FORTRAN language has been developed in such a way that it consists of a main program and a set of subprograms. The subprograms were designed to handle stages of different nature such as pipes, elbows, or tees, etc.; the main program was designed to take care of the overall calculation using both "processed" results from subprograms and other data. A program developed in this way is rather flexible for expanding and debugging. Since all subprograms are independent, they can be tested separately and other subprograms can be added easily as necessary in the further development of a more complex network.

The interactive program keeps the computer and user in contact while the program is being executed. Whenever the program requires input, the terminal will print messages or instructions and then wait. These messages or instructions show what type of data it needs, or asks the user to make certain decisions. After the requested data or decisions are received, the computer will continue to execute the program. Because of fast computer computation speed, as compared to its input and output time, the user will feel he is the only one using the computer. Communication between the user and the computer is instantaneous and it seems that the program is going on like a conversation. The computer printed messages are simple to follow; no special training in computer programming is needed. This makes it possible for most designers to use this program.

This program requires 3 data sets which are created on magnetic disks. One is created in a sequential manner for the purpose of storing the unit cost of pipe, elbow, tee, or connector, etc., and other information which

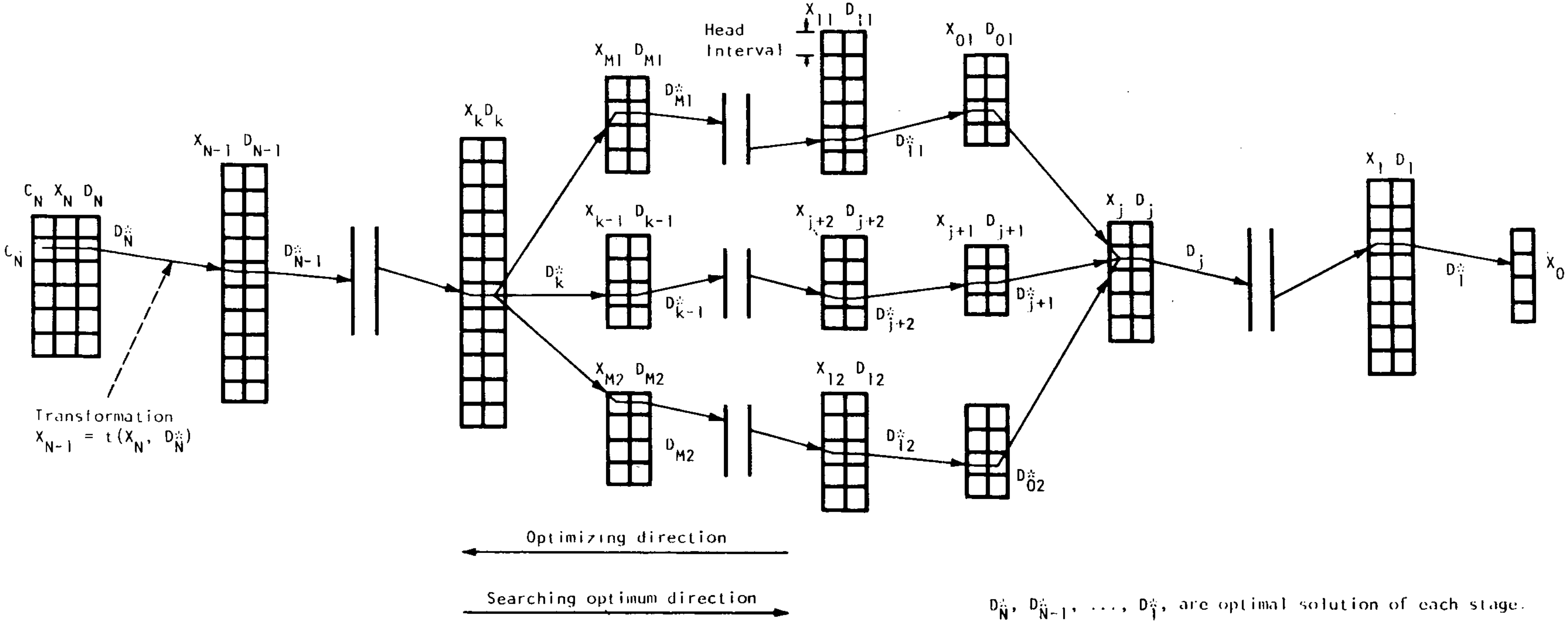



FIGURE 9. SEARCHING THE OPTIMAL DESIGN DIAGRAM

will not be changed during the execution of the program. In order to save time, this data set is created through the batch process instead of the terminal, and will be read into the computer memory after the program starts to proceed. This data set usually contains a vast amount of data; however, all of the data cannot be entered efficiently through a terminal. Data, other than material cost, can be overridden by entering data through the terminal after being read into the memory bank. The old data set can be updated. Several data sets for different sets of materials can be stored simultaneously on the disk for convenience, thus, the user can have access to the set he desires by copying that data set into the system.

The other data set which stores the feasible values of variables is created as a direct-access data set. Since the program is developed for capability in handling very complex systems with many branches, it is impossible to store the feasible values of variables from all previous calculations and their branch stages in the computer memory. When branches are merged in an optimization process, the feasible values of variables in previous corresponding branch stages can be retrieved from this data set and programmed into the computer memory for optimization. Since a direct-access data set is very convenient for fast data retrieval, the feasible calculated results of each stage are moved to this data set before starting the next stage. Every time before the program is used, enough storage space on the disk should be allowed for the direct-access data set. If the test will be interrupted and continued later, the third data set is used to store the intermediate data.

When this program starts, the information on the sequential data set will be read into computer memory first and will be printed on the output paper for checking. Then, the program will request input data or decisions. After receiving the input, calculation will start automatically. Intermediate results for each stage will be printed and stored on the direct-access data set while the programs wait for data or decisions needed for the calculation of the next stage. After all stages of the system have been analyzed, the program will also search the optimum solution from the direct-access data set and print the optimum solution.

The flow chart shown in Figure 10 explains the general structure of this program. The five important subprograms, ENDSTG, CONECT, MERGE, ELBOW, and BRANCH, were designed to handle different kinds of stages:

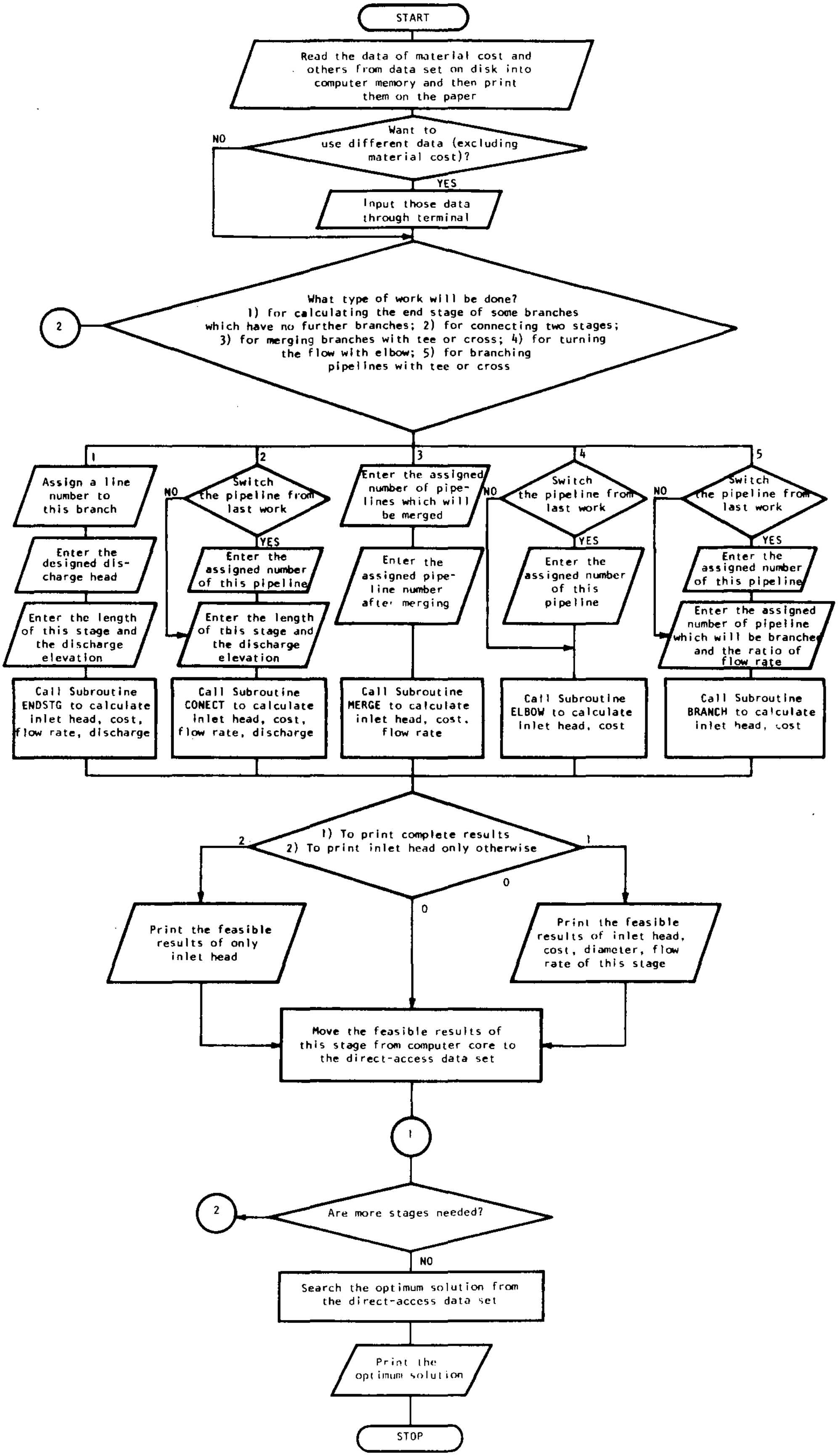



FIGURE 10. MAIN FLOW CHART

(1) The terminal stage of branch pipeline,

(2) Ordinary stages with or without discharge,

(3) Branch pipelines merging stage,

(4) Flow diversion or direction change stage, and

(5) Branch pipelines branching stage.

This program contains 1079 Fortran statements. A complete program listing is shown in Appendix B-1.

## APPLICATION OF THE COMPUTER PROGRAM

In order to illustrate how the developed computer program can be used to design a fluid network system, the following example problem is provided.

A fluid network design is required. The network layout is shown in Figure 11, in which circled numbers are assigned pipeline numbers; numbers within rectangular boxes are design discharge pressure and maximum allowable discharge pressure, in psi; the numbers enclosed within a triangle are discharge outlet elevations, in feet; and D represents discharge outlets. The design and maximum allowable pressure establish the pressure range for that particular discharge point. The discharge outlets are spaced 200 feet (61 m) apart along each pipeline. There are 10 different sizes of pipes, elbows, tee joint, and cross joints which may be used in the design. Both sudden change and gradual change type connectors provide the designer with a choice of desired alternatives. The maximum available total head at the inlet of the whole system is 62 psi (4.3586 kg/sq cm). Other required information is listed below:

Network life = 10 years,

Annual usage = 500 hours,

Annual interest of investment = 5 percent,

Unit power cost = $0.05/horsepower-hr,

Efficiency of converting source power into fluid power = 0.90,

Pipe roughness = 0.0002 in.

Fluid cost = $0.40/1000 cu ft.

Material costs can be found in Tables 1, 2, and 3.

Following the design procedure guided by questions from the terminal outlet, the designer can obtain the optimal design if he feeds the proper data into the computer. In short, the designer will be requested or prodded by the program to give data or to make decisions during tee execution

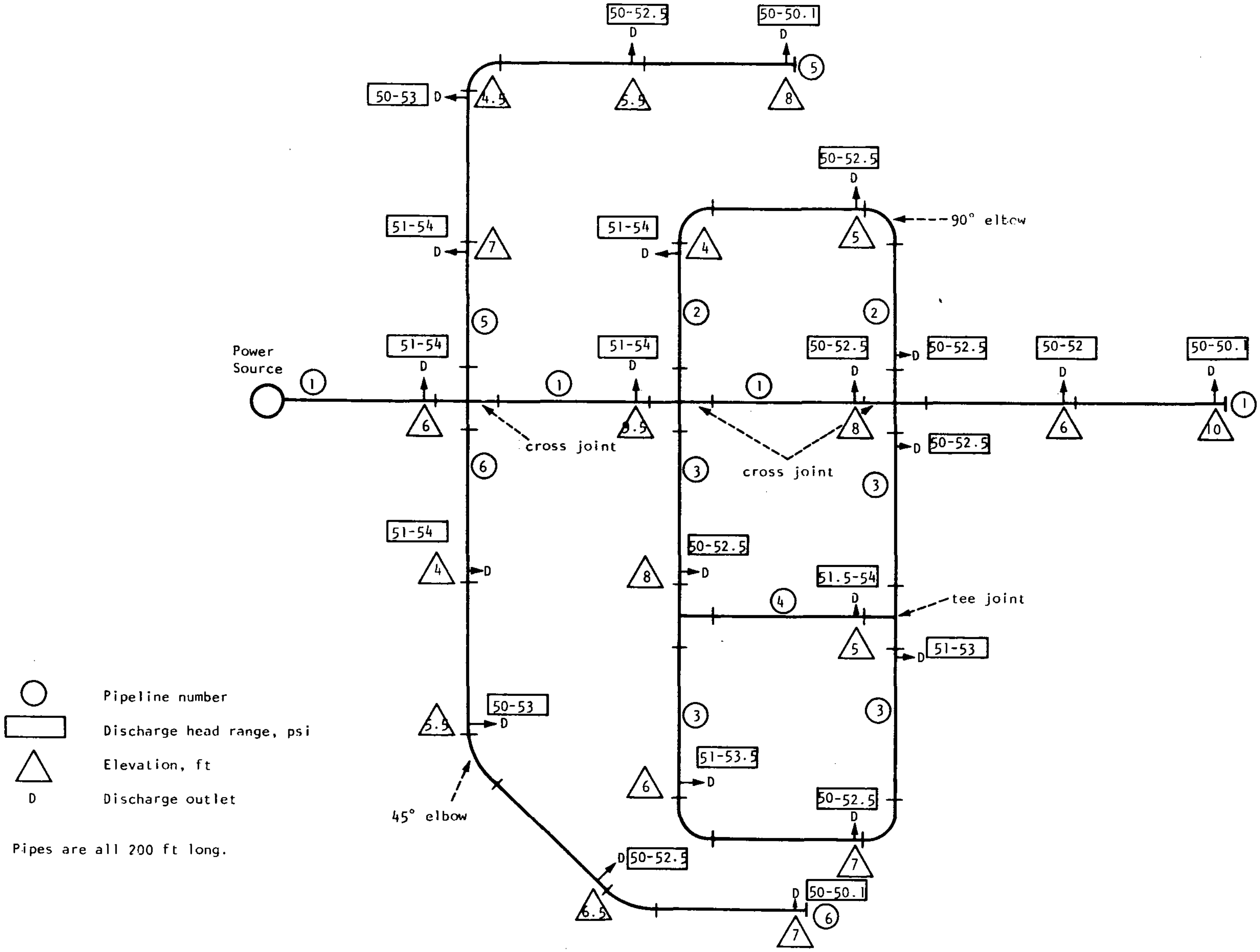



FIGURE 11. LAYOUT OF THE EXAMPLE PROBLEM

TABLE 1. COST OF PIPES, TEES, CROSSES, AND ELBOWS

| SIZE in. | PIPE $/100 ft | TEE (COST, dollars) | CROSS (COST, dollars) | ELBOW (COST, dollars) | ELBOW RADIUS in. |
|---|---|---|---|---|---|
| 2 | 25.30 | 2.18 | 2.89 | 1.54 | 6.00 |
| 3 | 38.20 | 3.87 | 4.10 | 1.85 | 7.00 |
| 4 | 51.10 | 4.12 | 4.58 | 2.24 | 7.50 |
| 5 | 68.00 | 4.86 | 5.05 | 3.56 | 8.00 |
| 6 | 93.70 | 5.38 | 6.63 | 4.13 | 10.00 |
| 7 | 126.90 | 6.98 | 7.45 | 5.68 | 12.00 |
| 8 | 154.20 | 7.74 | 8.10 | 6.35 | 14.50 |
| 10 | 210.50 | 9.70 | 11.18 | 8.16 | 16.00 |
| 12 | 285.30 | 13.85 | 17.44 | 11.98 | 17.50 |
| 15 | 408.70 | 21.65 | 24.84 | 16.58 | 20.00 |

TABLE 2. COST OF GRADUAL TYPE CONNECTORS

| END SIZE in. | END SIZE, in inches (dollars) 2 | 3 | 4 | 5 | 6 | 7 | 8 | 10 | 12 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | | 0.64 | 0.77 | 0.94 | 1.19 | 1.53 | 1.80 | 2.36 | 3.22 | 4.48 |
| 3 | | | 0.90 | 1.07 | 1.32 | 1.66 | 1.93 | 2.52 | 3.31 | 4.62 |
| 4 | | | | 1,20 | 1.46 | 1.79 | 2.07 | 2.73 | 3.48 | 4.71 |
| 5 | | | | | 1.63 | 1.96 | 2.23 | 2.84 | 3.75 | 4.88 |
| 6 | | | | | | 2.22 | 2.49 | 3.06 | 3.89 | 5.04 |
| 7 | | | | | | | 2.82 | 3.40 | 4.16 | 5.42 |
| 8 | | | | | | | | 3.76 | 4.52 | 5.70 |
| 10 | | | | | | | | | 5.06 | 6.25 |
| 12 | | | | | | | | | | 7.12 |
| 15 | | | | | | | | | | |

NOTE: ALL CONNECTORS ARE 2 ft LONG.

TABLE 3. COST OF SUDDEN TYPE CONNECTORS

| END SIZE in. | END SIZE, in inches (dollars) 2 | 3 | 4 | 5 | 6 | 7 | 8 | 10 | 12 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | | 0.58 | 0.70 | 0.86 | 1.13 | 1.45 | 1.72 | 2.16 | 2.93 | 4.08 |
| 3 | | | 0.87 | 0.91 | 1.21 | 1.54 | 1.83 | 2.32 | 3.17 | 4.35 |
| 4 | | | | 1.09 | 1.34 | 1.63 | 1.93 | 2.54 | 3.29 | 4.51 |
| 5 | | | | | 1.48 | 1.81 | 2.09 | 2.72 | 3.42 | 4.68 |
| 6 | | | | | | 2.08 | 2.31 | 2.84 | 3.64 | 4.92 |
| 7 | | | | | | | 2.62 | 3.08 | 3.94 | 5.18 |
| 8 | | | | | | | | 3.47 | 4.21 | 5.43 |
| 10 | | | | | | | | | 4.87 | 6.11 |
| 12 | | | | | | | | | | 6.74 |
| 15 | | | | | | | | | | |

of the program. Eventually, the designer will obtain optimum design of the fluid network. A complete list of instructions of using this program is also shown in Appendix B-5.

The design method discussed here was used and it yielded an optimum design with its system effectiveness rated at 3667.40 dollars per year. The optimum inlet total head of the whole system is 56.9470 psi (4.0034 kg/sq cm). Two printed solution messages shown in the computer printout indicated that identical total heads of corresponding branches did not occur at two merge points of the loops. In this situation, pressure reducers will be added to those branch pipelines with higher total head to bring them down to the lowest head at the merge point of the loops. Those pressure reducers are necessary in order to keep down stream stages to satisfy required flow conditions. The solution printed by computer is shown in Table 4 and is also summarized graphically in Figure 12.

An IBM 360-65 computer was used. The program was run under the IBM TSO system with an IBM 2741 remote terminal. The total terminal connect time used to solve this problem is about 3 hours and 40 minutes. The actual CPU time used was around 280 seconds and approximately 37 tracks of IBM 2314 disk packs storage were used for intermediate storage during optimization.

## CONCLUSION AND DISCUSSION

The design procedure based on dynamic programming and coded in interactive Fortran language has been applied successfully to the design of a water network with diverging branches and loops. The direction of flows within any branch or loop of the network was preassigned. Moderate pressure regulation may be needed occasionally at the downstream junction of a loop and, whenever it is needed, the computer printout will indicate the amount of pressure regulation required. Strictly speaking, the final design, without considering this pressure regulation cost, is not optimal. However, in a large network, this error will probably not be great compared to the overall cost of the system.

The design procedure does not provide explicit means for handling pumping or pressure stepup consideration in the intermediate stages of a network. Branches of the network converge at a downstream point; a conveying network, such as a multiple water source network, was not considered. However, the computerized design procedure can be used to handle these problems reasonably

TABLE 4. SOLUTION OF THE EXAMPLE PROBLEM FROM COMPUTER PRINTOUT

OPTIMAL SOLUTION:

TOTAL COST = 3667.40 DOLLARS PER YEAR

| STAGE | I.HEAD | DIAM. | LENGTH | I.FLOW | D.HEAD | DISCHARGE | ELEV. | TYPE | LINE NO. | BRANCHES NO. |
|---|---|---|---|---|---|---|---|---|---|---|
| 34 | 56.9470 | 15.00 | 200.00 | 6.409837 | 53.2847 | 0.295671 | 6.0 | CONG | 1 | |
| 33 | 56.0538 | 15.00 | | 6.114166 | | | | CRBG | 1 | 1 5 6 |
| 32 | 56.0173 | 8.00 | 200.00 | 1.164472 | 53.4055 | 0.296005 | 4.0 | CONS | 6 | |
| 31 | 55.1820 | 8.00 | 200.00 | 0.868466 | 52.2871 | 0.292890 | 5.5 | CONS | 6 | |
| 30 | 54.6876 | 6.00 | | 0.575576 | | | | ELBS | 6 | |
| 29 | 54.6829 | 6.00 | 200.00 | 0.575576 | 50.9151 | 0.289021 | 6.5 | CONS | 6 | |
| 28 | 53.7354 | 4.00 | | 0.286555 | | | | ELBS | 6 | |
| 27 | 53.7264 | 5.00 | 200.00 | 0.286555 | 50.0499 | 0.286555 | 7.0 | END | 6 | |
| | 53.0854 | | | | | | | | | |
| 26 | 56.0014 | 8.00 | 200.00 | 1.162068 | 52.0918 | 0.292342 | 7.0 | CONS | 5 | |
| 25 | 55.1749 | 7.00 | 200.00 | 0.869726 | 52.2545 | 0.292798 | 4.5 | CONS | 5 | |
| 24 | 54.2373 | 7.00 | | 0.576928 | | | | ELBS | 5 | |
| 23 | 54.2324 | 7.00 | 200.00 | 0.576928 | 51.3924 | 0.290373 | 5.5 | CONS | 5 | |
| 22 | 53.7864 | 6.00 | 200.00 | 0.286555 | 50.0499 | 0.286555 | 8.0 | END | 5 | |
| | 53.5190 | | | | | | | | | |
| 21 | 56.0076 | 15.00 | 200.00 | 3.787626 | 51.4910 | 0.290651 | 9.5 | CONG | 1 | |
| 20 | 55.6615 | 8.00 | | 3.496975 | | | | CRBG | 1 | 1 2 3 |
| 19 | 55.3684 | 12.00 | 200.00 | 1.923263 | 51.5765 | 0.290893 | 8.0 | CONG | 3 | |
| 18 | 55.0723 | 6.00 | | 1.632370 | | | | TEBG | 3 | 3 4 |
| 17 | 55.0096 | 10.00 | 200.00 | 1.107689 | 52.1319 | 0.292455 | 6.0 | CONG | 3 | |
| 16 | 54.7491 | 10.00 | | 0.815234 | | | | ELBG | 3 | |
| 15 | 54.7466 | 10.00 | 200.00 | 0.815234 | 51.5549 | 0.290832 | 7.0 | CONG | 3 | |
| 14 | 54.5966 | 10.00 | | 0.524403 | | | | ELBG | 3 | |
| 13 | 54.5956 | 10.00 | 200.00 | 0.524403 | 52.3581 | 0.293088 | 5.0 | CONG | 3 | |
| 12 | 55.0084 | 7.00 | 200.00 | 0.524681 | 52.4576 | 0.293367 | 5.0 | CONG | 4 | |

TABLE 4. CONTINUED

THE OUTLET PRESSURE OF STAGE 12 WAS REDUCED FROM 54.6313 TO 54.5272

| STAGE | I.HEAD | DIAM. | LENGTH | I.FLOW | D.HEAD | DISCHARGE | ELEV. | TYPE | LINE NO. | BRANCHES NO. |
|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 54.5272 | 4.00 | | 0.462629 | | | | TEMG | 3 | 3 4 |
| 10 | 54.5023 | 10.00 | 200.00 | 0.462629 | 50.9781 | 0.289200 | 8.0 | CONG | 3 | |
| 9 | 55.3657 | 10.00 | 200.00 | 1.051632 | 53.3809 | 0.295937 | 4.0 | CONG | 2 | |
| 8 | 55.1131 | 3.00 | | 0.755695 | | | | ELBG | 2 | |
| 7 | 54.9125 | 8.00 | 200.00 | 0.755695 | 52.3499 | 0.293065 | 5.0 | CONG | 2 | |
| 6 | 54.5293 | 4.00 | | 0.462629 | | | | ELBG | 2 | |
| 5 | 54.5023 | 10.00 | 200.00 | 0.462629 | 50.9781 | 0.289200 | 8.0 | CONG | 2 | |
| 4 | 55.3675 | 7.00 | 200.00 | 0.522081 | 51.5586 | 0.290842 | 8.0 | CONG | 1 | |

THE OUTLET PRESSURE OF STAGE 4 WAS REDUCED FROM 54.9938 TO 54.4479

| STAGE | I.HEAD | DIAM. | LENGTH | I.FLOW | D.HEAD | DISCHARGE | ELEV. | TYPE | LINE NO. | BRANCHES NO. |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 54.4470 | 8.00 | | 0.578096 | | | | CRMG | 1 | 1 2 3 |
| 2 | 54.4433 | 12.00 | 200.00 | 0.578096 | 51.8068 | 0.291541 | 6.0 | CONG | 1 | |
| 1 | 54.4095 | 10.00 | 200.00 | 0.286555 | 50.0499 | 0.286555 | 10.0 | END | 1 | |
| | 54.3863 | | | | | | | | | |

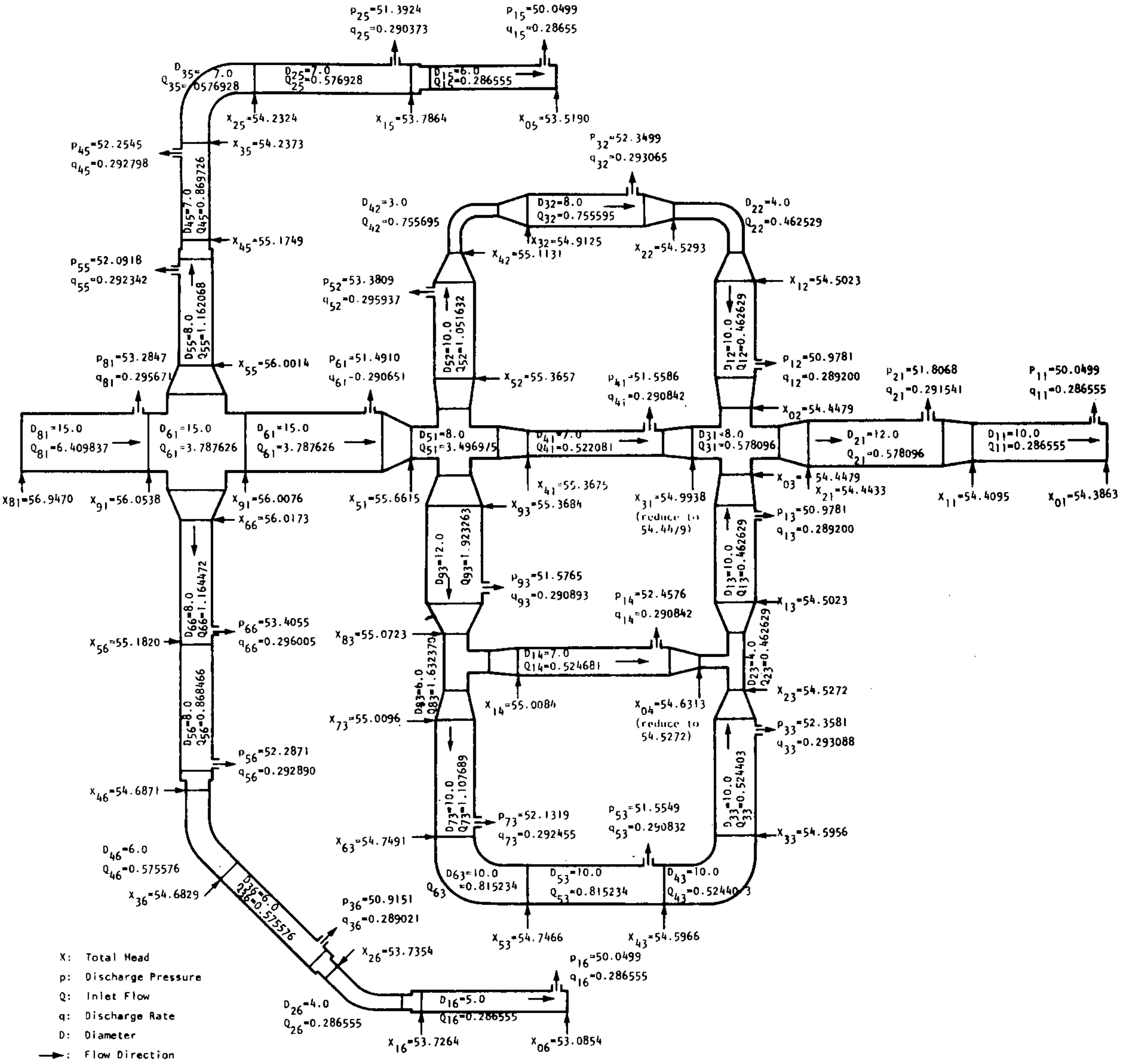



FIGURE 12. GRAPHICAL SOLUTION OF THE EXAMPLE PROBLEM

well if the network can be broken down into several manageable segments. A general guideline is provided (see Fig. 13) to accomplish this:

1. The downstream network below a predetermined possible pumping station (such as point C) should be separated from the rest of the network. The design procedure can then be applied independently of the rest of the network to this segment of network. The design will provide cost, $C(p_c)$, as a function of the water pressure at point C for any given design pressure at points D.
2. The design procedure can then be applied to the segment of network ABE and ABC while C is set at the most economical pressure range, indicated in the cost function obtained in 1.
   For any given C pressure, the cost function, $C(p_A)$, of the segment (ABE and ABC) of the network can be obtained in terms of water pressure at point A.
3. Let $C(Pi)$ be the cost of the segment from point A to point i as the most upstream point at pressure Pi. The $s_1A$ network segment and the $s_2A$ segment can be analyzed separately for any A pressure. In other words, any water source to point A is identified as an independent segment for design analysis. For the network in Figure 13, two cost relationships $C(p_{s1})$ and $C(p_{s2})$ can be obtained for segments from $s_1$ to A and $s_2$ to A.
4. For any feasible sequence of pressures $(p_{s1}, p_{s2}, p_a, p_c)$ at points s1, s2, A and C, the total cost of the network form segments is equal to $C = C(p_{s1})+C(p_{s2})\ C(p_a)+C(p_c)$. where $p_{s1} \leq p'_{s1}$, $p_{s2} \leq p'_{s2}$ and $p'_{s1}, p'_{s2}$ are the highest attainable pressure at points $s_1$ and $s_2$. The pressure sequence $(p^*_{s1}, p^*_{s2}, p^*_a, p^*_c)$ which minimizes C determines the optimal network design.

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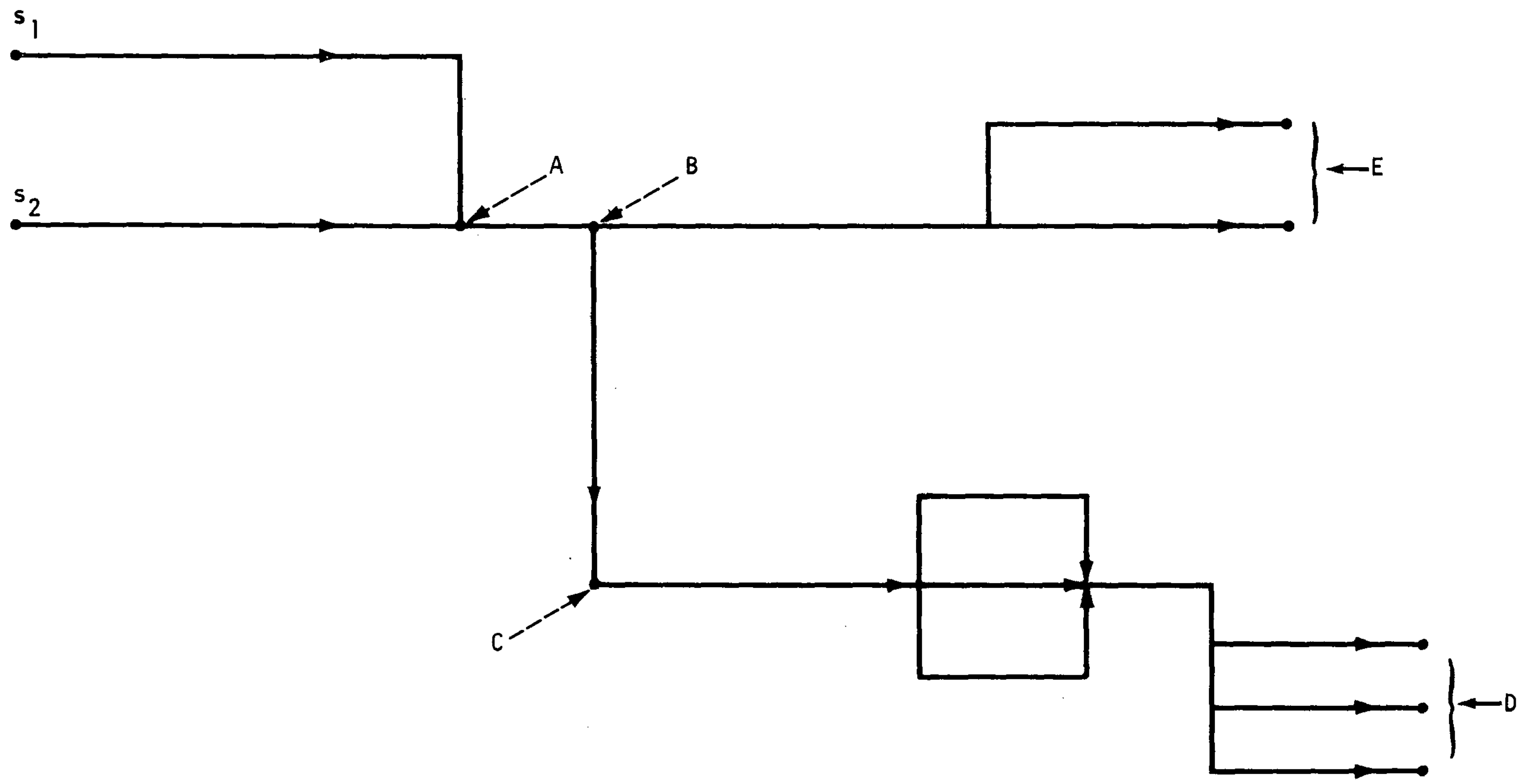


FIGURE 13. NETWORK WITH MULTIPLE POWER SOURCES

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# APPENDICES

## Appendix A. Glossary

$C_{ci}$ — Cost of connectors between ith and (i-1)th stage, in dollars

$\overline{C_{di}}$ — Unit cost of the ith pipe with a diameter of d-inch, in dollars per foot

$C'_{di}$ — Cost of an elbow, a tee, or a cross, in dollars with d-inch size

$\overline{C_e}$ — Unit power cost, in dollars per horsepower-hour

$C_{ei}$ — Cost of energy put into fluid in ith conduit, in dollars per year

$C_{pi}$ — Cost of ith conduit such as pipes, elbow, or tees, etc., in dollars per year

$\overline{C_w}$ — Water cost, in dollars per cubic foot

$C_{wi}$ — Cost of water wasted as discharged in excess of requirement in ith conduit, in dollars per year

CB — Loss coefficient due to charnge of flow direction in elbow, dimensionless

CJ — Loss coefficient in a tee or a cross, dimensionless

$CL_i$ — Loss coefficient in a connector between ith and (i-1)th conduits due to change of size, dimensionless

$D_i$ — Size of ith segment of conduit, in inches

E — Conversion efficiency from electrical or other power source to water power, as decimal

e — Pipe roughness, in inches

$f_i$ — Friction coefficient in ith conduit, dimensionless

$H_i$ — Length of the ith stage, in feet

I — Annual interest, in percent

L — Life of the fluid network, in years

N — Total number of conduit segments in the fluid network

$P_i$ — Designed discharge head of the ith stage, in psi

$PD_i$ — Discharge head at discharge outlet of the ith stage, in psi

| | |
|---|---|
| $Q_{i,j}$ | Inlet flow of the ith stage, jth branch, in cfs |
| $Q_{i-1,j}$ | Outlet flow of the ith stage, jth branch, in cfs |
| $q_i$ | Discharge rate at the ith stage discharge outlet, in cfs |
| $R_i$ | Reynolds number for ith conduit segment, dimensionless |
| $r_i$ | Cost, return function, due to ith segment of conduit, in dollars per year |
| S | Salvage value of conduits, as a fraction of the original cost |
| T | Usage of the system, in hours per year |
| $V_{i-1}$ | Velocity of the ith stage at outlet, in psi |
| $V'_{i-1}$ | Velocity head of the ith stage at discharge outlet (orifice), in psi |
| $X_i$ | Inlet total head of the ith stage, in psi |
| $X_{i-1}$ | Outlet total head of the ith stage or inlet total head of (i-1)th stage, in psi |
| $X'_{i-1}$ | Total head at discharge orifice, in psi |
| $Z_i$ | Elevation head at discharge orifice, in psi |
| $\nu$ | Fluid kinematic viscosity, in square feet per second |

# Appendix B-1. Main Computer Program

```
//PIPE    JOB    (1988),'YANG',MSGLEVEL=(1,1)
// EXEC  TSOCATP,NAME='T619880.YANG.PIPE.FORT'
// EXEC  TSOPDS,NAME='T619880.YANG.PIPE.FORT',MEMBER=DEMO
//GO.SYSIN  DD  *
C
C                           THIS IS THE MAIN PROGRAM
C
C
C      VIS     : FLUID KINEMATIC VISCOSITY, IN FT.**2/SEC. (1.21E-5 FOR
C                WATER AT 60 DEGREES F.)
C      CP      : PIPE UNIT COST, IN $/FT.
C      H       : PIPE LENGTH, IN FT.
C      Z       : DISCHARGE ELEVATION, IN FT.
C      F       : PIPE ROUGHNESS, IN IN.
C      DO      : DIAMETER OF PREVIOUS STAGE, IN IN.
C      QO      : EXIT FLUID FLOW RATE, IN CUBIC FT./SEC.
C      XO      : OUTLET TOTAL HEAD, IN PSI.
C      CO      : TOTAL COST UP TO PREVIOUS STAGE, IN $
C      QD      : DISCHARGE RATE, IN CUBIC FT./SEC.
C      RE      : REYNOLD'S NUMBER, DIMENSIONLESS
C      D       : PIPE OR OTHER JOINTS DIAMETER, IN IN.
C      Q1      : INLET FLUID FLOW RATE, IN CUBIC FT./SEC.
C      C       : TOTAL COST UP TO PRESENT STAGE, IN $
C      X1      : INLET TOTAL HEAD, IN PSI.
C      XMAX    : DESIGNED MAX. INLET TOTAL HEAD, IN PSI.
C      XMIN    : DESIGNED MIN. INLET TOTAL HEAD, IN PSI.
C      XDEL    : INTERVAL FOR ELIMINATING SAME INLET TOTAL HEAD, IN PSI.
C      XDMIN   : DESIGNED DISCHARGE PRESSURE, IN PSI.
C      XDMAX   : DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
C      XD      : DISCHARGE HEAD, IN PSI.
C      DC      : DISCHARGE COEFFICIENT, IN CUBIC FT./SEC./SQ.RT.(PSF.)
C      CC      : CONNECTORS COST, IN $
C      GH      : LENGTH OF GRADUAL CHANGE TYPE CONNECTORS, IN FT.
C      XOO     : OUTLET TOTAL HEAD BEFORE HEAD LOSS IN CONNECTOR, IN PSI.
C      VP      : VELOCITY HEAD, IN PSI.
C      CL      : HEAD LOSS COEFFICIENT, DIMENSIONLESS
C      QS      : REQUIRED DISCHARGE RATE, IN CUBIC FT./SEC.
C      KQ      : DECISION FOR DISCHARGE TYPE
C      KD      : DECISION FOR INCLUDING WASTED FLUID COST
C      KK      : STAGE CATAGORY
C      KV      : CONNECTION TYPE
C      KSZ     : DECISION FOR ALLOWING SMALLER PIPE IN UPSTREAM
C      KP      : DECISION FOR INCLUDING POWER COST
C      DCA     : ASSIGNED DISCHARGE COEF., IN CUBIC FT./SEC./SQ.RT.(PSF.)
C      NO      : NO. OF DIFFERENT SIZE OF PIPES OR OTHER JOINTS
C      DIA     : PIPE OR JOINTS SIZE, IN IN.
C      COPI    : COST OF PIPE, IN $/FT.
C      COTEE   : COST OF TEE JOINT, IN $
C      COCRS   : COST OF CROSS JOINT, IN $
C      COFLB   : COST OF ELBOW, IN $
C      ELBR    : RADIUS OF BENDING CURVATURE OF ELBOW, IN IN.
C      COSUD   : COST OF SUDDEN CHANGE TYPE CONNECTORS, IN $,
C                COSUD(I,J) & COSUD(J,I) ARE THE COST OF CONNECTOR BETWEEN
C                SIZE I AND J PIPES, IF I=J THEN COSUD=0.
C      COGRA   : COST OF GRADUAL CHANGE TYPE CONNECTOR, IN $
C      X1AAA,CAAA,QAAA,DAAA,XOAAA ARE WORKING SPACES TO STORE FEASIBLE
C      SOLUTIONS AT EACH STAGE
C      A,B ARE CONSTANTS
C      L       : ASSIGNED PIPELINE NUMBER
C      N       : NO. OF FEASIBLE SOLUTIONS AT EACH STAGE
C      NI      : RECORD INDEX ON DIRECT-ACCESS DATA SET
C      II      : NO. OF STAGES
C      IL      : NO. OF BRANCH AND MERGE JOINTS
C      IQ      : NO. OF MERGE JOINTS
C      NP      : NO. OF BRANCHES OF EACH BRANCH OR MERGE JOINT
C      IKKN,IKKL,IKKK,ILNP,IKKV,ILLL,RQQQ,HKKH,ZKKZ,DCKK ARE WORKING
C      SPACES TO STORE INFORMATION OF EACH STAGE
C      LF      : LIFE OF FLUID NETWORK, IN YR.
C      INT     : INTEREST OF INVESTMENT, IN PERCENT
C      S       : MATERIAL SALVAGE VALUE, IN DECIMAL OF ORIGINAL VALUE
C      CE      : UNIT ENERGY COST, IN $/HP-HR.
C      T       : ANNUAL USAGE TIME, IN HOUR
C      EFF     : EFFICIENCY OF CONVERTING SOURCE POWER TO FLUID POWER,
C                IN DECIMALS
C      CF      : FLUID COST, IN $/1000 CUBIC FEET
C
C
C
      REAL LF,INT
      COMMON /ITEM1/VIS,CP,H,Z,F,DO,QO,XO,CO,QD,RE,D,Q1,C,X1,XMAX,XMIN,
     *XDEL,XDMIN,XDMAX,XD,DC,CC,GH,XOO,VP,CL,QS,KQ,KD,KK,KV,KSZ,KP,DCA
      COMMON /ITEM2/NO,DIA(30),COPI(30),COTEE(30),COCRS(30),COELB(30),
     *ELBR(30),COGRA(30,30),COSUD(30,30)
      COMMON /ITEM3/X1AAA(2000),CAAA(2000),QAAA(2000),DAAA(2000),
     *XOAAA(2000),A,B,L,N,NI
      COMMON /ITEM4/II,IL,IQ,NP,IKKN(100),IKKL(100),IKKK(100),ILNP(50),
     *IKKV(100),ILLL(50,3),RQQQ(50,3),HKKH(100),ZKKZ(100),DCKK(100)
      COMMON /ITEM5/LF,INT,S,CE,T,EFF,CF
      VIS=1.21E-5
      DCA=0.0033754
      II=1
      IL=0
      IQ=0
      IKKN(1)=0
      A=-10.E25
      B=-10.E30
      DO 1 I=1,50
      DO 1 J=1,3
    1 RQQQ(I,J)=0.
      REWIND 1
      DEFINE FILE  2(3000,20,L,NI)
      READ(1,2) NO
    2 FORMAT(I5)
      DO 3 I=1,NO
    3 READ(1,4) DIA(I),COPI(I),COTEE(I),COCRS(I),COFLB(I),ELBR(I)
    4 FORMAT(F6.3,F8.4,4F6.2)
      READ(1,5) F,LF,INT,S,CE,T
    5 FORMAT(F8.6,F6.1,3F6.2,F6.1)
      READ(1,6) EFF,CF,GH
    6 FORMAT(3F6.2)
      DO 10 I=1,NO
      J1=1
      J2=6
    8 IF(J2.GT.NO) J2=NO
      READ(1,9) (COGRA(I,J),J=J1,J2)
    9 FORMAT(6F6.2)
      J1=J1+6
      J2=J2+6
      IF(J1.GT.NO) GO TO 10
      GO TO 8
   10 CONTINUE
      DO 20 I=1,NO
      J1=1
      J2=6
   15 IF(J2.GT.NO) J2=NO
      READ(1,9) (COSUD(I,J),J=J1,J2)
      J1=J1+6
      J2=J2+6
      IF(J1.GT.NO) GO TO 20
      GO TO 15
   20 CONTINUE
      WRITE(6,21)
   21 FORMAT('0ENTER 1 TO PRINT DATA OF MATERIAL COST, OTHERWISE 0')
      READ(5,*) K2
      IF (K2 .NE. 1) GO TO 45
      WRITE(6,22) NO
   22 FORMAT(/'0NUMBER OF AVAILABLE SIZE = ',I5,//,'0NO.',3X,'DIAM.IN.',
     *2X,'PIPE COST,$/FT',2X,'TEE COST,$',2X,'CROSS COST,$',2X,'ELBOW CO
     *ST,$',2X,'R. OF BENDING CURVATURE,IN.')
      DO 25 I=1,NO
   25 WRITE(6,26) I,DIA(I),COPI(I),COTEE(I),COCRS(I),COFLB(I),ELBR(I)
   26 FORMAT('0',I3,4X,F6.3,5X,F8.4,8X,F6.2,6X,F6.2,8X,F6.2,17X,F6.2)
      WRITE(6,27) GH,(DIA(I),I=1,NO)
   27 FORMAT(/'0COST OF GRADUAL CONNECTOR BETWEEN DIFFERENT DIAMETERS, I
     *N $',/,'0CONNECTOR LENGTH = ',F6.2,' FT.',/,(7X,10F8.3))
      DO 30 I=1,NO
   30 WRITE(6,31) DIA(I),(COGRA(I,J),J=1,NO)
   31 FORMAT(1X,F6.3,10F8.2,/,(7X,10F8.2))
      WRITE(6,32)
   32 FORMAT(/'0COST OF SUDDEN CONNECTOR BETWEEN DIFFERENT DIAMETERS, IN
     * $')
      DO 40 I=1,NO
   40 WRITE(6,31) DIA(I),(COSUD(I,J),J=1,NO)
   45 WRITE(6,46)
   46 FORMAT('0ENTER 1 IF CONTINUE FROM PREVIOUS INCOMPLETE TEST, OTHERW
     *ISE 0')
      READ(5,*) K1
      IF(K1.NE.1) GO TO 47
      CALL  CONTU1
      GO TO 100
   47 WRITE(6,48) VIS,F,LF,INT,S,CE,T,EFF,CF,DCA
   48 FORMAT(/'0FLUID KINEMATIC VISCOSITY = ',E10.3,' FT.**2/SEC.',/,'0P
     *IPE ROUGHNESS = ',F10.6,' IN.',/,'0PIPE LIFE = ',F8.1,' YR.',/,'0I
     *NTEREST = ',F8.2,' PERCENT',/,'0SALVAGE VALUE = ',F8.2,' OF ORIGIN
     *AL VALUE',/,'0ENERGY COST = ',F8.2,' $/HP-HR.',/,'0ANNUAL USAGE TI
     *ME = ',F8.1,' HR.',/,'0CONVERSION EFF. FROM POWER SOURCE TO FLUID
     *POWER = ',F8.2,/,'0FLUID COST = ',F8.2,' $/1000 CUBIC FT.',/,'0DIS
     *CHARGE COEFFICIENT = ',F11.7,' CFS./SQRT(PSF.)',//)
      WRITE(6,49)
   49 FORMAT('0ENTER 1 IF YOU WANT TO USE DATA OTHER THAN GIVEN ABOVE EX
     *CLUDING MATERIAL COSTS, OTHERWISE 0')
      READ(5,*) K1
      IF(K1.NE.1) GO TO 60
      WRITE(6,50)
   50 FORMAT('0ENTER FLUID KINEMATIC VISCOSITY, PIPE ROUGHNESS, PIPE LIF
     *E, INTEREST, SALVAGE VALUE,',/,'IN THE SAME UNITS AS ABOVE')
      READ(5,*) VIS,F,LF,INT,S

      WRITE(6,55)
   55 FORMAT('0ENTER ENERGY COST, ANNUAL USAGE TIME, CONVERSION EFF., FL
     *UID COST, AND DISCHARGE COEF.,',/,'IN THE SAME UNITS AS ABOVE')
      READ(5,*) CE,T,EFF,CF,DCA
   60 NI=1
      WRITE(6,61)
   61 FORMAT('0ENTER 1 IF SMALLER SIZED PIPE AT UPSTREAM IS NOT ALLOWED,
     * OTHERWISE 0')
      READ(5,*) KSZ
      WRITE(6,62)
   62 FORMAT('0ENTER 1 IF WASTED FLUID COST SHOULD BE INCLUDED, OTHERWIS
     *E 0')
      READ(5,*) KD
      WRITE(6,63)
   63 FORMAT('0ENTER 1 IF POWER COST SHOULD BE INCLUDED, OTHERWISE 0')
      READ(5,*) KP
      WRITE(6,66)
   66 FORMAT('0ENTER THE ASSIGNED NUMBER OF PIPE LINE')
      READ(5,*) L
      KK=1
  100 CONTINUE
      KV=1
      H=1.
      Z=0.
      N=0
      DO 110 I=1,2000
  110 X1AAA(I)=B
      IF (II.EQ.1) GO TO 160
      WRITE(6,115)
  115 FORMAT('0ENTER 1 TO CALCULATE THE END STAGES',/,'0',6X,'2 TO CONNE
     *CT TWO STAGES',/,'0',6X,'3 TO MERGE PIPELINES WITH TEE JOINT',/,
     *,'0',6X,'4 TO MERGE PIPELINES WITH CROSS JOINT',/,'0',6X,'5 TO TURN
     * THE FLOW WITH ELBOW',/,'0',6X,'6 TO BRANCH PIPELINES WITH TEE JOI
     *NT',/,'0',6X,'7 TO BRANCH PIPELINES WITH CROSS JOINT')
      READ(5,*) KK
  120 CONTINUE
      GO TO (130,130,240,240,130,130,130),KK
      GO TO 100
  130 IF (KK.EQ.1) GO TO 140
      WRITE(6,132)
  132 FORMAT('0ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0')
      READ(5,*) K1
      IF (K1 .NE. 1) GO TO 150
  140 WRITE(6,66)
      READ(5,*) L
  150 IF (KK.EQ.5)  GO TO 260
      IF (KK.EQ.6 .OR. KK.EQ.7)  GO TO 280
  160 WRITE(6,162)
  162 FORMAT('0ENTER 1 TO SPECIFY REQUIRED DISCHARGE',/,'0',6X,'2 TO USE
     * DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)',/,'0',6X,
     *'3 TO USE ORIGINAL ORIFICE SIZE')
      READ(5,*) KQ
      GO TO (170,180,190),KQ
      GO TO 160
  170 WRITE(6,172)
  172 FORMAT('0ENTER THE REQUIRED DISCHARGE, IN CFS.')
      READ(5,*) QS
      WRITE(6,174)
  174 FORMAT('0ENTER THE DESIGNED DISCHARGE PRESSURE, IN PSI.')
```

# Appendix B-1 (Contd)

```
      READ(5,*) XDMIN
      GO TO 210
  180 WRITE(6,182)
  182 FORMAT('OENTER THE DISCHARGE COEFFICIENT, IN CFS./SQRT(PSF.)',/,'O
     *ENTER O. IF DISCHARGE IS NOT NECESSARY')
      READ(5,*) DC
      IF(DC.LT.10.E-35) GO TO 210
      GO TO 200
  190 DC=DCA
  200 WRITE(6,202)
  202 FORMAT('OENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOW
     *ABLE MAX. DISCHARGE PRESSURE, IN PSI.')
      READ(5,*) XOMIN,XDMAX
  210 WRITE(6,212)
  212 FORMAT('OENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATIO
     *N, IN FT.')
      READ(5,*) H,Z
      CALL  RANGE
      IF (KK .EQ. 2)  GO TO 220
      CALL  ENDSTG
      CALL  RFSULT(&100,&1000,&300,&400)
  220 CALL  CONECT
      CALL  RESULT(&100,&1000,&300,&400)
  240 CALL  MERGE(&100,&250)
  250 CALL  RESULT(&100,&1000,&300,&400)
  260 CALL  RANGE
      CALL  ELBOW
      CALL  RFSULT(&100,&1000,&300,&400)
  280 CALL  BRANCH
      CALL  RFSULT(&100,&1000,&300,&400)
  300 WRITE(6,305)
  305 FORMAT('ONO RESULTS PRODUCED, RE-DO THIS STAGE')
      GO TO 120
  400 CALL  CONTU2
      GO TO 1500
 1000 CONTINUF
      CALL  OPTIM
 1500 STOP
      END


      SUBROUTINE  CONTU1
      REAL LF,INT
      COMMON /ITEM1/VIS,CP,H,Z,E,DO,QO,XO,CO,QD,RE,D,Q1,C,X1,XMAX,XMIN,
     *XDEL,XDMIN,XDMAX,XD,DC,CC,GH,XOO,VP,CL,QS,KQ,KD,KK,KV,KSZ,KP,DCA
      COMMON /ITEM3/X1AAA(2000),CAAA(2000),QAAA(2000),DAAA(2000),
     *XOAAA(2000),A,B,L,N,NI
      COMMON /ITEM4/II,IL,IQ,NP,IKKN(100),IKKL(100),IKKK(100),ILNP(50),
     *IKKV(100),ILLL(50,3),RQQQ(50,3),HKKH(100),ZKKZ(100),DCKK(100)
      COMMON /ITEM5/LF,INT,S,CE,T,EFF,CF
      REWIND 3
      READ(3,1) II,IL,IQ
    1 FORMAT(I5,2I3)
      DO 5 I=2,II
    5 READ(3,7) IKKN(I),IKKL(I),IKKK(I),IKKV(I),HKKH(I),ZKKZ(I),DCKK(I)
    7 FORMAT(I4,I3,2I1,3A4)
      IF (IL.LE.0)  GO TO 25
      DO 20 I=1,IL
      READ(3,9) NP,(ILLL(I,J),J=1,NP)
    9 FORMAT(I3,3I3)
   20 ILNP(I)=NP
   25 IF (IQ.LE.0)  GO TO 35
      DO 30 I=1,IQ
   30 READ(3,32) (RQQQ(I,J),J=1,3)
   32 FORMAT(3A4)
   35 CONTINUF
      READ(3,37) VIS,E,LF,INT,S
      READ(3,37) CE,T,EFF,CF,DCA
      READ(3,37) KSZ,KP,KD
   37 FORMAT(5A4)
      IK=II-1
      WRITE(6,40) IK,IKKL(II)
   40 FORMAT('OTHE LAST STAGE IN PREVIOUS STAGE WAS',I5,', AND THE LINE
     *NO. WAS ',I3,/,'OENTER A NUMBER N SUCH THAT THIS JOB WILL CONTINUE
     * FROM N STAGES BACK OF THE LAST STAGE OF LAST JOB',/,
     *'OENTER 0 IF CONTINUE FROM THE NEXT STAGE')
      READ(5,*) ISTAGE
      IF(ISTAGE.EQ.0) GO TO 60
      DO 50 I=1,ISTAGE
      JJ=II-(I-1)
      KK=IKKK(JJ)
      IF(KK.EQ.1 .OR. KK.EQ.2 .OR. KK.EQ.5)  GO TO 50
      IL=IL-1
      IF(KK.EQ.6 .OR. KK.EQ.7)  IQ=IQ-1
   50 CONTINUE
      II=II-ISTAGE
      CALL  CONTU2
   60 L=IKKL(II)
      NI=IKKN(II)+1
      RETURN
      END


      SUBROUTINE  CONTU2
      REAL LF,INT
      COMMON /ITEM1/VIS,CP,H,Z,E,DO,QO,XO,CO,QD,RE,D,Q1,C,X1,XMAX,XMIN,
     *XDEL,XDMIN,XDMAX,XD,DC,CC,GH,XOO,VP,CL,QS,KQ,KD,KK,KV,KSZ,KP,DCA
      COMMON /ITEM4/II,IL,IQ,NP,IKKN(100),IKKL(100),IKKK(100),ILNP(50),
     *IKKV(100),ILLL(50,3),RQQQ(50,3),HKKH(100),ZKKZ(100),DCKK(100)
      COMMON /ITEM5/LF,INT,S,CE,T,EFF,CF
      REWIND 3
      WRITE(3,1) II,IL,IQ
    1 FORMAT(I5,2I3)
      DO 5 I=2,II
    5 WRITE(3,7) IKKN(I),IKKL(I),IKKK(I),IKKV(I),HKKH(I),ZKKZ(I),DCKK(I)
    7 FORMAT(I4,I3,2I1,3A4)
      IF (IL.LE.0)  GO TO 25
      DO 20 I=1,IL
      NP=ILNP(I)
   20 WRITE(3,23) NP,(ILLL(I,J),J=1,NP)
   23 FORMAT(I3,3I3)
   25 IF (IQ.LE.0)  GO TO 35
      DO 30 I=1,IQ
   30 WRITE(3,34) (RQQQ(I,J),J=1,3)
   34 FORMAT(3A4)
   35 CONTINUE
      WRITE(3,37) VIS,E,LF,INT,S
      WRITE(3,37) CE,T,EFF,CF,DCA
      WRITE(3,37) KSZ,KP,KD
   37 FORMAT(5A4)
      RETURN
      END


      SUBROUTINE  ENDSTG
      REAL LF,INT
      COMMON /ITEM1/VIS,CP,H,Z,E,DO,QO,XO,CO,QD,RE,D,Q1,C,X1,XMA[illegible],
     *XDEL,XDMIN,XDMAX,XD,DC,CC,GH,XOO,VP,CL,QS,KQ,KD,KK,KV,KSZ,KP,DCA
      COMMON /ITEM2/NO,DIA(30),COPI(30),COTEE(30),COCRS(30),COELB(30),
     *ELBR(30),COGRA(30,30),COSUD(30,30)
      COMMON /ITEM3/X1AAA(2000),CAAA(2000),QAAA(2000),DAAA(2000),
     *XOAAA(2000),A,B,L,N,NI
      COMMON /ITEM5/LF,INT,S,CE,T,EFF,CF
      QO=0.
      CO=0.
      CC=0.
      VP=0.
      DO 100 J=1,10000
      AJ=J
      XOTEMP=XDMIN+(AJ-1.)*XDEL
      IF(KQ-1) 15,25,15
   15 IF(XOTEMP.GT.XDMAX) GO TO 200
      GO TO 35
   25 IF(XOTEMP.GT.XMAX) GO TO 200
   35 XO=XOTEMP+Z*14.7/33.9
      XOO=XO
      DO 90 I=1,NO
      D=DIA(I)
      CP=COPI(I)
      CALL  PRES(&90,&80)
   80 CALL  COST
      CALL  STORE
   90 CONTINUE
  100 CONTINUF
  200 RETURN
      END


      SUBROUTINE  CONECT
      REAL LF,INT
      COMMON /ITEM1/VIS,CP,H,Z,F,DO,QO,XO,CO,QD,RE,D,Q1,C,X1,XMAX,XMIN,
     *XDEL,XDMIN,XDMAX,XD,DC,CC,GH,XOO,VP,CL,QS,KQ,KD,KK,KV,KSZ,KP,DCA
      COMMON /ITEM2/NO,DIA(30),COPI(30),COTEE(30),COCRS(30),COELB(30),
     *ELBR(30),COGRA(30,30),COSUD(30,30)
      COMMON /ITEM3/X1AAA(2000),CAAA(2000),QAAA(2000),DAAA(2000),
     *XOAAA(2000),A,B,L,N,NI
      COMMON /ITEM4/II,IL,IQ,NP,IKKN(100),IKKL(100),IKKK(100),ILNP(50),
     *IKKV(100),ILLL(50,3),RQQQ(50,3),HKKH(100),ZKKZ(100),DCKK(100)
      COMMON /ITEM5/LF,INT,S,CE,T,EFF,CF
      CALL  RETRV(NJ,IND,IY,IK)
      DO 80 I=1,NJ
      READ(2'NI,5) XO,CO,QO,DO,XORETV
    5 FORMAT(5A4)
      IF (IND.EQ.1 .OR. IND.EQ.2)  GO TO 35
      GO TO 45
   35 QO=QO*RQQQ(IY,IK)
      IF (IND.EQ.1) CO=0.
   45 VP1=QO**2*16.*144.**2*14.7/(DO**4*3.1416**2*2.*32.2*33.9)
      DO 60 J=1,NO
      D=DIA(J)
      IF (KSZ.EQ.1 .AND. D.LT.DO) GO TO 60
      CP=COPI(J)
      IF (KV.EQ.1)    CALL SUDDEN
      IF (KV.EQ.2)    CALL GRADU
      XOO=XO+CL*VP1
      CALL  CONCO
      VP=QO**2*16.*144.**2*14.7/(D**4*3.1416**2*2.*32.2*33.9)
      CALL  PRES(&60,&50)
   50 CALL  COST
      CALL  STORE
   60 CONTINUE
   80 CONTINUE
      RETURN
      END


      SUBROUTINE  MERGE(*,*)
      REAL LF,INT
      COMMON /ITEM1/VIS,CP,H,Z,E,DO,QO,XO,CO,QD,RE,D,Q1,C,X1,XMAX,XMIN,
     *XDEL,XDMIN,XDMAX,XD,DC,CC,GH,XOO,VP,CL,QS,KQ,KD,KK,KV,KSZ,KP,DCA
      COMMON /ITEM2/NO,DIA(30),COPI(30),COTEE(30),COCRS(30),COELB(30),
     *ELBR(30),COGRA(30,30),COSUD(30,30)
      COMMON /ITEM3/X1AAA(2000),CAAA(2000),QAAA(2000),DAAA(2000),
     *XOAAA(2000),A,B,L,N,NI
      COMMON /ITEM4/II,IL,IQ,NP,IKKN(100),IKKL(100),IKKK(100),ILNP(50),
     *IKKV(100),ILLL(50,3),RQQQ(50,3),HKKH(100),ZKKZ(100),DCKK(100)
      COMMON /ITEM5/LF,INT,S,CE,T,EFF,CF
      DIMENSION LL(3),IND(3),IX1(3),IX2(3),X1TEMP(3),CTEMP(3),QTEMP(3),
     *DOTEMP(3)
      K1=0
      NP=KK-1
      WRITE(6,2)
    2 FORMAT('OENTER THE ASSIGNED NUMBER OF PIPELINES WHICH WILL BE MERG
     *ED')
      READ(5,*) (LL(I),I=1,NP)
      WRITE(6,3)
    3 FORMAT('OENTER THE ASSIGNED PIPELINE NUMBER AFTER MERGING')
      READ(5,*) L
      WRITE(6,4)
    4 FORMAT('OENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNE
     *CTION',/,'0',6X,'2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CO
     *NNECTION')
      READ(5,*) KV
    5 WRITE(6,6)
    6 FORMAT('OENTER THE ALLOWABLE PRESSURE DIFFERENCE AT THE MERGING PO
     *INT')
      READ(5,*) DIFF
      IF (K1.EQ.1) GO TO 7
      CALL  RANGE
      IK=II-1
    7 DO 20 K=1,NP
      DO 10 I=1,IK
      J=II-(I-1)
      IF (LL(K) .EQ. IKKL(J))  GO TO 15
   10 CONTINUE
      WRITE(6,11)
```

## Appendix B-1 (Contd)

```
 11 FORMAT('OERROR')
 15 IX1(K)=IKKN(J-1)+1
    IX2(K)=IKKN(J)
 20 IND(K)=IX1(K)
    IY1=IX1(1)
    IY2=IX2(1)
    DO 80 I=IY1,IY2
    NI=I
    FIND(2'NI)
    READ(2'NI,31) X1TEMP(1),CTEMP(1),QTEMP(1),DOTEMP(1),X0
 31 FORMAT(5A4)
    DO 50 K=2,NP
    IZ1=IND(K)
    IZ2=IX2(K)
    NI=IZ1
    DIFF2=DIFF
    DO 40 J=IZ1,IZ2
    FIND(2'NI)
    READ(2'NI,31) X1,C,Q1,D,X0
    DELP2=X1TEMP(1)-X1
    DELP=ABS(DELP2)
    IF(DELP2.LT.0. .AND. J.EQ.IZ2 .AND. DELP.GT.DIFF)  GO TO 90
    IF (DELP2.GT.DIFF .AND. IND(K).EQ.IZ1)  GO TO 80
    IF (DELP.GT.DIFF2 .AND. DIFF2.LT.DIFF)  GO TO 50
    IF (DELP.GT.DIFF2)  GO TO 40
    DIFF2=DELP
    IND(K)=J
    X1TEMP(K)=X1
    CTEMP(K)=C
    QTEMP(K)=Q1
    DOTEMP(K)=D
 40 CONTINUE
 50 CONTINUE
    Q0=0.
    C0=0.
    DO 60 K=1,NP
    Q0=Q0+QTEMP(K)
 60 C0=C0+CTEMP(K)
    X0=X1TEMP(1)
    VP1=QTEMP(1)**2*16.*144.**2*14.7/(DOTEMP(1)**4*3.1416**2*2.*32.2*
   *33.9)
    DO 70 JJ=1,NO
    D=DIA(JJ)
    TCC=0.
    DO 65 K=1,NP
    DO=DOTEMP(K)
    IF (KSZ.EQ.1 .AND. D.LT.DO) GO TO 70
    CALL  CONCO
 65 TCC=TCC+CC
    CC=TCC
    IF(KK.EQ.3) CP=COTEE(JJ)
    IF(KK.EQ.4) CP=COCRS(JJ)
    IF(KV.EQ.1)  CALL  SUDDEN
    IF(KV.EQ.2)  CALL  GRADU
    X00=X0+CL*VP1
    DO=SQRT(NP*D*D)
    CALL  SUDDEN
    VP=(Q0**2-QTEMP(1)**2)*16.*144.**2*14.7/(D**4*3.1416**2*2.*32.2*
   *33.9)
    X1=X00+VP*CL
    Q1=Q0
    QD=0.
    CALL  COST
    CALL  STORE
    N=N+1
 70 CONTINUE
 80 CONTINUE
 90 CONTINUE
    IF (N .EQ. 0)  GO TO 150
    IL=IL+1
    DO 120 K=1,NP
120 ILLL(IL,K)=LL(K)
    ILNP(IL)=NP
    GO TO 200
150 WRITE(6,155)
155 FORMAT('ONO MATCHED PRESSURE, ENTER 1 TO REENTER INTERVAL, ENTER 2
   * TO GO BACK TO DO OTHER CONNECTIONS')
    READ(5,*) K1
    IF (K1 .EQ. 1) GO TO 5
    IF (K1 .EQ. 2) RETURN 1
200 RETURN 2
    END


    SUBROUTINE   ELBOW
    REAL LF,INT
    COMMON /ITEM1/VIS,CP,H,Z,E,DO,Q0,X0,C0,QD,RF,D,Q1,C,X1,XMAX,XMIN,
   *XDEL,XDMIN,XDMAX,XD,DC,CC,GH,X00,VP,CL,QS,KQ,KD,KK,KV,KSZ,KP,DCA
    COMMON /ITEM2/NO,DIA(30),COPI(30),COTEE(30),COCRS(30),COELB(30),
   *ELBR(30),COGRA(30,30),COSUD(30,30)
    COMMON /ITEM3/X1AAA(2000),CAAA(2000),QAAA(2000),DAAA(2000),
   *XOAAA(2000),A,B,L,N,NI
    COMMON /ITEM4/II,IL,IQ,NP,IKKN(100),IKKL(100),IKKK(100),ILNP(50),
   *IKKV(100),ILLL(50,3),RQQQ(50,3),HKKH(100),ZKKZ(100),DCKK(100)
    COMMON /ITEM5/LF,INT,S,CE,T,EFF,CF
    DIMENSION E90(9),RD(9)
    DATA E90/1.26,1.0,.7,.4,.22,.13,.1,.08,.08/
    DATA  RD/0.,.25,.5,.75,1.,2.,4.,6.,1000./
    WRITE(6,2)
  2 FORMAT('OENTER THE ELBOW ANGLE, IN DEGREE')
    READ(5,*) ANG
    CALL  RETRV(NJ,IND,IY,IK)
    DO 80 IJ=1,NJ
    READ(2'NI,4) X0,C0,Q0,DO,XORETV
  4 FORMAT(5A4)
    VP1=Q0**2*16.*144.**2*14.7/(DO**4*3.1416**2*2.*32.2*33.9)
    DO 70 J=1,NO
    D=DIA(J)
    IF (KSZ.EQ.1 .AND. D.LT.DO) GO TO 70
    IF(KV.EQ.1)  CALL SUDDEN
    IF(KV.EQ.2)  CALL GRADU
    X00=X0+CL*VP1
    CP=COELB(J)
    CALL  CONCO
    VP=Q0**2*16.*144.**2*14.7/(D**4*3.1416**2*2.*32.2*33.9)
    RATIO=ELBR(J)/D
    DO 30 I=1,8
    IF(RATIO.EQ.RD(I)) GO TO 40
    IF(RATIO.GT.RD(I) .AND. RATIO.LT.RD(I+1)) GO TO 50
 30 CONTINUE
 40 CL=E90(I)*ANG/90.
    GO TO 60
 50 CL=E90(I)-(E90(I)-E90(I+1))*(RATIO-RD(I))/(RD(I+1)-RD(I))
    CL=CL*ANG/90.
 60 X1=X00+CL*VP
    QD=0.
    Q1=Q0
    CALL  COST
    CALL  STORE
 70 CONTINUE
 80 CONTINUE
    RETURN
    END


    SUBROUTINE   BRANCH
    REAL LF,INT
    COMMON /ITEM1/VIS,CP,H,Z,E,DO,Q0,X0,C0,QD,RF,D,Q1,C,X1,XMAX,XMIN,
   *XDEL,XDMIN,XDMAX,XD,DC,CC,GH,X00,VP,CL,QS,KQ,KD,KK,KV,KSZ,KP,DCA
    COMMON /ITEM2/NO,DIA(30),COPI(30),COTEE(30),COCRS(30),COELB(30),
   *ELBR(30),COGRA(30,30),COSUD(30,30)
    COMMON /ITEM3/X1AAA(2000),CAAA(2000),QAAA(2000),DAAA(2000),
   *XOAAA(2000),A,B,L,N,NI
    COMMON /ITEM4/II,IL,IQ,NP,IKKN(100),IKKL(100),IKKK(100),ILNP(50),
   *IKKV(100),ILLL(50,3),RQQQ(50,3),HKKH(100),ZKKZ(100),DCKK(100)
    COMMON /ITEM5/LF,INT,S,CE,T,EFF,CF
    DIMENSION RQ(3),LL(3)
    NP=KK-4
    WRITE(6,1)
  1 FORMAT('OENTER THE ASSIGNED NUMBER OF PIPELINES WHICH WILL BE BRAN
   *CHED')
    READ(5,*) (LL(I),I=1,NP)
    WRITE(6,2)
  2 FORMAT('OENTER THE RATIO OF FLOW RATE IN THESE PIPELINES, THE SUM
   *OF THESE NUMBERS IS 1., FOR INSTANCE, .5,.3,.2')
    READ(5,*) (RQ(I),I=1,NP)
    CALL  RANGE
    CALL  RETRV(NJ,IND,IY,IK)
    DO 30 I=1,NJ
    READ(2'NI,5) X0,C0,Q0,DO,XORETV
  5 FORMAT(5A4)
    VP1=Q0**2*16.*144.**2*14.7/(DO**4*3.1416**2*2.*32.2*33.9)
    DO 20 J=1,NO
    D=DIA(J)
    IF (KSZ.EQ.1 .AND. D.LT.DO)  GO TO 20
    IF (KK.EQ.6)  CP=COTEE(J)
    IF (KK.EQ.7)  CP=COCRS(J)
    IF (KV.EQ.1)  CALL SUDDEN
    IF (KV.EQ.2)  CALL GRADU
    X00=X0+CL*VP1
    CALL  CONCO
    DO=SQRT(D*D/NP)
    CALL  SUDDEN
    QTEMP=Q0*RQ(1)
    VP=(Q0**2-QTEMP**2)*16.*144.**2*14.7/(D**4*3.1416**2*2.*32.2*33.9)
    X1=X00+VP*CL
    Q1=Q0
    QD=0.
    CALL  COST
    CALL  STORE
 20 CONTINUE
 30 CONTINUE
    IL=IL+1
    IQ=IQ+1
    DO 40 K=1,NP
    ILLL(IL,K)=LL(K)
 40 RQQQ(IQ,K)=RQ(K)
    ILNP(IL)=NP
    RETURN
    END


    SUBROUTINE  RANGE
    COMMON /ITEM1/VIS,CP,H,Z,E,DO,Q0,X0,C0,QD,RF,D,Q1,C,X1,XMAX,XMIN,
   *XDEL,XDMIN,XDMAX,XD,DC,CC,GH,X00,VP,CL,QS,KQ,KD,KK,KV,KSZ,KP,DCA
    WRITE(6,1)
  1 FORMAT('OENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI
   *.')
    READ(5,*) XMIN,XMAX
    WRITE(6,2)
  2 FORMAT('OENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PS
   *I.')
    READ(5,*) XDEL
    RETURN
    END


    SUBROUTINE  RETRV(NJ,IND,IY,IK)
    COMMON /ITEM1/VIS,CP,H,Z,E,DO,Q0,X0,C0,QD,RF,D,Q1,C,X1,XMAX,XMIN,
   *XDEL,XDMIN,XDMAX,XD,DC,CC,GH,X00,VP,CL,QS,KQ,KD,KK,KV,KSZ,KP,DCA
    COMMON /ITEM3/X1AAA(2000),CAAA(2000),QAAA(2000),DAAA(2000),
   *XOAAA(2000),A,B,L,N,NI
    COMMON /ITEM4/II,IL,IQ,NP,IKKN(100),IKKL(100),IKKK(100),ILNP(50),
   *IKKV(100),ILLL(50,3),RQQQ(50,3),HKKH(100),ZKKZ(100),DCKK(100)
    WRITE(6,3)
  3 FORMAT('OENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNE
   *CTION',/,'0',6X,'2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CO
   *NNECTION')
    READ(5,*) KV
    IK=0
    IY=IQ
    IX=IL
    IND=0
    III=II-1
    DO 60 I=1,III
    J=II-(I-1)
    IF (IKKK(J).EQ.3 .OR. IKKK(J).EQ.4)  IX=IX-1
    IF (IKKK(J).EQ.6 .OR. IKKK(J).EQ.7)  GO TO 30
    IF (L .EQ. IKKL(J))  GO TO 80
    GO TO 60
 30 NP=ILNP(IX)
    DO 40 K=1,NP
    IF (L.EQ.ILLL(IX,K))  GO TO 50
 40 CONTINUE
    IX=IX-1
    IY=IY-1
```

# Appendix B-1 (Contd)

```
      GO TO 60
   50 IND=1
      IF (K.EQ.1) IND=2
      IK=K
      GO TO 80
   60 CONTINUE
      WRITE(6,62)
   62 FORMAT('0ERROR')
   80 NI=IKKN(J-1)+1
      FIND(2'NI)
      NJ=IKKN(J)-IKKN(J-1)
      RETURN
      END


      SUBROUTINE  CONCO
      COMMON /ITEM1/VIS,CP,H,Z,E,DO,QO,XO,CO,QD,RE,D,Q1,C,X1,XMAX,XMIN,
     *XDEL,XDMIN,XDMAX,XD,DC,CC,GH,XOO,VP,CL,QS,KQ,KD,KK,KV,KSZ,KP,DCA
      COMMON /ITEM2/NO,DIA(30),COPI(30),COTEE(30),COCRS(30),COELB(30),
     *ELBR(30),COGRA(30,30),COSUD(30,30)
      DO 10 I=1,NO
      IF (DO.EQ.DIA(I)) GO TO 20
   10 CONTINUE
   20 DO 30 J=1,NO
      IF (D.EQ.DIA(J)) GO TO 40
   30 CONTINUE
   40 IF(KV.EQ.1) CC=COSUD(I,J)
      IF(KV.EQ.2) CC=COGRA(I,J)
      RETURN
      END


      SUBROUTINE  SUDDEN
      COMMON /ITEM1/VIS,CP,H,Z,E,DO,QO,XO,CO,QD,RE,D,Q1,C,X1,XMAX,XMIN,
     *XDEL,XDMIN,XDMAX,XD,DC,CC,GH,XOO,VP,CL,QS,KQ,KD,KK,KV,KSZ,KP,DCA
      DIMENSION RATIO(11)
      DATA  RATIO/.5,.43,.37,.3,.25,.2,.15,.1,.07,.03,0./
      IF (D.LT.DO)  CL=(1.-(D*D)/(DO*DO))**2
      IF (D.EQ.DO)  CL=0.
      IF (D.GT.DO) GO TO 10
      GO TO 50
   10 A=DO**2/D**2
      DO 20 I=1,10
      AI=(I-1)*0.1
      BI=I*0.1
      IF (A.EQ.AI)  GO TO 25
      IF (A.GT.AI .AND. A.LT.BI)  GO TO 30
   20 CONTINUE
   25 CL=RATIO(I)
      GO TO 50
   30 CL=RATIO(I)-(RATIO(I)-RATIO(I+1))*(AI-RATIO(I))/0.1
   50 RETURN
      END


      SUBROUTINE  GRADU
      COMMON /ITEM1/VIS,CP,H,Z,E,DO,QO,XO,CO,QD,RE,D,Q1,C,X1,XMAX,XMIN,
     *XDEL,XDMIN,XDMAX,XD,DC,CC,GH,XOO,VP,CL,QS,KQ,KD,KK,KV,KSZ,KP,DCA
      DIMENSION THETA(9),VAL(9)
      DATA THETA/180.,90.,60.,30.,15.,7.5,0.,-180.,-360./
      DATA VAL/.95,.90,.83,.78,.32,.12,0.,0.48,0.48/
      IF(D.EQ.DO) GO TO 80
      IF(D.GT.DO) GO TO 10
      IF(D.LT.DO) GO TO 20
      GO TO 90
   10 ADA=DO**2/D**2
      ANG=(D-DO)/2./GH/12.
      ANG=-ATAN(ANG)*180./6.2832
      GO TO 30
   20 ADA=D**2/DO**2
      ANG=(DO-D)/2./GH/12.
      ANG=ATAN(ANG)*180./6.2832
   30 CLO=(1-ADA)**2
      DO 40 I=1,7
      IF(ANG.EQ.THETA(I)) GO TO 50
      IF(ANG.LT.THETA(I) .AND. ANG.GT.THETA(I+1)) GO TO 60
   40 CONTINUE
   50 CL=CLO*VAL(I)/0.95
      GO TO 90
   60 VALB=VAL(I)-(VAL(I)-VAL(I+1))*(THETA(I)-ANG)/(THETA(I)-THETA(I+1))
      CL=CLO*VALB/0.95
      GO TO 90
   80 CL=0.
   90 RETURN
      END


      SUBROUTINE  RESULT(*,*,*,*)
      COMMON /ITEM1/VIS,CP,H,Z,E,DO,QO,XO,CO,QD,RE,D,Q1,C,X1,XMAX,XMIN,
     *XDEL,XDMIN,XDMAX,XD,DC,CC,GH,XOO,VP,CL,QS,KQ,KD,KK,KV,KSZ,KP,DCA
      COMMON /ITEM3/X1AAA(2000),CAAA(2000),QAAA(2000),DAAA(2000),
     *XOAAA(2000),A,B,L,N,NI
      COMMON /ITEM4/II,IL,IQ,NP,IKKN(100),IKKL(100),IKKK(100),ILNP(50),
     *IKKV(100),ILLL(50,3),RQQQ(50,3),HKKH(100),ZKKZ(100),DCKK(100)
      IF(N.EQ.0) RETURN 3
      NI=IKKN(II)+1
      FIND(2'NI)
      NN=IFIX((XMAX-XMIN)/XDEL+2.)
      IF (NN .GT. 2000)  NN=2000
      J=1
      DO 10 I=1,NN
      IF (X1AAA(I) .LT. A)  GO TO 10
      X1AAA(J)=X1AAA(I)
      CAAA(J)=CAAA(I)
      QAAA(J)=QAAA(I)
      DAAA(J)=DAAA(I)
      XOAAA(J)=XOAAA(I)
      J=J+1
   10 CONTINUE
      N=J-1
      WRITE(6,11)
   11 FORMAT('0ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY T
     *HE INLET HEAD, OTHERWISE 0')
      READ(5,*) K1
      IF (K1 .EQ. 1)  CALL PRINT
      IF(K1.EQ.2) GO TO 15
      GO TO 25
   15 WRITE(6,17)
   17 FORMAT('0ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED
     * EVERY N NUMBER')
      READ(5,*) I1
      IF (K1 .EQ. 2)  WRITE(6,19) (X1AAA(I),I=1,N,I1)
   19 FORMAT(8(1X,F12.6,','))
   25 DO 30 I=1,N
   30 WRITE(2'NI,35) X1AAA(I),CAAA(I),QAAA(I),DAAA(I),XOAAA(I)
   35 FORMAT(5A4)
      II=II+1
      IKKN(II)=IKKN(II-1)+N
      IKKL(II)=L
      IKKK(II)=KK
      HKKH(II)=H
      ZKKZ(II)=Z
      DCKK(II)=DC
      IKKV(II)=KV
      WRITE(6,40)
   40 FORMAT('0ENTER 1 IF MORE STAGES ARE NEEDED',/,'0',6X,'2 IF YOU WAN
     *T TO CONTINUE THIS JOB LATER',/,'0',6X,'0 IF END OF THIS JOB')
      READ(5,*) K1
      IF (K1 .EQ. 0)  RETURN 2
      IF(K1.EQ.2) RETURN 4
      RETURN 1
      END


      SUBROUTINE  PRES(*,*)
      COMMON /ITEM1/VIS,CP,H,Z,E,DO,QO,XO,CO,QD,RE,D,Q1,C,X1,XMAX,XMIN,
     *XDEL,XDMIN,XDMAX,XD,DC,CC,GH,XOO,VP,CL,QS,KQ,KD,KK,KV,KSZ,KP,DCA
      ZP=Z*14.7/33.9
      XD=XCO-VP-ZP
      IF(KQ.EQ.1) GO TO 10
      IF (DC.LT.10.E-35) GO TO 5
      IF (XD.LT.XDMIN .OR. XD.GT.XDMAX)  GO TO 20
    5 QD=DC*SQRT(XD*144.)
      GO TO 15
   10 IF(XD.LT.XDMIN) GO TO 20
      QD=QS
      DC=QD/SQRT(XDMIN*144.)
   15 Q1=QO+QD
      RE=4.*Q1/(3.1416*VIS*D/12.)
      IF (E.LT.10.E-35)  GO TO 30
      IF (RE .LT. 2000.) GO TO 25
      IF (RE.LT.4000.) GO TO 35
      CALL FRICO(F)
      GO TO 40
   20 RETURN 1
   25 F=64./RE
      GO TO 40
   30 F=0.316/RE**0.25
      GO TO 40
   35 F=3.24*10.**(-5)*RE**0.85
   40 X1=XOO+0.0252*F*H*Q1**2/((D/12.)**5)
      RETURN 2
      END


      SUBROUTINE FRICO(F)
      EXTERNAL FCT
      XLI=0.01
      XRI=0.08
      EPS=0.001
      IEND=500
      CALL  RTMJ(F,VAL,FCT,XLI,XRI,EPS,IEND,IER)
      RETURN
      END


      FUNCTION  FCT(F)
      COMMON /ITEM1/VIS,CP,H,Z,E,DO,QO,XO,CO,QD,RE,D,Q1,C,X1,XMAX,XMIN,
     *XDEL,XDMIN,XDMAX,XD,DC,CC,GH,XOO,VP,CL,QS,KQ,KD,KK,KV,KSZ,KP,DCA
      ARG=E/D+9.35/(RE*SQRT(F))
      FCT=1.0/(SQRT(F))-1.14+2.*ALOG10(ARG)
      RETURN
      END


      SUBROUTINE  COST
      REAL LF,INT
      COMMON /ITEM1/VIS,CP,H,Z,E,DO,QO,XO,CO,QD,RE,D,Q1,C,X1,XMAX,XMIN,
     *XDEL,XDMIN,XDMAX,XD,DC,CC,GH,XOO,VP,CL,QS,KQ,KD,KK,KV,KSZ,KP,DCA
      COMMON /ITEM5/LF,INT,S,CE,T,EFF,CF
      PIPECO=(H*CP+CC)*(1.0/LF+(1.0-S)*INT/200.)
      AKP=KP
      ENEGCO=0.262*CE*T*(Q1*(X1-XOO)+XOO*QD+(XOO-XO)*QO)/EFF*AKP
      IF(KQ.EQ.1) GO TO 10
      IF (KK.EQ.1 .OR. KK.EQ.2)  GO TO 5
      GO TO 10
    5 XDD=XD-XDMIN
      IF(XDD.LT.0.) GO TO 10
      AKD=KD
      FLUDCO=CF/1000.*T*DC*SQRT(XDD*144.)*AKD
      C=CO+PIPECO+ENEGCO+FLUDCO
      GO TO 20
   10 C=CO+PIPECO+ENEGCO
   20 RETURN
      END


      SUBROUTINE  STORE
      COMMON /ITEM1/VIS,CP,H,Z,E,DO,QO,XO,CO,QD,RE,D,Q1,C,X1,XMAX,XMIN,
     *XDEL,XDMIN,XDMAX,XD,DC,CC,GH,XOO,VP,CL,QS,KQ,KD,KK,KV,KSZ,KP,DCA
      COMMON /ITEM3/X1AAA(2000),CAAA(2000),CAAA(2000),DAAA(2000),
     *XOAAA(2000),A,B,L,N,NI
      IF (X1.GT.XMAX .OR. X1.LT.XMIN) GO TO 100
      DO 10 I=1,2000
      AI=I
      UP=XMAX-(AI-1.)*XDEL
      DOWN=UP-XDEL
      IF(I.EQ.1 .AND. X1.LE.UP .AND. X1.GE.DOWN) GO TO 20
      IF(X1.LT.UP .AND. X1.GE.DOWN) GO TO 20
   10 CONTINUE
   20 IF(X1AAA(I) .LT. A) GO TO 30
      IF (C .LT. CAAA(I)) GO TO 30
      IF(C.EQ.CAAA(I) .AND. D.GT.DAAA(I)) GO TO 30
      GO TO 100
   30 X1AAA(I)=X1
      CAAA(I)=C
```

# Appendix B-1 (Contd)

```
      QAAA(I)=Q1
      DAAA(I)=D
      XOAAA(I)=XO
      N=N+1
  100 RETURN
      END


      SUBROUTINE  PRINT
      COMMON /ITEM3/X1AAA(2000),CAAA(2000),QAAA(2000),DAAA(2000),
     *XOAAA(2000),A,B,L,N,NI
      WRITE(6,5)
    5 FORMAT('0INLET TOTAL HEAD',7X,'DIAMETER',10X,'COST',8X,'OUTLET TOT
     *AL HEAD',6X,'INLET VOLUMN')
      DO 10 I=1,N
   10 WRITE(6,15) X1AAA(I),DAAA(I),CAAA(I),XOAAA(I),QAAA(I)
   15 FORMAT('0',2X,F12.6,10X,F6.2,5X,F12.2,9X,F12.6,8X,F11.6)
      WRITE(6,20)
   20 FORMAT(/)
      RETURN
      END


      SUBROUTINE  OPTIM
      COMMON /ITEM1/VIS,CP,H,Z,E,DO,QO,XO,CO,QD,RE,D,Q1,C,X1,XMAX,XMIN,
     *XDEL,XOMIN,XOMAX,XC,DC,CC,GH,XOO,VP,CL,QS,KQ,KD,KK,KV,KSZ,KP,DCA
      COMMON /ITEM3/X1AAA(20CC),CAAA(2000),CAAA(2000),CAAA(2000),
     *XOAAA(2000),A,B,L,N,NI
      COMMON /ITEM4/II,IL,IQ,NP,IKKN(100),IKKL(100),IKKK(100),ILNP(50),
     *IKKV(100),ILLL(50,3),RCCQ(50,3),HKKH(100),ZKKZ(100),DCKK(100)
      DIMENSION XOMIN(100),NAME(14),XORD(1CC),XHRD(100)
      DATA NAME/' END',' END','CONS','CONG','TEBS','TEBG','CRBS','CRBG',
     *'ELBS','ELBG','TEMS','TEMG','CRMS','CRMG'/
      CALL  CONTU2
      WRITE(6,1)
    1 FCRMAT('0ENTER THE MIN. AND MAX. AVAILABLE TCTAL HEAD AT POWER SOU
     *RCE, IN PSI.')
      READ(5,*) XMIN,XMAX
      DO 5 I=1,100
    5 XGRD(I)=B
      IX=IL
      CMIN=10.E20
      DO 10 I=1,N
      IF (X1AAA(I).GT.XMAX .CR. X1AAA(I).LT.XMIN)  GC TO 10
      IF (CAAA(I).GT.CMIN)  GC TO 10
      IF (CAAA(I).EQ.CMIN .AND. DAAA(I).LE.DAAA(1))  GC TO 10
      CMIN=CAAA(I)
      X1AAA(1)=X1AAA(I)
      QAAA(1)=QAAA(I)
      DAAA(1)=DAAA(I)
      XOAAA(1)=XOAAA(I)
   10 CONTINUE
      WRITE(6,11) CMIN
   11 FORMAT(///,'0OPTIMAL SCLUTION :',//,'0TCTAL CCST = ',F12.2,' DOLLA
     *RS PER YEAR')
      WRITE(6,12)
   12 FORMAT(//,'0STAGE',3X,'I.HEAD',3X,'DIAM.',4X,'LENGTH',6X,'I.FLOW',
     *6X,'D.HEAD',3X,'DISCHARGE',3X,'ELEV.',2X,'TYPE',2X,'LINE NC.',2X,'
     *BRANCHES NO.')
      IF (KK.EQ.3 .OR. KK.EQ.4)  GO TO 15
      XOMIN(L)=XOAAA(1)
      GO TO 25
   15 DO 20 K=1,NP
      L1=ILLL(IX,K)
   20 XOMIN(L1)=XOAAA(1)
      IX=IX-1
   25 IK=II-1
      IF (II.LE.2) GO TC 100
      DO 80 J=2,IK
      JJ=II-(J-1)
      KK=IKKK(JJ)
      L=IKKL(JJ)
      NI=IKKN(JJ-1)+1
      NJ=IKKN(JJ)-IKKN(JJ-1)
      FIND(2'NI)
      IF (KK.EQ.6 .OR. KK.EQ.7)  GO TO 26
      GO TO 35
   26 L1=ILLL(IX,1)
      XOTEMP=XOMIN(L1)
      NP=ILNP(IX)
      K1=1
      DO 27 K=1,NP
      L1=ILLL(IX,K)
      IF(XOMIN(L1).GT.XOTEMP) GC TO 27
      XOTEMP=XOMIN(L1)
      K1=K
   27 CONTINUE
      DO 30 K=1,NP
      L1=ILLL(IX,K)
      IF(XOMIN(L1).LE.XCTEMP) GC TO 30
      J1=J
      J2=J-1
      DO 28 J3=1,J2
      JJ1=JJ+J3
      J1=J1-1
      IF(IKKL(JJ1).EQ.L1) GO TO 29
   28 CONTINUE
   29 XORD(J1)=XOTEMP
      XHRD(J1)=XOMIN(L1)
   30 CONTINUE
      IX=IX-1
      XOMIN(L)=XOTEMP
   35 DIFF=10.E25
      DO 40 I=1,NJ
      READ(2'NI,37) X1RETV,CRETV,QRETV,DRETV,XORETV
   37 FORMAT(5A4)
      DELP=X1RETV-XOMIN(L)
      DELP2=ABS(DELP)
      IF (DELP2.GT.DIFF)  GO TO 40
      X1AAA(J)=X1RETV
      CAAA(J)=CRETV
      QAAA(J)=QRETV
      DAAA(J)=DRETV
      XOAAA(J)=XORETV
      DIFF=DELP2
   40 CONTINUE
      IF (KK.EQ.3 .OR. KK.EQ.4)  GO TO 45
      XOMIN(L)=XOAAA(J)
      GO TO 80
   45 NP=ILNP(IX)
      DO 50 K=1,NP
      L1=ILLL(IX,K)
   50 XOMIN(L1)=XOAAA(J)
      IX=IX-1
   80 CONTINUE
  100 DO 200 I=1,IK
      J=II-(I-1)
      JJ=J-1
      HH=HKKH(J)
      KK=IKKK(J)
      L=IKKL(J)
      ZZ=ZKKZ(J)
      DC=DCKK(J)
      KV=IKKV(J)
      IJ=KK*2+(KV-2)
      IF(KK.EQ.1) IJ=1
      IF(KK.EQ.3 .OR. KK.EQ.4) GO TO 180
      IF (KK.EQ.6 .OR. KK.EQ.7)  GO TO 180
      I1=I+1
      IX=IL
      IC1=IQ
      DO 120 K1=I1,IK
      J1=II-(K1-1)
      IF (IKKK(J1).EQ.6 .OR. IKKK(J1).EQ.7)  GO TO 112
      IF (L.EQ.IKKL(J1)) GO TC 125
      GO TO 120
  112 NP1=ILNP(IX)
      DO 113 K2=1,NP1
      L2=ILLL(IX,K2)
      IF (L.EQ.L2)  GO TC 118
  113 CONTINUE
      IX=IX-1
      IQ1=IQ1-1
      GO TO 120
  118 QD=QAAA(I)-RQCQ(IQ1,K2)*QAAA(K1)
      GO TO 135
  120 CONTINUE
      IF (KK.EQ.1) GO TC 130
      WRITE(6,121)
  121 FORMAT('0ERROR')
  125 QD=QAAA(I)-QAAA(K1)
      IF(KK.EQ.5) GC TC 170
      GO TO 135
  130 QD=QAAA(I)
  135 IF(DC.LT.10.E-35) GO TC 140
      XD=(QD/DC)**2/144.0
      GO TO 150
  140 XD=0.
  150 WRITE(6,151) JJ,X1AAA(I),DAAA(I),HH,QAAA(I),XD,QD,ZZ,NAME(IJ),L
  151 FCRMAT('0',I4,1X,F9.4,2X,F6.3,2X,F8.2,2X,F11.6,2X,F9.4,2X,F10.6,
     *2X,F6.1,2X,A4,3X,I4)
      IF(KK.NE.1) GC TO 200
      WRITE(6,155) XOAAA(I)
  155 FORMAT('0',5X,F9.4)
      GC TO 200
  170 WRITE(6,175) JJ,X1AAA(I),DAAA(I),QAAA(I),NAME(IJ),L
  175 FORMAT('0',I4,1X,F9.4,2X,F6.3,12X,F11.6,33X,A4,3X,I4)
      GO TO 200
  180 NP=ILNP(IL)
      WRITE(6,185) JJ,X1AAA(I),DAAA(I),QAAA(I),NAME(IJ),L,
     *(ILLL(IL,K),K=1,NP)
  185 FORMAT('0',I4,1X,F9.4,2X,F6.3,12X,F11.6,33X,A4,3X,I4,5X,3I4)
      IL=IL-1
      IF (KK.EQ.6 .CR. KK.EQ.7)  IQ=IQ-1
  200 IF(XORD(I).GT.A)   WRITE(6,205) JJ,XHRD(I),XCRD(I)
  205 FORMAT(/,'0',7X,'THE OUTLET PRESSURE CF STAGE',I4,' WAS REDUCED FR
     *OM ',F9.4,' TO ',F9.4,/)
      RETURN
      END


C
C        SUBROUTINE RTMJ
C
C        PURPOSE
C           TO SOLVE GENERAL NONLINEAR EQUATIONS OF THE FORM FCT(X)=0
C           BY MEANS OF MUELLER-S ITERATION METHOD.
C
C        USAGE
C           CALL RTMJ (X,F,FCT,XLI,XRI,EPS,IEND,IER)
C           PARAMETER FCT REQUIRES AN EXTERNAL STATEMENT.
C
C        DESCRIPTION OF PARAMETERS
C           X      - RESULTANT ROOT OF EQUATION FCT(X)=0.
C           F      - RESULTANT FUNCTION VALUE AT ROOT X.
C           FCT    - NAME OF THE EXTERNAL FUNCTION SUBPROGRAM USED.
C           XLI    - INPUT VALUE WHICH SPECIFIES THE INITIAL LEFT BOUND
C                    OF THE ROOT X.
C           XRI    - INPUT VALUE WHICH SPECIFIES THE INITIAL RIGHT BOUND
C                    OF THE ROOT X.
C           EPS    - INPUT VALUE WHICH SPECIFIES THE UPPER BOUND OF THE
C                    ERROR OF RESULT X.
C           IEND   - MAXIMUM NUMBER OF ITERATION STEPS SPECIFIED.
C           IER    - RESULTANT ERROR PARAMETER CODED AS FOLLOWS
C                     IER=0 - NO ERROR,
C                     IER=1 - NO CONVERGENCE AFTER IEND ITERATION STEPS
C                             FOLLOWED BY IEND SUCCESSIVE STEPS OF
C                             BISECTION,
C                     IER=2 - BASIC ASSUMPTION FCT(XLI)*FCT(XRI) LESS
C                             THAN OR EQUAL TO ZERO IS NOT SATISFIED.
C
C        REMARKS
C           THE PROCEDURE ASSUMES THAT FUNCTION VALUES AT INITIAL
C           BOUNDS XLI AND XRI HAVE NOT THE SAME SIGN. IF THIS BASIC
C           ASSUMPTION IS NOT SATISFIED BY INPUT VALUES XLI AND XRI, THE
C           PROCEDURE IS BYPASSED AND GIVES THE ERROR MESSAGE IER=2.
C
C        SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C           THE EXTERNAL FUNCTION SUBPROGRAM FCT(X) MUST BE FURNISHED
C           BY THE USER.
C
C        METHOD
C           SOLUTION OF EQUATION FCT(X)=0 IS DONE BY MEANS OF MUELLER-S
C           ITERATION METHOD OF SUCCESSIVE BISECTIONS AND INVERSE
C           PARABOLIC INTERPOLATION, WHICH STARTS AT THE INITIAL BOUNDS
C           XLI AND XRI. CONVERGENCE IS QUADRATIC IF THE DERIVATIVE OF
```

# Appendix B-1 (Contd)

```
C          FCT(X) AT ROOT X IS NOT EQUAL TO ZERO. ONE ITERATION STEP
C          REQUIRES TWO EVALUATIONS OF FCT(X). FOR TEST ON SATISFACTORY
C          ACCURACY SEE FORMULAE (3,4) OF MATHEMATICAL DESCRIPTION.
C          FOR REFERENCE, SEE G. K. KRISTIANSEN, ZERO OF ARBITRARY
C          FUNCTION, BIT, VOL. 3 (1963), PP.205-206.
C
C
      SUBROUTINE RTMJ(X,F,FCT,XLI,XRI,EPS,IEND,IER)
C
      COMMON /ITEM1/VIS,CP,H,Z,E,DO,LO,XO,CC,CD,KE,C,W1,C,X1,XMAX,XMIN,
     *XDEL,XDMIN,XDMAX,XD,DC,LC,GH,XOO,VP,CL,GS,KO,KD,KK,KV,KSZ,KP,DCA
C
C     PREPARE ITERATION
      IER=0
      XL=XLI
      XR=XRI
      X=XL
      TOL=X
      F=FCT(TOL)
      IF(F)1,16,1
    1 FL=F
      X=XR
      TOL=X
      F=FCT(TOL)
      IF(F)2,16,2
    2 FR=F
      IF(SIGN(1.,FL)+SIGN(1.,FR))25,3,25
C
C     BASIC ASSUMPTION FL*FR LESS THAN 0 IS SATISFIED.
C     GENERATE TOLERANCE FOR FUNCTION VALUES.
    3 I=0
      TOLF=100.*EPS
C
C
C     START ITERATION LOOP
    4 I=I+1
C
C     START BISECTION LOOP
      DO 13 K=1,IEND
      X=.5*(XL+XR)
      TOL=X
      F=FCT(TOL)
      IF(F)5,16,5
    5 IF(SIGN(1.,F)+SIGN(1.,FR))7,6,7
C
C     INTERCHANGE XL AND XR IN ORDER TO GET THE SAME SIGN IN F AND FR
    6 TOL=XL
      XL=XR
      XR=TOL
      TOL=FL
      FL=FR
      FR=TOL
    7 TOL=F-FL
      A=F*TOL
      A=A+A
      IF(A-FR*(FR-FL))8,9,9
    8 IF(I-IEND)17,17,9
    9 XR=X
      FR=F
C
C     TEST ON SATISFACTORY ACCURACY IN BISECTION LOOP
      TOL=EPS
      A=ABS(XR)
      IF(A-1.)11,11,10
   10 TOL=TOL*A
   11 IF(ABS(XR-XL)-TOL)12,12,13
   12 IF(ABS(FR-FL)-TOLF)14,14,13
   13 CONTINUE
C     END OF BISECTION LOOP
C
C     NO CONVERGENCE AFTER IEND ITERATION STEPS FOLLOWED BY IEND
C     SUCCESSIVE STEPS OF BISECTION OR STEADILY INCREASING FUNCTION
C     VALUES AT RIGHT BOUNDS. ERROR RETURN.
      IER=1
   14 IF(ABS(FR)-ABS(FL))16,16,15
   15 X=XL
      F=FL
   16 RETURN
C
C     COMPUTATION OF ITERATED X-VALUE BY INVERSE PARABOLIC INTERPOLATION
   17 A=FR-F
      DX=(X-XL)*FL*(1.+F*(A-TOL)/(A*(FR-FL)))/TOL
      XM=X
      FM=F
      X=XL-DX
      TOL=X
      F=FCT(TOL)
      IF(F)18,16,18
C
C     TEST ON SATISFACTORY ACCURACY IN ITERATION LOOP
   18 TOL=EPS
      A=ABS(X)
      IF(A-1.)20,20,19
   19 TOL=TOL*A
   20 IF(ABS(DX)-TOL)21,21,22
   21 IF(ABS(F)-TOLF)16,16,22
C
C     PREPARATION OF NEXT BISECTION LOOP
   22 IF(SIGN(1.,F)+SIGN(1.,FL))24,23,24
   23 XR=X
      FR=F
      GO TO 4
   24 XL=X
      FL=F
      XR=XM
      FR=FM
      GO TO 4
C     END OF ITERATION LOOP
C
C     ERROR RETURN IN CASE OF WRONG INPUT DATA
   25 IER=2
      RETURN
      END
/*
//
```

# Appendix B-2. Program for Creating a Data Set of Material Cost on Disk

```
//DATA    JOB   (1988),'YANG'
// EXEC  FORTCG
//SYSIN  DD   *
C
C      THIS PROGRAM IS FOR CREATING A SEQUENTIAL DATA SET OF MATERIAL
C      COST ON THE MAGNETIC DISK
C
C
C      NO      : NO. OF DIFFERENT SIZE OF PIPES OR OTHER JOINTS
C      DIA     : PIPE OR JOINTS SIZE, IN IN.
C      COPI    : COST OF PIPE, IN $/FT.
C      COTEE   : COST OF TEE JOINT, IN $
C      COCRS   : COST OF CROSS JOINT, IN $
C      COELB   : COST OF ELBOW, IN $
C      ELBR    : RADIUS OF BENDING CURVATURE OF ELBOW, IN IN.
C      E       : PIPE ROUGHNESS, IN IN.
C      LF      : LIFE OF FLUID NETWORK, IN YR.
C      INT     : INTEREST OF INVESTMENT, IN PERCENT
C      S       : MATERIAL SALVAGE VALUE, IN DECIMAL OF ORIGINAL VALUE
C      CE      : UNIT ENERGY COST, IN $/HP-HR.
C      T       : ANNUAL USAGE TIME, IN HOUR
C      EFF     : EFFICIENCY OF CONVERTING SOURCE POWER TO FLUID POWER,
C                IN DECIMALS
C      CF      : FLUID COST, IN $/1000 CUBIC FEET
C      GH      : LENGTH OF GRADUAL CHANGE TYPE CONNECTORS, IN FT.
C      COSUD   : COST OF SUDDEN CHANGE TYPE CONNECTORS, IN $,
C                COSUD(I,J) & COSUD(J,I) ARE THE COST OF CONNECTOR BETWEEN
C                SIZE I AND J PIPES, IF I=J THEN COSUD=0.
C      COGRA   : COST OF GRADUAL CHANGE TYPE CONNECTOR, IN $
C
C
      REAL LF,INT
      DIMENSION COGRA(30),COSUD(30)
      REWIND 1
      READ(5,1) NO
    1 FORMAT(I5)
      WRITE(1,1) NO
      WRITE(6,2) NO
    2 FORMAT('0',I5)
      DO 5 I=1,NO
      READ(5,3) DIA,COPI,COTEE,COCRS,COELB,ELBR
    3 FORMAT(F6.3,F8.4,4F6.2)
      WRITE(1,3) DIA,COPI,COTEE,COCRS,COELB,ELBR
      WRITE(6,4) I,DIA,COPI,COTEE,COCRS,COELB,ELBR
    4 FORMAT('0',I5,F6.3,F8.4,4F6.2)
    5 CONTINUE
      READ(5,6) E,LF,INT,S,CE,T,EFF,CF,GH
    6 FORMAT(F8.6,F6.1,3F6.2,F6.1,3F6.2)
      WRITE(1,11) E,LF,INT,S,CE,T
   11 FORMAT(F8.6,F6.1,3F6.2,F6.1)
      WRITE(6,12) E,LF,INT,S,CE,T
   12 FORMAT('0',F8.6,F6.1,3F6.2,F6.1)
      WRITE(1,13) EFF,CF,GH
   13 FORMAT(3F6.2)
      WRITE(6,14) EFF,CF,GH
   14 FORMAT('0',3F6.2)
      DO 20 I=1,NO
      J1=1
      J2=6

   15 IF(J2.GT.NO) J2=NO
      READ(5,16) (COGRA(J),J=J1,J2)
      WRITE(1,16) (COGRA(J),J=J1,J2)
   16 FORMAT(6F6.2)
      WRITE(6,17) (COGRA(J),J=J1,J2)
   17 FORMAT('0',6F6.2)
      J1=J1+6
      J2=J2+6
      IF(J1.GT.NO) GO TO 20
      GO TO 15
   20 CONTINUE
      DO 30 I=1,NO
      J1=1
      J2=6
   25 IF(J2.GT.NO) J2=NO
      READ(5,16) (COSUD(J),J=J1,J2)
      WRITE(1,16) (COSUD(J),J=J1,J2)
      WRITE(6,17) (COSUD(J),J=J1,J2)
      J1=J1+6
      J2=J2+6
      IF(J1.GT.NO) GO TO 30
      GO TO 25
   30 CONTINUE
      STOP
      END
/*
//GO.FT01F001  DD  DSN=T61988C.YANG.INFORM1.DATA,UNIT=TSSDA1,
//               SPACE=(TRK,(1,1)),DISP=(NEW,CATLG),
//               DCB=(RECFM=FB,LRECL=40,BLKSIZE=7280)
//GO.SYSIN  DD   *
   10
  2.00  0.2530  2.18  2.89  1.54  6.00
  3.00  0.3820  3.87  4.10  1.85  7.00
  4.00  0.5110  4.12  4.58  2.24  7.50
  5.00  0.6800  4.86  5.05  3.56  8.00
  6.00  0.9370  5.38  6.63  4.13 10.00
  7.00  1.2690  6.98  7.45  5.68 12.00
  8.00  1.5420  7.74  8.10  6.35 14.50
 10.00  2.1050  9.70 11.18  8.16 16.00
 12.00  2.8530 13.85 17.44 11.98 17.50
 15.00  4.0870 21.65 24.84 16.58 20.00
0.000200  10.0  5.00  0.05  0.05 500.0  0.90  0.40  2.00
  0.0   0.64  0.77  0.94  1.19  1.53
  1.80  2.36  3.22  4.48
  0.64  0.0   0.90  1.07  1.32  1.66
  1.93  2.52  3.31  4.62
  0.77  0.90  0.0   1.20  1.46  1.79
  2.07  2.73  3.48  4.71
  0.94  1.07  1.20  0.0   1.63  1.96
  2.23  2.84  3.75  4.88
  1.19  1.32  1.46  1.63  0.0   2.22
  2.49  3.06  3.89  5.04
  1.53  1.66  1.79  1.96  2.22  0.0
  2.62  3.40  4.16  5.42
  1.80  1.93  2.07  2.23  2.49  2.82
  0.0   3.76  4.52  5.70
  2.36  2.52  2.73  2.84  3.06  3.40
  3.76  0.0   5.06  6.25
  3.22  3.31  3.48  3.75  3.89  4.16
  4.52  5.06  0.0   7.12
  4.48  4.62  4.71  4.88  5.04  5.42
  5.70  6.25  7.12  0.0
  0.0   0.58  0.70  0.86  1.13  1.45
  1.72  2.16  2.93  4.08
  0.58  0.0   0.87  0.91  1.21  1.54
  1.83  2.32  3.17  4.35
  0.70  0.87  0.0   1.09  1.24  1.63
  1.93  2.54  3.29  4.51
  0.86  0.91  1.09  0.0   1.48  1.81
  2.09  2.72  3.42  4.68
  1.13  1.21  1.34  1.48  0.0   2.08
  2.31  2.84  3.64  4.92
  1.45  1.54  1.63  1.81  2.08  0.0
  2.62  3.08  3.94  5.18
  1.72  1.83  1.93  2.09  2.31  2.62
  0.0   3.47  4.21  5.43
  2.16  2.32  2.54  2.72  2.84  3.08
  3.47  0.0   4.87  6.11
  2.93  3.17  3.29  3.42  3.64  3.94
  4.21  4.87  0.0   6.74
  4.08  4.35  4.51  4.68  4.52  5.18
  5.43  6.11  6.74  0.0
/*
//
```

## Appendix B-3. Program for Creating Direct-Access Data Set

```
//CREATE1   JOB   (1988,20S),'YANG'
// EXEC  FORTCG
//SYSIN  DD   *
C
C     THIS PROGRAM WILL ALLOCATE  A SPACE ON DISK FOR THE DIRECT-ACCESS
C     DATA SET WHICH IS FOR STORING THE CALCULATED RESULTS OF EACH
C     STAGE
C
      INTERGER A,B,C,D,E
      DEFINE FILE  1(3000,20,L,N)
      N-1
   10 READ(5,11,END=100) A,B,C,D,E
   11 FORMAT(5A4)
      WRITE(1'N,11) A,B,C,D,E
      WRITE(6,12) A,B,C,D,E
   12 FORMAT(1H ,5A4)
      GO TO 10
  100 STOP
      END
/*
//GO.FT01F001  DD  DSN=T619880.YANG.RESULT.DATA,UNIT=TSSDA1,
//               DISP=(NEW,CATLG),SPACE=(20,(3000,50))
//GO.SYSIN  DD   *
AAAAAAAAAAAAAAAAAAAA
BBBBBBBBBBBBBBBBBBBB
CCCCCCCCCCCCCCCCCCCC
DDDDDDDDDDDDDDDDDDDD
EEEEEEEEEEEEEEEEEEEE
FFFFFFFFFFFFFFFFFFFF
GGGGGGGGGGGGGGGGGGGG
HHHHHHHHHHHHHHHHHHHH
IIIIIIIIIIIIIIIIIIII
JJJJJJJJJJJJJJJJJJJJ
KKKKKKKKKKKKKKKKKKKK
LLLLLLLLLLLLLLLLLLLL
MMMMMMMMMMMMMMMMMMMM
NNNNNNNNNNNNNNNNNNNN
OOOOOOOOOOOOOOOOOOOO
PPPPPPPPPPPPPPPPPPPP
QQQQQQQQQQQQQQQQQQQQ
RRRRRRRRRRRRRRRRRRRR
SSSSSSSSSSSSSSSSSSSS
TTTTTTTTTTTTTTTTTTTT
/*
//
```

Appendix B-4. Program for Creating Intermediate Information in Case of Interruption during Execution of the Main Program

```
//CREATE2   JOB   (1988),'YANG'
// EXEC  FORTCG
//SYSIN  DD   *
C
C     THIS PROGRAM WILL ALLOCATE A SPACE ON THE DISK FOR A SEQUENTIAL
C     DATA SET WHICH IS FOR STORING INTERMEDIATE INFORMATION IF THE
C     PROGRAM HAS TO BE INTERRUPTED AND CONTINUED LATER
C
      INTERGER A,B,C,D,E,F
   10 READ(5,11,END=100) A,B,C,D,E,F
   11 FORMAT(5A4,A1)
      WRITE(1,11) A,B,C,D,E,F
      WRITE(6,12) A,B,C,D,E,F
   12 FORMAT(' ',5A4,A1)
      GO TO 10
  100 STOP
      END
/*
//GO.FT01F001  DD  DSN=T619880.YANG.CONTU.DATA,UNIT=TSSDA1,
//               SPACE=(TRK,(1,1)),DISP=(NEW,CATLG),
//               DCB=(RECFM=FB,LRECL=21,BLKSIZE=7245)
//GO.SYSIN  DD   *
AAAAAAAAAAAAAAAAAAAAA
BBBBBBBBBBBBBBBBBBBBB
CCCCCCCCCCCCCCCCCCCCC
DDDDDDDDDDDDDDDDDDDDD
EEEEEEEEEEEEEEEEEEEEE
FFFFFFFFFFFFFFFFFFFFF
GGGGGGGGGGGGGGGGGGGGG
HHHHHHHHHHHHHHHHHHHHH
IIIIIIIIIIIIIIIIIIIII
JJJJJJJJJJJJJJJJJJJJJ
KKKKKKKKKKKKKKKKKKKKK
LLLLLLLLLLLLLLLLLLLLL
MMMMMMMMMMMMMMMMMMMMM
NNNNNNNNNNNNNNNNNNNNN
OOOOOOOOOOOOOOOOOOOOO
PPPPPPPPPPPPPPPPPPPPP
QQQQQQQQQQQQQQQQQQQQQ
RRRRRRRRRRRRRRRRRRRRR
SSSSSSSSSSSSSSSSSSSSS
TTTTTTTTTTTTTTTTTTTTT
/*
//
```

## Appendix B-5. Printout of Actual Program Run to Solve the Example Problem.

```
exec yang.comm.clist 'yang.inform1.data' list

 ALLOC DA(YANG.INFORM1.DATA) FI(FT01F001)
 ALLOC DA(YANG.RESULT.DATA) FI(FT02F001)
 ALLOC DA(YANG.CONTU.DATA) FI(FT03F001)
 TIME
 CPU - 00:02:46  EXECUTION - 00:17:29  SESSION - 01:22:55
 LOADGO YANG.PIPE.OBJ(DEMO) FORTLIB LIB('SYS1.FORTLO2') LET

 ENTER 1 TO PRINT DATA OF MATERIAL COST, OTHERWISE 0
 ?
1

 NUMBER OF AVAILABLE SIZE =    10

 NO.   DIAM.IN.  PIPE COST,$/FT  TEE COST,$  CROSS COST,$  ELBOW COST,$  R. OF BENDING CURVATURE,IN.
   1     2.00       0.2530          2.18        2.89          1.54                  6.00
   2     3.00       0.3820          3.87        4.10          1.85                  7.00
   3     4.00       0.5110          4.12        4.58          2.24                  7.50
   4     5.00       0.6800          4.86        5.05          3.56                  8.00
   5     6.00       0.9370          5.38        6.63          4.13                 10.00
   6     7.00       1.2690          6.98        7.45          5.68                 12.00
   7     8.00       1.5420          7.74        8.10          6.35                 14.50
   8    10.00       2.1050          9.70       11.18          8.10                 16.00
   9    12.00       2.8530         13.85       17.44         11.98                 17.50
  10    15.00       4.0870         21.65       24.84         16.58                 20.00

 COST OF GRADUAL CONNECTOR BETWEEN DIFFERENT DIAMETERS, IN $
 CONNECTOR LENGTH =    2.00 FT.
          2.00   3.00   4.00   5.00   6.00   7.00   8.00  10.00  12.00  15.00
   2.00   0.0    0.64   0.77   0.94   1.19   1.53   1.80   2.36   3.22   4.48
   3.00   0.64   0.0    0.90   1.07   1.32   1.66   1.93   2.52   3.31   4.62
   4.00   0.77   0.90   0.0    1.20   1.46   1.79   2.07   2.73   3.48   4.71
   5.00   0.94   1.07   1.20   0.0    1.63   1.96   2.23   2.84   3.75   4.88
   6.00   1.19   1.32   1.46   1.63   0.0    2.22   2.49   3.06   3.89   5.04
   7.00   1.53   1.66   1.79   1.96   2.22   0.0    2.82   3.40   4.16   5.42
   8.00   1.80   1.93   2.07   2.23   2.49   2.82   0.0    3.76   4.52   5.70
  10.00   2.36   2.52   2.73   2.84   3.06   3.40   3.76   0.0    5.06   6.25
  12.00   3.22   3.31   3.48   3.75   3.89   4.16   4.52   5.00   0.0    7.12
  15.00   4.48   4.62   4.71   4.88   5.04   5.42   5.70   6.25   7.12   0.0

 COST OF SUDDEN CONNECTOR BETWEEN DIFFERENT DIAMETERS, IN $
   2.00   0.0    0.58   0.70   0.86   1.13   1.45   1.72   2.16   2.93   4.08
   3.00   0.58   0.0    0.87   0.91   1.21   1.54   1.83   2.32   3.17   4.35
   4.00   0.70   0.87   0.0    1.09   1.34   1.63   1.93   2.54   3.29   4.51
   5.00   0.86   0.91   1.09   0.0    1.48   1.81   2.09   2.72   3.42   4.68
   6.00   1.13   1.21   1.34   1.48   0.0    2.08   2.31   2.84   3.64   4.92
   7.00   1.45   1.54   1.63   1.81   2.08   0.0    2.62   3.08   3.94   5.18
   8.00   1.72   1.83   1.93   2.09   2.31   2.62   0.0    3.47   4.21   5.43
  10.00   2.16   2.32   2.54   2.72   2.84   3.08   3.47   0.0    4.87   6.11
  12.00   2.93   3.17   3.29   3.42   3.64   3.94   4.21   4.87   0.0    6.74
  15.00   4.08   4.35   4.51   4.68   4.92   5.18   5.43   6.11   6.74   0.0
 ENTER 1 IF CONTINUE FROM PREVIOUS INCOMPLETE TEST, OTHERWISE 0
 ?

  logon t619880/dy
  logon t619880/dy
 IKJ54011I TSO IS NOT ACTIVE
  logon t619880/dy
 logon t619880/dy
 T619880 LOGON IN PROGRESS AT 10:17:02 ON JUNE 3, 1974
 5/31/74....SUBROUTINE READTB IS NOW OPERATIONAL
 6-2-74:  V3.1 OF TOO UTILITIES COPY, MERGE, LIST, FORMAT INSTALLED
 ** STARTED JOB #1988 - T619880 , APPROXIMATE BALANCE =  61107.46
 CPU - 00:00:02  EXECUTION - 00:00:14  SESSION - 00:00:14
 READY
 COMMAND #LOGON   NOT FOUND
 READY
exec yang.comm.clist 'yang.inform1.data' list
 ALLOC DA(YANG.INFORM1.DATA) FI(FT01F001)
 ALLOC DA(YANG.RESULT.DATA) FI(FT02F001)
 ALLOC DA(YANG.CONTU.DATA) FI(FT03F001)
 TIME
 CPU - 00:00:04  EXECUTION - 00:2:2  SESSION - 00:02:23
 LOADGO YANG.PIPE.OBJ(DEMO) FORTLIB LIB('SYS1.FORTLB2') LET
 ENTER 1 TO PRINT DATA OF MATERIAL COST, OTHERWISE 0
 ?
0
 ENTER 1 IF CONTINUE FROM PREVIOUS INCOMPLETE TEST, OTHERWISE 0
 ?
0

 FLUID KINEMATIC VISCOSITY =  0.121E-04 FT.**2/SEC.
 PIPE ROUGHNESS =   0.000200 IN.
 PIPE LIFE =    19.0 YR.
 INTEREST =     5.00 PERCENT
 SALVAGE VALUE =     0.05 OF ORIGINAL VALUE
 ENERGY COST =     0.05 $/HP-HR.
 ANNUAL USABE TIME =   500.0 HR.
 CONVERSION EFF. FROM POWER SOURCE TO FLUID POWER =      0.00
 FLUID COST =     0.40 $/1000 CUBIC FT.
 DISCHARGE COEFFICIENT =   0.0033754 CFS./SQRT(PSF.)

 ENTER 1 IF YOU WANT TO USE DATA OTHER THAN GIVEN ABOVE EXCLUDING MATERIAL COSTS, OTHERWISE 0
 ?
0
 ENTER 1 IF SMALLER SIZED PIPE AT UPSTREAM IS NOT ALLOWED, OTHERWISE 0
 ?
0
 ENTER 1 IF WASTED FLUID COST WILL BE CALCULATED, OTHERWISE 0
 ?
1
 ENTER 1 IF POWER COST SHOULD BE INCLUDED, OTHERWISE 0
 ?
1
 ENTER THE ASSIGNED MEMBER OF PIPE LINE
 ?
1
 ENTER 1 TO SPECIFY REQUIRED DISCHARGE
       2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
       3 TO USE ORIGINAL ORIFICE SIZE
 ?
3
 ENTER THE DESIGNED DISCHARGE PRESSURE  AND DESIGNED ALLOWABLE MAX DISCHARGE PRESSURE  IN PSI
```

## Appendix B-5 (Contd)

```
?
→50.,50.1
ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
?
→200.,10.
ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
?
→60.,62.
ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
?
→0.05
ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
?
→1
INLET TOTAL HEAD   DIAMETER   COST     OUTLET TOTAL HEAD   INLET VOLUMN
    61.946152        3.00     138.71       54.436264         0.286698
    61.009350        3.00     139.52       54.386261         0.286555
    56.311661        4.00     130.14       54.436264         0.286698
    56.259870        4.00     129.98       54.386261         0.286555
    55.077881        5.00     131.75       54.436264         0.286698
    55.027890        5.00     131.58       54.386261         0.286555
    54.703842        6.00     137.33       54.436264         0.286698
    54.653610        6.00     137.17       54.386261         0.286555
    54.564148        7.00     145.28       54.436264         0.286698
    54.514025        7.00     145.10       54.386261         0.286555
    54.453705        8.00     161.73       54.386261         0.286555
    54.409485       10.00     165.57       54.386261         0.286555
    54.395981       12.00     184.05       54.386261         0.286555

ENTER 1 IF MORE STAGES ARE NEEDED
      2 IF YOU WANT TO CONTINUE THIS JOB LATER
      0 IF END OF THIS JOB
?
→1
ENTER 1 TO CALCULATE THE END STAGES
      2 TO CONNECT TWO STAGES
      3 TO MERGE PIPELINES WITH TEE JOINT
      4 TO MERGE PIPELINES WITH CROSS JOINT
      5 TO TURN THE FLOW WITH ELBOW
      6 TO BRANCH PIPELINES WITH TEE JOINT
      7 TO BRANCH PIPELINES WITH CROSS JOINT
?
→2
ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
?
→0
ENTER 1 TO SPECIFY REQUIRED DISCHARGE
      2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
      3 TO USE ORIGINAL ORIFICE SIZE
?
→3
ENTER THE DESIGNER DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
?
→50.,52.
ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
?
→200.,0.
ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
?
→54.,62.
ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
?
→0.05
ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
      2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
?
→1
ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
?
→1
INLET TOTAL HEAD   DIAMETER   COST     OUTLET TOTAL HEAD   INLET VOLUMN
    61.336578        4.00     294.29       54.653610         0.578581
    61.244858        4.00     302.12       54.564148         0.578473
    61.180761        4.00     301.75       54.514023         0.578189
    61.124878        4.00     308.20       54.453705         0.578019
    61.078033        4.00     321.96       54.409485         0.577895
    56.836807        5.00     287.81       54.564146         0.578593
    56.784668        5.00     287.40       54.514023         0.578308
    56.723160        5.00     293.94       54.453705         0.578140
    56.678055        5.00     307.71       54.409485         0.578015
    55.507996        6.00     288.03       54.564148         0.578637
    55.457031        6.00     288.30       54.514023         0.578353
    55.398240        6.00     294.76       54.453705         0.578163
    55.338028        6.00     327.07       54.395981         0.578021
    55.013748        7.00     294.50       54.564148         0.578655
    54.963226        7.00     294.17       54.514023         0.578371
    54.902679        7.00     300.95       54.453705         0.578201
    54.858276        7.00     314.72       54.409485         0.576077
    54.800858        8.00     300.71       54.564148         0.576664
    54.750519        8.00     300.38       54.514023         0.578360
    54.690679        8.00     300.47       54.453705         0.578210
    54.645294       10.00     314.06       54.564146         0.578672
    54.595108       10.00     313.74       54.514023         0.576388
    54.534744       10.00     320.22       54.453705         0.578218
    54.490494       10.00     333.45       54.409485         0.578094
    54.445298       12.00     352.38       54.409485         0.578096

ENTER 1 IF MORE STAGES ARE NEEDED
      2 IF YOU WANT TO CONTINUE THIS JOB LATER
      0 IF END OF THIS JOB
?
→1
ENTER 1 TO CALCULATE THE END STAGES
      2 TO CONNECT TWO STAGES
      3 TO MERGE PIPELINES WITH TEE JOINT
      4 TO MERGE PIPELINES WITH CROSS JOINT
      5 TO TURN THE FLOW WITH ELBOW
      6 TO BRANCH PIPELINES WITH TEE JOINT
      7 TO BRANCH PIPELINES WITH CROSS JOINT
?
→7
ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
?
→0
ENTER THE ASSIGNED NUMBER OF PIPELINES WHICH WILL BE BRANCHED, MAIN LINE FIRST
?
→1,2,3
ENTER THE RATIO OF FLOW RATE IN THESE PIPELINES, THE SUM OF THESE NUMBERS IS 1., FOR INSTANCE, .5,.3,.2
?
→.4,.3,.3
ENTER THE ELEVATION OF THIS STAGE, IN FT.
?
8.
ENTER THE DESIGNER MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
?
54.,62.
ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
?
→0.05
ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
```

# Appendix B-5 (Contd)

```
      2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE POINTED EVERY N NUMBER
   61.572852,   61.481155,   61.411896,   61.367850,   61.345520,   61.288962,   61.220062,   61.197878,
   61.144472,   61.093628,   58.032806,   57.979402,   57.917297,   57.871674,   57.072800,   57.020038,
   56.958766,   56.911602,   56.859467,   56.815521,   56.759744,   56.703461,   56.651321,   56.609828,
   56.690045,   56.208774,   56.157074,   58.085026,   55.905544,   55.944081,   59.882904,   55.835600,
   55.780264,   55.743881,   56.692648,   55.631780,   55.582785,   55.531693,   55.487701,   55.426895,
   55.391433,   55.346146,   55.285588,   55.198837,   55.138155,   55.088425,   55.037827,   54.993820,
   54.933268,   54.875504,   54.825089,   54.781062,   54.720637,   54.698074,   54.625641,   54.599777,
   54.649469,   54.492484,   54.447937,
ENTER 1 IF MORE STAGES ARE NEEDED
      2 IF YOU WANT TO CONTINUE THIS JOB LATER
      0 IF END OF THIS JOB
ENTER 1 TO CALCULATE THE END STAGES
      2 TO CONNECT TWO STAGES
      3 TO MERGE PIPELINES WITH TEE JOINT
      4 TO MERGE PIPELINES WITH CROSS JOINT
      5 TO TURN THE FLOW WITH ELBOW
      6 TO BRANCH PIPELINES WITH TEE JOINT
      7 TO BRANCH PIPELINES WITH CROSS JOINT
ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
ENTER 1 TO SPECIFY REQUIRED DISCHARGE
      2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
      3 TO USE ORIGINAL ORIFICE SIZE
ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
50.,52.5
ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
200.,0.
ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
55.,62.
ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
0.05
ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
      2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
   61.595234,   61.538727,   61.472877,   61.430893,   61.374375,   61.328262,   61.272095,   61.206558,
   61.258325,   61.202810,   61.055939,   60.990540,   60.904190,   60.807251,   60.751556,   60.686284,
   60.637283,   60.581741,   60.536355,   60.470184,   60.412827,   60.357483,   60.311096,   60.246033,
   60.147232,   60.085628,   60.010880,   59.957642,   57.850908,   57.796315,   57.745422,   57.692383,
   57.645340,   57.592453,   57.529968,   57.481918,   57.428298,   57.383498,   57.321136,   57.292206,
   57.256496,   57.141998,   57.089569,   57.027328,   56.977061,   56.925385,   56.880560,   56.818451,
   56.760834,   56.708755,   56.661940,   56.601929,   56.578964,   56.534393,   56.482498,   56.420929,
   56.371643,   56.319916,   56.275565,   56.214081,   56.185460,   56.121076,   56.089550,   56.038346,
   55.984909,   55.967425,   55.872596,   55.822296,   55.777008,   55.716705,   55.659058,   55.607841,
   55.563558,   55.502457,   55.462708,   55.411789,   55.367523,   55.306656,   55.285675,   55.249023,
   55.154022,   55.120944,   55.070608,   55.021759,   54.977524,   54.916910,   54.894207,   54.821793,
   54.795852,   54.745892,   54.602993,   54.616699,   54.585613,   54.526520,   54.475963,
ENTER 1 IF MORE STAGES ARE NEEDED
      2 IF YOU WANT TO CONTINUE THIS JOB LATER
      0 IF END OF THIS JOB
TIME
CPU - 00:00:24  EXECUTION - 00:07:55  SESSION - 00:27:10
HARDS T619866.YANG.RESULT.DATA
DSNAME: T619880.YANG.RESULT.DATA                          VOL-SER: UNTS01
  CREATED: 74100    PURGED: 74154      DS_ORG:   SEQ     REC_FM: F
  REC_LEN:     20   BLKSIZE:     20   2ND ALLOC:     2   ALL_TYPE: TRK
LAST_BLK_PTR(TRL):    201  61| -87   DIRC_BLKS:     0 BLKS_USED:      0
    EXT FIRST LAST LENG    EXT FIRST LAST LENG    EXT FIRST LAST LENG
     0   322   323    2     5  1472  1473    2    10   192   192    1
     1   785   786    2     6  1749  1750    2    11   198   196    1
     2  1068  1068    1     7   130   130    1    12   204   204    1
     3  1252  1253    2     8   184   184    1    13   224   224    1
     4  1281  1282    2     9   187   187    1    14   228   228    1
            TOTAL TRACKS ALLOC:     21
END
READY
logoff
TSO TIME JOB FA988 - T619880  ON 02C, CONNECT=  0.20.02  MUS=  0.00.48
T619880 LOGGED OFF TSO AT 10:48:10 ON JUNE 3, 1974+
```

NOTE: CPU TIME USED = 24 - 4 = 20 sec.
CONNECT TIME = 24 min 47 sec.

## Appendix B-5 (Contd)

```
logon t619880/dy
T619880 LOGON IN PROGRESS AT 15:32:03 ON JUNE 3, 1974
5/31/74....SUBROUTINE READTB IS NOW OPERATIONAL
6-2-74:  V3.1 OF TSO UTILITIES COPY, MERGE, LIST, FORMAT INSTALLED
** STARTED JOB #1986 - T619880 , APPROXIMATE BALANCE =   $1183.99
CPU - 00:00:02  EXECUTION - 00:00:10  SESSION - 00:00:15
READY
exec yang.comm.clist 'yang.informl.data' list
ALLOC DA(YANG.INFORM1.DATA) FI(FT01F001)ALLOC DA(YANG.RESULT.DATA) FI(FT02F001)
ALLOC DA(YANG.CONTU.DATA) FI(FT03F001)
TIME
CPU - 00:00:8  EXECUTION - 00:00:28  SESSION - 00:01:24
LOADGO YANG.PIPE.OBJ(DEMO) FORTLIB LIB('SYS1.FORTIB2') LET
ENTER 1 TO PRINT DATA OF MATERIAL COST, OTHERWISE 0
?
0
ENTER 1 IF CONTINUE FROM PREVIOUS INCOMPLETE TEST, OTHERWISE 0
?
1
LINE NO. OF LAST STAGE IN PREVIOUS JOB WAS  1
ENTER 1 TO CALCULATE THE END STAGES
      2 TO CONNECT TWO STAGES
      3 TO MERGE PIPELINES WITH TEE JOINT
      4 TO MERGE PIPELINES WITH CROSS JOINT
      5 TO TURN THE FLOW WITH ELBOW
      6 TO BRANCH PIPELINES WITH TEE JOINT
      7 TO BRANCH PIPELINES WITH CROSS JOINT
?
2
ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
?
1
ENTER THE ASSIGNED NUMBER OF PIPE LINE
?
1
ENTER 1 TO SPECIFY REQUIRED DISCHARGE
      2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
      3 TO USE ORIGINAL ORIFICE SIZE
?
2
ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
?
5.,5.5
ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
?
...,0.
ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
?
54.,62.
ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
?
0.05
ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
      2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
?
2
ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
?
2
ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
?
1
   60.470737,   60.405319,   60.362305,   60.308946,   60.200880,   60.205673,   60.140854,   60.091782,
   60.036728,   59.990570,   59.923873,   59.896057,   59.840332,   59.742329,   59.687576,   59.627010,
   59.573196,   59.518616,   59.472427,   59.407990,   59.349808,   59.295410,   59.249222,   59.161255,
   59.086196,   59.006341,   58.951141,   58.898146,   57.487770,   57.425323,   57.382126,   57.328407,
   57.283325,   57.230774,   57.168533,   57.119385,   57.066584,   57.022263,   56.960129,   56.931229,
   56.877747,   56.780887,   56.728718,   56.666782,   56.616652,   56.564996,   56.520157,   56.458267,
   56.400575,   56.384262,   56.303864,   56.271827,   56.242096,   56.170181,   56.145828,   56.060085,
   56.015976,   55.964645,   55.936844,   55.886566,   55.835251,   55.774017,   55.724060,   55.672913,
   55.628686,   55.567474,   55.509674,   55.458694,   55.434366,   55.353376,   55.330658,   55.257858,
   55.231812,   55.181039,   55.129562,   55.078705,   55.022354,   54.998725,   54.927124,   54.850832,
   54.835754,   54.799393,   54.748718,   54.657028,   54.606430,   54.552867,   54.502358,   54.470673,
ENTER 1 IF MORE STAGES ARE NEEDED
      2 IF YOU WANT TO CONTINUE THIS JOB LATER
      0 IF END OF THIS JOB
?
1
ENTER 1 TO CALCULATE THE END STAGES
      2 TO CONNECT TWO STAGES
      3 TO MERGE PIPELINES WITH TEE JOINT
      4 TO MERGE PIPELINES WITH CROSS JOINT
      5 TO THRU THE FLOW WITH ELBOW.
      6 TO BRANCH PIPELINES WITH TEE JOINT
      7 TO BRANCH PIPELINES WITH CROSS JOINT
?
5
ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
?
0
ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
?
54.,62.
ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
?
0.05
ENTER THE ELEVATION OF THIS STAGE, IN FT.
?
5.
ENTER THE ELBOW ANGLE, IN DEGREE
?
30.
ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
      2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
?
2
ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
?
2
ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
?
1
   60.827087,   60.761734,   60.718735,   60.663025,   60.616882,   60.561340,   60.546029,   60.497843,
   60.447098,   60.391706,   60.334106,   60.288040,   60.282808,   60.167969,   60.118881,   60.068812,
   60.017639,   59.962911,   59.926407,   59.871475,   59.818207,   59.769518,   59.762103,   59.698744,
   59.600143,   59.544284,   59.545532,   59.499329,   59.425839,   59.374678,   59.322250,   59.276047,
   59.236572,   59.161407,   59.112915,   59.080521,   59.032089,   58.977876,   58.984566,   57.844086,
   57.781296,   57.738129,   57.685059,   57.638901,   57.564560,   57.502029,   57.458832,   57.406052,
   57.376617,   57.314148,   57.257996,   57.205010,   57.195862,   57.154277,   57.098818,   57.036423,
   56.973146,   56.917328,   56.872406,   56.816181,   56.752243,   56.742722,   56.055197,   56.040839,
   56.598094,   56.534105,   56.496506,   56.418365,   56.379562,   56.317719,   56.255005,   56.221390,
   56.158722,   56.143566,   56.080963,   56.040009,   55.977509,   55.911831,   55.850057,   55.800079,
   55.765259,   55.703984,   55.655716,   55.606093,   55.565495,   55.530853,   55.490067,   55.406285,
   55.359375,   55.333420,   55.256916,   55.208023,   55.187814,   55.105852,   55.084671,   55.026819,
   54.964193,   54.920028,   54.874726,   54.826401,   54.775711,   54.743527,   54.681810,   54.633408,
   54.677377,   54.529206,   54.497528,
ENTER 1 IF MORE STAGES ARE NEEDED
```

## Appendix B-5 (Contd)

```
      2 IF YOU WANT TO CONTINUE THIS JOB LATER
      0 IF END OF THIS JOB
?
1
ENTER 1 TO CALCULATE THE END STAGES
      2 TO CONNECT TWO STAGES
      3 TO MERGE PIPELINES WITH TEE JOINT
      4 TO MERGE PIPELINES WITH CROSS JOINT
      5 TO TURN THE FLOW WITH ELBOW
      6 TO BRANCH PIPELINES WITH TEE JOINT
      7 TO BRANCH PIPELINES WITH CROSS JOINT
?
2
ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
?
0
ENTER 1 TO SPECIFY REQUIRED DISCHARGE
      2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
      3 TO USE ORIGINAL ORIFICE SIZE
?
3
ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
?
60.,52.5
ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
?
200.,5.
ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
?
54.4,62.
ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
?
0.05
ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
      2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
?
2
ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
?
1
ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
?
1
   58.373734,   58.323532,   58.266937,   58.216827,   58.184811,   56.233715,   56.163513,   56.108429,
   56.058304,   56.028245,   55.412323,   55.361640,   55.307587,   55.257004,   55.225113,   55.016891,
   54.963699,   54.912476,   54.880601,   54.765747,   54.714096,   54.661514,   54.639816,   54.585846,
   54.519211,
ENTER 1 IF MORE STAGES ARE NEEDED
      2 IF YOU WANT TO CONTINUE THIS JOB LATER
      0 IF END OF THIS JOB
?
2
TIME
CPU - 00:00:34  EXECUTION - 00:04:56  SESSION - 00:20:43
NAPOS T619880.YANG.RESULT.DATA
DSNAME: T619880.YANG.RESULT.DATA                         VOL=SER: UHT601
  CREATED: 74200   PURGED: 74154     DS_ORG:   SEQ     REC_FM: F
  REC_LEN:    20   BLKSIZE:     20  2ND ALLOC:     2  ALL_TYPE: TRK
LAST_BLK_PTR(TRL):   201  611 -87  DIRC_BLKS:     0 BLKS_USED:      0
   EXT FIRST LAST LENG   EXT FIRST LAST LENG   EXT FIRST LAST LENG
    0   322   323    2    5  1472  1473    2   10   192   192    1
    1   765   766    2    6  1749  1750    2   11   196   196    1
    2  1068  1068    1    7   130   130    1   12   204   204    1
    3  1252  1253    2    8   184   184    1   13   224   224    1
    4  1281  1282    2    9   187   187    1   14   228   228    1
              TOTAL TRACKS ALLOC:    21
END
READY
logoff
TSO TIME JOB #1388 - T619880  ON 02C, CONNECT=  0.22.42  MUS=  0.01.01
T619880 LOGGED OFF TSO AT 15:54:50 ON JUNE 3, 1974+
```

NOTE: CPU TIME USED = 34 - 3 = 31 sec.
CONNECT TIME = 19 min 19 sec.

## Appendix B-5 (Contd)

```
logon t619880/dy
T619880 LOGON IN PROGRESS AT 15:46:05 ON JUNE 3, 1974
5/31/74....SUBROUTINE READTB IS NOW OPERATIONAL
6-2-74: V3.1 OF TSO UTILITIES COPY, MERGE, LIST, FORMAT INSTALLED
** STARTED JOB #1988 - T619880 , APPROXIMATE BALANCE =   $1181.16
CPU - 00:00:62  EXECUTION - 00:00:13  SESSION - 00:00:16
READY
exec yang.comm.clist 'yang.informl.data' list
ALLOC DA(YANG.INFORM1.DATA) F1(FT01F001)
ALLOC DA(YANG.RESULT.DATA) F1(FT02F001)
ALLOC DA(YANG.CONTU.DATA) F1(FT03F001)
TIME
CPU - 00:00:08  EXECUTION - 00:00:38  SESSION - 00:01:28
LOADED YANG.PIPE.CPU(DEMO) FORTLIB LIB('SYS1.FORTLIB2') LET
ENTER 1 TO PRINT DATA OF MATERIAL COST, OTHERWISE 0
?
0
ENTER 1 IF CONTINUE FROM PREVIOUS INCOMPLETE TEST, OTHERWISE 0
?
1
LINE NO. OF LAST STAGE IN PREVIOUS JOB WAS  2
ENTER 1 TO CALCULATE THE END STAGES
      2 TO CONNECT TWO STAGES
      3 TO MERGE PIPELINES WITH TEE JOINT
      4 TO MERGE PIPELINES WITH CROSS JOINT
      5 TO TURN THE FLOW WITH ELBOW
      6 TO BRANCH PIPELINES WITH TEE JOINT
      7 TO BRANCH PIPELINES WITH CROSS JOINT
?
5
ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
?
0
ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
?
54.,62.
ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
?
0.05
ENTER THE ELEVATION OF THIS STAGE, IN FT.
?
4.
ENTER THE ELBOW ANGLE, IN DEGREE
?
45.
ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
      2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
?
2
ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
?
2
ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
?
1

   59.307770,   59.257233,   59.200256,   59.149811,   58.575027,   58.524750,   58.464079,   58.408081,
   58.357184,   58.339523,   58.251129,   58.232803,   58.192825,   57.146805,   57.096252,   57.040802,
   56.990341,   56.415054,   56.364777,   56.344650,   56.285706,   56.229675,   56.179474,   56.124390,
   56.074249,   56.042191,   55.988318,   55.694775,   55.643201,   55.696518,   55.613434,   55.562898,
   55.508549,   55.444451,   55.433740,   55.370020,   55.320362,   55.265382,   55.217667,   55.164398,
   55.113098,   55.051590,   55.021515,   54.966185,   54.917899,   54.861740,   54.800448,   54.781906,
   54.733368,   54.677658,   54.631990,   54.594345,   54.535309,
ENTER 1 IF MORE STAGES ARE NEEDED
      2 IF YOU WANT TO CONTINUE THIS JOB LATER
      0 IF END OF THIS JOB
?
1
ENTER 1 TO CALCULATE THE END STAGES
      2 TO CONNECT TWO STAGES
      3 TO MERGE PIPELINES WITH TEE JOINT
      4 TO MERGE PIPELINES WITH CROSS JOINT
      5 TO TURN THE FLOW WITH ELBOW
      6 TO BRANCH PIPELINES WITH TEE JOINT
      7 TO BRANCH PIPELINES WITH CROSS JOINT
?
2
ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
?
0
ENTER 1 TO SPECIFY REQUIRED DISCHARGE
      2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
      3 TO USE ORIGINAL ORIFICE SIZE
?
3
ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
?
50.,52.5
ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
?
200.,0.
ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
?
54.5,62.
ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
?
0.05
ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
      2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
?
2
NO RESULTS PRODUCED, RE-DO THIS STAGE
ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
?
0
ENTER 1 TO SPECIFY REQUIRED DISCHARGE
      2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
      3 TO USE ORIGINAL ORIFICE SIZE
?
3
ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
?
51.,54.
ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
?
200.,4.
ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
?
54.5,62.
ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
?
0.05
ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
      2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
?
2
ENTER 1 TO DISPLAY THE RESULTS  ENTER 2 TO DISPLAY ONLY THE INLET HEAD  OTHERWISE 0
```

# Appendix B-5 (Contd)

```
ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
2
ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
1
   61.957733,   61.901031,   61.846405,   61.784012,   61.688257,   61.642138,   61.587128,   61.524948,
   61.452427,   61.394882,   61.316857,   61.247025,   58.583483,   58.411041,   58.356948,   58.303560,
   58.276306,   58.224243,   58.159164,   58.116745,   58.051743,   58.009430,   57.934742,   57.902069,
   57.806190,   57.754623,   57.690990,   57.647446,   57.563370,   57.513321,   57.456345,   57.379780,
   57.311722,   57.080475,   56.946076,   56.895599,   56.811172,   56.759827,   56.654550,   56.588593,
   56.548447,   56.494547,   56.442535,   56.374313,   56.319901,   56.268829,   56.214310,   56.182526,
   56.131485,   56.065643,   56.026077,   55.968322,   55.932684,   55.866760,   55.815918,   55.761627,
   55.716019,   55.674957,   55.607666,   55.570028,   55.502792,   55.476505,   55.428497,   55.365677,
   55.337448,   55.258713,   55.218689,   55.154068,   55.120351,   55.085785,   55.019184,   54.973694,
   54.914687,   54.881104,   54.837234,   54.776764,   54.701058,   54.653039,   54.634744,   54.570084,
ENTER 1 IF MORE STAGES ARE NEEDED
      2 IF YOU WANT TO CONTINUE THIS JOB LATER
      0 IF END OF THIS JOB
1
ENTER 1 TO CALCULATE THE END STAGES
      2 TO CONNECT TWO STAGES
      3 TO MERGE PIPELINES WITH TEE JOINT
      4 TO MERGE PIPELINES WITH CROSS-JOINT
      5 TO TURN THE FLOW WITH ELBOW
      6 TO BRANCH PIPELINES WITH TEE JOINT
      7 TO BRANCH PIPELINES WITH CROSS-JOINT
2
ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
1
ENTER THE ASSIGNED NUMBER OF PIPE LINE
3
ENTER 1 TO SPECIFY REQUIRED DISCHARGE
      2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
      3 TO USE ORIGINAL ORIFICE SIZE
3
ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
?
50.,52.5
ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
?
200.,8.
ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
?
50.,62.
ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
?
0.05
ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
      2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
2
ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
2
ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
1
   60.470537,   60.405318,   60.361305,   60.306946,   60.260888,   60.205673,   60.140854,   60.081782,
   60.036788,   59.985570,   59.925873,   59.896057,   59.840332,   59.742825,   59.687576,   59.623016,
   59.578198,   59.518616,   59.472427,   59.407990,   59.349808,   59.298418,   59.249222,   59.161255,
   59.006136,   59.005341,   58.952141,   58.898148,   57.487778,   57.425323,   57.382126,   57.329407,
   57.285325,   57.230774,   57.168525,   57.119385,   57.066986,   57.022263,   56.960129,   56.931228,
   56.877747,   56.780807,   56.728714,   56.686702,   56.616852,   56.564836,   56.520157,   56.458267,
   56.400375,   56.384262,   56.303864,   56.271027,   56.242098,   56.170161,   56.145828,   56.068085,
   56.015376,   55.964645,   55.986844,   55.886566,   55.855261,   55.774017,   55.724060,   55.672915,
   55.628586,   55.567474,   55.506674,   55.458604,   55.414368,   55.353370,   55.330658,   55.257658,
   55.291812,   55.181030,   55.129562,   55.078705,   55.022954,   54.990725,   54.827124,   54.850632,
   54.835754,   54.759393,   54.748718,   54.657028,   54.606430,   54.552827,   54.502359,   54.470673,
ENTER 1 IF MORE STAGES ARE NEEDED
      2 IF YOU WANT TO CONTINUE THIS JOB LATER
      0 IF END OF THIS JOB
0
TIME
CPU - 00:00:28  EXECUTION - 00:04:18  SESSION - 00:23:25
MAPDS T619880.YANG.RESULT.DATA
DSNAME: T619880.YANG.RESULT.DATA                               VOL-SER: UNT801
  CREATED: 74100      PURGED: 74154      DS_ORG:   SEQ     REC_FM: F
  REC_LEN:     20     BLKSIZE:     20   2ND ALLOC:     2   ALL_TYPE: TRK
LAST_BLK_PTR(TRL):    201   611 -87   DIRC_BLKS:       0 BLKS_USED:        0
   EXT FIRST LAST LENG    EXT FIRST LAST LENG    EXT FIRST LAST LENG
    0   322   328   7      5  1472  1473   2      10  192   192   1
    1   765   766   2      6  1749  1750   2      11  196   196   1
    2  1068  1068   1      7   130   130   1      12  204   204   1
    3  1252  1255   2      8   184   184   1      13  224   224   1
    4  1281  1282   2      9   187   187   1      14  228   228   1
            TOTAL TRACKS ALLOC:    21
END
READY
logoff
TGO TIME JOB #1980 - T619880 ON 020, CONNECT= 0.25.08 MUS= 0.00.64
T619880 LOGGED OFF TGO AT 10:11:17 ON JUNE 3, 1974+
```

NOTE: CPU TIME USED = 28 - 3 = 25 sec.
CONNECT TIME = 21 min 57 sec.

# Appendix B-5 (Contd)

```
 logon t619880/dv
→logon t619880/dv
 T619880 LOGON IN PROGRESS AT 11:02:32 ON JUNE 4, 1974
 6/31/74....SUBROUTINE READTB IS NOW OPERATIONAL
 6-2-74:  V3.1 OF TSO UTILITIES COPY, MERGE, LIST, FORMAT INSTALLED
 ** STARTED JOB #1986 - T619880 , APPROXIMATE BALANCE =   $1050.03
 CPU - 00:0:02  EXECUTION - 00:00:15  SESSION - 00:00:19
 READY
 COMMAND #LOGON   NOT FOUND
 READY
→exec yang.comm.clist 'yang.informl.data' list
 ALLOC DA(YANG.INFORML.DATA) FI(FT01F001)ALLOC DA(YANG.RESULT.DATA) FI(FT02F01)
 ALLOC DA(YANG.CONTU.DATA) FI(FT03F001)TIME
 CPU - 00:00:4  EXECUTION - 00:00:85  SESSION - 00:01:55
 LOADGO YANG.PIPE.OBJ(DEMO) FORTLIB LIB('SYS1.FORTLIB') LET
 ENTER 1 TO PRINT DATA OF MATERIAL COST, OTHERWISE 0
 ?
→0
 ENTER 1 IF CONTINUE FROM PREVIOUS INCOMPLETE TEST, OTHERWISE 0
 ?
→1
 LINE NO. OF LAST STAGE IN PREVIOUS JOB WAS  3
 ENTER 1 TO CALCULATE THE END STAGES
       2 TO CONNECT TWO STAGES
       3 TO MERGE PIPELINES WITH TEE JOINT
       4 TO MERGE PIPELINES WITH CROSS JOINT
       5 TO TURN THE FLOW WITH ELBOW
       6 TO BRANCH PIPELINES WITH TEE JOINT
       7 TO BRANCH PIPELINES WITH CROSS JOINT
 ?
→6
 ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
 ?
→0
 ENTER THE ASSIGNED NUMBER OF PIPELINES WHICH WILL BE BRANCHED, PATH LINE FIRST
 ?
→3,4
 ENTER THE RATIO OF FLOW RATE IN THESE PIPELINES, THE SUM OF THESE NUMBERS IS 1., FOR INSTANCE, .5,.3,.2
 ?
→.5,.5
 ENTER THE ELEVATION OF THIS STAGE, IN FT.
 ?
→5.
 ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
 ?
→54.,62.
 ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
 ?
→0.05
 ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
       2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
 ?
→2
 ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
 ?
→2
 ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
 ?
→1

    60.877108,   60.811763,   60.768799,   60.713043,   60.666885,   60.611262,   60.550568,   60.540082,
    60.497009,   60.441559,   60.395172,   60.330098,   60.285660,   60.244040,   60.171092,   60.145920,
    60.090790,   60.025848,   59.976013,   59.921936,   59.874634,   59.803799,   59.751572,   59.702434,
    59.650391,   59.648361,   59.561936,   59.543030,   59.486542,   59.405289,   59.350764,   59.320683,
    59.297546,   59.240265,   59.165085,   59.111328,   59.084198,   59.020038,   58.976898,   58.922279,
    58.899399,   57.894198,   57.831360,   57.788393,   57.755077,   57.058904,   57.635956,   57.573334,
    57.524135,   57.471390,   57.426453,   57.663937,   57.354900,   57.281082,   57.246276,   57.183990,
    57.131500,   57.069107,   57.019241,   56.966888,   56.921936,   56.859665,   56.801727,   56.753906,
    56.704620,   56.696122,   56.642471,   56.599319,   56.545812,   56.467621,   56.415192,   56.363617,
    56.320969,   56.267136,   56.224625,   56.170837,   56.146790,   56.093063,   56.040939,   55.969594,
    55.910594,   55.859238,   55.814642,   55.755311,   55.730469,   55.657410,   55.631241,   55.580124,
    55.528351,   55.477246,   55.409439,   55.355606,   55.376598,   55.259074,   55.205933,   55.191360,
    55.103577,   55.088928,   55.024658,   54.952042,   54.929260,   54.877960,   54.824265,   54.773575,
    54.749405,   54.684937,   54.631271,   54.577728,   54.527176,   54.495499,
 ENTER 1 IF MORE STAGES ARE NEEDED
       2 IFYOU WANT TO CONTINUE THIS JOB LATER
       3 IF END OF THIS JOB
 ?
→1
 ENTER 1 TO CALCULATE THE END STAGES
       2 TO CONNECT TWO STAGES
       3 TO MERGE PIPELINES WITH TEE JOINT
       4 TO MERGE PIPELINES WITH CROSS JOINT
       5 TO TURN THE FLOW WITH ELBOW
       6 TO BRANCH PIPELINES WITH TEE JOINT
       7 TO BRANCH PIPELINES WITH CROSS JOINT
 ?
→2
 ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
 ?
→1
 ENTER THE ASSIGNED NUMBER OF PIPE LINE
 ?
→4
 ENTER 1 TO SPECIFY REQUIRED DISCHARGE
       2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
       3 TO USE ORIGINAL ORIFICE SIZE
 ?
→3
 ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
 ?
→51.5,54.
 ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
 ?
→200.,5.
 ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
 ?
→56.4,62.
 ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
 ?
→0.05
 ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
       2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
 ?
→2
 ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
 ?
→2
 ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
 ?
→1
    61.851242,   61.823349,   61.760693,   61.709991,   61.654495,   61.580334,   61.529999,   61.481827,
    61.414978,   61.396289,   61.311815,   61.288524,   60.227760,   61.171432,   61.116186,   61.050491,
    60.993698,   60.848565,   60.831279,   60.720840,   60.644921,   60.586810,   60.540358,   60.484926,
    60.427472,   60.373047,   60.347426,   60.279694;   60.226083,   60.168030,   60.113758,   60.079967,
```

## Appendix B-5 (Contd)

```
   58.104616,   58.079653,   58.024551,   57.970871,   57.918121,   57.845032,   57.791977,   57.746281,
   57.659515,   57.357724,   57.505020,   57.451708,   57.398200,   57.336078,   57.255402,   57.176288,
   57.136330,   57.001068,   56.958226,   56.938080,   56.883632,   56.838767,   56.786926,   56.732040,
   56.679862,   56.630224,   56.589805,   56.535049,   56.481005,   56.428062,   56.096805,   56.330866,
   56.278824,   56.207886,   56.150208,   56.134293,   56.056427,   56.001907,   55.987091,   55.914047,
   55.883930,   55.810838,   55.790421,   55.723511,   55.671585,   55.617111,   55.563842,   55.541058,
   55.476898,   55.422455,   55.384715,   55.317583,   55.285660,   55.202194,   55.151238,   55.126602,
   55.062620,   55.008428,   54.954773,   54.905946,   54.872162,   54.850617,   54.776428,   54.725725,
   54.603985,   54.046149,   54.563858,   54.524308,
ENTER 1 IF MORE STAGES ARE NEEDED
      2 IF YOU WANT TO CONTINUE THIS JOB LATER
      0 IF END OF THIS JOB
1
ENTER 1 TO CALCULATE THE END STAGES
      2 TO CONNECT TWO STAGES
      3 TO MERGE PIPELINES WITH TEE JOINT
      4 TO MERGE PIPELINES WITH CROSS JOINT
      5 TO TURN THE FLOW WITH ELBOW
      6 TO BRANCH PIPELINES WITH TEE JOINT
      7 TO BRANCH PIPELINES WITH CROSS JOINT
2
ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
1
ENTER THE ASSIGNED NUMBER OF PIPE LINE
3
ENTER 1 TO SPECIFY REQUIRED DISCHARGE
      2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
      3 TO USE ORIGINAL ORIFICE SIZE
3
ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
51.,53.
ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
200.,0.
ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
58.4,62.
ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
0.05
ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
      2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
2
ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
2
ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
1
   60.831879,   60.720840,   60.644928,   60.586910,   60.540359,   60.484528,   60.427672,   60.373047,
   60.347626,   60.279694,   60.223083,   60.168030,   60.113358,   60.079987,   57.001008,   56.538840,
   56.863632,   56.839767,   56.786926,   56.732046,   56.679862,   56.569805,   56.535049,   56.461003,
   56.429062,   56.396605,   55.898331,   55.819039,   55.729511,   55.671585,   55.617111,   55.563842,
   55.541458,   55.482422,   55.422455,   55.384713,   55.305223,   55.266406,   55.202194,   55.151230,
   55.126862,   55.062820,   55.009423,   54.972585,   54.948212,   54.884537,   54.830017,   54.754532,
   54.725723,   54.699707,   54.646140,   54.505551,   54.524399,
ENTER 1 IF MORE STAGES ARE NEEDED
      2 IF YOU WANT TO CONTINUE THIS JOB LATER
      0 IF END OF THIS JOB

1
4
TIME
CPU - 00:00:38  EXECUTION - 00:04:40  SESSION - 00:22:22
MAPDS T619880.YANG.RESULT.DATA
DSNAME: T619880.YANG.RESULT.DATA                          VOL-SER: UNT301
  CREATED: 74180     PURGED: 74155      DS_ORG:   SEQ     REC_FM: F
  REC_LEN:    20   BLKSIZE:      20   2ND ALLOC:       2  ALL_TYPE: TRK
LAST_BLK_PTR(TRL):     201  611 -87   DIPE_BLKS:       0  BLKS_USED:       0
   EXT FIRST LAST LENG    EXT FIRST LAST LENG    EXT FIRST LAST LENG
    0   522   523    2     5  1472  1475    2    10   192   192    1
    1   785   786    2     6  1749  1750    2    11   196   196    1
    2  1008  1008    1     7   130   130    1    12   204   204    1
    3  1252  1253    2     8   184   184    1    13   224   224    1
    4  1281  1282    2     9   187   187    1    14   228   228    1
            TOTAL TRACKS ALLOC:     21
END
READY
logoff
TSO TIME JOB #1088 - T679880  ON 02C, CONNECT=  0.20.02  MUS=  0.01.08
T619880 LOGGED OFF TSO AT 11:28:43 ON JUNE 4, 1974
```

NOTE: CPU TIME USED = 38 - 4 = 34 sec.
CONNECT TIME = 20 min 27 sec.

# Appendix B-5 (Contd)

```
→logon tc19886/dy
 TC19880 LOGON IN PROGRESS AT 08:21:22 ON JUNE 5, 1974
 LATEST NEWS 6-4-74, TYPE TSONEWS
 ** STARTED JOB #1938 - TC19880 , APPROXIMATE BALANCE =   $1018.04
 CPU - 00:00:02  EXECUTION - 00:00:14  SESSION - 00:00:25
 READY
→exec yang.comm.clist 'yang.informl.data' list
 ALLOC DA(YANG.INFORML.DATA) FI(FT01F001)
 ALLOC DA(YANG.RESULT.DATA) FI(FT02F001)
 ALLOC DA(YANG.CONTU.DATA) FI(FT03F001)
 TIME
 CPU - 00:00:03  EXECUTION - 00:00:25  SESSION - 00:01:52
 LOADGO YANG.PIPE.OBJ(DEMO) FORTLIB LIB('SYS1.FORTLB2') LET
 I
 READY
→exec yang.comm.clist 'yang.informl.data' list
 ALLOC DA(YANG.INFORML.DATA) FI(FT01F001)
 ALLOC DA(YANG.RESULT.DATA) FI(FT02F001)
 ALLOC DA(YANG.CONTU.DATA) FI(FT03F001)
 TIME
 CPU - 00:00:06  EXECUTION - 00:01:07  SESSION - 00:03:15
 LOADGO YANG.PIPE.OBJ(DEMO) FORTLIB LIB('SYS1.FORTLB2') LET
 ENTER 1 TO PRINT DATA OF MATERIAL COST, OTHERWISE 0
 ?
→0
 ENTER 1 IF CONTINUE FROM PREVIOUS INCOMPLETE TEST, OTHERWISE 0
 ?
→1
 LINE NO. OF LAST STAGE IN PREVIOUS JOB WAS  3
 ENTER 1 TO CALCULATE THE END STAGES
       2 TO CONNECT TWO STAGES
       3 TO MERGE PIPELINES WITH TEE JOINT
       4 TO MERGE PIPELINES WITH CROSS JOINT
       5 TO TURN THE FLOW WITH ELBOW
       6 TO BRANCH PIPELINES WITH TEE JOINT
       7 TO BRANCH PIPELINES WITH CROSS JOINT
 ?
→5
 ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
 ?
→0
 ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
 ?
→54.5,62.
 ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
 ?
→0.05
 ENTER THE ELEVATION OF THIS STAGE, IN FT.
 ?
→7.
 ENTER THE ELBOW ANGLE, IN DEGREE
 ?
→30.
 ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
       2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION

 ?
→2
 ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
 ?
→2
 ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
 ?
→1
    61.285294,  61.173492,  61.097855,  61.018363,  60.992447,  60.929002,  60.866470,  60.817886,
    60.755371,  60.757503,  60.679474,  60.601425,  60.581375,  60.524668,  60.482311,  60.467455,
    60.319698,  60.319656,  60.257446,  60.230670,  60.184601,  60.147675,  60.096542,  57.453156,
    57.390488,  57.315567,  57.291367,  57.238129,  57.182983,  57.130539,  57.098495,  57.017685,
    56.961029,  56.957073,  56.884155,  56.829268,  56.768617,  56.748611,  56.696533,  56.631989,
    56.551590,  56.542755,  56.463518,  56.445587,  56.399216,  56.349930,  56.272715,  56.174561,
    56.122238,  56.067595,  56.015884,  55.995773,  55.906052,  55.899490,  55.820831,  55.768814,
    55.714294,  55.651855,  55.624817,  55.573932,  55.517319,  55.486481,  55.430145,  55.365590,
    55.338104,  55.299255,  55.237000,  55.186006,  55.130905,  55.097565,  55.043152,  54.989334,
    54.949234,  54.864731,  54.846725,  54.760391,  54.734344,  54.699951,  54.630142,  54.596573,
    54.541961,
 ENTER 1 IF MORE STAGES ARE NEEDED
       2 IF YOU WANT TO CONTINUE THIS JOB LATER
       0 IF END OF THIS JOB
 ?
→1
 ENTER 1 TO CALCULATE THE END STAGES
       2 TO CONNECT TWO STAGES
       3 TO MERGE PIPELINES WITH TEE JOINT
       4 TO MERGE PIPELINES WITH CROSS JOINT
       5 TO TURN THE FLOW WITH ELBOW
       6 TO BRANCH PIPELINES WITH TEE JOINT
       7 TO BRANCH PIPELINES WITH CROSS JOINT
 ?
→2
 ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
 ?
→0
 ENTER 1 TO SPECIFY REQUIRED DISCHARGE
       2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
       3 TO USE ORIGINAL ORIFICE SIZE
 ?
→3
 ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
 ?
→51.,53.5
 ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
 ?
→200.,7.
 ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
 ?
→54.5,62.
 ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
 ?
→0.05
 ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
       2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
 ?
→2
 ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
 ?
→2
 ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
 ?
→1
    59.892883,  59.838211,  59.789337,  59.687271,  59.605408,  59.559845,  59.494888,  59.440521,
    59.383393,  59.347427,  59.290131,  59.238672,  59.196991,  59.107010,  59.048466,  58.973206,
    58.937945,  58.887480,  58.839147,  58.771164,  57.340729,  57.287781,  57.194229,  57.108626,
    57.066525,  57.001633,  56.949249,  56.893051,  56.803284,  56.750214,  56.709858,  56.622925,
    56.516312,  56.491135,  56.359650,  56.328110,  56.269012,  56.230072,  56.179520,  56.142044,
```

## Appendix B-5 (Contd)

```
     56.076565,    56.024818,    55.960800,    55.928965,    55.871816,    55.832535,    55.781097,    55.745304,
     55.679031,    55.627701,    55.571457,    55.538773,    55.484055,    55.429764,    55.385513,    55.385145,
     55.286377,    55.249843,    55.195389,    55.140386,    55.099777,    55.070800,    54.987528,    54.912282,
     54.886283,    54.825531,    54.781904,    54.748582,    54.695236,    54.618042,    54.565812,
  ENTER 1 IF MORE STAGES ARE NEEDED
        2 IF YOU WANT TO CONTINUE THIS JOB LATER
        0 IF END OF THIS JOB
  ?
-->1
  ENTER 1 TO CALCULATE THE END STAGES
        2 TO CONNECT TWO STAGES
        3 TO MERGE PIPELINES WITH TEE JOINT
        4 TO MERGE PIPELINES WITH CROSS JOINT
        5 TO TURN THE FLOW WITH ELBOW
        6 TO BRANCH PIPELINES WITH TEE JOINT
        7 TO BRANCH PIPELINES WITH CROSS JOINT
  ?
-->5
  ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
  ?
-->0
  ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
  ?
-->54.5,62.
  ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
  ?
-->0.05
  ENTER THE ELEVATION OF THIS STAGE, IN FT.
  ?
-->8.
  ENTER THE ELBOW ANGLE, IN DEGREE
  ?
-->30.
  ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
        2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
  ?
-->2
  ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
  ?
-->2
  ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
  ?
-->1
     60.988571,    60.932922,    60.886124,    60.779461,    60.700867,    60.653122,    60.587592,    60.532864,
     60.474655,    60.437868,    60.378852,    60.329825,    60.286911,    60.176743,    60.128938,    60.074127,
     60.025711,    59.976098,    59.938182,    59.878484,    59.848221,    59.799162,    59.727448,    59.697266,
     59.600052,    59.578850,    59.535680,    59.480667,    59.446381,    59.393372,    59.330200,    59.296975,
     59.248596,    59.173936,    59.128510,    59.098434,    59.013199,    58.991821,    58.947876,    58.882065,
     58.847738,    58.789734,    58.654402,    58.383699,    58.285767,    58.201035,    58.158752,    58.093384,
     58.040054,    57.987261,    57.891953,    57.839564,    57.798340,    57.710368,    57.682112,    57.576721,
     57.524210,    57.454498,    57.426130,    57.359436,    57.346222,    57.297623,    57.212906,    57.199787,
     57.125351,    57.085861,    57.020309,    56.967911,    56.911713,    56.898529,    56.823915,    56.768860,
     56.728119,    56.663071,    56.461526,    56.564240,    56.504288,    56.466019,    56.412781,    56.308744,
     56.337952,    56.278814,    56.220108,    56.160958,    56.109238,    56.030390,    56.001872,    55.966248,
     55.934402,    55.876033,    55.821823,    55.765597,    55.711990,    55.663283,    55.835118,    55.576874,
     55.492823,    55.489856,    55.435181,    55.394714,    55.310547,    55.291779,    55.214264,    55.197891,
     55.143699,    55.057166,    55.035660,    54.998826,    54.905130,    54.886779,    54.830200,    54.765398,
     54.749063,    54.698533,    54.636795,    54.582558,
  ENTER 1 IF MORE STAGES ARE NEEDED
        2 IF YOU WANT TO CONTINUE THIS JOB LATER
        0 IF END OF THIS JOB

  ?
-->1
  ENTER 1 TO CALCULATE THE END STAGES
        2 TO CONNECT TWO STAGES
        3 TO MERGE PIPELINES WITH TEE JOINT
        4 TO MERGE PIPELINES WITH CROSS JOINT
        5 TO TURN THE FLOW WITH ELBOW
        6 TO BRANCH PIPELINES WITH TEE JOINT
        7 TO BRANCH PIPELINES WITH CROSS JOINT
  ?
-->2
  ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
  ?
-->0
  ENTER 1 TO SPECIFY REQUIRED DISCHARGE
        2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
        3 TO USE ORIGINAL ORIFICE SIZE
  ?
-->3
  ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
  ?
-->51.,53.5
  ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
  ?
-->200.,0.
  ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
  ?
-->54.5,62.
  ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
  ?
-->0.05
  ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
        2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
  ?
-->2
  ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
  ?
-->2
  ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
  ?
-->1
     61.975418,    59.255249,    59.201019,    59.170047,    59.100739,    59.063033,    59.032288,    58.966217,
     58.910855,    58.852280,    58.753448,    58.717896,    58.659774,    58.581604,    58.514404,    58.472458,
     58.384263,    58.289124,    58.218246,    58.105499,    58.068130,    57.971319,    57.892487,    57.828172,
     57.757141,    57.685816,    57.630997,    57.554981,    57.473038,    57.405045,    57.343330,    57.290989,
     57.250881,    57.178284,    57.133133,    57.087549,    57.040405,    56.951835,    56.957269,    56.774521,
     56.706558,    56.674057,    56.646729,    56.593521,    56.535431,    56.483598,    56.402033,    56.376480,
     56.345386,    56.256866,    56.202713,    56.198044,    56.139572,    56.076721,    56.030396,    55.978775,
     55.931976,    55.895645,    55.880249,    55.751480,    55.742447,    55.697250,    55.612518,    55.572144,
     55.544312,    55.459584,    55.404617,    55.399429,    55.319607,    55.297241,    55.285229,    55.166397,
     55.149719,    55.094925,    55.008552,    54.997391,    54.944824,    54.874466,    54.804947,    54.786240,
     54.745804,    54.675140,    54.620085,
  ENTER 1 IF MORE STAGES ARE NEEDED
        2 IF YOU WANT TO CONTINUE THIS JOB LATER
        0 IF END OF THIS JOB
  ?
-->2
  TIME
  CPU - 00:00:46  EXECUTION - 00:06:35  SESSION - 00:28:34
  MAPDS T619880.YANG.RESULT.DATA
  DSNAME: T619880.YANG.RESULT.DATA                           VOL-SER: UNT801
    CREATED: 74100     PURGE: : 74156      DS_ORG:   SEQ     REC_FM: F
    REC_LEN:     20    BLKSIZE:      20   2ND ALLOC:     2   ALL_TYPE: TRK
  LAST_BLK_PTR(TRL):     201  021 -87   DIRS_BLKS:      0 BLKS_USED:        6
     EXT FIRST LAST LENG   EXT FIRST LAST LENG    EXT FIRST LAST LENG
      0   322   323   2     5  1472  1473   2     10   192   192   1
      1   785   786   2     6  1749  1750   2     11   196   196   1
      2  1068  1068   1     7   130   130   1     12   204   204   1
      3  1252  1253   2     8   184   184   1     13   224   224   1
      4  1281  1282   2     9   187   187   1     14   228   228   1
                 TOTAL TRACKS ALLOC:    21
```

NOTE: CPU TIME USED = 46 - 6 = 40 sec.
CONNECT TIME = 26 min 42 sec.

## Appendix B-5 (Contd)

```
→exec yang.comm.clist 'yang.informl.data' list
  ALLOC DA(YANG.INFORM1.DATA) FI(FT01F001)
  ALLOC DA(YANG.RESULT.DATA) FI(FT02F001)
  ALLOC DA(YANG.CONTU.DATA) FI(FT03F001)
  TIME
  CPU - 00:00:12  EXECUTION - 00:01:52  SESSION - 00:10:00
  LOADGO YANG.PIPE.OBJ(DEMO) FORTLIB LIB('SYS1.FORTLB2') LET
  ENTER 1 TO PRINT DATA OF MATERIAL COST, OTHERWISE 0
  ?
→0
  ENTER 1 IF CONTINUE FROM PREVIOUS INCOMPLETE TEST, OTHERWISE 0
  ?
→1
  THE LAST STAGE IN PREVIOUS STAGE WAS   17, AND THE LINE NO. WAS    3
  ENTER A NUMBER N SUCH THAT THIS JOB WILL CONTINUE FROM N STAGES BACK OF THE LAST STAGE OF LAST JOB
  ENTER 0 IF CONTINUE FROM THE NEXT STAGE
  ?
→0
  ENTER 1 TO CALCULATE THE END STAGES
        2 TO CONNECT TWO STAGES
        3 TO MERGE PIPELINES WITH TEE JOINT
        4 TO MERGE PIPELINES WITH CROSS JOINT
        5 TO TURN THE FLOW WITH ELBOW
        6 TO BRANCH PIPELINES WITH TEE JOINT
        7 TO BRANCH PIPELINES WITH CROSS JOINT
  ?
→3
  ENTER THE ASSIGNED NUMBER OF PIPELINES WHICH WILL BE MERGED
  ?
→3,4
  ENTER THE ASSIGNED PIPELINE NUMBER AFTER MERGING
  ?
→3
  ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
        2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
  ?
→2
  ENTER THE ALLOWABLE PRESSURE DIFFERENCE AT THE MERGING POINT
  ?
→0.005
  ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
  ?
→54.5,62.
  ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
  ?
→0.05
  ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
  ?
→2
  ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
  ?
  1
     61.705231,   61.641129,   61.588349,   60.717880,   60.646652,   60.408676,   60.243973,   60.095230,
     59.955444,   59.123062,   58.887015,   58.571335,   58.427185,   58.292404,   58.237137,   58.191422,
     58.125977,   58.034714,   57.969818,   57.876114,   57.686218,   57.618073,   57.588928,   57.544220,
     57.498672,   57.309464,   57.273468,   57.212509,   57.198502,   57.082916,   57.014572,   56.985336,
     56.962979,   56.854523,   56.802307,   56.724335,   56.666092,   56.613983,   56.555481,   56.503435,
     56.491867,   56.325195,   56.156479,   56.014633,   55.931641,   55.863251,   55.743195,   55.675537,
     55.646530,   55.578308,   55.548294,   55.468399,   55.449951,   55.382492,   55.327896,   55.280212,
     55.212601,   55.183655,   55.139832,   55.072327,   55.043427,   54.908310,   54.894302,
  ENTER 1 IF MORE STAGES ARE NEEDED
        2 IF YOU WANT TO CONTINUE THIS JOB LATER
        0 IF END OF THIS JOB
  ?
→1
  ENTER 1 TO CALCULATE THE END STAGES
        2 TO CONNECT TWO STAGES
        3 TO MERGE PIPELINES WITH TEE JOINT
        4 TO MERGE PIPELINES WITH CROSS JOINT
        5 TO TURN THE FLOW WITH ELBOW
        6 TO BRANCH PIPELINES WITH TEE JOINT
        7 TO BRANCH PIPELINES WITH CROSS JOINT
  ?
→2
  ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
  ?
→0
  ENTER 1 TO SPECIFY REQUIRED DISCHARGE
        2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
        3 TO USE ORIGINAL ORIFICE SIZE
  ?
→3
  ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
  ?
→50.,52.5
  ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
  ?
→200.,0.
  ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
  ?
→54.8,62.
  ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
  ?
→0.05
  ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
        2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
  ?
→2
  ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
  ?
→2
  ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
  ?
→1
     60.176605,   60.027634,   59.931717,   59.861771,   59.736603,   59.667496,   59.638138,   59.568344,
     59.538635,   59.453064,   59.430283,   58.361374,   59.306625,   59.258209,   59.159851,   59.110779,
     59.012573,   58.874363,   58.144821,   58.032547,   57.963333,   57.835922,   57.766373,   57.736923,
     57.667892,   57.638046,   57.561234,   57.535858,   57.466507,   57.411469,   57.364899,   57.266006,
     57.220825,   57.151443,   57.122101,   56.971527,   56.659836,   56.591141,   56.458847,   56.387772,
     56.289261,   56.163284,   56.092422,   56.036453,   55.973251,   55.942505,   55.874178,   55.843218,
     55.751316,   55.749344,   55.679230,   55.621994,   55.581909,   55.509171,   55.478500,   55.420482,
     55.368378,   55.337753,   55.286087,   55.202438,   55.187820,   55.145660,   55.010483,   54.895316,
  ENTER 1 IF MORE STAGES ARE NEEDED
        2 IF YOU WANT TO CONTINUE THIS JOB LATER
        0 IF END OF THIS JOB
  ?
→2
  TIME
  CPU - 00:00:29  EXECUTION - 00:05:41  SESSION - 00:22:39
  MAPDS T619880.YANG.RESULT.DATA
  DSNAME: T619880.YANG.RESULT.DATA                        VOL-SER: UHT602
    CREATED: 74164    PURGED: 74165     DS_ORG:    SEQ     REC_FM: F
    REC_LEN:      0   BLKSIZE:     20  2ND ALLOC:    50  ALL_TYPE: BLK
  LAST_BLK_PTR(TRL):    491  G01   34  DIRC_BLKS:     0 BLKS_USED:     0
      0  2498  2547    50
              TOTAL TRACKS ALLOC:     50
  FREE FI(FT01F001),FI(FT02F001),FI(FT03F001)
  END
```

NOTE: CPU TIME USED = 29 - 12 = 17 sec.
CONNECT TIME = 12 min 39 sec.

## Appendix B-5 (Contd)

```
→exec yang.comm.clist 'yang.informl.data' list
  ALLOC DA(YANG.INFORM1.DATA) FI(FT01F001)
  ALLOC DA(YANG.RESULT.DATA) FI(FT02F001)
  ALLOC DA(YANG.CONTU.DATA) FI(FT03F01)
  TIME
  CPU - 00:01:19  EXECUTION - 00:03:57  SESSION - 00:18:42
  LOADGO YANG.PIPE.OBJ(DEMO) FORTLIB LIB('SYS1.FORTLIB') LET
  ENTER 1 TO PRINT DATA OF MATERIAL COST, OTHERWISE 0
  ?
→0
  ENTER 1 IF CONTINUE FROM PREVIOUS INCOMPLETE TEST, OTHERWISE 0
  ?
→ 1
  THE LAST STAGE IN PREVIOUS STAGE WAS   21, AND THE LINE NO. WAS   1
  ENTER A NUMBER N SUCH THAT THIS JOB WILL CONTINUE FROM N STAGES BACK OF THE LAST STAGE OF LAST JOB
  ENTER 0 IF CONTINUE FROM THE NEXT STAGE
  ?
→2
  ENTER 1 TO CALCULATE THE END STAGES
        2 TO CONNECT TWO STAGES
        3 TO MERGE PIPELINES WITH TEE JOINT
        4 TO MERGE PIPELINES WITH CROSS JOINT
        5 TO TURN THE FLOW WITH ELBOW
        6 TO BRANCH PIPELINES WITH TEE JOINT
        7 TO BRANCH PIPELINES WITH CROSS JOINT
  ?
→4
  ENTER THE ASSIGNED NUMBER OF PIPELINES WHICH WILL BEMERGED
  ?
→1,2,3
  ENTER THE ASSIGNED PIPELINE NUMBER AFTER MERGING
  ?
→1
  ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
        2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
  ?
→2
  ENTER THE ALLOWABLE PRESSURE DIFFERENCE AT THE MERGING POINT
  ?
→0.005
  ENTER THE DESIGNER MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
  ?
→54.0,62.
  ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
  ?
→0.05
  ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
  ?
→1
  INLET TOTAL HEAD     DIAMETER        COST      OUTLET TOTAL HEAD     INLET VOLUMN
      60.067520          4.00        2088.07        55.367525          3.496975
      57.293198          5.00        2017.58        55.367525          3.496975
      56.296448          6.00        1992.48        55.367525          3.496975
      55.869019          7.00        1981.52        55.367523          3.496975
      55.681469          8.00        1976.76        55.367523          3.496975
      55.487839         10.00        1972.39        55.367523          3.496975
      55.425522         12.00        1971.67        55.367525          3.496975
      55.381296         15.00        1972.90        55.367523          3.496975

  ENTER 1 IF MORE STAGES ARE NEEDED
        2 IF YOU WANT TO CONTINUE THIS JOB LATER

        0 IF END OF THIS JOB
  ?
→2
  TIME
  CPU - 00:01:32  EXECUTION - 00:00:03  SESSION - 00:29:01
  MAPDS T619880.YANG.RESULT.DATA
  DSNAME: T619880.YANG.RESULT.DATA                      VOL=SER: UNTS02
    CREATED: 74164    PURGED: 74165      DS_ORG:   SEQ    REC_FM: F
    REC_LEN:     0    BLKSIZE:     20  2ND ALLOC:    58   ALL_TYPE: BLK
  LAST_BLK_PTR(TRL):    491  601   30  DIRO_BLKS:     0 BLKS_USED:      0
     5  2436  2947    50
              TOTAL TRACKS ALLOC:     50
  FREE FI(FT01F001),FI(FT02F02),FI(FT03F01)
  END
  READY
```

NOTE: CPU TIME USED = 32 - 19 = 13 sec.
CONNECT TIME = 9 min 19 sec.

## Appendix B-5 (Contd)

```
→logon tl19880/dy
 TG19880 LOGON IN PROGRESS AT 10:58:54 ON JUNE 15, 1974
 LATEST NEWS: TIME SHARING NUMBER RENEWAL, 6-12-74, TYPE TSONEWS
 ** STARTED JOB #1988 - TG19880 , APPROXIMATE BALANCE =     $512.67
 CPU - 00:00:01  EXECUTION - 00:00:08  SESSION - 00:00:08
 READY
→exec yang.comm.clist 'yang.informl.data' list

 ALLOC DA(YANG.INFORM1.DATA) FI(FT01F001)
 ALLOC DA(YANG.RESULT.DATA) FI(FT02F001)
 ALLOC DA(YANG.CONTU.DATA) FI(FT03F001)
 TIME
 CPU - 00:00:03  EXECUTION - 00:00:22  SESSION - 00:01:05
 LOADGO YANG.PIPE.OBJ(DEMO) FORTLIB LIB('SYS1.FORTLB2') LET
 ENTER 1 TO PRINT DATA OF MATERIAL COST, OTHERWISE 0
 ?
→0
 ENTER 1 IF CONTINUE FROM PREVIOUS INCOMPLETE TEST, OTHERWISE 0
 ?
→1
 THE LAST STAGE IN PREVIOUS STAGE WAS   20, AND THE LINE NO. WAS   1
 ENTER A NUMBER N SUCH THAT THIS JOB WILL CONTINUE FROM N STAGES BACK OF THE LAST STAGE OF LAST JOB
 ENTER 0 IF CONTINUE FROM THE NEXT STAGE
 ?
→0
 ENTER 1 TO CALCULATE THE END STAGES
       2 TO CONNECT TWO STAGES
       3 TO MERGE PIPELINES WITH TEE JOINT
       4 TO MERGE PIPELINES WITH CROSS JOINT
       5 TO TURN THE FLOW WITH ELBOW
       6 TO BRANCH PIPELINES WITH TEE JOINT
       7 TO BRANCH PIPELINES WITH CROSS JOINT
 ?
→2
 ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
 ?
→0
 ENTER 1 TO SPECIFY REQUIRED DISCHARGE
       2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
       3 TO USE ORIGINAL ORIFICE SIZE
 ?
→3
 ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
 ?
→51.,54.
 ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
 ?
→200.,9.5
 ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
 ?
→55.3,62.
 ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
 ?
→0.05
 ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
       2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
 ?
→2
 ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
 ?
→1
 INLET TOTAL HEAD       DIAMETER        COST       OUTLET TOTAL HEAD     INLET VOLUME
      59.752899           10.00        2260.77         57.293198          3.791625
      58.737369           10.00        2231.05         56.296443          3.788795
      58.304657           10.00        2219.34         55.869019          3.787579
      58.095215           10.00        2213.80         55.661469          3.786988
      57.920715           10.00        2208.45         55.487839          3.786496
      57.858429           10.00        2208.15         55.425522          3.786320
      57.693863           15.00        2253.56         57.293198          3.792345
      57.315323           12.00        2211.42         56.296448          3.789214
      56.879471           12.00        2198.83         55.869019          3.787991
      56.668854           12.00        2193.34         55.661469          3.787396
      56.493668           12.00        2188.43         55.487839          3.786902
      56.431183           12.00        2186.88         55.425522          3.786725
      56.397110           12.00        2188.88         55.391296          3.786629
      56.220581           15.00        2211.46         55.869019          3.788227
      56.007599           15.00        2205.90         55.661469          3.787626
      55.830566           15.00        2200.93         55.487839          3.787127
      55.767593           15.00        2200.10         55.425522          3.788949
      55.733278           15.00        2200.34         55.391296          3.786852

 ENTER 1 IF MORE STAGES ARE NEEDED
       2 IF YOU WANT TO CONTINUE THIS JOB LATER
       0 IF END OF THIS JOB
 ?
→1
 ENTER 1 TO CALCULATE THE END STAGES
       2 TO CONNECT TWO STAGES
       3 TO MERGE PIPELINES WITH TEE JOINT
       4 TO MERGE PIPELINES WITH CROSS JOINT
       5 TO TURN THE FLOW WITH ELBOW
       6 TO BRANCH PIPELINES WITH TEE JOINT
       7 TO BRANCH PIPELINES WITH CROSS JOINT
 ?
→1
 ENTER THE ASSIGNED NUMBER OF PIPE LINE
 ?
→5
 ENTER 1 TO SPECIFY REQUIRED DISCHARGE
       2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
       3 TO USE ORIGINAL ORIFICE SIZE
 ?
→3
 ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
 ?
→50.,50.1
 ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
 ?
→200.,8.
 ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
 ?
→50.,62.
 ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
 ?
→0.05
 ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
 ?
→2
 ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
 ?
→1
   61.078903,    61.022110,    55.444412,    55.392731,    54.210632,    54.160049,    53.836584,    53.786382,
   53.696899,    53.646774,    53.588456,    53.542236,
 ENTER 1 IF MORE STAGES ARE NEEDED
       2 IF YOU WANT TO CONTINUE THIS JOB LATER
```

# Appendix B-5 (Contd)

```
        0 IF END OF THIS JOB
 ?
→1
  ENTER 1 TO CALCULATE THE END STAGES
        2 TO CONNECT TWO STAGES
        3 TO MERGE PIPELINES WITH TEE JOINT
        4 TO MERGE PIPELINES WITH CROSS JOINT
        5 TO TURN THE FLOW WITH ELBOW
        6 TO BRANCH PIPELINES WITH TEE JOINT
        7 TO BRANCH PIPELINES WITH CROSS JOINT
 ?
→2
  ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
 ?
→0
  ENTER 1 TO SPECIFY REQUIRED DISCHARGE
        2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
        3 TO USE ORIGINAL ORIFICE SIZE
 ?
→3
  ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
 ?
→50.,52.5
  ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
 ?
→200.,5.5
  ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
 ?
→53.5,62.
  ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
 ?
→0.05
  ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
        2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
 ?
→1
  ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
 ?
→2
  ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
 ?
→1
     60.837238,   60.830643,   60.491669,   60.435455,   60.342712,   60.286621,   60.221710,   60.173538,
     56.480530,   56.427917,   56.100357,   56.048096,   55.958309,   55.906250,   55.844543,   55.798782,
     55.151093,   55.090670,   54.776215,   54.725143,   54.661179,   54.610199,   54.534946,   54.524445,
     54.456009,   54.405197,   54.306244,   54.283020,   54.232391,   54.190338,   54.143951,   54.072968,
     54.022507,   53.988953,   53.931641,   53.881302,   53.821487,   53.778031,   53.728745,   53.666687,
     53.622787,   53.575714,
  ENTER 1 IF MORE STAGES ARE NEEDED
        2 IF YOU WANT TO CONTINUE THIS JOB LATER
        0 IF END OF THIS JOB
 ?
→1
  ENTER 1 TO CALCULATE THE END STAGES
        2 TO CONNECT TWO STAGES
        3 TO MERGE PIPELINES WITH TEE JOINT
        4 TO MERGE PIPELINES WITH CROSS JOINT
        5 TO TURN THE FLOW WITH ELBOW
        6 TO BRANCH PIPELINES WITH TEE JOINT
        7 TO BRANCH PIPELINES WITH CROSS JOINT
 ?
→5
  ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
 ?
→0
  ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
 ?
→53.5,62.
  ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
 ?
→0.05
  ENTER THE ELBOW ANGLE, IN DEGREE
 ?
→90.
  ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
        2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
 ?
→1
  ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
 ?
→2
  ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
 ?
→1
     61.597122,   61.539841,   61.198990,   61.138672,   61.060516,   61.003738,   60.977692,   60.928970,
     60.872530,   60.828568,   60.742188,   60.664322,   60.607941,   60.552475,   60.533249,   60.476990,
     60.433380,   60.384232,   60.328094,   60.284546,   60.219650,   60.171463,   57.109848,   57.056825,
     56.727386,   56.674515,   56.646896,   56.594101,   56.500626,   56.435291,   56.447983,   56.266113,
     56.213684,   56.157578,   56.105255,   56.068100,   56.043340,   55.963348,   55.926224,   55.864502,
     55.844788,   55.799026,   55.741180,   55.689178,   55.364166,   55.300720,   55.249146,   55.159393,
     55.108994,   55.099899,   55.016327,   54.964951,   54.925293,   54.874084,   54.835754,   54.784637,
     54.734436,   54.666199,   54.615097,   54.594223,   54.535522,   54.457291,   54.420303,   54.369553,
     54.338852,   54.288177,   54.237274,   54.152344,   54.124924,   54.074417,   54.025208,   53.983521,
     53.933136,   53.883987,   53.824173,   53.775543,   53.741089,   53.690872,   53.646973,   53.598145,
  ENTER 1 IF MORE STAGES ARE NEEDED
        2 IF YOU WANT TO CONTINUE THIS JOB LATER
        0 IF END OF THIS JOB
 ?
→2
  TIME
  CPU - 00:00:20  EXECUTION - 00:05:12  SESSION - 00:21:47
  MAPDS T619880.YANG.RESULT.DATA
  DSNAME: T619880.YANG.RESULT.DATA                          VOL=SER: UITSO2
    CREATED: 74164    PURGED: 74166     DS_ORG:   SEQ    REC_FM: F
    REC_LEN:     0    BLKSIZE:     20  2ND ALLOC:     50  ALL_TYPE: BLK
  LAST_BLK_PTR(TRL):    49|  60|  34  DIRC_BLKS:      0 BLKS_USED:      0
      0  2498  2547   50
              TOTAL TRACKS ALLOC:     50
  FREE FI(FT01F001),FI(FT02F001),FI(FT03F001)
  END
  READY
  mapds t619880.yang.contu.data
  DSNAME: T619880.YANG.CONTU.DATA                           VOL=SER: UITSO1
    CREATED: 74142    PURGED: 74166     DS_ORG:   SEQ    REC_FM: FB
    REC_LEN:    21    BLKSIZE:   7245  2ND ALLOC:      1  ALL_TYPE: TRK
  LAST_BLK_PTR(TRL):     0|   1|6449  DIRC_BLKS:      0 BLKS_USED:      0
      0   100   100    1
              TOTAL TRACKS ALLOC:      1
  READY
→logoff
  TSO TIME JOB #1988 - T619880  ON 040, CONNECT=  0.24.15  MUS=  0.00.47
  T619880 LOGGED OFF TSO AT 11:23:16 ON JUNE 15, 1974+
  ?
```

NOTE: CPU TIME USED = 20 - 1 = 19 sec.
CONNECT TIME = 20 min 42 sec.

# Appendix B-5 (Contd)

```
→ logon t619380/dy
T619880 LOGON IN PROGRESS AT 08:44:23 ON JUNE 17, 1974
  LATEST NEWS 6/16/74, TYPE TSONEWS
  LOGON PROCEEDING
  LOGON PROCEEDING
  ** STARTED JOB #1988 - T619880 , APPROXIMATE BALANCE =    $482.35
  CPU - 00:00:02  EXECUTION - 00:00:13  SESSION - 00:05:13
  READY
→ exec yang.comm.clist 'yang.inform1.data' list

  ALLOC DA(YANG.INFORM1.DATA) FI(FT01F001)
  ALLOC DA(YANG.RESULT.DATA) FI(FT02F001)
  ALLOC DA(YANG.CONTU.DATA) FI(FT03F001)
  TIME
  CPU - 00:00:03  EXECUTION - 00:00:26  SESSION - 00:06:05
  LOADGO YANG.PIPE.OBJ(DEMO) FORTLIB LIB('SYS1.FORTLB2') LET

  ENTER 1 TO PRINT DATA OF MATERIAL COST, OTHERWISE 0
  ?
→ 0
  ENTER 1 IF CONTINUE FROM PREVIOUS INCOMPLETE TEST, OTHERWISE 0
  ?
→ 1
  THE LAST STAGE IN PREVIOUS STAGE WAS   24, AND THE LINE NO. WAS   5
  ENTER A NUMBER N SUCH THAT THIS JOB WILL CONTINUE FROM N STAGES BACK OF THE LAST STAGE OF LAST JOB
  ENTER 0 IF CONTINUE FROM THE NEXT STAGE
  ?
→ 0
  ENTER 1 TO CALCULATE THE END STAGES
        2 TO CONNECT TWO STAGES
        3 TO MERGE PIPELINES WITH TEE JOINT
        4 TO MERGE PIPELINES WITH CROSS JOINT
        5 TO TURN THE FLOW WITH ELBOW
        6 TO BRANCH PIPELINES WITH TEE JOINT
        7 TO BRANCH PIPELINES WITH CROSS JOINT
  ?
→ 2
  ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
  ?
→ 0
  ENTER 1 TO SPECIFY REQUIRED DISCHARGE
        2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
        3 TO USE ORIGINAL ORIFICE SIZE
  ?
→ 3
  ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
  ?
→ 50.,53.
  ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
  ?
→ 200.,4.5
  ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
  ?
→ 53.5,62.
  ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
  ?
→ 0.05
  ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
        2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
  ?
→ 1
  ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
  ?
→ 2
  ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
  ?
→ 1
     59.604614,   59.594406,   59.515701,   59.477325,   59.427963,   59.367661,   59.213516,   59.198914,
     59.038786,   59.028870,   58.864014,   58.809265,   58.788391,   58.714706,   58.660095,   58.639238,
     58.576950,   58.498215,   58.432083,   58.385727,   58.335541,   56.977722,   56.868362,   56.815430,
     56.712570,   56.598526,   56.489075,   56.365814,   56.313324,   56.211975,   56.149475,   56.097168,
     56.004730,   55.998840,   55.866058,   55.814011,   55.793152,   55.708314,   55.670105,   55.645645,
     55.556900,   55.528366,   55.487381,   55.423340,   55.366486,   55.314896,   55.231598,   55.174942,
     55.107574,   55.090591,   55.003347,   54.962753,   54.925491,   54.819992,   54.762222,   54.727600,
     54.692764,   54.641754,   54.568348,   54.517471,   54.478638,   54.411301,   54.375443,   54.315277,
     54.283980,   54.235046,   54.192154,   54.123250,   54.050659,   54.030182,   53.990723,   53.926437,
     53.897369,   53.839462,   53.792419,   53.745561,   53.697647,
  ENTER 1 IF MORE STAGES ARE NEEDED
        2 IF YOU WANT TO CONTINUE THIS JOB LATER
        0 IF END OF THIS JOB
  ?
→ 1
  ENTER 1 TO CALCULATE THE END STAGES
        2 TO CONNECT TWO STAGES
        3 TO MERGE PIPELINES WITH TEE JOINT
        4 TO MERGE PIPELINES WITH CROSS JOINT
        5 TO TURN THE FLOW WITH ELBOW
        6 TO BRANCH PIPELINES WITH TEE JOINT
        7 TO BRANCH PIPELINES WITH CROSS JOINT
  ?
→ 2
  ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
  ?
→ 0
  ENTER 1 TO SPECIFY REQUIRED DISCHARGE
        2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
        3 TO USE ORIGINAL ORIFICE SIZE
  ?
→ 3
  ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
  ?
→ 51.,54.
  ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
  ?
→ 200.,7.
  ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
  ?
→ 53.6,62.
  ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
  ?
→ 0.05
  ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
        2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
  ?
→ 1
  ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
  ?
→ 2
  ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
  ?
→ 1
     [illegible]
```

# Appendix B-5 (Contd)

```
    60.300558,    60.243744,    60.187790,    60.081960,    59.970169,    59.897697,    59.726669,    59.674158,
    59.566364,    59.504089,    59.448792,    59.355073,    59.347595,    59.232836,    59.177780,    59.132965,
    59.029663,    58.981166,    58.918777,    58.881729,    58.847382,    58.785416,    58.718719,    58.664132,
    58.558058,    58.520081,    58.459871,    58.405304,    58.301056,    58.273041,    58.138065,    58.106522,
    58.077179,    58.038364,    57.950287,    57.903900,    57.896393,    57.827209,    57.793640,    57.715973,
    57.662292,    57.641968,    57.553701,    57.522095,    57.461570,    57.408112,    57.367737,    57.335007,
    57.262222,    57.209808,    57.150101,    57.117554,    57.054474,    57.017517,    56.955139,    56.902130,
    56.898622,    56.823105,    56.760239,    56.700043,    56.697876,    56.645081,    56.591095,    56.500153,
    56.474426,    56.421829,    56.387497,    56.312164,    56.259003,    56.229614,    56.194717,    56.142395,
    56.065872,    56.001434,    55.967896,    55.942337,    55.854904,    55.833496,    55.757553,    55.705399,
    55.663651,    55.611786,    55.558228,    55.513184,    55.471466,    55.441986,    55.389328,    55.346588,
    55.258759,    55.203003,    55.168716,    55.142181,    55.061615,    55.007965,    54.970730,    54.925461,
    54.852890,    54.848648,    54.797318,    54.736221,    54.694443,    54.642532,    54.594391,    54.514038,
    54.474762,    54.440018,    54.359726,    54.308472,    54.295624,    54.244431,    54.166763,    54.093842,
  ENTER 1 IF MORE STAGES ARE NEEDED
        2 IF YOU WANT TO CONTINUE THIS JOB LATER
        0 IF END OF THIS JOB
  ?
→1
  ENTER 1 TO CALCULATE THE END STAGES
        2 TO CONNECT TWO STAGES
        3 TO MERGE PIPELINES WITH TEE JOINT
        4 TO MERGE PIPELINES WITH CROSS JOINT
        5 TO TURN THE FLOW WITH ELBOW
        6 TO BRANCH PIPELINES WITH TEE JOINT
        7 TO BRANCH PIPELINES WITH CROSS JOINT
  ?
→1
  ENTER THE ASSIGNED NUMBER OF PIPE LINE
  ?
→6
  ENTER 1 TO SPECIFY REQUIRED DISCHARGE
        2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
        3 TO USE ORIGINAL ORIFICE SIZE
  ?
→3
  ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
  ?
→50.,50.1
  ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
  ?
→200.,7.
  ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
  ?
→50.,62.
  ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
  ?
→0.05
  ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
  ?
→2
  ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
  ?
→1
    60.645264,    60.588470,    55.010773,    54.959091,    53.776093,    53.726410,    53.402954,    53.352722,
    53.263260,    53.213135,    53.152817,    53.108597,    53.095093,
  ENTER 1 IF MORE STAGES ARE NEEDED
        2 IF YOU WANT TO CONTINUE THIS JOB LATER
        0 IF END OF THIS JOB
  ?
→1
  ENTER 1 TO CALCULATE THE END STAGES
        2 TO CONNECT TWO STAGES
        3 TO MERGE PIPELINES WITH TEE JOINT
        4 TO MERGE PIPELINES WITH CROSS JOINT
        5 TO TURN THE FLOW WITH ELBOW
        6 TO BRANCH PIPELINES WITH TEE JOINT
        7 TO BRANCH PIPELINES WITH CROSS JOINT
  ?
→5
  ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
  ?
→0
  ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
  ?
→53.,62.
  ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
  ?
→0.05
  ENTER THE ELBOW ANGLE, IN DEGREE
  ?
→45.
  ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
        2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
  ?
→1
  ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
  ?
→2
  ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
  ?
→1
    60.840637,    60.782990,    60.726074,    60.659607,    60.602798,    55.118500,    55.066711,    55.015808,
    54.964218,    53.864838,    53.814178,    53.752914,    53.735382,    53.481140,    53.430832,    53.375107,
    53.336639,    53.286438,    53.232620,    53.170486,    53.124451,    53.098160,
  ENTER 1 IF MORE STAGES ARE NEEDED
        2 IF YOU WANT TO CONTINUE THIS JOB LATER
        0 IF END OF THIS JOB
  ?
→1
  ENTER 1 TO CALCULATE THE END STAGES
        2 TO CONNECT TWO STAGES
        3 TO MERGE PIPELINES WITH TEE JOINT
        4 TO MERGE PIPELINES WITH CROSS JOINT
        5 TO TURN THE FLOW WITH ELBOW
        6 TO BRANCH PIPELINES WITH TEE JOINT
        7 TO BRANCH PIPELINES WITH CROSS JOINT
  ?
→2
  ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
  ?
  0
  ENTER 1 TO SPECIFY REQUIRED DISCHARGE
        2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
        3 TO USE ORIGINAL ORIFICE SIZE
  ?
→3
  ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
  ?
→50.,52.5
  ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
  ?
→200.,6.5
  ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
  ?
→53.,62.
  ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
  ?
→0.05
  ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
        2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
  ?
```

# Appendix B-5 (Contd)

```
ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
?
→2
ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
?
→1
    61.710338,    61.652649,    61.093491,    61.036240,    60.687057,    60.630173,    60.533966,    60.477188,
    60.351028,    59.981461,    59.830490,    59.764648,    59.715860,    59.679947,    57.287659,    57.233932,
    56.863968,    56.610662,    56.472535,    56.419525,    56.325195,    56.272232,    56.074142,    55.980484,
    55.921967,    55.688736,    55.537369,    55.485153,    55.436203,    55.303101,    55.251038,    55.236771,
    55.150497,    55.142883,    55.098633,    55.004791,    54.953033,    54.917892,    54.866198,    54.800949,
    54.772827,    54.705882,    54.682938,    54.560776,    54.509369,    54.499069,    54.410998,    54.354584,
    54.342926,    54.276321,    54.202530,    54.167252,    54.131775,    54.005386,    53.963623,    53.861389,
    53.820572,    53.753189,    53.711975,    53.650406,    53.610413,    53.581665,    53.548141,    53.461121,
    53.445633,    53.399567,    53.340210,    53.192642,    53.128296,
ENTER 1 IF MORE STAGES ARE NEEDED
      2 IF YOU WANT TO CONTINUE THIS JOB LATER
      0 IF END OF THIS JOB
?
→1
ENTER 1 TO CALCULATE THE END STAGES
      2 TO CONNECT TWO STAGES
      3 TO MERGE PIPELINES WITH TEE JOINT
      4 TO MERGE PIPELINES WITH CROSS JOINT
      5 TO TURN THE FLOW WITH ELBOW
      6 TO BRANCH PIPELINES WITH TEE JOINT
      7 TO BRANCH PIPELINES WITH CROSS JOINT
?
→5
ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
?
→0
ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
?
→53.1,62.
ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
?
→0.05
ENTER THE ELBOW ANGLE, IN DEGREE
?
→45.
ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
      2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
?
→1
ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
?
→2
ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
?
→1
    61.962585,    61.904587,    61.856750,    61.825099,    61.767868,    61.731323,    61.673569,    61.640488,
    61.530624,    61.472931,    61.344254,    61.279282,    61.200160,    61.150803,    61.114304,    61.057037,
    61.024155,    60.968826,    60.936890,    60.872147,    60.801285,    60.784958,    60.707794,    60.650294,
    60.618118,    60.599960,    60.535446,    60.464859,    60.406876,    60.371689,    60.339020,    60.262314,
    60.223538,    60.165253,    60.125427,    60.094910,    60.002060,    59.969482,    59.943756,    59.851059,
    59.818527,    59.785202,    59.730404,    59.668015,    57.646301,    57.592224,    57.396011,    57.342178,
    57.270584,    57.244003,    57.167404,    56.971878,    56.918381,    56.874008,    56.820587,    56.775024,
    56.680557,    56.627228,    56.580109,    56.520932,    56.455902,    56.428467,    56.379480,    56.334468,
    56.282211,    56.240967,    56.181193,    56.110382,    56.087493,    56.016693,    55.990433,    55.926651,
    55.855331,    55.802811,    55.795380,    55.724838,    55.698654,    55.628555,    55.576248,    55.523987,
    55.439207,    55.438660,    55.382660,    55.330521,    55.280240,    55.241348,    55.189392,    55.126501,
    55.096420,    55.043655,    54.998123,    54.901260,    54.891449,    54.805573,    54.773315,    54.721466,
    54.687561,    54.639175,    54.590256,    54.510162,    54.458435,    54.424606,    54.377808,    54.345352,
    54.281204,    54.237366,    54.162781,    54.148544,    54.076782,    54.042099,    53.998283,    53.925476,
    53.855270,    53.824402,    53.784088,    53.714355,    53.681519,    53.641266,    53.578995,    53.549469,
    53.471497,    53.446243,    53.399323,    53.341537,    53.256302,    53.218445,    53.193253,    53.139343,
ENTER 1 IF MORE STAGES ARE NEEDED
      2 IF YOU WANT TO CONTINUE THIS JOB LATER
      0 IF END OF THIS JOB
?
→2
TIME
CPU - 00:00:45  EXECUTION - 00:06:58  SESSION - 00:38:25
NAPDS TG19880.YANG.RESULT.DATA
DSNAME: TG19880.YANG.RESULT.DATA                           VOL=SER: UNTS02
  CREATED: 74164     PURGED: 74168     DS_ORG:   SEQ     REC_FM: F
  REC_LEN:     0   BLKSIZE:    20  2ND ALLOC:    50  ALL_TYPE: BLK
LAST_BLK_PTR(TRL):   49|  60|  34  DIRC_BLKS:     0 BLKS_USED:     0
    0  2498  2547   50
            TOTAL TRACKS ALLOC:    50
FREE FI(FT01F001),FI(FT02F001),FI(FT03F001)
END
READY
→logoff
TSO TIME JOB #1988 - TG19880  ON 041, CONNECT=  0.40.59  MUS=  0.01.13
TG19880 LOGGED OFF TSO AT 09:25:29 ON JUNE 17, 1974+
```

NOTE: CPU TIME USED = 45 - 3 = 42 sec.
CONNECT TIME = 32 min 20 sec.

# Appendix B-5 (Contd)

```
→exec yang.comm.clist 'yang.informl.data' list

   ALLOC DA(YANG.INFORM1.DATA) FI(FT01F001)
   ALLOC DA(YANG.RESULT.DATA) FI(FT02F001)
   ALLOC DA(YANG.CONTU.DATA) FI(FT03F001)
   TIME
   CPU - 00:02:02  EXECUTION - 00:11:05  SESSION - 00:48:43
   LOADGO YANG.PIPE.OBJ(DEMO) FORTLIB LIB('SYS1.FORTLB2') LET

   ENTER 1 TO PRINT DATA OF MATERIAL COST, OTHERWISE 0
   ?
→0
   ENTER 1 IF CONTINUE FROM PREVIOUS INCOMPLETE TEST, OTHERWISE 0
   ?
→1
   THE LAST STAGE IN PREVIOUS STAGE WAS   30, AND THE LINE NO. WAS   6
   ENTER A NUMBER N SUCH THAT THIS JOB WILL CONTINUE FROM N STAGES BACK OF THE LAST STAGE OF LAST JOB
   ENTER 0 IF CONTINUE FROM THE NEXT STAGE
   ?
→0
   ENTER 1 TO CALCULATE THE END STAGES
         2 TO CONNECT TWO STAGES
         3 TO MERGE PIPELINES WITH TEE JOINT
         4 TO MERGE PIPELINES WITH CROSS JOINT
         5 TO TURN THE FLOW WITH ELBOW
         6 TO BRANCH PIPELINES WITH TEE JOINT
         7 TO BRANCH PIPELINES WITH CROSS JOINT
   ?
→2
   ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
   ?
→0
   ENTER 1 TO SPECIFY REQUIRED DISCHARGE
         2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
         3 TO USE ORIGINAL ORIFICE SIZE
   ?
→3
   ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
   ?
→50.,53.
   ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
   ?
→200.,5.5
   ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
   ?
→53.1,62.
   ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
   ?
→0.05
   ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
         2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
   ?
→1
   ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
   ?
→2
   ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
   ?
→1
     60.295959,   60.058960,   59.935211,   59.870175,   59.810150,   59.652527,   59.586696,   59.531540,
     59.448792,   59.304779,   59.171097,   59.059884,   58.951534,   58.940018,   58.878922,   58.827886,
     58.716431,   58.699234,   58.540111,   58.479019,   58.328136,   58.262421,   58.231293,   58.153397,
     58.102921,   58.041840,   57.886139,   57.827408,   57.431107,   57.320694,   57.199295,   57.075256,
     56.928909,   56.775406,   56.740814,   56.654663,   56.471573,   56.385651,   56.312546,   56.251312,
     56.235916,   56.177612,   56.102158,   56.080081,   56.006683,   55.930222,   55.860184,   55.848099,
     55.798328,   55.745117,   55.654724,   55.618027,   55.581940,   55.539948,   55.478989,   55.400574,
     55.352203,   55.300659,   55.258469,   55.236679,   55.181976,   55.112835,   55.091812,   55.016678,
     54.991272,   54.917511,   54.871307,   54.833832,   54.797119,   54.730148,   54.675125,   54.630615,
     54.589188,   54.518723,   54.486481,   54.415710,   54.375061,   54.349289,   54.271866,   54.209137,
     54.134796,   54.056427,   54.036499,   53.991440,   53.928925,   53.894104,   53.821472,   53.714645,
     53.679642,   53.612747,   53.566071,   53.506302,   53.468074,   53.413956,   53.359253,   53.261871,
     53.218277,
   ENTER 1 IF MORE STAGES ARE NEEDED
         2 IF YOU WANT TO CONTINUE THIS JOB LATER
         0 IF END OF THIS JOB
   ?
→1
   ENTER 1 TO CALCULATE THE END STAGES
         2 TO CONNECT TWO STAGES
         3 TO MERGE PIPELINES WITH TEE JOINT
         4 TO MERGE PIPELINES WITH CROSS JOINT
         5 TO TURN THE FLOW WITH ELBOW
         6 TO BRANCH PIPELINES WITH TEE JOINT
         7 TO BRANCH PIPELINES WITH CROSS JOINT
   ?
→2
   ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
   ?
→0
   ENTER 1 TO SPECIFY REQUIRED DISCHARGE
         2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
         3 TO USE ORIGINAL ORIFICE SIZE
   ?
→3
   ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
   ?
→51.,54.
   ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
   ?
→200.,4.
   ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
   ?
→53.2,62.
   ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
   ?
→0.05
   ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
         2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
   ?
→1
   ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
   ?
→2
   ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
   ?
→1
     61.950665,   61.921143,   61.843460,   61.727051,   61.676498,   61.619797,   61.568115,   61.496323,
     61.396881,   61.339020,   61.234207,   61.180108,   59.228226,   59.168030,   59.112518,   58.981705,
     58.921158,   58.834763,   58.760223,   58.704269,   58.666550,   58.611908,   58.542648,   58.468231,
     58.445969,   58.359512,   58.266571,   58.223114,   58.186630,   58.148895,   58.083832,   58.023315,
     57.971848,   57.936646,   57.866180,   57.821365,   57.750671,   57.718369,   57.686172,   57.600479,
     57.534983,   57.465424,   57.395508,   57.340942,   57.250443,   57.212097,   57.179153,   57.143173,
     57.069321,   57.029861,   56.992737,   56.940781,   56.896652,   56.847702,   56.775497,   56.703873,
     56.682251,   56.600906,   56.577133,   56.505539,   56.460632,   56.449127,   56.380414,   56.308151,
     56.262741,   56.230667,   56.180450,   56.137268,   56.087051,   56.017288,   55.997086,   55.925522,
     55.850235,   55.842651,   55.776352,   55.749954,   55.667206,   55.649246,   55.583054,   55.507355,
     [illegible]
```

## Appendix B-5 (Contd)

```
     55.461121,     55.423601,     55.373230,     55.315430,     55.276459,     55.244675,     55.198582,     55.115143,
     55.099258,     55.035343,     54.956039,     54.910965,     54.861954,     54.802795,     54.766296,     54.706116,
     54.695541,     54.632477,     54.551163,     54.541153,     54.488220,     54.417450,     54.396622,     54.315155,
     54.273575,     54.210815,     54.160965,     54.107559,     54.096832,     54.044952,     53.996017,     53.937408,
     53.893921,     53.830444,     53.786896,     53.728485,     53.681747,     53.639496,     53.585571,     53.542740,
     53.474609,     53.402145,     53.378448,     53.301193,     53.258194,
  ENTER 1 IF MORE STAGES ARE NEEDED
        2 IF YOU WANT TO CONTINUE THIS JOB LATER
        0 IF END OF THIS JOB
  ?
->1
  ENTER 1 TO CALCULATE THE END STAGES
        2 TO CONNECT TWO STAGES
        3 TO MERGE PIPELINES WITH TEE JOINT
        4 TO MERGE PIPELINES WITH CROSS JOINT
        5 TO TURN THE FLOW WITH ELBOW
        6 TO BRANCH PIPELINES WITH TEE JOINT
        7 TO BRANCH PIPELINES WITH CROSS JOINT
  ?
->4
  ENTER THE ASSIGNED NUMBER OF PIPELINES WHICH WILL BE MERGED
  ?
->1,5,6
  ENTER THE ASSIGNED PIPELINE NUMBER AFTER MERGING
  ?
->1
  ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
        2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
  ?
->2
  ENTER THE ALLOWABLE PRESSURE DIFFERENCE AT THE MERGING POINT
  ?
->0.01
  ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
  ?
->55.7,62.
  ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
  ?
->0.05
  ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
  ?
->2
  ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
  ?
->1
     59.716293,    57.796021,    56.972839,    56.573380,    56.239349,    56.119476,    56.053757,
  ENTER 1 IF MORE STAGES ARE NEEDED
        2 IF YOU WANT TO CONTINUE THIS JOB LATER
        0 IF END OF THIS JOB
  ?
->1
  ENTER 1 TO CALCULATE THE END STAGES
        2 TO CONNECT TWO STAGES
        3 TO MERGE PIPELINES WITH TEE JOINT
        4 TO MERGE PIPELINES WITH CROSS JOINT
        5 TO TURN THE FLOW WITH ELBOW
        6 TO BRANCH PIPELINES WITH TEE JOINT
        7 TO BRANCH PIPELINES WITH CROSS JOINT
  ?
->2
  ENTER 1 TO SHIFT PIPE LINE, OTHERWISE 0
  ?
->0
  ENTER 1 TO SPECIFY REQUIRED DISCHARGE
        2 TO USE DIFFERENT ORIFICE SIZE (OR NO DISCHARGE AT THIS STAGE)
        3 TO USE ORIGINAL ORIFICE SIZE
  ?
->3
  ENTER THE DESIGNED DISCHARGE PRESSURE, AND DESIGNED ALLOWABLE MAX. DISCHARGE PRESSURE, IN PSI.
  ?
->51.,54.
  ENTER THE LENGTH OF THIS STAGE AND THE DISCHARGE ELEVATION, IN FT.
  ?
->200.,6.
  ENTER THE DESIGNED MIN. AND MAX. TOTAL INLET HEAD, IN PSI.
  ?
->56.,62.
  ENTER THE INTERVAL FOR ELIMINATING SAME INLET HEAD, IN PSI.
  ?
->0.05
  ENTER 1 FOR SUDDEN EXPANSION OR CONTRACTION TYPE OF CONNECTION
        2 FOR GRADUAL EXPANSION OR CONTRACTION TYPE OF CONNECTION
  ?
->2
  ENTER 1 TO DISPLAY THE RESULTS, ENTER 2 TO DISPLAY ONLY THE INLET HEAD, OTHERWISE 0
  ?
->2
  ENTER THE NUMBER N SO THAT THE INLET HEAD WILL BE PRINTED EVERY N NUMBER
  ?
->1
     59.624466,    59.215637,    58.878892,    58.756518,    58.691299,    57.479278,    57.134857,    57.012985,
     56.946360,
  ENTER 1 IF MORE STAGES ARE NEEDED
        2 IF YOU WANT TO CONTINUE THIS JOB LATER
        0 IF END OF THIS JOB
  ?
->0
```

## Appendix B-6. Program Procedures

The procedures described in the following are necessary steps, from creating the program and required data sets to actual running of the program, to solve a fluid network design problem:

1. Create a data set for the program on a disk of the TSO system by reading punched deck through batch. (YANG,PIPE.FORT is the data set name in the example.)
2. Create three required data sets on TSO disk from batch:
   a. Check all available materials such as pipes, elbows, joints, and connectors first and then run the program which is shown in Appendix B-2. A sequential data set for storing all material costs will be created. The record length is 40. YANG. INFORM1.DATA is the data set name in the example.
   b. Create a direct-access data set with record length 20 to store calculated results from each stage; allow enough space for a large network design problem. The program for creating this data set is shown in Appendix B-3. YANG.RESULT.DATA is the data set name in the example.
   c. Create another sequential data set for storing intermediate data if the program has to be interrupted and continued later. The record length of this data set is 21. The program for creating this data set is shown in Appendix B-4. YANG.CONTV. DATA is the data set name in the example.
3. Compile the created source program through terminal (by typing FORT.YANG.PIPE.FORT [demo] in the example). During compilation, the computer will print any detected errors. Correct errors through terminal or batch and recompile. After compiling, the computer will automatically save the object module. YANG.PIPE.OBJ is the data set name in the example.

The above procedures are needed only the first time to use the program. Once the program and required data set have been created, the user can start from Step 4 to solve his problem.

4. Prepare a layout or a drawing of the network with a number assigned to each main or branch pipeline. A pipeline is a serially connected pipe segment without branches. These numbers are assigned

arbitrarily, but all pipelines must be assigned a different number. The pipeline number before branching, or after merging, can be different or the same as one of its branches. These pipeline numbers are needed to identify pipelines in the network optimization process and optimal result retrieval. Flow directions are predetermined in a complex loop system; reverse flow is not supposed to be allowed. Other design criteria for each stage should also be set up.

5. Turn on the terminal and type in the execution command. In the example EXEC YANG.COMM.CLIST'YANG.INFORM1.DATA' list was typed in. YANG.COMM.CLIST is a collection of TSO commands which are:
   a. proc 1 input
   b. alloc da(& input.) fi(ft01f001)
   c. alloc da(yang.result.data) fi(ft02f001)
   d. alloc da(yang.contu.data) fi(ft03f001)
   e. time
   f. loadgo yang.pipe.obj(demo) fortlib lib('sys1.fortlb2') let
   g. time
   h. mapds t619880.yang.result.data
   i. end

Three alloc commands will bring three required data sets into the system. Whatever appears within quotes of exec command goes to first alloc command. In this way, user is allowed to access his desired data set of material cost if there are more than one on the disk. Two time commands will print CPU time, as well as connection time, before and after running the program. The differences of the two printed time messages are the actual CPU time and connection time used to run the program. Command (h) will show how much disk space is allocated to the direct-access data set for calculated results storage. This command collection data set, YANG.COMM. CLIST, can be created from the terminal in Edit Mode.

6. Use the five different kinds of stages in the optimization process:
   a. End stage of pipelines (no further stagesin downstream). The end stage of pipelines which converge to other pipelines does not belong in this category. Required data are pipeline number, stage length, discharge elevation, discharge pressure range, inlet total head range and its resolution interval.

b. Regular discharge stage: This stage is the same as the end stage (a) except there are other stages in downstream. Required data are the same as end stage (a) except that a connection type is also needed. In these two kinds of stages (a and b), the discharge condition may be specified by required flow rate instead of pressure range. Conditions of different orifice size or no orifice on the pipe are also provided by the program for broader application.

c. Merge stage: This stage is used to converge pipelines in optimization. The user is cautioned that this is a diverge stage of fluid flow in an actual network, and since optimization is done backward, branches converge into one pipeline at this stage. Required data are pipeline numbers before and after merge, allowable total head difference at branch inlet, connection type, inlet total head range and its resolution interval.

d. Elbow stage: This stage is used to change flow direction. Required data are pipeline number, flow turning angle, connection type, inlet total head range and its resolution interval.

e. Branch stage: This stage is used to diverge pipelines in optimization. The user is cautioned that theis is a converge stage of fluid flow in an actual network. Required data are pipeline numbers before and after branch, flow rate ratio in branches, connection type, inlet total head range and its resolution interval.

7. Select a reference level such that all elevations of discharge orifices will be positive.
8. Override data other than material cost through the terminal by typing new desired data.
9. This program provides options in including or excluding wasted fluid cost and power cost, also in allowing or not allowing smaller pipe used in upstream.
10. This program can be interrupted during optimization process when any stage in network is completed. The optimization process will continue if the program is rerun later. Continuation may start from the next stage or several stages previous to the last stage

of an incomplete computer run.

In this way, it is possible for the designer to re-do the stages with unsatisfactory results. Also, the designer can interrupt the program if undesired results were found, and re-run the program to continue the optimization process from the stage prior to that which produced the undesired results.

11. Input data through the terminal are integers (without decimal points) for pipeline numbers and making decisions, and real numbers (with decimal points) for the remaining calculation data. If more than one data are required for each input, they are separated by commas. (Input through terminal in Appendix B-5 is indicated by arrows.)